5th International Scientific Conference on Print and Media Technology
for junior scientists and PhD students

Proceedings

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September 10 - 12, 2013
General Conference Chair: Prof. Dr. Reinhard R. Baumann
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Welcome to the Printing Future Days 2013!

The organizing committee of the 5th Printing Future Days in Chemnitz has the pleasure to welcome you both, young and well experienced scientists from all around the globe at the Technische Universität Chemnitz to hold our biennial conference on Print and Media Technology.

This year, we are very pleased to announce that we could convince the iarigai - the International Association of Research Organisations for the Information, Media and Graphic Arts Industries - to celebrate the 40th anniversary of the International Research Conference "Advances in Printing and Media Technology" in Chemnitz as well. As a highlight, we will have joint sessions to bring together young scientists and senior scientists entitled as "Digitalization of Print exchanging ideas across generations".

Therefore we have the pleasure to hold the 5th Printing Future Days and the 40th iarigai conference within one week here in Chemnitz. And the participants of the Printing Future Days feel honoured that iarigai took over the auspices again.

The Printing Future Days conference, dedicated to young scientists presenting their first scientific results on an international event, is rather unique since it satisfies mutual networking interests of students, university scientists as well as industry and company representatives. The Printing Future Days 2013 address topics related to print and media technologies and the promising field of functional printing and printed electronics and will provide a snapshot of the international research carried out recently in this field. We will present a great line-up of well-known keynote speakers in a special keynote session held jointly with the 40th International Research Conference. All oral and interactive presentations are given by young scientists who are highly motivated to contribute their results to our community and to foster the research in printing and coating technologies. Besides interesting presentations, we provide a social program - this year together with the iarigai - which is an ideal platform for networking and career planning.

This booklet contains all papers presented on the Printing Future Days 2013. We wish to thank you - the contributors and attendees for sharing their results and for discussing advances in the area of printing technologies, a field with long tradition and with a promising future as manufacturing technology for functional layers and flexible electronics.

We also would like to thank our colleagues on the conference committee, the session chairs and all the staff members of the Department of Digital Printing and Imaging Technology as well as the Department of Print and Media Technology of Technische Universität Chemnitz for their dedication and hard work which has made the Printing Future Days 2013 possible.

We are looking forward to a comprehensive and cheerful conference in Chemnitz!

Prof. Dr. Reinhard R. Baumann
General Conference Chair

Jens Hammerschmidt, Enrico Sowade, Frank Siegel
Organizing Committee

We are looking forward to welcoming you again in Chemnitz on the occasion of the

Printing Future Days 2015!
All scientific contributions were thankworthy assessed by our international review committee consisting of top-ranking senior scientists active in print and media technology:

- Prof. Dr. Rajendrakumar Anayath (Heidelberg AG, India)
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September 10, 2013
Functional Printing I
Printable and flexible large-area sensors for magnetic field mapping

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Abstract

Printed electronics are about to revolutionize the field of conventional electronics offering low-cost, large-area, high volume, high-throughput production in roll-to-roll or sheet-feed processing techniques [1,2]. In order to realize the vision of printable electronics, it is necessary to replicate all components of conventional rigid electronics in a printable form. The field of modern electronics is very general including, interconnects, optoelectronics and magnetoelectronics. Cost-efficient versatile electronic building blocks, such as transistors, diodes, resistors and printable communication modules are already available as printed counterparts of conventional semiconductor elements. However, printable magnetoelectronics operating at ambient conditions had been reported only very recently [3]. For this purpose, magnetic sensors relying on the giant magnetoresistive (GMR) effect have been successfully developed as a paste. This paste can be brought onto planar or curved surfaces of rigid or flexible supports and will result in a high sensitivity printed magnetic field sensor operating at ambient conditions. One application direction of the printable magnetoelectronics was suggested where GMR sensor was printed on a postcard and was acting as a contactless magnetic field driven switch [3].

Unique feature of these printable and flexible magnetic sensor elements is the possibility to produce large-area sensors, which is crucial if averaging of local differences in magnetic field is favorable. Here, we extend the already developed concept of flexible and printable magnetic sensorics and aim on the fabrication of large-area magnetic field sensors. These individual sensing elements will be assembled in an array on a single flexible polymeric membrane to realize mapping of a spatially inhomogeneous magnetic field.

Keywords: printable electronics, printable magnetoelectronics, magnetoresistive sensors

References

Enhanced Organic Field-Effect Transistors based on printed, high-resolution source/drain electrodes with improved conductivity and stability

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Abstract

Herein, Cyflex-printed electrodes with enhanced conductivity and stability are presented. Due to an applied solvent post-treatment, the conductivity of the utilized poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) electrodes could be distinctly improved. In fact, the tests conducted with a variety of source/drain structures, revealed an average increase of conductivity of 99%. This effect is accompanied by the change of the electrode’s morphology. In particular, the explicit decrease of the electrode’s thickness and cross-sectional area was observed, indicating the reduction of excess PSS within the printed PEDOT:PSS layer. These improved source/drain structures have a crucial effect on the performance of organic field-effect transistors (OFETs), which were fabricated on the basis of the same. In fact, an increase of the maximum source-drain current of about two orders of magnitude is achieved, which corresponds to an increase of mobility in the similar range.

Keywords: Printed Electronics, Organic Field-Effect Transistors, S/D Electrodes

1. Introduction

During the last years, the vision to produce electronic devices by means of mass printing technologies has attracted rather great attention. The interest is founded by the idea to produce devices on an extremely low price on the basis of typical printing substrates, such as paper and foil, which can give rise to the exploitation of completely new areas for electronics [1], as for instance paper photovoltaic [2], flexible loudspeakers on paper [3] or fully mass-printed OFETs [4] and circuits [5] on flexible substrates.

One essential material, incorporated in the mentioned devices, is represented by the conducting polymer PEDOT:PSS, which is known for its comparably high conductivity among currently commercially available polymer conductors. However, the use of printed PEDOT:PSS electrodes in organic devices can represent a critical factor, since PSS, necessary to disperse the conducting PEDOT in water, is present in the solution-processed electrodes after printing. On the one hand, this might cause an interference of the conduction path and accordingly lower conductivity. On the other hand, due to the hygroscopic character of the ionomer, excess PSS in the polymer film leads to adverse water absorption, which further contributes to the serious impairment of conductivity and device stability [6].

However, several approaches to avoid or reduce disadvantageous changes in conductivity and to improve the environmental stability are described in the literature. For instance, an increase of conductivity by several orders of magnitude can be achieved due to the addition of sorbitol to the PEDOT:PSS dispersion. Moreover, the modification of PEDOT:PSS by sorbitol is suspected to improve the environmental stability of the produced films [7]. Rather similar improvements can be achieved by the addition of polar solvents, such as dimethyl sulfoxide as described by F. Xue et al. [8]. Besides the modification of the PEDOT:PSS dispersions, post-treatments...
with polar solvents, e.g. methanol and ethanol, have been proved to enhance the conductivity of PEDOT:PSS films [9]. Moreover, Y. H. Kim et al. [6] demonstrated distinct conductivity improvements of PEDOT:PSS electrodes induced by an applied ethylene glycol post-treatment. The latter was adopted herein for the enhancement of Cyflex-printed source/drain electrodes, which form the base of all-solution processed OFETs. Besides the effect of the treatment on the electrode’s morphology and conductivity, the influence on device performance will be demonstrated.

2. Experimental

All experiments were carried out in ambient conditions. As the basis for the experiments, Cyflex-printed source/drain electrodes have been utilized. These electrodes were printed at the Institute of Print and Media Technology at TU Chemnitz, Germany. The mass printed structures are based on PEDOT:PSS and offer channel length in the low micrometer range. The so called ‘Cyflex’ technology is described in detail in reference [10].

Cyflex source/drain electrodes were post-treated with ethylene glycol by spreading the solvent on top of the electrodes and centrifuging the material at 3000 rpm for 30 seconds after an exposure of 2 minutes. Afterwards the electrodes were dried at 110 °C for another 2 minutes.

TGBG OFETs were fabricated with a commercially available p-type semiconductor, namely Lisicon SP300-1589 (Merck). The material was spin cast at 1000 rpm for 30 seconds and dried at 120 °C for 10 minutes, resulting in an approximate thickness of 100 nm.

The well known amorphous polymer Cytop (Asahi Glass) served as gate dielectric. The dielectric was spin cast at 1200 rpm for 20 seconds and dried for 10 minutes at 120 °C, resulting in a layer thickness of approximately 1.8 μm.

Device fabrication was completed by flexographic printing of the gate electrodes (test printing machine, Erichsen), utilizing a water-based Cu-particle Ink.

The dimensions and morphological properties of electrodes and devices were investigated with a laser scanning microscope (Keyence VK9700) and a profilometer (Dektak 8-Advanced Development Profiler).

Electrical characterization of source/drain electrodes and OFETs was performed with a probe system, Prober SÜSS PM5, which had been connected to a Keithley 2612 System SourceMeter. On the basis of the measured resistance R and the determined dimensions of the electrodes, the conductivity could be calculated according to the general equations. Transfer curves of fabricated OFETs were obtained by sweeping the gate voltage from +60V to -60V, while keeping the drain voltage constant at -10V or -60V. By sweeping the drain voltages from 0 to -60V, for constant gate voltages of 10 to -60V (in steps of 10V), corresponding output curves were gained. The measurements further included the determination of the gate capacitance and the gate leakage current I_{GS}.

3. Results and Discussion

3.1 Cyflex Source/Drain Electrodes

The first part of the experiment consisted in the investigation of the PEDOT:PSS electrode’s stability and the probable increase of the conductivity due to the described post-treatment. Four types of electrodes were considered, varying in terms of the printed layout and in regard to the utilized gravure cylinder, as summarized in Table 1, which further contains the results of an initial characterization carried out after printing.

After the initial condition of the electrodes had been assessed, the conductivity of these electrodes was monitored for a period of more than 3 months (Table 1).
Table 1: Cyflex-printed electrodes: layout, utilized gravure cylinders and determined characteristics

<table>
<thead>
<tr>
<th>Denotation</th>
<th>Gravure cylinder</th>
<th>Layout (nominal)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screening</td>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td>RW60-L38-F100</td>
<td>60</td>
<td>15</td>
<td>38</td>
</tr>
<tr>
<td>RW60-L30-F100</td>
<td>60</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>RW70-L30-F100</td>
<td>70</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>RW70-L30-F75</td>
<td>70</td>
<td>11</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 1: Stability of Cyflex-printed electrodes (a) untreated electrodes (b) comparison of untreated and post-treated Cyflex-electrodes on example RW60-L38-F100.

Even though variations were observed, it can be stated that the conductivity of the investigated electrodes remained rather constant for the considered period of 15 weeks. As an example, Cyflex-electrodes, denoted as RW60-L38-F100, are considered. While the initially measured conductivity of untreated electrodes accounted for 77 ± 14 S/cm and the average value (averaged over all measurements made within the observed 15 weeks) amounted to 91 ± 12 S/cm, conductivity measurements after 15 weeks revealed an average value of 95 ± 7 S/cm. Simultaneously, potential improvements of the conductivity due the ethylene glycol post-treatment were considered. Therefore, the electrodes were post-treated, as described in the experimental section and again characterized in regard to their morphological properties. As expected from the referred literature [6], cross-sectional area A and electrode thickness d reduced (Figure 2), which is associated with the removal or rather reduction of excess PSS, as described by Y. H. Kim et al. In particular, the average decrease of the source/drain electrode’s thickness accounts for 27 %, while the cross-sectional area of the source/drain electrodes decreased in average to 83 %. On the example RW60-L38-F100 (profile Figure 2), this did amount to an initial cross-sectional area and electrode thickness of 14.72 ± 1.73 µm² and 193 ± 20 nm, which were decreased to 11.69 ± 1.45 µm² and 143 ± 17 nm after the post-treatment.

Afterwards, the conductivity of the post-treated electrodes was determined. The results in comparison to the values of untreated electrodes are shown in Figure 1 (b) on the example RW60-L38-F100. As mentioned before, the average conductivity of untreated electrodes accounted for 91 ± 12 S/cm. In comparison an average value of 178 ± 17 S/cm was determined for post-treated electrodes. This corresponds to an average increase of 97 %, which is in well accordance with the overall obtained increase of 99 %, averaged for all investigated Cyflex-electrodes.
3.2 Comparison of OFET Characteristics

The effect of the post-treatment of source/drain electrodes on OFET performance was tested with p-type devices, fabricated on the basis of Cyflex source/drain electrodes, which had been stored in ambient conditions for more than one year and on which drastic deterioration of OFET performance had been observed. During storage, the conductivity of the electrodes had been decreased to 37 S/cm, which could be increased to 132 S/cm due to the applied post-treatment. The effect of this improvement on OFET’s performance becomes rather distinct, if considering the transfer curves of the fabricated devices as shown in Figure 3, which further depicts the basic structural characteristics of the examined OFETs.

Indeed, if comparing the maximum source-drain current, averaged over at least 13 OFETs, an improvement in the range of two orders of magnitude can be stated. In fact, the average current $I_{ds}$ accounts for only 573 nA for OFETs based on untreated electrodes. In comparison, an average current $I_{ds}$ of 35μA was measured for OFETs, which had been fabricated on the basis of post-treated Cyflex electrodes. Accordingly, the extracted saturation mobilities increased from $2.03 \times 10^{-4}$ cm$^2$/Vs to $1.89 \times 10^{-2}$ cm$^2$/Vs. The transfer curve further depicts the increase of the off-current, which might be a considerable drawback. However, since the increase of the off-current is proportionally small as compared to the increase of the on-current, the on-/off-current ratio of devices, based on post-treated electrodes is still higher than the one, obtained for OFETs on untreated electrodes. In particular, while $I_{on}/I_{off}$ of the latter accounted for $3.5 \times 10^3$, an on-/off-current ratio of $6.6 \times 10^2$ was achieved for OFETs, which were based on untreated electrodes.
4. Summary

Even if the explanation of the mechanisms involved in the vast improvement of OFET performance, generated by the applied solvent post-treatment will require further investigations, the basic phenomenon could be depicted. In fact, the distinct enhancement of the conductivity and stability of PEDOT:PSS electrodes was shown and the improvement of the OFET’s performance by the implementation of a rather simple electrode post-treatment process into the device fabrication procedure was demonstrated.

References


Functional Printing II
Reliability of Interconnections in Inkjet Printed Electronics

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Abstract

Printed electronics has been studied with increasing intensity over the last years and significant improvements have been reached in performance but the reliability of the printed structures has not been studied as much even though reliability plays a significant role in electronics. Therefore, it is important to include reliability testing and "design for reliability" into the printed electronics technology development.

This contribution will gather up the current knowledge of the reliability of interconnections in printed electronics as well as analyze the reliability requirements which come with the new manufacturing processes and materials. Reliability and performance of the printed interconnections are also compared to traditional solder-based interconnections as this will give a better understanding of their capabilities compared to currently used technology.

Keywords: Inkjet, interconnections, hybrid, reliability

1. Introduction

Advances in the electronics industry are heavily dictated by customer demand. As customers are used to certain level of functionality the change of manufacturing technique can not mean a drawback in functionality as the customers are reluctant to take "a step backwards" in terms of functionality.

Developers of the printing techniques are dreaming of all-printed electrical devices and some progress has already been made in very simple devices. [1,2,3] All-printed structures and applications have, however, the major challenge that materials heavily limit their potential functionality. Functionality is especially limited by the low performance of printable semiconductive materials and printing process. Consequently, the level of functionality required of today’s consumer electronic devices can be achieved only by using a hybrid technique that incorporates printable electronics with traditional manufacturing methods and takes advantage of the strengths of both techniques [4,5]. Inkjet—printing can be used in electronics miniaturization and integration to create new kind of component connections [6,7].

Attaching external components as well as power and signal connectors to printed structures requires external interconnections. Special attention has to be paid on the reliability of the interconnections as external connections are one the most common locations of failures in traditional electronics [8].

2. Solder

Soldering is by far the most widely used component attachment method in today’s electronics industry, but it has significant compatibility issues with silver which happens to be the most
commonly used conductive material in printed electronics. These material incompatibilities between inkjet silver ink and solder are caused by the leaching effect of the solder material. [9] In traditional electronics, leaching is solved by adding silver to the solder material, which though not canceling the effect yet obviates it as a problem in traditional thick film manufacturing. In inkjet-printing, however, the layer thickness is so much smaller that even the slightest leaching can cause open circuits and thus functional errors [10,11]. Therefore using solder with inkjet-printed silver structures would require deposition of an additional contact layer of another metal in order to protect the silver from leaching effect. Additional layer would, in turn, reduce the benefits gained from the additive and flexible manufacturing enabled by the inkjet-printing. Soldering has also shown problematic incompatibility with printed copper structures and thin copper layer has diffusion issues with solder materials if no barrier layer is used. The solder processing suffers from poor wetting of the solder material on top of the printed copper due to high surface roughness and heterogeneity. [9] Optimization of copper printing and post-processing might help reduce the incompatibility problems.

3. Electrically conductive adhesives

Adhesives do not have the same leaching effect as solders so they are more compatible with the inkjet-printing materials. Conductive adhesives have several other advantages over solder materials. Conductive adhesives have lower processing temperatures than solder materials and therefore they enable the use of cheaper substrates, they do not need flux treatment prior the processing and their high elasticity makes them preferred choices for flexible applications. [12] Conductive adhesives have also some drawbacks compared to solder materials, such as the tendency to contact resistance shift during exposure to elevated temperature and humidity as well as poor impact resistance. [12] Adhesive-based interconnections are also harder to repair because they lack the reworkability properties of most solder materials. Usability of electrically conductive adhesives as replacements for solder connections has been investigated in flexible electronics in general. [13, 14] Conclusion of these studies has been that adhesives do not have as good reliability as solder interconnections but still adequate for most applications. It has also been noted that failure mechanisms may be different for the different interconnection materials: in solder interconnections the cracking usually occurs through the solder material itself whereas in adhesive connections the failure is due to a delamination in the interface between adhesive and a component terminal or cracking of the component lead. Stress relaxation of adhesive base material may also cause problems in adhesive connections. [14] The electrical performance of isotropically conductive adhesives (ICA) attachment is deemed adequate for SMD attachment and found a viable solution for component attachment on inkjet-printed substrates [15]. However, because electronic applications must sustain long-term use, performance alone is not enough. Therefore, ICA connections are also tested and analyzed for long-term reliability in order to evaluate their overall feasibility on inkjet-printed applications and the results show that even though the adhesive interconnections are not as reliable as solder connections, the difference is because of the adhesive material itself and inkjet-printing as a fabrication technology for the printed structures does not have a significant effect [16]. Anisotropically conductive adhesive materials (ACA) have also been tested and preliminary results are very promising as ACAs have shown better long-term reliability in accelerated testing than ICAs. These results will be published later this year.

4. Direct connections using printed electronics

Accuracy of inkjet-printing is high enough to enable a direct connection of a bare silicon chip with grid array connectors [4,6,7]. Use of printed interconnections enables the use of bare silicon chips thus saving simplifying the manufacturing process and saving precious assembly space in
both area and height in final products.\[7\]

Figure 1: Interconnection between two inkjet-printed structures using ACA adhesive

Using bare silicon chips saves time and process steps as no packaging is required and IC chips can be used straight after silicon processing. Bare silicon chips are, however, more susceptible for external factors, such as moisture, static charges and mechanical stresses, from which the packaging traditionally protects the silicon chip. Therefore handling, assembly and process parameters have to be considered carefully in order not to damage the sensitive silicon chip.

Figure 2: Inkjet-printed direct IC chip interconnections

Direct connection of silicon chips by inkjet-printing is basically meant to supplement and in some cases even replace the traditional wire-bonding. Wire-bonding is widely used in traditional electronics manufacturing but is problematic to be used with printed electronics due to porosity and low small Young’s modulus of printed structures. However, successful wire-bonding on printed structures are also shown and wire-bondability seems to depend on the sintering conditions of the printed structures. One way to ensure wire-bondability is introduction of an additional plating layer on top of printed contact pads which in turn complicates the manufacturing process and diminishes the advantages of the additive manufacturing. \[17,18\]

Clear advantage of the direct connection is that the silicon connections can be fabricated si-
multaneously with the rest of the circuitry and no separate process step is needed just for the component attachment. However, in some cases combining the general circuitry and fine-pitch silicon chip attachment into same process step might require compromises in printing process optimization. Tighter packaging solutions would be greatly beneficial in today’s electronics manufacturing, especially when considering mobile devices and their size requirements. Preliminary reliability tests have been performed on the direct connections using inkjet-printing and the first results have been promising. The results will be published later and further analysis will be done with more accelerated environmental testing.

5. Reliability requirements

Printed electronics sets different requirements for the structures and interconnections than the regular rigid electronics. Flexible substrates are generally seen as one of the most important advantages of printed electronics as they enable the roll-to-roll manufacturing and thus fast large scale fabrication required by the electronics industry. Flexible substrates make it possible for the circuitry and interconnections to meet mechanical stresses they would not face in rigid substrates. These include, but are not limited to, stresses caused by the bending motion during assembly and in some cases during use.

Printed electronics are also usually fabricated from different materials than traditional rigid electronics and material incompatibilities need to be reconsidered, such as in the case of silver and solder materials. Adoption of novel manufacturing techniques also changes some of the structure parameters which affect the interconnection fabrication. For example inkjet-printed structures are significantly thinner in profile than their etched counterparts and this has to be taken into account when designing and fabricating the interconnections as these changes may affect the applicability and/or reliability of the interconnection techniques.

6. Conclusions

As a conclusion it can be said that fabrication of interconnections on printed electronics has different requirements than traditional rigid electronics and manufacturing processes and materials are not directly interchangeable.

Both electrically conductive adhesives and direct inkjet-printed connections have provided promising preliminary results and seem viable options for interconnection methods for printed electronics.

More research is, however, needed on both conductive adhesives and direct chip attachment in order to make these technologies applicable to larger scale electronics manufacturing. Special attention should be paid to the long-term reliability studies as this field has been overlooked in earlier studies.

Acknowledgement

The author J. Niittynen would like to thank Tuula ja Yrjö Neuvon rahasto, Ulla Tuomisen säätiö, Karjalaisen rahasto and Nokia Foundation for financial support. The author M. Mäntysalo is supported by Academy of Finland under grant n° 251882.
References


Optimization of screen printing processes for OLED substrate patterning

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Abstract

The current standard for OLED substrate patterning is photolithography [1, 2]. This relatively expensive method allows very little structural resolution, but this is not necessary for OLED lighting [3]. One way to reduce the production cost of OLED substrates are alternative patterning methods, such as laser ablation and screen printing processes developed by Fraunhofer COMEDD [4].

This paper focuses onto the optimization and further development of these substrate patterning technologies on glasses and polymer films in sheet-to-sheet processes. For this, alternatives to the currently used printing pastes are examined in order to eliminate problems with residues of the printing paste at the active area, solvent residues and the large roughness of the printed layers.

The goal of this optimization is a significant improvement of the substrate quality for subsequent deposition technology and a corresponding increase in the yield of flawless OLEDs.

Keywords: OLED, screen printing, substrate patterning, substrate characterization

1. Introduction

The screen printing technology offers the possibility to produce cost-efficient substrates for OLED and OPV applications. Necessary for this are suitable pastes for metallization (contacts, shunt lines) and the electrical isolation, which prevents short circuits between the printed metal and the evaporated metal cathode.

For the patterning of the substrates at Fraunhofer COMEDD a standard set of pastes (metal and isolation) is used, but these can’t meet all the demanded requirements. Thus, it has already been shown [5], that the used default isolation can be replaced (paste IsoA) by an alternative (paste IsoB) which caused significantly fewer defects, as depicted in Figure 1.

![Figure 1: left: Residues of Paste IsoA; right: no residues with the alternative paste IsoB.](image-url)
The following investigations aim to replace the alternative paste to the standard isolating paste for the production of substrates for OLED and OPV elements. This requires that the good results which are shown in [5], confirmed by further reliability tests.

2. Experimental

The following sections describe the conditions to establish the alternative paste IsoB as the new standard, by proving their reliability even in other OLED coating experiments. All substrates were printed with the screen printer EKRA X4 Professional, while the electro-optically characterization was performed with an Autronic Melchers DMS401 photometer.

2.1 Reliability tests (Lifetime)

In order to assess the reliability of alternative isolation paste IsoB finally, two more OLED coatings (E2, E3) with varying module design and different coating systems (Sunicel200, Sunicel400) were deposited, as presented in Table 1.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Tool</th>
<th>Module design, substrate size</th>
<th>Substrate batch</th>
<th>Number of modules</th>
<th>Active area (per module)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Sunicel400</td>
<td>4-segment, 370 × 470 mm²</td>
<td>1</td>
<td>48</td>
<td>4 × 14.92 mm²</td>
</tr>
<tr>
<td>E2</td>
<td>Sunicel200</td>
<td>4-segment, 35 × 50 mm²</td>
<td>1</td>
<td>12</td>
<td>4 × 14.92 mm²</td>
</tr>
<tr>
<td>E3</td>
<td>Sunicel200</td>
<td>TABOLA, 370 × 470 mm²</td>
<td>2</td>
<td>16</td>
<td>1 × 8300 mm²</td>
</tr>
</tbody>
</table>

Further experiments showed an inconsistent behavior. The coating E2 yielded similar results as E1, both for the electrical/optical characteristics and also in terms of reliability. But for E3 there was a massive failure of the OLED elements already after a very short operating time of a few hours at the burn-in test. The OLED devices revealed massive shorts in the printed areas of patterning, as displayed in Figure 2. The layer structure in these areas is shown in Figure 3. Consequently, there was a short circuit between the printed metallization and the evaporated metal cathode. This can only happen in these areas if the isolation layer has voids. Also, the electro-optically characterization indicates problems with the substrate quality of the batch LE1033 (substrate batch 2), as the tested devices with the alternative paste IsoB showed higher and more fluctuating voltages. Also compared to the reference (paste IsoA) the test paste (IsoB) revealed, significantly higher current densities at -5 V indicating short circuits in the device already before the device finally fails, cf. Figure 4.

![Figure 2: Short circuits after burn-in (marked area).](image1)

![Figure 3: Layer structure for the OLED in the marked area.](image2)
Figure 4: Comparison of the variability of the voltages and current densities at -5V of paste IsoA and paste IsoB.

This error image was examined more in detail, since it suggests a limited reproducibility of the substrate quality, which can’t be tolerated for a standard production process.

2.2 Defect analysis

Because of the error image uncoated substrates of LE1033 were optically analyzed again. Figure 5 presents the isolated defects. An electrical test showed a leakage current after a short operating time of 5 min and thus, these sites are responsible for the failure of the devices.

Figure 5: Substrate of the batch LE1033 (same position as the marked area in Figure 2).

Further measurements showed that the combination of standard metallization (MetA) and an isolation layer with IsoB can’t be guaranteed due to the particle size of the metal paste (D90 = 7 µm, several particles ≥ 25 µm and the layer thickness of the isolation (∼ 10 µm) defect free substrates.

To eliminate the error image two ways are offered. On the one hand it would be possible to increase the thickness of the isolating layer and hence, covering the metal particles. But a greater layer thickness is not desirable for reasons of encapsulation. The second possibility is to replace the standard metallization material by a paste with a smaller particle size.
2.3 Alternative metallization

As an alternative for the used standard metallization (paste MetA) a silver paste (paste MetB) with significantly reduced particle size (D50=0.4 μm, D90=0.8 μm) was selected. For this reason, it was necessary to determine the optimal parameters for screen printing and curing. The goal was a flawless print and a very low sheet and contact resistance to the ITO.

For the optimal print parameters a pressure of 130 N, a velocity of 65 mm/s and a distance between substrate and screen from 2 mm be determined. A 280 Mesh screen was chosen. Good curing conditions, such as a temperature of 200°C and a time of 60 min, with a sheet resistance of 40 mΩ/□ and a contact resistance of 38 mΩmm² was determined as a good trade-off between cost and benefit. These values are valid for glass substrates, for other substrate materials (e.g. polymer films), the parameters need to be readjusted. Figure 6 shows the measured values of the sheet resistance. Afterwards, the surface roughness was examined. The metallization MetB showed with \( R_a = 0.368 \, \mu m \) and \( R_{\text{max}} = 2.51 \, \mu m \) on average up to 50% lower values than MetA.

Based on these results substrates were patterned using the pastes MetB and IsoB and were optically characterized. Figure 7 displays substrates having the pastes MetA + IsoA and MetB + IsoB. No residue of the printing pastes in the active area and voids in the isolation layer were found, hence, OLEDs were built on these substrates. These devices were electro-optically characterized. Figure 8 shows an example of the comparison between two OLEDs. Obviously, the characteristics of the OLED on a substrate using the paste MetB and IsoB are better. Thus, these OLEDs show a lower leakage current (at -5 V) by an order of magnitude. By determining the lifetime a comparable value could be measured both with the substrates applying pastes MetA + IsoA and MetB + IsoB.
Optimization of screen printing processes for OLED substrate patterning

3. Summary

It could be shown that without changing the standard metallization MetA the use of alternative isolation paste IsoB does not allow a stable quality of the substrate. After changing the metallization to MetB the defects described above could not be found. Due to the small particle size of MetB it is now possible to cover them securely with IsoB. This was demonstrated by patterning several substrate batches. A first OLED coating on patterned substrates with MetB + IsoB shows that excellent characteristics (leakage current, characteristic curve) could be achieved on these substrates.

For a final release of the alternative printing pastes MetB + IsoB as the new standard for the substrate patterning further OLED coatings are required to confirm the reliability (lifetime).
Acknowledgement

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References


Transparent and conductive inks: an alternative to ITO

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Abstract

Nowadays, transparent and conductive materials are increasingly used, especially for thin photovoltaic films or tactile objects. The main material used for the conductive layers of solar cells is the ITO (Indium Tin Oxide). This material has great potential: it has a high optical transmission combined with a high conductivity and quite a long lifetime. However, using ITO causes various environmental and economic issues. Indeed, this material is rare and synthesized from exhaustible resources, making it very expensive. Moreover, the ITO is rigid. For all these reasons, alternative transparent and conductive materials are under investigation. In this study, we reviewed and compared these new materials, with a special focus on how they can be introduced into printing inks.

The development of special printing inks was recently facilitated by the increasing use of nanoparticles. Indeed, several new inks are being formulated based on nanoparticles or nanowires of silver, copper or carbon nanotubes. Simultaneously, silver-ion based inks are under development.

The main difficulty in such formulation is to find particles, which could provide conductive and transparent properties to the ink. It is important to keep in mind that this ink should remain stable and printable, with specific requirements in the case of inkjet printing. More precisely, it is hard to combine these antagonist properties: transparency is optimal with a wide grid of particles and large voids in the material, whereas conductivity requires a thin grid. Each application requires an ink with specific properties, such as flexibility and high or low sintering temperature. Even if inkjet seems to be the most suitable printing process, it restricts the size of the particles, due to the nozzle dimensions. To conclude, the study investigates other printing processes, such as screen-printing and flexography in order to suggest additional solutions.

Keywords: transparent, conductive, nanoparticles, inkjet

1. Introduction

Nowadays, some markets such as touch screen, flat screen or photovoltaic cells represent a large market share. Currently, the market of touch screen is growing up at the rate of 13.7% per year. Over 80% of households have a flat screen and the market of photovoltaics has nearly tripled over 4 years. All these products need the use of transparent conductive materials, identified as Transparent Conducting Oxides (TCO).

TCOs are complex to produce; indeed, transparency and conductivity are two antagonist properties. Transparency is optimal with a wide grid of particles and large voids in the material, whereas conductivity requires a thin grid.

Figure 1 shows that when the transmission goes up, the resistivity rises. The resistivity is the reverse of the conductivity. This graph confirms that the two properties are antagonist. Difficulties arise when both properties must be enhanced. In addition, these properties are intrinsic.
2. Presentation of ITO

Nowadays, the most used TCO is **Indium Tin Oxide (ITO)**. This material is a solid solution of Indium (III) oxide (In2O3) and Tin(IV) oxide (SnO2). Indium is a rare mineral; it can be found in China, Korea or the United States. 66% of indium is used to produce flat screens. The main quality of this material is to combine a high electrical conductivity ($10^4$ S/cm) and a good optical transparency (70%). Thanks to its long lifetime (over 10 years), it can be used as the anode in solar cells. Table 1 shows the main characteristics of ITO.

<table>
<thead>
<tr>
<th>Properties</th>
<th>ITO Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Résistance</td>
<td>commercial solvents</td>
</tr>
<tr>
<td>Flame temperature</td>
<td>high temperatures (until 1 400 °C)</td>
</tr>
<tr>
<td>Specific weight</td>
<td>1537 °C-1926 °C</td>
</tr>
<tr>
<td></td>
<td>7150 kg/m²</td>
</tr>
</tbody>
</table>

 Currently there are different processes used to deposit ITO thin layers:

- evaporation by electron beam
- vapor deposition
- physical vapor deposition

Whatever the process, when depositing the layers, it is necessary to create a vacuum to improve the adhesion between the layers.
Unfortunately, this material has numerous defects. The most important one is the supply of Indium. Indeed, resources of Indium are exhaustible: according to US Geological Survey, there will be no more Indium in 2020. This fact is really a warning; it shows the necessity to find an alternative. Moreover, Indium is subject to market and economic forces, so that its price is fluctuating.

Figure 2 shows the effect of the development of photovoltaic cells in 2004 on the ITO’s price. Because of this fluctuating price, the cost of productions using ITO is variable. In addition, if the performance of the sputtering process and the cost of deposition are taken into account, it increases the price by 800 $/kg. For example, the production of an LCD display costs 4.8 $/m².

Regarding recyclability, ITO cannot be considered as a "green" product. Indeed, nowadays most of the flat screens are burnt at the end of their life. However, abundant research is made in order to improve recycling of the ITO and better results are being obtained. Last, but not least, brittleness and non-ability to be flexed multiple times are other limitations of ITO.

Consequently, ITO has relevant properties but is not a long term solution. Moreover, changing the TCO would allow having a better carbon footprint and different physical properties. Thanks to those properties, innovative products could be designed. ITO replacement is potentially an attractive and promising market.

3. Conductive, transparent and printable inks

For all these reasons, alternative transparent and conductive materials are under investigation in order to formulate new printable inks. Currently, searchers work with various compounds:

- TCO,
- metal flakes (their conductivity is smaller by 4 or 5 times to pure metals because of the resin and the additives which coat the flakes),
- nanoparticles,
- organic compounds.
In the field of nanoparticles, the most used metals are silver and copper (which is less expensive but more restrictive). They can be found as nanoparticles (between 5 and 1,000 nm), nanowires or nanotubes (100 μm length and less than 10 μm of diameter).

Organic compounds are also under investigation. First, the PEDOT:PSS is already used to replace the ITO. It is a mixture of two ionomers: sodium polystyrene sulfonate (PSS) and poly(3,4-ethylenedioxythiophene) (PEDOT). This compound is generally applied as a dispersion of gelled particles in water. Its conductivity is about 1,000S/cm and can be improved by post-treatments. It is a fragile molecular complex which can be degraded by ultraviolet light or under high temperature or humidity. However, it has flexible properties.

Graphene and carbon nanotubes (CNT) are also used. They are composed of benzenic cycles which provide their conductive properties (6,000 S/cm and more) All these organic compounds show a transparency of about 80%.

Last, silver ion-based inks are starting to emerge. Such inks are liquid and result into a metallic silver film when they are printed and cured.

4. Inks requirements

In addition to conductivity and transparency, these components must have printability properties. They should remain stable during storage and printing.

Metallic flakes must be finely dispersed in a resin suspension matrix for the ink to be conductive. Moreover, high conductivity levels can be achieved when the suspension matrix contains glass particles or ceramics and when the sintering temperature is high (>650°C). In terms of printability, the ink formulation should integrate a milling agent in order to prevent sticking.

In nanoparticles-based inks, the maximum size of the particles must remain under 500 nm in order to avoid clogging of the nozzles during inkjet printing. In addition, in order to allow printing on most flexible substrates, the sintering temperature must be low. An enhanced conductivity can be obtained through a correct aggregation of the particles after printing.

Copper-based inks need an encapsulation process to prevent oxidization of the conducting particles.

To print such inks, inkjet and screen printing are the most widespread processes. They both enable deposits of various thicknesses and can print precise patterns.

5. Main applications

5.1 Photovoltaics

Photovoltaics are a "green" technology which consists in generating electrical power by converting solar radiation into electricity. A solar cell consists of different layers. One of the electrodes is made by ITO. It could be interesting to replace ITO by conductive, transparent and printable inks but the lifetime of the particles used in these inks is too short (1 to 5 years only). Consequently, researchers keep looking for alternatives. The different layers of solar cells can be manufactured using classical printing processes. The most suitable methods are gravure and screen printing. For each process, there are advantages and limitations.
Table 2: Comparison of gravure and flexographic processes

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravure</td>
<td>Important inker surfaces, Unvenen printing</td>
</tr>
<tr>
<td></td>
<td>Printed precision</td>
</tr>
<tr>
<td>Flexographic</td>
<td>Double report</td>
</tr>
</tbody>
</table>

5.2 OLED: Organic Light Emitting Diodes

These inks are the main compound of some layers in Organic Light Emitting Diodes. The latter are multi-layer devices made of:

- a transparent substrate (PET or glass),
- a transparent anode which creates electron gaps thanks to an electric stimulation. It is made of ITO,
- a metal cathode, which is the electron emitting layer, mainly composed by metal such as aluminum, calcium or magnesium,
- a conductive organic layer sandwiched between the anode and the cathode. This layer is composed of several organic ones:
  - a conductive layer which transports the gaps from the anode,
  - an emitting layer which transports the electrons from the cathode.

This device is based on electroluminescence. This phenomenon is both optical and electrical. It enables a material to emit light in response to an electrical current flowing through. Indeed, it is the result of the recombination of electrons (emitted by the metal cathode) and the gaps (present in the transparent anode: ITO) created by the two electrodes thanks to the application of a potential difference. This recombination is the source of light emission.

Considering the market trend, we can see that the market share of OLED will double by 2016.

6. conclusion

To summarize the merits of these news inks, we will analyze in a SWOT diagram the strengths, the weaknesses, the opportunities and the threats of the latter.

First, the strengths. These inks enable printing of conductive and transparent layers on flexible substrates and large surfaces. They are made of non-rare resources, compare to ITO.

In addition, when they are optimized, the costs of the materials and the process will be cheap enough to enhance the replacement of ITO. As weaknesses, we should notice that the toxicity of the nanoparticles might be an issue in the development of their use. The particle size, especially for the inkjet process, can also be a problem.

But these inks reveal a real potential which can be extended to the other print processes (lithography, gravure, flexography). One of the main limits in these development prospects is the availability of the raw materials. Indeed, silver flakes are produced on a huge scale (thousands of tons per year) but nowadays, nanoparticles are not developed that much. However, there is a strong likelihood that the nanoparticle production will spread in the long term. This process will be helped by the fact that nanoparticles (silver and copper) will find uses in other areas (such as healthcare).
References


Fully printed flexible ITO- and Silver-free Electroluminescent Displays

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Abstract

One of the main applications of electroluminescent displays (ELD) is background lighting on rigid and flexible substrates in many different areas such as the advertisement sector or the automotive industry. The usual capacitor-like build-up consists of an electroluminescent film as well as a dielectric layer between a translucent top electrode and a silver back electrode. The electroluminescent layer is a phosphorous material which is usually a metal doped zinc sulfide. The general approach when preparing EL devices for background lighting via screen printing is to use expensive and brittle indium tin oxide (ITO) as the translucent electrode and a comparatively thick film of expensive silver as the counter electrode.

In this work, we utilize highly conductive translucent poly (3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) films instead of ITO together with a phosphorous paste to create ITO-free electroluminescent displays. Going one step further, we also use PEDOT:PSS as a replacement for the silver electrode for fully printed flexible ELDs. This demonstrates how the costs for such EL devices can be significantly reduced by replacing ITO and silver. In detail, we show the relationship between the thickness, conductivity and transparency of printed PEDOT:PSS electrodes. Furthermore, the properties of the PEDOT:PSS films are exploited to evaluate the possibilities to induce light intensity gradients in the device active area by variation of the thickness and, correspondingly, the space-resolved conductivity.

Keywords: Electroluminescent devices, ITO-free, Silver-free, PEDOT:PSS

1. Introduction

Today’s ELDs for background lighting in advertisement and other fields usually use ITO and silver as electrode materials [1][2], as shown in Fig. 1 a). These materials are commercially available and work well in terms of functionality and lifetime [1]. But silver and ITO are expensive materials and ITO is difficult to process [3] and rather brittle. Therefore, it is desirable to replace either one or both of the materials with a substance that excludes the previously mentioned drawbacks and can be applied by coating and printing. Earlier works of other groups and ourselves [4][5] have shown that different formulations of poly (3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) can be used for conductive layers such as electrodes. ITO-free ELDs with PEDOT:PSS formulations were already reported [6]. In this work, the ITO and silver electrodes were replaced with PEDOT:PSS films both on glass and on foil substrates as shown in Fig. 1 b) and Fig. 1 c). The possibility of using PEDOT:PSS as an electrode material for ELDs and evaluation of the achievable luminesce and lifetime were explored in detail.
Figure 1: Layer stacks of a) an conventional ELD, b) an ITO-free ELD and c) an ITO- and Silver-free ELD (referred to as "PEDOT-only" device).

2. Experimental Setup

2.1 Materials

For processing the ELDs, three substrates were utilized including the following: ITO covered glass for the conventional ELDs, glass only substrates for the ITO-free and "PEDOT-only" devices (when ITO as well as silver was replaced by PEDOT:PSS) and a PET foil for the flexible fully printed ELDs. The ensuing layers of dielectric (Briflex Paste System) and phosphorous material (Phosphor Paste Green/Blue) were commercially obtained as screen printing pastes from Metalor and GWENT Group, respectively. The silver paste was also purchased from METALOR. Two different PEDOT:PSS variations were utilized based on CLEVIOS™ P AI4083 and CLEVIOS™ PH500. The formulations for the evaluated PEDOT:PSS electrodes are shown in Table 1.

Table 1: Contents of the PEDOT:PSS formulations which were examined in this work. All values are given in vol.%

<table>
<thead>
<tr>
<th>Formulation</th>
<th>AI4083</th>
<th>PH500</th>
<th>H2O</th>
<th>IPA</th>
<th>EG</th>
<th>Zonyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELD_1</td>
<td>60.0</td>
<td>30.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td>+ 0.4</td>
</tr>
<tr>
<td>ELD_2</td>
<td>57.0</td>
<td>28.5</td>
<td>9.5</td>
<td>5.0</td>
<td></td>
<td>+ 0.4</td>
</tr>
</tbody>
</table>

The formulations in Table 1 were chosen based on our earlier results which revealed that ELD_1 represents a "low conductivity" formulation while ELD_2 is a "high conductivity" formulation [5]. The use of these two formulations together with variations of the film thickness would show the impact of conductivity on the functionality and efficiency of ELDs.

2.2 Methods

In order to measure the layer thickness and topography of the PEDOT:PSS layers, glass substrates were cleaned with isopropyl alcohol and a clean room tissue and dried with nitrogen. The same pre-treatment was done for the ITO coated glass substrates for the conventional ELDs and the PET foil substrates for the fully printed PEDOT-only devices. All PEDOT:PSS layers prepared in this work were done by doctorblading with an Erichsen Coatmaster 510 in air at a substrate temperature of 40 °C and a coating speed of 10 mm/sec. Different dry film thicknesses were achieved with doctorblading by using different gaps varying from 15 μm up to 95 μm. The PEDOT:PSS layers were then dried and thermal annealed on a
hotplate at 130 °C for 10 minutes. Convention ELDs, ITO-free devices and PEDOT-only devices were all prepared via doctor blading. In addition, screen printing was also used to prepare PEDOT-only devices on PET with an Easy Coater EC32 from Coatema.

A Veeco Dektak 150 profilometer was used for measuring thickness of all layers and for examining the roughness of the phosphorous, dielectric and silver layers. the surface topography of the ITO replacing PEDOT:PSS films were examined via atomic force microscopy (AFM) with a Nanosurf® easyScan 2. UV/Vis measurements were carried out with a Lambda 950 Spectrometer from Perkin Elmer. Luminescence measurements of the completed devices were done with a CS-2000 spectroradiometer from Konica-Minolta immediately after preparation and again after 24 hours of constant operation with alternating current voltage at 120 V and 1000Hz. The top side of all ELDs was not encapsulated and all processing, storage and measurements were done in air at ambient conditions with a temperature of ~ 21°C and ~ 50 % relative humidity.

3. Results and Discussion

3.1 Coated ITO-and silver-free ELDs on glass substrates

The doctorbladed PEDOT:PSS films used as ITO replacement showed similar Peak-Valley-Height (Ry) values for both ELD_1 and ELD_2 as shown in Table 2. The distribution of the Peak-Valley-Heights however was more evenly for the highly conductive formulation ELD_2, which may speak for a more homogeneous film. The Root Mean Square roughness (Rq) values were 1.5 nm and 1.9 nm for ELD1 and 2, respectively. These low values compared to the rather high Peak-Valley-Height values could indicate the presence of some impurities in the films. Gaps of 15 µm and 21 µm were used when preparing the films. The resulting dry thicknesses and gap can also be found in Table 2.

Table 2: AFM topography scans and roughness values for doctorbladed PEDOT:PSS prepared from different formulations. The roughness is given as the Root Mean Square (Rq) and the Peak-Valley-Height (Ry) in nm. The scanning area is 6.25 µm²

<table>
<thead>
<tr>
<th></th>
<th>ELD_1</th>
<th>ELD_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rq</td>
<td>1.5 ; Ry: 12.0</td>
<td>1.9 ; Ry: 16.1</td>
</tr>
<tr>
<td>Dry thickness, 15 µm gap:</td>
<td>68 nm</td>
<td>55 nm</td>
</tr>
<tr>
<td>Dry thickness, 21 µm gap:</td>
<td>81 nm</td>
<td>70 nm</td>
</tr>
</tbody>
</table>

PEDOT:PSS itself is not a clear ink and films become more blue and opaque the thicker the films get. Loss of transmittance due to the PEDOT:PSS bottom electrode however was almost negligible with the chosen layer thickness, as demonstrated via UV/Vis spectrometer measurements in Fig. 2.
The resulting dry thicknesses for the doctorbladed phosphorous, dielectric and silver films for the ELDs on glass substrates are shown in Table 3 together with the Peak-Valley-Heights.

Table 3: Dry thickness and Peak-Valley-Height for doctorbladed ELD materials

<table>
<thead>
<tr>
<th>Layer</th>
<th>Mean dry thickness in μm</th>
<th>Peak-Valley-Height in μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>phosphorous</td>
<td>23.2</td>
<td>27.1</td>
</tr>
<tr>
<td>dielectric</td>
<td>22.9</td>
<td>22.9</td>
</tr>
<tr>
<td>silver</td>
<td>12.7</td>
<td>9.5</td>
</tr>
</tbody>
</table>

After applying the terminal layer of PEDOT:PSS as silver replacement on the dielectric layer and testing the functionality of the devices, several observations were made. Formulation ELD_1 was neither suitable as ITO replacement nor as an alternative for silver due to the lack of sufficient conductivity. None of the devices which were prepared with ELD_1 functioned as ELDs. When using the highly conductive formulation ELD_2, functional ELDs were achieved both for ITO-free and PEDOT-only devices. However, a minimum thickness is necessary to overcome the rather rough surface of the dielectric layer when replacing the silver layer with PEDOT:PSS by doctorblading. Fig. 3 shows a comparison of PEDOT-only devices during operation with a PEDOT:PSS thickness of 325 nm or 55 nm. The latter thickness corresponds to a coating gap of only 15 μm. As shown in Table 3, the peak-Valley-Height of the dielectric layer was nearly 23 μm. Therefore, the PEDOT:PSS film didn’t completely cover the printing area which caused inhomogeneous lighting and defects.

Table 4 shows a summary of the luminescent measurements of all different ELD types on glass substrates examined for this work. Different layer thicknesses of said PEDOT:PSS layers were also evaluated as well as the drop in luminescence after 24 hours of constant operation.
Figure 3: Backside view of the PEDOT:PSS electrode (left), demonstration of PEDOT-only ELDs with 325 nm (middle) and 55 nm (right) PEDOT:PSS as silver replacement. The active area was 53 cm$^2$.

Table 4: Luminescence measurements on ELDs with different layer stacks and thickness which were driven at 120 V and 1000 Hz

<table>
<thead>
<tr>
<th>ELD type</th>
<th>Bottom PEDOT:PSS electrode thickness</th>
<th>Top PEDOT:PSS electrode thickness</th>
<th>$L_v$ in cd/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>-</td>
<td>-</td>
<td>160</td>
</tr>
<tr>
<td>Conventional, 24 h operation</td>
<td>-</td>
<td>-</td>
<td>113 (drop by 29 %)</td>
</tr>
<tr>
<td>ITO-free</td>
<td>-</td>
<td>55 nm</td>
<td>135</td>
</tr>
<tr>
<td>ITO-free</td>
<td>-</td>
<td>70 nm</td>
<td>128</td>
</tr>
<tr>
<td>ITO-free, 24h operation</td>
<td>-</td>
<td>55 nm</td>
<td>98 (drop by 27 %)</td>
</tr>
<tr>
<td>PEDOT-only</td>
<td>55 nm</td>
<td>70 nm</td>
<td>106</td>
</tr>
<tr>
<td>PEDOT-only</td>
<td>55 nm</td>
<td>140 nm</td>
<td>107</td>
</tr>
<tr>
<td>PEDOT-only</td>
<td>55 nm</td>
<td>210 nm</td>
<td>114</td>
</tr>
<tr>
<td>PEDOT-only</td>
<td>70 nm</td>
<td>325 nm</td>
<td>107</td>
</tr>
<tr>
<td>PEDOT-only, 24h operation</td>
<td>70 nm</td>
<td>325 nm</td>
<td>88 (drop by 18 %)</td>
</tr>
<tr>
<td>PEDOT-only, 1/2 active area</td>
<td>70 nm</td>
<td>325 nm</td>
<td>110</td>
</tr>
</tbody>
</table>

The conventional devices showed the highest luminescence and were well within the reported values for common ELDs with a $L_v$ of 160 cd/m$^2$ [1]. For the ITO-free devices, the thinner PEDOT:PSS layer of 55 nm reached the highest value of 135 cd/m$^2$. For the PEDOT-only devices, the influence of increasing thickness (and therefore conductivity) of the silver replacing PEDOT:PSS layer on the luminescence of the ELD was examined. Top electrodes with thicknesses of 70, 140, 210 and 325 nm were applied and the luminescence measurements revealed that there was no significant increase for thicker layers. The differences in values are minor, not noticeable by the human eye and within the error range of the measurement setup. The measured luminescence was not influenced by the size of the active area. A PEDOT-only device was cut in half and an insignificant change in the luminescence was recorded for the same measurement parameters (120 V, 1000 Hz).

A comparison of the luminescence after 24 hours of operation indicates that ELDs with PEDOT:PSS electrodes may be as stable as conventional devices or may perform even better. While the conventional ELD showed a drop of 29 %, the PEDOT-only device had an efficiency loss of only 18 %.

3.2 Printed ITO-and silver-free ELDs on foil substrates

In order to show the applicability of the examined PEDOT-only devices for industrial applications, flexible ELDs on PET substrates without ITO or silver were coated and printed. Both PEDOT:PSS electrodes were doctorbladed and all other layers were screen printed. Screen print-
ing the ensuing layers, which was done with a squeegee pressure between 4 and 5 bars, did not
damage the underlying PEDOT:PSS layer. The corresponding results are shown in Fig. 4.

![Figure 4: Demonstration of fully printed PEDOT-only flexible ELD.](image)

The thickness of the PEDOT:PSS layers were 70nm for the ITO replacement and 150 nm for the
silver replacement. The phosphorous layer was 30 μm thick and the dielectric layer was 25 μm.
The achieved luminance was 133 cd/m², which is seven better than the PEDOT-only devices
prepared on glass substrates. This was attributed to the slightly thicker phosphorous layer.

4. Conclusions and Summary

We were able to show that flexible ELDs, which do not require ITO or silver, can be processed
with adequate luminescence values. This ensures a significant reduction in the production costs.
When one compares the typical prices for ITO coated foils and silver pastes with the costs for
the PEDOT:PSS formulation used in this work and incorporate the typical layer thicknesses,
one ends up with electrode costs for conventional ELDs of ~45 €/m² and only 9 €/m² for
PEDOT-only devices.

It was not possible to induce light intensity gradients in the device active area by variation of the
PEDOT:PSS electrode thickness as shown in Table 4. The achievable total lifetime and possible
drawbacks of said devices have yet to be further examined. However, this work has shown a
promising approach towards cheap, flexible ITO- and silver-free ELDs which could open the field
to new applications.

Acknowledgement

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References


Graphic Printing I
Digital watermarking in RGB and YCbCr color space for protection of color images

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Abstract

To copyright, a digital image may be watermarked and one can find numerous algorithms how to do it. When digital watermarks have been embedded the usual wish is to store the image in any graphical format. One of the most popular formats is JPEG, however JPEG is typically lossy and it introduces distortion in watermarks. Therefore it needs watermarking techniques that are robust to JPEG compression. This problem is well known.

We study a particular case embedding of binary image into digital color image in RGB and YCbCr space. This problem was not enough considered in literature and it plays an important role for protection of the printed images. We use next simple observation. JPEG converts any color image into YCbCr space with luminance Y represented with more bits than two chrominance Cb and Cr. It means that Y seems to be preferable for robust watermarking.

The aim of our work is to investigate distortion introduced in digital watermarks by JPEG to find a balance between the compression level and the quality of the extracted watermarks. To test quality of extracted watermarks we use a set of common objective measures particularly RMSE (Root Mean Squre Error), that is Euclidian metric. However the visual quality of watermarks can also play an important role and to take into account Human Visual System we use the Watson measure that is based on the perceptual model.

We have tested watermarking in YCbCr and RGB space for a thousand of color images and found: 1) which of the used distortion measures can be suitable for our problem, 2) watermarking in YCbCr color space can be more robust to JPEG compression and there are unique images for which watermarking in blue channel of RGB space is more preferable.

Keywords: watermarking, color image, JPEG compression, robustness

1. Introduction

To copyright, a digital image may be watermarked and one finds numerous techniques how to do it. When considering color images any technique is based on the next main points: 1) selection of the color space, 2) domain of embedding, space or frequency, 3) embedding and detection algorithms, 4) possible transformations of stego images.

Digital images are represented by numerous color spaces. In RGB space any image has three color channels R, G and B that can be used for watermarking. In Stego Color Cycle technique the channels are selected cyclically [1], the Pixel Indicator Techniques [2] recommends a label, that indicates the channel. In color model YCbCr, that is used in JPEG format, luminosity Y is assumed to be preferable for embedding [3]. However, together with the Y channel of YCbCr, YUV, YIQ color space the chrominance Q and I are exploited [4].

Embedding in frequency domain can be achieved by orthogonal transformations, most popular of which are DCT [5] and DWT. DWT is specified by wavelet function and by the level of expansion.
For example, in [4] the Haar wavelet was used and the levels up to \( j = 3 \) was discussed [4]. Embedding in YCbCr color space with three level DWT and 9/7 biorthogonal wavelet has considered in [6].

For digital watermarking one finds a large number of embedding and detection algorithms [7]. A generalization of the additive algorithm has been proposed in [8] for embedding of the color image into color one. In this approach called \( \alpha \)-Blending Technique the DWT coefficients of both images are mixed by an \( \alpha \) blending transformation to generate stego image.

Any transformations of stego image can introduce distortion into watermarks. From the practice point of view such transformation as lossy compression and printing are important. In fact, let one wishes to send his stego image to somebody, then this image has to be stored in any graphical format, for example, in JPEG, then it may be printed and scanning to extract watermark. In literature JPEG compression and printing are named as J2J (Jpeg-to-Jpeg) [9] and PS (Print-Scan) [10], both transformations are studied by many authors.

We consider watermarking of color image given in RGB or YCbCr model by a LSB method in space domain. The aim of our work is to investigate distortion introduced by JPEG to find optimal schemes of embedding and detection. We test quality of extracted watermarks with the help of two distortion measures. First is RMSE (Root Mean Square Error), that is a mathematical matrix, and second is Watson’s measure based on the perceptual model. Watson’s measure was proposed as a visual criterion for design of quantization matrices for JPEG compression [11]. By testing of a thousand color image we found next. First, watermarking of G and Y channels shows close robust to JPEG compression, if before compression the stego image watermarked in YCbCr is convert into RGB color space. Second, the distortion of the watermarks embedded into Y channel may be less than for G channel.

The paper is organized as follows, first we describe the scheme of embedding and detection and introduce the Watson’s perceptual measure of distortion, next, the results testing of a thousand color images are presented.

2. Embedding and detection scheme

We assume that the cover image \( C \) is represented in RGB or YCbCr color space and watermark \( M \) is a binary image that is embedded into a bit plane of the channel R, G, B or Y, Cb and Cr. Let the bit plane \( V \) have its weight \( 2^{V-1} \), then all bit planes up to \( V = 4 \) can be used without introducing noticeable distortion. For analyze we selected \( V = 3 \) and embedding algorithm adds bits of \( M \) with bits of the third bit plane. The obtained image with hidden watermark, the stego image, is converted by J2J transform. It means that digital image is storied in JPEG file, that is decompressed later. We consider the J2J transformation as mapping \( A \rightarrow A_q \), where \( q \in [1, 100] \). Parameter \( q \) describes the loss due to JPEG, the more \( q \) the loss is less and the quality of storied image is better. Detection is assumed to be blind, it means that it needs the cover image. It may be taken or its J2J transform \( C_q \), however \( C_q \) leads to less distortions of the extracted watermarks.

Figure 1 presents the embedding and detection scheme in RGB and YCbCr color spaces. The scheme has numerous ways of embedding, JPEG compression and detection. Here and later color space of the image will be specified by abbreviation RGB or YCbCr. At the scheme we selected the paths that show the best results for RGB and YCbCr. As for RGB it means that the binary image \( M \) is embedded into G channel of the cover image \( C\_RGB \) and compressed by JPEG. Then with the help of the compressed cover image \( C_q\_RGB \) the hidden watermarks are extracted from \( Sq\_RGB \). Output is watermark \( MG \). Next paths lead to watermarks \( MR, MB \) embedded into or channel and extracted from \( Sq\_RGB \).
Figure 1: Digital watermarking in RGB and YCbCr color space. Abbreviations RGB and YCbCr denote two spaces of color representation. The cover image is \( C_{\text{RGB}} \) or \( C_{\text{YCbCr}} \), the watermark is a binary image. Embedding algorithm uses bit planes of the channels R,G,B or Y, Cb and Cr. The images with watermark hidden \( S_{\text{RGB}}, S_{\text{YCbCr}} \) are compressed by JPEG, where indicates degree of loss. Detection needs the cover image. The watermarks are extracted from \( Sq_{\text{RGB}}, Sq_1_{\text{YCbCr}} \) or \( Sq_2_{\text{YCbCr}} \) from by different ways shown by possible paths. Output of the scheme are nine watermarks \( MR, MG, MB, MY, MCB, MCR \) and \( MUY, MUCB, MUCR \). The selected paths result in the smallest distortion.

As for YCbCr the selected paths tell that watermark \( M \) is embedded into the Y channel of the cover image \( C_{\text{YCbCr}} \) that is converted to \( S_{\text{RGB}} \). Then after JPEG compression the image \( Sq_{\text{RBG}} \) is transformed into \( Sq_1_{\text{YCbCr}} \) to detect hidden watermarks. Detection needs \( Cq_{1\_YCbCr} \) obtained from the cover image \( C_{\text{RGB}} \). As result there is the extracted watermark \( MUY \). Other paths lead to a set of watermarks \( MY, MCB, MCR \) embedded into the channel Y, Cb, Cr and extracted from \( Sq_2_{\text{YCbCr}} \) and there is a set of watermarks \( MUCB, MUCR \) embedded into the channels Cb, Cr and extracted from \( Sq_1_{\text{YCbCr}} \).

3. Measures of distortion

To analyze the scheme it needs a set of measure of distortions that describe distinguishably between the initial and extracted watermarks. We focus on two measures as RMSE and Watson’s measure. For matrix \( A \) and \( B \) of the same size RMSE also known as Euclidian distance reads

\[
RMSE(A, B) = \sqrt{\frac{1}{\Omega} \sum_{m,n} (A[m,n] - B[m,n])^2},
\]

where \( \Omega \) is total number of the matrix elements. This is an objective measure that is often used as rough test because of two images with the same RMSE may be not perceptually equivalent. The problem with RMSE is that it treats changes in all terms of the image equally. However, HVS is not uniform and its response differently depends on the frequency and strength of the input. Together with RMSE we take the Watson’s measure based on the visual model. Watson’s measure uses the block DCT transform and a DCT frequency sensitive matrix \( T \). This
matrix is a function of a number of parameters particular the image resolution, and it has the form [12]

\[
t = \begin{pmatrix}
1.40 & 1.01 & 1.16 & 1.66 & 2.40 & 3.43 & 4.79 & 6.56 \\
1.01 & 1.45 & 1.32 & 1.52 & 2.00 & 2.71 & 3.67 & 4.93 \\
1.16 & 1.32 & 2.24 & 2.59 & 2.98 & 3.64 & 4.60 & 5.88 \\
1.66 & 1.52 & 2.59 & 3.77 & 4.55 & 5.30 & 6.28 & 7.60 \\
2.40 & 2.00 & 2.98 & 4.55 & 6.15 & 7.46 & 8.71 & 10.17 \\
3.43 & 2.71 & 3.64 & 5.30 & 7.46 & 9.62 & 11.58 & 13.51 \\
7.79 & 3.67 & 4.60 & 6.28 & 8.71 & 11.58 & 14.50 & 17.29 \\
6.56 & 4.93 & 5.88 & 7.60 & 10.17 & 13.51 & 17.29 & 21.15
\end{pmatrix}
\]

Here a smaller value indicates that the eye is more secretive to this frequency. The perceptual distance between an original images \( A \) and its distorted version \( B \) is defined as follows [11]

\[
WATSN(A, B) = \left\{ \sum_{k,p,b} \left( \frac{a[k,p,b] - b[k,k,b]}{s[k,p,b]} \right)^{1/2} \right\}^{1/2},
\]

where \( a[k,p,b], b[k,p,b] \) are DCT coefficients of a \( 8 \times 8 \) block \( b = 1, 2, \cdots \) and \( s[k,p,b] \) is an array based on sensitive matrix \( T \) and the masking properties of the original image \( A \).

In more detailed \( s \) is defined as

\[
S[k,p,b] = \max \left\{ t[k,p,b], |a[k,p,b]| \omega t[k,p,b]^{1-\omega} \right\},
\]

where \( \omega = 0.7 \) and

\[
t[k,p,b] = T[k,p,b] \left( \frac{a[0,0,b]}{c} \right)^{u},
\]

where \( a[0,0,b] \) is DC coefficient of the \( b \)th block and \( c \) is the average of \( a[0,0,b] \) over blocks,

\( u = 0.649 \). By means of Eqs 1 and Eqs 2 the luminance and contrast masking is taken into account.

To estimate correlation between the distortion measures and the observer score, we performed a test with the help of the database IVC_SubQualityDB used in [13]. We examined 25 grayscale images with JPEG distortion and its MOS given in [1; 5] and calculated the Pearson’s coefficients. For RMSE and Watson’s measure the Pearson’s coefficients were 0.9943 and 0.9931. It tells about a very high level of correlation.

4. Experiment

Figure 2 shows the extracted watermarks \( MR, MG \) and \( MUY \) embedded in the Red, Green and luminosity channels. Parameter \( q \) is 67 , 70, 75, 80 , note, by default \( q = 75 \) in MATLAB. The watermarks have various degree of distortions due to JPEG. The main point is that \( MG \) and \( MUY \) are close visually and its quality is better than at MR. This observation has been examined by testing a thousand color images.

Figure 3 presents results of the test. Embedding into RGB and YCbCr color space is illustrated by the Watson’s measure and RMSE shown at Figure (A) and (B). Both measures describe the extracted watermarks \( MB, MR, MG \) and \( MUY \). Each line is obtained by averaging over 1000 color images. It follows that the Watson’s measure and RMSE are in agreement. The less measure of distortion the less is degradation introduced, so \( MUY \) has the smallest degradation. More of than by considering the remainder watermarks we found that \( MUY \) has the minimum degradation. In the same time properties of \( MUY \) and \( MG \) may be close. It follows from its probability distribution functions shown at Figure (D). These two distributions are overlapped. In contrast, the distribution of \( MUY \) is well distinguishable from \( MCB, MY \) and \( MCR \), Figure
Figure 2: Extracted watermarks after JPEG compression with quality $q = 67, 70, 75, 80$. The Watermark $MR$, $MG$ and $MUY$ was embedded into R, G and Y channel.

(C). It tells, that the channel Y has more significant features than others.

An example storing of the watermarked color image is presented at Figure 4. We used G and Y channels for embedding a binary image shown at Figure (D) bottom in the center. In both cases the watermark is invisible. Really, the color images (A) and (B) look similar, instead of one of them has the watermark in its elder bit plane, $V > 3$ of the green channel. After storing in JPEG format with quality $q = 75$ two extracted watermarks $MG$ and $MUY$ are shown at (E) and (C). Though their distributions are overlap (see, Figure 3 (D)), the visual quality of $MUY$ is better. Indeed, the binary image can be created from grayscale by numerous ways. For example a simple threshold algorithm may be chosen, however it results in a low quality of image and a large distortions after extraction. For binarisation we used an algorithm introduced in our work [14].

Figure 3: Testing of 1000 color images. (A) and (B) Watson’s measure and RMSE averaged over 1000 color images. (C) probability density functions for watermark $MCR$, $MY$, $MCB$, $MUY$ (D) probability density functions for watermark $MG$ and $MUY$
Figure 4: Performance of the algorithms. Top: One of the color images has watermark in its elder bit plane of the green channel. Bottom: Watermarks. (E) and (C) the extracted watermarks MG and MUY after JPEG compression with $q = 75$, (D) the initial watermark hidden in one of the color images.

5. Conclusions

In the RGB and YCbCr color spaces one finds numerous ways watermarking. We consider embedding of binary image into the bit planes of the color channels and study robust to JPEG compression. Indeed, the smallest degradation of the watermarks is achieved in YCbCr space for Y channel if the stego image is converted into RGB before compression. It can be explained as follows. Thanks to transformation from YCbCr into RGB the embedded watermarks are scattered into image even more. That is an immunity to compression because of the embedding algorithm may exploit only a fraction of the image redundancy removed by compression. Indeed, watermark-ing of G and Y channel is close. It aries from JPEG, that any input image transforms into YCbCr color space. As known the luminosity Y is obtained from superposition of R, G and B, where the weight of G is taken to be the maximum in accordance with the color sensitivity of HVS. Because of Y component is compressed more carefully, one finds that watermark embedded in B has a high immunity to degradation.

References


Digital watermarking in RGB and YCbCr color space for protection of color images


On the secrete key for embedding of a binary image into a grayscale image

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Abstract

Watermarking of digital gray scale images with the secrete key is considered. The LSB and additive embedding algorithms have been used. It has been found that some keys created by a pseudo-random generators are not robust to a simple attack that displays difference between the cover and stego image. This fact results from the features of the human vision. Using the criterion of -security based on the Kullback-Leubler entropy we have found which of two algorithms is more secrete.

Keywords: watermaking, digital image, secret key, noise generator

1. Introduction

Watermarking that is commonly used for protection of digital media against illegitimate copying its content is a privacy tool. Many watermarking systems have secrete key for embedding and detection [1]. In accordance with the fundamental principle by Kerckhoff’s the security of the system should reside only in the key chosen and class of encryption transformations are publicity known. However steganography has its unique features due to human perception. When considering the cover and watermarked images, one can finds that they are indistinguishable even a secrete key was not used. This simple observation results in the so-called -secrecy introduced by Cahin [2]. In practice this criterion can answer the question which of two systems with secrete key is more secure.

The role of secrete key plays a pseudo-random array. It may be a pseudo-random path chosen across all pixels or a matrix. Both cases provide privacy because of any illegitimate user which has no secrete key, needs to solve a problem of searching that is a hard problem from the computational point of view. In fact, if the key is a binary 10×10 matrix, the total number of matrices is about 10^{30} and searching seems to be impossible. However for watermarking it is not absolutely true. The reason is that it needs to take into account properties of Human Vision System (HVS) and the secret key has to be generated in accordance with HVS.

In this work we discuss watermarking of a gray scale image with secrete key and two algorithms embedded a binary watermark. The secret key is presented by a matrix carried out by a pseudo-random generator. First algorithm is based on LSB technique and uses the bit planes of cover image, second is an additive algorithm. The aim of this work is to consider which of random binary matrices can be suitable as secrete keys and which of the algorithms is more secure.

By testing the second algorithm we found that it could be not robust to a simple attack that displays difference between the cover and the watermarked images. It results from the fact that both the key and the watermark could have the same spatial spectrum in low frequency range. Thus embedding introduces a slightly distortion in watermark. Because of the human eye is more sensitive to low frequencies the hidden data becomes visible. With use of the $\epsilon$-secrecy criterion we found which of our algorithms is more secure.
2. Embedding with the secrete key

Assume that the cover image $C$ is a digital halftone, the watermark $M$ is a binary image and the key $K$ is a binary pseudo-random matrix represented a noise. Watermarking with the secret key can be describe by the next mapping

$$
E : C \otimes M \otimes K \rightarrow S,
$$
$$
D : C \otimes S \otimes K \rightarrow M
$$

where $S$ is the cover image with watermark hidden or stego image, $E$ and $D$ is embedding and detection algorithm.

The first algorithm $A_1$ is based on LSB-embedding, and it use a selected bit plane $B_V$, of the cover image $C$, where $V = 1, 2, \cdots, W$. Assume that bit depth of $C$ is $W$, then one finds representation over bit planes

$$
C = B_W 2^{W-1} + \cdots + B_1 2^0.
$$

Usually $W = 8$ and the least significant bits belong to $B_1 = C \ mod(2)$. It means that $B_1$ looks as binary noise.

$$
B_V \rightarrow B_{VM} = B_V \otimes M \otimes K,
$$

where all bits are added by modulo 2. As result

$$
A_1 : C \rightarrow S = C - 2^{V-1}(B_V - B_{VM}).
$$

Second algorithm is additive, bit of secrete key $K$ is added or subtracted depending on whether the watermark bit is 1 or 0:

$$
A_2 : C \rightarrow S = C - \beta(2 - M)K.
$$

Here the added key is scaled by an input parameter $\beta$. The value $\beta$ controls the trade of between visibility and robustness of the watermark.

3. Secrete key

In practice secrete keys are carried out by a pseudo-random generator which has to be actually selected in accordance with HVS. This statement is illustrated by Fig.1 presented performance of the additive algorithm $A_2$.

Here a binary image is embedded into the cover image with a secrete key obtained by the generator of Poisson noise. The secrete key is a matrix from an array of random numbers chosen from the Poisson distribution. We use $\beta = 0.6$ and the watermark is invisible in the stego image. Difference between the cover and stego image $S-C$ is shown at the bottom of Fig.1. One can see the watermark and a piece of the key. This effect appears in the case of the uniform noise in contrast key obtained from the Gauss noise. Indeed, both the Poisson noise and the Gauss noise are visually indistinguishable. The present effect means that generally the key does not guarantee privacy in the image watermarking.

We think that the reasons are features of HVS. In fact, human eye works as a spatial low-pass filter so it is sensitive to information on low frequencies. Instead of noises seem to be indistinguishable, they can have various spectrum particularly at a range of low frequencies. In the digital image the semantic information is concentrated on the low frequencies. The difference $S-C$ is denoted by product of the watermark and key presented by noise $MK$. Thus the watermark would be more affected by the noise which low frequency spectrum is more differ from the spectrum of watermark. This observations are illustrated by Fig.2 shows the spatial spectrum of the Poisson
On the scret key for embedding of a binary image into a grayscale image

Figure 1: The additive embedding algorithm with secret key formed from the Poisson noise. Top: The stego image with a hidden watermark, $\beta = 0.6$. The watermark is invisible and the stego image looks as the cover. Bottom: Difference between the cover and stego image. One sees the embedded watermark and a piece of the secret key at right side.

noise, watermark and the Gauss noise. The spectrum is obtained by DCT and a low frequency range is presented. Both the Poisson noise and the Gauss noise seem to be similar but its spectrums are quite different. In contrast to the Gauss noise, the Poisson noise is more regular in the low frequency range and is more close to the spectrum of the watermark. Thus the Gauss noise more affects on the watermark that becomes invisible in the difference S-C.

Figure 2: Spatial spectrum of noise and the watermark. Center: Watermark which is binary image, Left and right figures correspond to the Gauss and Poisson noise. In the low frequency the spectrums of these noises are different. However both the Poisson noise and noise of the watermark have the similar spatial spectrum.
4. Secrecy of algorithms

To answer the question which of two algorithms is more secret we use criterion of $\epsilon$—secrecy. It tells, that steganographic system is-secure if the Kullback-Leibler (KL) entropy

$$D(C||S) \leq \epsilon,$$

and it is perfect secure if $\epsilon = 0$. In the case of digital images KL entropy is denoted as

$$D(C||S) = \sum_i p_C[i](\log_2 p_C[i] - p_S[i]),$$

where $p_C[i], p_S[i]$ are normalized histogram of brightness for the cover and stego image, $i$ is the pixel brightness. Being non negative, the KL entropy is a measure of how different two distribution are. In fact, if $p_C[i] = p_S[i]$ then $D(C||S) = 0$, clear that if $p_C$ is close to $p_S$, than the cover image C is close to S and both images became indistinguishable.

In practice the problem of comparison of algorithms is difficult, the main reason is irregularity, when properties can change from image to image. So it needs a database of large number of samples to give some averaged estimations.

Fig.3 presents the KL entropy for two algorithm $A_1$ and $A_2$. As for key the pseudo-random generator of the Gauss noise was chosen. The plots were obtained by averaging over 2000 images. For algorithm $A_1$ we restrict the operational range by the bit planes from $V = 1$ up to $V = 4$. The reason is that embedding in the elder bit planes results in visible watermark. For algorithm $A_2$ the operational parameter $\beta$ is smaller than 0.5. In this range $A_2$ has its KL entropy in $[0.0148, 0.02]$ which almost up to 2 order is less than KL entropy of algorithm $A_1$. It means that instead of both algorithms have it’s secret keys $A_2$ is more secure.

![Figure 3: The Kullback-Leibler entropy averaged over 2000 images. Left: Performance of the algorithm $A_1$. Right: Performance of the algorithm $A_2$.](image)

References


Functional Printing III
UV-mediated coalescence and mixing of inkjet printed drops

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Abstract

The coalescence of droplets is a widely investigated phenomenon. However, most investigations focus on relatively large droplets with sizes starting at 1mm, primarily because of speed of the coalescence process and the difficulty of imaging smaller droplets. In inkjet printing micrometer sized droplets are deposited on a substrate which, when positioned close enough to each other, will coalesce and mix. Although this is common in inkjet printing, still little is known about the flow and mixing behaviour within these small droplets.

In this investigation we focus on the coalescence and subsequent mixing of inkjet printed droplets by in situ changing the wetting properties of the substrate by UV exposure. Two droplets with different colored dyes are inkjet printed at a sufficiently large pitch such that they do not touch each other. Upon UV-exposure the contact angle between the droplet and substrate diminishes, increasing the droplet radii until the printed droplets touch and start to coalesce. The subsequent coalescence and internal mixing of the merged droplets is followed in course of time using fluorescent microscopy. The coalescence of droplets of equal and unequal volume with ratios of 1:2 and 1:4 was followed. Due to the speed of the coalescence process, investigation of the meniscus growth proved difficult, especially at short timescales. However, the transport of the dyes from one droplet to the other could be well monitored in time.

For droplets of equal volume ratio, it was found that the transport of the dyes can be described fully by diffusion only. For droplets with unequal volume ratios, it was found that in the first second of the coalescence process, convective flows induced by the formation of the meniscus bridge have a large influence on the transport of the dye. As the bridge growth stops, the convective flows cease to be present and the transport of the dye is governed by diffusion only.

Keywords: Coalescence, Mass transport, inkjet, printing.
Optimized printing conditions for gravure-printed silver conductive layer in flexible OPV applications

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Abstract

In this research, the gravure printing method was examined to manufacture the conductive layer of an OPV on a flexible PET substrate using silver based ink (DuPont 8210). The sheet-fed gravure printing test station IGT G1-5 was used to deposit silver ink on the flexible substrate. The concentration of ink and printing parameters (such as printing speed, printing force, resolution of patterns on gravure printing cylinder) were varied to study the quality of the printed conductive layer. Properties of printed conductive layer (thickness, sheet resistance, conductivity) were measured and analyzed. An optimizing method was utilized to analyze the collected data in order to propose the most suitable printing conditions (ink's concentration, printing parameters) for obtaining best quality of printed conductive layer. The lowest sheet resistance value of printed conductive layer was 0.184 Ohm/square when using 95% wt. of silver ink solvent with 0.2 m/s printing speed and 700 N printing force. In addition, a roll-to-roll (R2R) gravure printing system was also used for depositing the silver conductive layer on PET substrate applied in flexible OPV. The optimized printing conditions obtained before were applied in this R2R system. The printed conductive layer was characterized and the result data were analyzed. This approaching method is useful to save time and money in finding suitable gravure printing conditions for depositing silver conductive layer of flexible OPV.

Keywords: gravure, printing, conductive, silver

1. Introduction

Conductive layer plays an important role in many electronic devices (such as capacitors, solar cells, transistors, RFID antennas, etc.) since it transmits the electric current in the working device. In order to manufacture a stable, high efficient device, the process of depositing a conductive layer should be carefully considered. In printed electronics area, there are many printing methods used for depositing conductive layers [1]. Among these methods, gravure printing is used to fabricate conductive layers in roll-to-roll process due to its high resolution, fast, mass productivity and low cost. A variety of products like conductive grid [2], organic solar cell [3], RFID tags [4], OLEDs [5] are fabricated by gravure printing method. Beside the advantages of gravure printing, one challenge is determining the printing conditions (web speed, web tension, printing force, etc.) for each type of ink. In this paper, we present a method to find the most suitable printing condition for our roll-to-roll gravure printing system by using a test station, the sheet-fed gravure printing machine IGT G1-5. The concentration of ink and printing parameters (such as printing speed, printing force, resolution of patterns on gravure printing cylinder) were varied to study the quality of the printed conductive layer. Subsequently the printing condition to get best quality of the printed conductive layer was applied on our roll-to-roll gravure printing system.
2. Experimental Setup

2.1 IGT G1-5 test station

The printing test station is a sheet-fed gravure printing machine with different printing conditions in speed (from 0.2 m/s to 1 m/s) and pressing force of gravure cylinder to the substrate (from 50 N to 1000 N). The silver ink used in this experiment is a commercial ink PV8210 from DuPont. The gravure cylinders used to print have 60 lines/cm and 90 lines/cm resolution and the substrate on which we printed is PET substrate with 100 µm in thickness. The printing speed was chosen at 0.2 m/s. After printing of one sheet, the sample was then sintered in an oven for 10 minutes with a temperature of 120 C. For characterizing process, the printed conductive layers were measured for the layer thickness and sheet resistance by using Veeco Dektak 150 profilometer and the manual probe system PM5 from Süss Microtec respectively.

![Figure 1: Sheet-fed gravure printing test station IGT G1-5](image1)

2.2 Roll-to-roll gravure printing system Gravure man

![Figure 2: Roll-to-roll gravure printing system Gravurman](image2)
The most suitable printing condition for the silver conductive printed layer was then applied on the Gravurman, our roll-to-roll printing system. The gravure cylinders for printing the patterns to PET substrate also have 60 lines/cm and 90 lines/cm resolution. As the next step, the printed samples were also examined by Veeco Dektak 150 profilometer and the manual probe system PM5.

3. Results and Discussion

3.1 Silver conductive layer printed with IGT G1-5 test station

Silver conductive layers after sintering are shown in Fig. 3. Generally, the differences between two printed samples are not much. Nevertheless we can see eventually the differences when the samples were examined under microscope viewing in Fig. 4. For the case of using gravure cylinder with 60 lines/cm resolution, the printed silver layer is not a closed area but a dotted area. This leads to the non-conductive of the printed layer. The measurement of sheet resistance with the manual 4-probe system also gives the result that only the printed silver layers with 90 lines/cm is conductive. The result helps us to narrow the range of gravure cylinder’s resolution to be selected for printing with real roll-to-roll printing system.

![Figure 3: Printed silver conductive layer by IGT G1-5 after sintering](image)

![Figure 4: Microscope images of printed conductive layers](image)

After the first result showing that there is no conductivity in printed layer with 60 lines/cm resolution gravure cylinder, we moved to the next step to investigate the conductivity of layer printed by 90 lines/cm cylinder. The concentration of silver ink was varied with three values: 95
wt%, 93 wt% and 90 wt%. The silver ink was then deposited on PET substrate with different printing forces. Fig. 5 shows the sheet resistance of printed layers changing due to applying different printing forces on the substrate. Obviously in the same printing force conditions, the printed layer’s sheet resistance of higher weight percent silver ink is lower than the one of lower concentration silver ink. In addition, the graph in Fig. 5 shows the trend of increasing the sheet resistance of printed layers when the printing force was increased from 700 N to 800 N. This can be explained that there was fewer silver ink deposited to PET substrate during printing with higher force.

As the result of printing silver conductive layer with IGT G1-5 testing station, the most suitable printing condition to get highest conductivity was chosen as following: 95 wt% of ink concentration, 0.2 m/s printing speed and 700 N printing force. This printing parameters were then applied on the roll-to-roll gravure printing system to evaluate this optimizing method.

![Figure 5: Sheet resistance v.s. printing force of different ink concentration](image)

### 3.2 Silver conductive layer printed with roll-to-roll system Gravurman

In order to evaluate the optimizing method of printing conditions, we also printed with two options for gravure cylinder layer’s resolution: 60 lines/cm and 90 lines/cm. Fig. 6 shows the printed conductive lines/patterns of two options at different angles. With the design line width 0.3mm, printed lines at 0° were not much different. For other line angles at 45° and 90°, the difference was easy to recognize, especially at 90° angle line. The affect of changing printed line angle had strong impact on the quality of the printed conductive line.

![Figure 6: Comparison of conductive lines/patterns printed by different gravure cylinder’s resolution: 60 lines/cm and 90 lines/cm in case of 0.3 mm line width](image)
As a further investigation, the 0.1 mm printed conductive lines of two options were also compared in Fig. 7. For the case of 60 lines/cm resolution of gravure cylinder, it is obviously that there is no link of printed dots to form a line in all three values of line angle. As a result, these lines are not conductive as expected. Even for the case of 90 lines/cm resolution of gravure cylinder, the quality of printed lines is also not good at 45° and 90° line angle.

![Image](image_url)

**Figure 7:** Comparison of conductive lines/patterns printed by different gravure cylinder’s resolution: 60 lines/cm and 90 lines/cm in case of 0.1 mm line width

In addition, the changing of sheet resistance of printed conductive layers due to variation of printing force was also considered. In Fig. 8, the sheet resistance is reduced when increasing printing force. Due to the limitation of our roll-to-roll gravure printing system, we could not increase the printing pressure to a high value to get more data. However, the tendency shows in these graph is useful when handling this roll-to-roll system. Furthermore, the value of sheet resistance of printed layer by 90 lines/cm gravure cylinder is much smaller then the value in case of 60 lines/cm. The result shows the advantage of 90 lines/cm gravure cylinder to 60 lines/cm gravure cylinder as we expected when printing with the IGT G1-5 gravure test station.
Figure 8: Sheet resistance of conductive layers printed by different gravure cylinder’s resolution: 60 lines/cm and 90 lines/cm when changing printing pressure
4. Conclusion

This work successfully applied the gravure printing method to manufacture the conductive layer of an OPV on a flexible PET substrate using silver based ink (DuPont 8210). The gravure printing test station IGT G1-5 was used to determine the suitable printing conditions for different types of silver conductive ink. These optimized printing conditions were then applied on a roll-to-roll gravure printing system. Printed conductive layers by roll-to-roll system had good characteristics as expected. This approach to optimize printing conditions helps to save time and money when handling large roll-to-roll gravure printing systems.

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Multi Wavelength Imaging for Drop Watching Systems

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Abstract

For measurements of drop speeds and trajectory angles, which are independent of a minimum jetting frequency and unaffected by jitter time on the firing of drops, drop watching systems flash twice with a short flash delay between the flashes during the exposure of one image. The drop speeds and trajectory angles can then be calculated with the displacement of the same drops in the image during the flash delay. By overlaying replicate measurements in one image, the variance of the properties can qualitatively be measured for a print system configuration in an efficient way. The main disadvantages limiting the reliability of such measurements, may be errors in the correlation of overlaid objects, a reduction of the contrast or overlapping artifacts.

To enable reliable overlaid measurements or increase the performance and reliability of drop watching systems, a solution with a multi wavelength imaging system is introduced in this paper.

Keywords: Inkjet, drop watching, waveform optimization, machine vision

1. Introduction

Beam splitter based multi wavelength imaging (MWLI) systems are used in many devices. They can be found in multi-CCD cameras [5,6], high resolution projectors [1] or microscope systems [7,8]. The idea behind MWLI is to capture light of different wavelengths on different cameras or different areas of the same imaging device. Whereas for color imaging, the light is split into RGB color channels, in medical applications with MWLI systems, fluorescent light is captured on a different color channel than other wavelengths of interest [2,4,7]. For drop watching systems (DWSs) MWLI can be used to simultaneously capture overlays for speed-or trajectory measurements on different color channels. Thereby overlapping artifacts of the same drops can be avoided, the correlation of drops is simplified and the efficiency of the evaluation can be improved.

2. Single Channel and Multi Wavelength Drop Watching

2.1 Overlaid Imaging on Single Channel Drop Watching Systems

A typical drop watching system (DWS) consists out of a calibrated camera and a strobe flash, which are synchronized with a printhead by a synchronization device. Figure 1 depicts a typical measurement set up for DWSs and a sample timing chart for overlaid measurements. For each trigger of the printhead drops are jetted. During the measurement, the camera integrates all strobe flashes from the LED. Starting with a printhead trigger, the LED is triggered first after a certain flash delay to adjust the throw distance for the measurement. For measurements of drop speeds or trajectory angles a second flash is triggered after a typically shorter measurement delay. In relation to the exposure time and the jetting frequency multiple such measurements with single or double flashes per considered printhead trigger can be overlaid in one image.

Figure 2 depicts images of overlaid measurements with a single or double flash per printhead trigger, captured with a DWS according to the set up in Figure 1. As each visible object in both pictures is ideally an overlay of 100 droplets, a blurring of the objects, as a result of a statistical spread of the droplet positions, may be noticed. The statistical spread of the drop
locations is sufficiently small, and therefore the overlaid drops form connected objects. Due to overlaying, the objects appear to be darker where drops overlay on the same location and look blurred in relation to the variance of the drop position. Compared to single flashes, the contrast with double flashes the contrast is reduced to 50%, as during one exposure all drops are flashed twice at non-overlapping locations. With double flashes, parts of the second overlay may overlap in the area of the first overlay like the drop tails in the right image of Figure 2.

![Figure 2: Overlaid drops in flight with a single or double flash per printhead trigger, captured with a monochrome camera](image)

Considering that all overlaid droplets have a known, identical shape, and there are no satellite droplets present, information on the velocity distribution of the droplets forming an overlaid object can be calculated out of the brightness distributions of the objects in the image. For most measurements with DWSs, such ideal conditions for overlaying are not met. Therefore, in most cases only qualitative information on velocity distributions can be gained, and an accurate reconstruction of properties may not be possible. Especially overlapping artifacts, as a result of double flashing, may be difficult to cope with. A further difficulty at higher jetting frequencies is to correctly correlate a droplet to its trigger pulse. With grayscale capabilities of current print heads, depending on the jetting parameters, instead of a single combined droplet being developed before its break-off, multiple droplets per trigger can be generated. Therefore, just before the actual measurement, certain DWSs capture multiple images with different delay settings in order to ensure correct correlation of droplets.

2.2 Multi Wavelength Imaging on Drop Watchers

Figure 3 depicts a simple multi wavelength DWS for improved overlaid measurements. The system consists of a dual color LED, a beam splitter and two cameras with color filters. With a non-polarizing beam splitter, the light sent to the cameras can be split into equal parts, so
that both cameras see identical images with half of the intensity. With the band pass filters matched to the spectra of the LEDs, each camera sees only light sent from its matching emitter. Similar to overlaid imaging with a single monochrome emitter, the synchronization device may trigger, synchronized to the droplet generation, a first flash after the flash delay with the first emitter and a second flash after the additional measure delay with the second emitter. Due to the band pass filters, the first and second overlays are captured on the different cameras.

By replacing wavelength independent beam splitters with dichroic mirrors, efficiently reflecting and transmitting light dependent on its wavelength, the optical efficiency can be increased. With additional cameras, in combination with beam splitters and matching emitter and filter pairs, additional independent capture channels can be added. MWLI systems can be realized with single imaging chips, as well. As most color imaging devices use Bayer RGB color filters, by matching the emitter wavelengths to the color filters of the imaging device, a simple solution for a MWLI system can be realized even without additional optics. The main disadvantages may be color crosstalk due to overlapping transmission curves of filters and that, by using raw pixel information without color interpolation, the resolution of the separated color planes is reduced to a quarter of the specified camera resolution. Alternatively, a system with a single monochrome camera and an image splitting optic that redirects the color split image to different areas of the imaging chip, can be used [2,3,7]. When using single chip RGB LEDs as a light source, color crosstalk may occur due to overlapping spectra of the emitters. By utilizing discrete emitters with band pass filters after each emitter, color crosstalk of the light source can be avoided.

2.3 Test Setup for Dual Wavelength Drop Watching

Figure 4 shows the imaging assemblies of the test setup for dual wavelength drop watching. The light source is realized by a RGB LED (LedEngin LZR-80MC40) with a condensing lens. A non-polarizing beam splitter is used to split the image via two edge pass filters (Edmund Optics NT49-819 / Thorlabs FEL0600) on two monochrome CMOS cameras (AVT GuppyPRO F-503B). For dual wavelength imaging, either the blue or the green emitter of the LED can be used in combination with the red emitter. The alignment tolerance of the CMOS cameras is compensated by image processing, similar to the method described by [4]. By adjusting the emitter voltages, the brightness of both cameras is set to the same level while maintaining identical flash durations.

3. Results and Discussion

Figure 5 shows drops in flight captured with the test setup described in chapter 2.3. The displayed sections of both cameras cover the same physical area. In order to measure drop speeds for each
flash of the red emitter, the green emitter is triggered with a measure delay of 20 $\mu$s. For better visualization, the images of both cameras are overlaid on the red and green color planes of a color image.

With little variance on drop speeds and trajectory angles as well as repeatable drop formation, the overlaid objects in Figure 5 look similar to the actual droplets. The variance in drop speed may be calculated with a reference measurement of the actual drop shape. As both overlays are captured independently, compared to a double flash overlay with a single channel DWS, the contrast is doubled. In addition to the increased contrast, the correlation between overlaid objects in the first image of camera 1 to the same objects in the image of camera 2 is improved. Figure 6 shows captured images of a less ideal print system configuration with two drops per trigger and higher variance on droplet properties.

With the first and second overlay captured on different acquisition channels, the overlaid objects can clearly be correlated, thus increasing the reliability of image processing. Due to the presence of two drops per trigger as well as proximate drops fired at neighboring cycles, for correct correlation of the overlaid objects with a single channel imaging system, a second measurement may be necessary. In that case, measurements with a dual wavelength imaging system are more efficient.
Apart from improved overlaid measurements, MWLI on DWSs enables simultaneous measurements of different jetting properties or with different magnifications on a single imaging device. With an image splitting optic, as proposed by A. Hijazi [3], measurements of drop volumes with a single flash per measurement can be realized in a different magnification together with multiple overlaid droplets on a different area of the imaging chip. Further, with a multi wavelength DWS the rate at which drops are captured can be multiplied by the number of independent acquisition channels. On the test set up for dual wavelength drop watching, this can be accomplished by delaying either the exposure of one camera or the flashes of one emitter to capture different drops.

4. Conclusions and Summary

In order to enhance overlaid measurements on drop watching systems, possible solutions with multi wavelength imaging (MWLI) systems are proposed. The main enhancements with multi wavelength drop watching solutions are qualitatively verified by a test setup for dual wavelength drop watching. Underlined by sample measurements with the dual wavelength drop watching system, it can be concluded that MWLI on drop watching systems does improve overlaid measurements in terms of reliability, contrast ratio or efficiency. Further advantages with MWLI on drop watching systems may include increased rates of acquisition or simultaneous measurements of different jetting properties in different magnifications.

References

Single Droplet Formation Monitoring using a Novel MEMS-based Multi-Exposure System

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Abstract

Advanced manufacturing with high reliability, good accuracy and fully digital pattern generation is proposed to replace existing technologies, which involve precious materials as well as very thin and brittle substrates. As functionality of the layers is of utmost importance, deeper understanding of the physics of droplet formation was required to optimize the ingredients of such uids with a minimum impact on their performance in the dried state.

While the above investigations have led to a multitude of analysis techniques for judging the jetting performance in various types of inkjet printheads qualitatively, some characteristics observed in industrial applications have still not been correlated to independently acquired measurements. It is therefore still necessary to jet these uids in the screening process in order to verify how minute changes to an ink recipe re ect into the real world.

In order to reduce the impact of the printhead’s internal statistics, initiated by crosstalk, temperature and pressure uctuations among other things, observations based on single droplet formation events are often considered in order to detect the progression of the impingement along the formed ligament. These experiments are commonly conducted using low-resolution high-speed cameras or high-resolution imaging utilizing stroboscopic illumination.

In this paper we combine the two approaches to find a simple system for accurate experiments on droplet formation. The system employs a pulsed laser diode illuminating the trajectory of the droplet according to an electrical pulse train. The slow and fast axes of the laser are conveniently used to image an area of approx. 1000×300 μm\textsuperscript{2}. This beam, producing a shadowgraph of the droplet is then swept across the sensor of a low-speed CCD camera using a resonant MEMS mirror. In this fashion up to 10 successive images of a single droplet formation event can be recorded.

1. Introduction

Fundamental understanding of functional printing processes triggered extensive research \cite{1}. Especially the fluid formulation is a key feature for these applications, as the addition of process-relevant substances such as dispersing additives and surfactants often change the jetting behavior in inkjet printing entirely. For this reason, recent academic research has produced a number of papers on the quantitative analysis of rheology with respect to low satellite count and high reliability inks \cite{2}.

However, jetting the fluid is still the best predictor for the final application, where high-speed or high resolution imaging are widely used techniques offered from various suppliers \cite{3,4}. While economical solutions using stroboscopic illumination offer a good first understanding, they typically are incapable of capturing the evolution of a single droplet in order to quantify the phenomena. High-speed cameras, in contrast, provide the evolution of a single droplet but with a trade-off in resolution at their maximum frame rates.
In this paper we present a novel approach to combine the stroboscopic illumination with the approach of high-speed imaging. The pulse train of a triggered laser illuminates the droplet being formed at the nozzle. Using the slow and fast axis of the diode to illuminate a rectangular field, this beam is suited to image a drop from the nozzle up to a distance of 2 mm along its trajectory. The beam from the laser diode is then magnified using an optical setup and swept over the CCD-chip of a low-speed camera using a resonant MEMS-mirror device, placing images in the course of time next to each other on the sensor array. In this fashion up to 10 high-resolution images of the same droplet can be captured during its transition from the nozzle plate to a typical throw distance of 1-1.5 mm.

2. System Design

The system full system presented in this paper is shown in Figure 1. It comprises three interacting subsystems: (1) the illumination of a droplet using a laser diode and its imaging with a fixed magnification onto a CCD chip using a resonant MEMS mirror, (2) a system monitoring the motion of the mirror and the respective triggering of the light source, (3) a control circuit generating the triggering signal as well as the nanosecond pulses for the laser source.

![Figure 1: Schematic overview of the designed system including (1) imaging, (2) triggering and (3) the control components.](image)

2.1 Illumination Conditions

For the system design small dimensions of 5 µm as well as high velocities of approx. 10 ms\(^{-1}\) have to be considered. To suppress motion blur from these combinations the illumination time \(t_{\text{ill}}\) has to ensure that the object does not move more than a tenth of its size [5]. For the considered characteristics this restricts the illumination time to 50 ns. Using the signal-to-noise ratio (SNR) one can estimate the required number of photons. The SNR is given by

\[
\text{SNR} = \frac{S_{\text{ph}}}{\sqrt{\delta_{\text{ph}}^2 + \delta_{\text{d}}^2 + \delta_{\text{r}}^2}}
\]

where \(S_{\text{ph}}\) represents the incident photon signal and \(\delta\) are the photon noise (ph), dark noise (d) and the read-out noise (r), respectively.

In this first order approximation we consider the dark noise will be nil due to the very short illumination times. The photon noise follows a Poisson distribution and can be calculated using
\[ \delta_{ph} = \sqrt{I_{\text{ill}} Q_e} \]

where \( I \) is the intensity and \( Q_e \) is the quantum efficiency of the sensor.

Recalling that \( I_{\text{ill}} \) is equal to the number of photons \( N \), the SNR relation can be rearranged to give the required number of photons per pixel.

\[ N = \frac{\text{SNR}^2}{2Q_e} \left( 1 + \sqrt{1 + \frac{4\delta_p^2}{\text{SNR}^2}} \right) \]

To have a means of comparison, the total number of emitted photons from the laser diode can be calculated using

\[ N_{\text{las}} = \frac{P_{\text{las}} t_{\text{ill}} \lambda}{h c} \]

where \( P_{\text{las}} \) is the nominal power of the laser, \( \lambda \) is the wavelength of the radiation, \( h \) is the Planck constant and \( c \) is the speed of light.

This amount of photons will in best case be distributed of the respective area on the CCD, which in our case is 128\times960 \, \text{px}². Using a SNR of 20 [6], a \( Q_e \) of 0.5 and a read-out-noise of 10 electrons this gives a required number of photons for the complete strip to be illuminated of \( 1.2 \times 10^8 \). The laser diode with 600 mW peak power and a wavelength of 630 nm generates \( 9.7 \times 10^{10} \), leaving a fair margin of photons to be lost due to reflection, absorption or insufficient collimation.

### 2.2 Optics and Theoretical Resolution

In order to achieve a focused projection of an object at a distance of 112.5 mm from a lens with a focal length \( f \) of 50 mm, the required image distance equates to 225 mm using the Gaussian lens formula.

The minimum optically resolvable feature size \( d_{\text{min,opt}} \) is determined by [5]

\[ d_{\text{min,opt}} = 1.22\lambda g / L \]

where \( g \) is the object distance and \( L \) is the diameter of the lens used. With the wavelength \( \lambda \) being 630 nm, the object distance \( g \) being 112.5 mm and a lens diameter \( L \) being 50 mm this results in a resolvable length scale of 1.8 \( \mu \text{m} \).

However, with a digital sensor the Nyquist-Shannon sampling theorem has to be considered, which under consideration of the magnification \( M \) of the system and the CCD’s pixel size \( d_p \) is given as

\[ d_{\text{min,dig}} = \frac{2d_p}{M} \]

For the given \( d_p \) of the sensor and a magnification of two, this restricts the resolution of the system to the pixel size of 3.75 \( \mu \text{m} \).

The depth of focus \( \delta_f \) can be assessed using the lens diameter \( L \), the pixel size \( d_p \) and imaging distance \( b \)

\[ \delta_f = \frac{2 \, d_p \, b}{L} \]

which for the given values results in a depth of focus of 33.8 \( \mu \text{m} \).
2.3 Implications of the Resonant MEMS Mirror

In order to sweep the light over the complete sensor during the transit time, a half-angle $\alpha_m$ can be computed using

$$\alpha_m = \tan^{-1}\left(\frac{w_s}{2b_m}\right)$$

where $w_s$ is the width of the sensor and $b_m$ is the distance between the mirror and the sensor. For the given sensor and $b_m$ of 100 mm this results in a tilting angle of $1.37^\circ$. Given a typical transit time of 100 $\mu$s, this translates into a resonating frequency of 5 kHz and, hence, a speed of the beam on the CCD of 48 ms$^{-1}$. Recalling the discussions of motion-blur and considering an illumination time of 50 ns this decreases the resolution to a minimum spherical feature of 6.9 pL.

The change in path length due to the tilting of the mirror can be estimated using the Pythagorean theorem. In this fashion using $ab_m$ of 100 mm this results in a difference of 29 $\lambda$, which is insufficient to blur the image as it is smaller than the depth of field.

3. Experimental

The system as depicted in 1 has been realized on an optical breadboard table, using a 500mW, 638 nm laser diode (ML520G72, peak power 600 mW, Mitsubishi Electric, JP) with an appropriate collimation lens (focal length 3.1 mm, 352330-A, Thorlabs, UK). Driving the laser diode was accomplished using a commercially available laser driver module (iC-HG HG1D, iC-Haus, DE). Imaging was carried out with a projection lens having a focal length of 75 mm and a diameter of 50 mm. The projection was swept over a progressive CCD sensor (Pixel size 3.75x3.75 $\mu$m$^2$, ICX445, Sony, JP) using an off the shelf VarioScan MEMS mirror (diameter 3 mm, tilt angle $8^\circ$, Fraunhofer IPMS, DE) with a resonant frequency of 5.85 kHz and a diameter of 3 mm. The mirror was driven at twice its resonance frequency using a sinusoidal signal from a function generator (Model 164, Wavetek, US) amplified by a high voltage converter (WMA-01, Falco Systems, NL).

The system was controlled using an Arduino UNO (Arduino, IT). To generate short pulses from the output of the micro controller a monostable multi-vibrator (DM74123, Fairchild, US) was connected to a resistor of 5 k$\Omega$ and a capacitance of 1 pF. The triggering setup comprised a 1 mW red laser pointer and a photodetector (AEPX65, Centronic, UK) supplied with a 5V bias voltage. Waveforms were recorded with a digital oscilloscope (PicoScope 2206B, Pico Technology, UK).

Jetting experiments were carried out using a Xaar 126/50 pL printhead with an unpigmented oil ink (Toyo Ink Group, JP) at room temperature. The waveform was chosen such that the droplet velocity yielded 6 m/s.

4. Results and Discussion

4.1 Triggering Circuit and Pulse Shaping

The triggering circuit, as depicted in Fig. 1, consisted of a 1 M$\Omega$ resistor in conjunction with the photodetector. The resulting relationship of driving voltage amplitude to resulting signal strength is depicted in Fig. 2 (left).

The response indicated good applicability of the triggering circuit up to 110 V$_{p-p}$. This driving voltage generated a deflection amplitude of 5.5$, which was fully sufficient for the application of the circuit for the presented application. Above the 110 V level, the deflection became too large and decreased the residence time of the laserson on the photodetector in order to generate sufficient current. The resulting response from the triggering circuit was furthermore dependent from the position of the detector in the light fan generated by the mirror. In order to have a
clear definition of the direction of the laser, the detector was placed in the maximum deflection point of the generated laser fan.

![Graph](Figure 2: (left) Amplitude of the triggering signal as a function of driving voltage of the mirror. (right) Output from the pulse-shortening circuit used to convert the pulses from an Arduino microcontroller into a triggering signal for the laser as well as the light output measured using a photodetector in conjunction with a 1 MΩ resistor.)

As discussed in the design section, a very short laser pulse had to be established in order to have negligible motion-blur in the resulting image. While the output of the Arduino microcontroller was only capable of giving square signals of \( \geq 5 \) μs, a shortening logic was established to generate ns length pulses on the rising edge of the signal. A monostable multi-vibrator in conjunction with a variable resistor being set to 5 kΩ and a 1 pF capacitance produced stable single pulses. Fig. 2(right) shows the superposition of 30 successively recorded pulses from the shortening logic and confirms the pulse width reduction to a FWHM of 13.5 ± 0.2 ns and a characteristic pulse length \( (e^{-4} \text{ level}) \) of 32.6 ± 0.5 ns. In addition to the first pulse some remaining oscillation, most likely caused by impedance mismatch, was found but did not exceed the 2 V threshold of the laser driver and could be therefore neglected. The image furthermore depicts the resulting light pulse coming from the laser using a photodetector in conjunction with a 1 MΩ resistor. Using the normalized data presented the Gaussian fit of the data gave a FWHM of 9.0 ± 0.2 ns and a characteristic width of 21.7 ± 0.5 ns. The visible oscillations are here attributed to the charging and discharging of capacitances in the photodetector. The obtained results proved the illumination capability of the system to provide light pulses much shorter than 50 ns. The photon dose was accordingly adjusted using the incorporated variable resistor as well as the diode current in order to give high contrast images.

**4.2 Imaging Results**

In order to test the system a Xaar 126/50pL printhead was mounted and operated at room temperature. Triggering of the respective channels was accomplished by sending encoder signals to the external electronics of the printhead. Fig. 3 shows the formation of a droplet from this printhead using the presented system. The image sequence shows ejection of a droplet with a long filament as a result of the break-up between the fluid in the nozzle and the forward accelerated fluid mass (1). A non-axisymmetric tail geometry was observed in this stage, which moved along the tail in the course of time (1-3). The instability finally triggered disintegration of the long filament (4-6), leaving the main droplet connected to a first satellite by a very thin thread (6). Eventually, surface tension forced the fluid into round droplets (7) and combined the following satellites to a satellite moving at comparable speed to that of the main droplet.
The quality of the imaging shown in Fig. 3 was good enough to detect small features such as the filamentary connection between the main droplet and the first satellite (Fig. 3, exposure 6). However, the theoretical resolution could not be reproduced. The overall resolution was limited by the cell size of 3.75 μm of the used sensor. In addition to this, motion blur was found and was most likely not introduced by the illumination of the laser, but by the sweeping of the light beam over the CCD sensor. In this fashion, a reduced resolution of 13.8 μm could be estimated for a pulsewidth of 28 ns. Other influences comprise the small aperture of the MEMS mirror, the homogeneity of the laser diode output, as well as some slight misplacement of the optical components.

The imaging depicted in Fig. 3 furthermore showed some interference patterns, originating from the diffraction of the monochromatic radiation by the shape of the droplets but also from debris in the beam path. For a visual inspection of the images, these do not pose a major obstacle, but will for the numerical analysis using thresholding techniques. Means for reducing these effects have been widely discussed in the literature [7,8] and are fully applicable to the system.

5. Conclusion and Outlook

In this contribution, we have presented a proof-of-principle imaging system using a laser diode illumination source in conjunction with a resonant MEMS mirror for potential high-speed, high resolution imaging of flying droplets. While the presented system shows fine features such as small filaments between main and satellite droplets, the overall resolution was hindered by the fast scanning of the light beam across the sensor.

Future developments will include the optimization of the light sources as well as the optical beam path in order to improve the overall resolution and provide a low-cost high-speed imaging system.

References

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Printing Future Days Design
Concept for integrated printed electronics in wallpapers using the example of dynamic exit route borders

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Abstract

Printed electronics offer a possibility for integrating complex electronic circuits in wallpapers, thus allowing for new and interactive uses of a mainly decorative element in interior design. Wallpapers can easily be retrofitted into existing structures without changing the room’s general appearance. While this concept paper describes a possible use case for dynamic exit route borders, the idea for printed electronics in wallpapers can be extended to more advanced and interactive uses as outlined in the last section of this document.

Keywords: printed electronics, wallpaper, exit route, wayfinding

1. Introduction

The technological advance of printing electronic circuits and components on different substrates offers multiple opportunities in the field of interior design. Printed on wallpapers, new concepts for interactive rooms and intelligent buildings become possible. Easy to install, these wallpapers can be retrofitted into existing buildings and rooms without major changes to their structure. They are unobtrusive and customizable, allowing for a wide range of applications from way-finding to assisted living. Compared to other interactive wallpaper concepts containing LEDs [1] and custom circuit boards [2] or using projection technologies [3], a completely printed approach would allow for a fast and cheap mass production.

2. Design Concept: Dynamic exit routes with printed borders

One possible application for printed electronics in wallpapers are dynamic exit route borders.

2.1 Concept

Applied to the walls horizontally, the exit route borders provide means to route people dynamically away from danger. In case of an emergency, arrows light up to indicate the nearest emergency exit, usually indicated by static exit signs (Figure 1). Once installed, the borders can also be used for different purposes, e.g. way-finding within the building.

2.2 Setup

Borders are normally meant to add a decorative element to a room in form of a horizontal design, glued to a wall like a wallpaper (Figure 2). They are usually 15 to 30cm in height and printed on the same material as wallpapers.

As borders are smaller than wallpapers and usually applied horizontally, it is simple to retrofit them into existing rooms without major structural changes.

While inactive, the dynamic exit route borders would seamlessly integrate in eye-height with the existing wallpapers. They hold printed arrows, alternating left and right, as well as the
Figure 1: Emergency Exit, Photo: CC-BY Rupert Ganzer on flickr, http://www.flickr.com/photos/loop-oh

Figure 2: Borders, Photo: CC-BY mjtmail (tiggy) on flickr, http://www.flickr.com/photos/mjtmail
electronics to control them (Figure 3). These arrows are capable of glowing in different colors once activated.

\[\text{Figure 3: Borders with arrow design, inactive}\]

\section{2.3 Functionality}

In case of an emergency, the arrows would light up in a green color and point to the nearest emergency exit (Figure 4). If the system is connected to the building’s fire detectors (Figure 5), it could be programmed to dynamically route [4] the people away from fire (Figure 6), thus being of a major advantage compared to traditional illuminated but static emergency exit signs.

\[\text{Figure 4: The borders pointing towards the nearest emergency exit}\]
Figure 5: A possible setup

Figure 6: The borders pointing towards the next accessible emergency exit, routing dynamically away from danger
Due to the possibility of glowing in different colors, the same system could be utilized for different purposes, e.g. way-finding within the building. In that case, a blue color could indicate the walking directions. A constant illumination mode could operate as a security light at night, possibly equipped with or connected to motion detectors.

3. Outlook and further applications

It has been shown that printed electronics on wallpaper borders offer multiple possibilities in the field of exit routes and way-finding.

By increasing the size of the printed electronics borders to standard room covering wallpapers, a whole new range of applications become imaginable.

Given that way-finding is an important issue in public places like universities and nursing homes [5,6] and due to the growing demand on assisted living solutions [7], new and improved alarm and guiding systems become possible in an unobtrusive way.

The integration of sensors, e.g. for smoke or heat, could expand the functionality and thereby replace or upgrade an existing alarm system.

However, the next steps in the development of the dynamic exit route borders will be the construction of a small scale prototype in form of a miniature building, as well as the circuit-design and layout of a printed electronics prototype of the actual border.

References

Abstract

This project proposes a concept for printed electronics in architecture. Through the attachment of intelligent transparent foils to the inside and outside of windows, light and temperature can be controlled as well as the image on the window. The foils are controlled by a smartphone app changing their properties to one of their five operational functions - brightening or darkening the inside, changing the image outside the window, blocking warmth from going through the glass and changing the window into a mirror-like reflective surface from the outside. The focus of the project aims at achieving a stable and natural illumination while using the brightening function and daylight harvesting with solar cells. A sensor on the outer foil measures the natural light intensity.

Keywords: transparent solar cells, electrochromic, printed organic electronics, architecture

1. Introduction

Printed electronics are a type of organic electronics, which can be produced at low cost on paper-thin substrates like plastic or, as in this case, foil. [1] These electronics are compatible with everyday objects as there is no need for higher integration and they can even become the object themselves (e.g. books or displays). Conductors and semiconductors can be printed onto the organic materials using a low processing temperature, creating flexible electronic devices. The electronic compounds required in this project (solar cells, OLEDs, transistors, RFID tags) can already be manufactured [1]. Printing electronics is therefore a relatively cheap way of obtaining flexible and affordable electronics. As is needed for this project, they can be printed onto foil and can be manufactured at a larger scale.

The Light-Foil project uses, amongst other things, the concept of the flexible active-matrix display [2] for its purposes. The foil is used as a flexible display using the principles of OLED and electrophoretic displays. The latter creates a grey-scale screen and with the help of filters can be used for creating images on the inside of the window. "Contrarily to electrophoretic displays where ambient light is reflected on the display" [2] the OLED display uses organic transistors to create light-emitting pixels. That characteristic can be used for the brightening function of the Light-Foil.

Like SunCast [3], the Light-Foil attains energy through daylight harvesting to create a stable illumination inside. But whereas the Light-Foil uses energy gathered through solar cells to power its OLED or electrophoretic display, SunCast is a fine-grained sunlight prediction framework. Its algorithms can be used to enhance existing daylight harvesting systems through historical data tracing.

The Light-Foil concept also deals with one of the most important criteria in the manufacturing of windows: thermal transmittance. The ability to stop increasing indoor temperatures in hot climates not only curtails the cost of electricity and produced greenhouse emissions, it also adds
significantly to the comfort of residents [4]. One of the most effective methods of achieving these goals is electrochromic glass. It can moderate the solar light flux input, saving AC energy and providing a uniform luminance [5]. But where the Light-Foil stays transparent, the glazing of the electrochromic glass creates a blue light when in solar control mode, which can be very unattractive to residents [6]. Compared to the glass, the foil can also be manually operated and changed to the thermal control mode at any time, which we believe users of the glass would appreciate [5].

2. Design Concept

2.1 Concept Description

Attaching a transparent and conductive foil to the inside and outside of window glass is the basic idea of the Light-Foil concept. The materials are used to control the light, temperature and window-image inside and outside of a building. The two foils should be fire- and weather resistant and capable of not only brightening and darkening a room naturally; they can also show a different image of the outside world and hide the inside through the image of a reflection. Both foils are controlled by a smart phone app, which can change their structure or behavior. Integrated sensors in the outside foil measure the natural lighting conditions, which can later be used to control the light situation inside. Transparent solar cells are embedded into the outside foil and provide the power to maintain the brightening effect. The inside foil is used to control the light and view characteristics of a window. The outside foil is used to protect from heat and an unwanted visual audience. The latter is achieved by using a Venetian mirror effect.

2.2 Technical setup

To provide the foil with the tools necessary for its functions, it is going to consist of at least four "layers". The inside foil will need OLEDs, an electrophoretic display with RGB filters and an RFID tag to connect it to a smart phone. The outside foil requires a sensor to measure the natural light intensity, transparent solar cells for daylight harvesting, a coating for thermal protection, another RFID tag and a layer for the mirror effect. Both foils possess patterned conductive traces that are used to route signals from the smart phone to the relevant component in the integrated multi-layered printed circuit to display the needed function [6]. The inside foil features a display layer of integrated OLEDs. Their efficiency nearly succeeds the one of conventional lighting and inorganic LEDs, and they are suitable for large-area usage. They consist of an organic semiconductive layer that can creates a rising electrical current, which leads to light emission. In combination with a red, green, and blue organic emission a white emission with a high Color Rendering Index (CRI) of 90 can be created. The CRI determines to which degree a light emission is "pleasant" (100) or "unpleasant" (0) [7]. The electrophoretic layer can temporarily or permanently display an image uploaded from the smartphone without having a constant power supply [8]. The backplane of this display could either be an organic thin-film transistor (OTFT) or a flexible printed circuit (FPC). The backplane is connected to the electrophoretic display and consists of a driver and controller [8]. The controller is powered by solar cells and it gets the driver to send the appropriate signals to the electrophoretic display. These two layers are used for the window-image and darkening function.

The outside foil originally could be equipped with an integrated light sensor, which can be discounted, as the OLEDs on the inside foil are capable of displaying the right mixture of colors and wavelengths to create a natural luminance [7]. Important parts of the concept are transparent solar cells. The highest power conversion efficiency organic solar cells have until recently been achieved by using substrates possessing an indium tin oxide (ITO) electrode [9]. These solar cells however are expensive and not applicable for a low-cost concept like the Light-Foil. Therefore an
alternative is used, which consist of a stack of aluminum doped zinc oxide and thin silver layers. These cells have a transparency of over 75% and can achieve a power conversion efficiency of 6.1% [10]. The solar cells can be printed in a roll-to-roll process onto the foil. The final electrode at the top is applied by screen printing a grid structure that allows for light transmission [11]. The integrated solar cells are used to power other functions of the Light-Foil. To enable the foil to protect the resident from thermal transmittance, the outside is coated with an electrochromic layer. Using a single roll coater to spray or slot-die coat an electrochromic layer onto the flexible foil it is possible to switch between a transparent and colorful state [12]. As it seems not to be possible to use the electrochromic layer in a transparent state to keep heat outside, white would be used as a colorful thermal control state. The one-way mirror effect of the concept has to be discounted, as it is not yet possible to print the needed components or alternatives for them. To activate the foil-modes a smart phone is supposed to communicate wirelessly connected via RFID/NFC tags printed onto the foils. A protective layer for the outside RFID tag has to be considered as environmental stresses can affect the performance of the antenna: high temperature for example can improve performance due to the positive effect on the ink film, but coupled with high humidity the threshold power increases, backscattered power decreases and the read range shortens [13].

2.3 Planned application

The Light-Foil uses window glass as a subsurface. Windows are the natural sources of light in architecture. They are capable of establishing a feeling of protection and safety while also allowing a connection with the outside world. The foils build on these characteristics and extend their functionality. The transparency of the material is therefore an important part of the concept, as the connection to the outside and the natural feeling would otherwise get lost.

The light effect is a crucial aspect of the design. Artificial illumination through lamps is to be replaced by natural light, saving cost and energy. Using the foil, urban households and indoor spaces can be illuminated and a natural feeling generated. The foils can be used instead of lamps, saving money and space. They can be brightened beyond the point of the lighting conditions outside to emulate bright sunshine. Another important feature of the Light-Foil is the possibility of darkening the windows. It is useful for people working night shifts, as it makes undisturbed sleeping in the darkness possible. Due to the fact that melatonin production is hemmed by light, many shift workers are suffering from sleep disorders, loss of alertness [14] and superior risk of endometrial cancer [15]. The foil allows in its darkened mood for the hormone to be produced, even by day.

Ground level windows where people pass everyday can be made reflective from the outside with a mirror effect.

There are two further characteristics of the light-foil: thermal protection and control of the window-image. Like electrochromic glass [16], the outer foil is able to reduce solar heat gains significantly. This can be essential for office buildings, which are predominantly designed with glass fronts. The image control is an inside foil effect. Activating it, the view from inside to outside can be changed to an image or live feed residing on a smart phone. It is a useful application for people living in group homes or hospitals, as the presence of windows can reduce stress levels, anxiety and depression [17].

3. Results and Discussion

3.1 Prototype Concept

The Prototype of the Light-Foil consists of two foils attached to the in- and outside of a window. Both foils are equipped with different functionalities, which make them suitable to their respective tasks. The inside foil naturally illuminates a room with OLEDs and is capable of showing another
image of the outside world with the usage of an electrophoretic display. Both layers also use an RGB-filter layer to mix and display colors. The outside foil on the other hand protects from thermal transmission through an electrochromic layer and possesses integrated transparent solar cells for daylight harvesting. Both foils should be connected to the user’s smart phone via RFID or NFC communication. The one-way mirror functionality of the Light-Foil cannot be implemented at the moment and the originally integrated light sensors aren’t needed.

3.2 Application

The Light-Foil can be used as a natural light source instead of conventional light or inorganic LEDs in urban households. Brightening via OLEDs and darkening a room through an electrophoretic screen enables shift workers and others to control the luminance inside their home. Also using the electrophoretic display, a temporary image can be seen from the inside of the window. The user can send an image to be displayed - a live feed currently seems impossible. Thermal protection through a sprayed or Inkjet printed electrochromic layer is possible, as well. Residents are capable of manually reducing solar heat gains.

4. Conclusions and Outlook

The Light-Foil is a first concept for printed electronics in architecture. The printing cost for large-area foils would be less expensive than the production of electrochromic glass. Through its production and function, energy costs and greenhouse gas emissions could eventually be significantly lowered. The foils are lightweight and easy to attach to a window, as well as equipped with integrated RFID/NFC tags to use as mode-controls by the users. The electronic compounds required in this project (transparent solar cells, OLEDs, electrophoretic displays, electrochromic coating, RFID tags) can already be manufactured. The two most important aspects of the Light-Foil concept (brightening a room naturally and the use of transparent solar cells) can be achieved through printed electronics. The application of an intelligent foil as natural and comfortable light source inside a building can replace the usage of lamps. It is a way of saving space and money, and also gives the user the sense of daylight instead of artificial light. The use of transparent solar cells is a good fit for this project, as they don’t impede the user’s view and are efficient enough to power other foil functionalities.

A cost effective production of the Light-Foil in the future appears to be possible. The implementation of a one-way mirror into the foils seems to be possible in the future, although some research has to be conducted in the printing and application of a highly reflective surface that transmits light in only one direction.

References


Light-Foil - a design proposal for the use of printed electronics in architecture


Abstract

The project develops a concept for a remote interaction using tangible interactive cards, allowing the sender and the receiver to communicate via tangible messages with the card and Internet. Printed electronics on the card allow for different input and output signals to be embedded in the card. The sender and the receiver connect via the interactive cards system and a computer or smartphone. The In-touch interactive cards system allows a playful and haptic interaction through light and interactive folding patterns. This interface is meant to make long distance communication more sensual allowing partners to stay in touch through tangible messages.

Keywords: tangible user interface, remote communication, printed and organic electronics, paper electronics, cultural product, emotional design.

1. Introduction

Surfaces like paper, textiles and skins are the medium of the closest proximity with the human being. In this context the communication transports a haptic stimulus with a sensual expression, through tangible surfaces such as books, letters, cards and so on. In this paper we explore the use of modern technology and the development in printed electronics that are supposed to provide a new form of short communication.

The following work presents the design of a tangible communication between sender and receiver via the Internet through interactive cards that have inputs and outputs. The In-touch interactive card functions as the input using capacitive sensors and as the output manipulating actuators such as lighting and small motions through shape memory wire. (see details in the setup description).

The design of the cards is inspired by the following goals:

- Tangible and physical interactive elements should be used to develop a more user-friendly interaction.
The use of the interactive card system should enable and support the playful discovery of new forms of communication.

The system is designed to overcome language boundaries.

Explore the materiality of the physical cards to discover the haptic and sensorial attributes of this new material.

Recreate the feeling of a person, who is in another part of the world, through a multi sensorial experience.

The postcard used to be a universal medium of correspondence [1], however nowadays it is considered an almost old-fashioned way to connect between people. This tangible medium can not only express pictographic and verbal meanings but also transmit aesthetic, cultural, and other non-verbal qualities.

In-touch interactive cards system is a work motivated by the development of traditional techniques and exchange of experiences from a long distance. This development can be seen in the paper "Sticking Together" [2], in the research of exchanging sensations and signals through touching an interface [3], and in the design of technologies that support intimacy and relationships [4]. These works confirm that the development of the interactive cards system allows younger and elderly people to use a simple medium with a strong emotional connection.

Experimentation with a material like paper permits the interaction of different techniques and material qualities due to the versatility of the paper [5], [6]. In this context, Marcelo Coelho discusses his work on the possibilities to work with paper at a very low cost and without the need for software upgrades or everlasting battery supplies [6]. In the development of electronic paper, we can think about the integration of new techniques and technologies such as printed electronics of OLEDs circuits, RFID antennas, and solar cells [7] as well as the integration of other actuators like shape memory alloys [8]. The improvements to printed electronics and customizing this kind of high technologies allows the production of media with new qualities [9]. This work in process has a big potential in mixing technologies and techniques from paper and printmaking to create smart materials and new devices [10],[11].

2. Experimental Setup or Materials and Methods

2.1 Description of the concept

Nowadays objects in contemporary design have a special responsive function [12] and in this way the interactive cards establish an interaction by sending and receiving short messages/signals through a responsive tangible system.

2.2 Design of the System

In the first use case scenario the design consists of a pair of cards. The sender keeps one of the cards and the other one is sent per post (as a postcard) to the receiver. The In-touch interactive cards can transmit their unique ID via the RFID or NFC antenna embedded in the card. This establishes the connection to the smart phone or computer. A short digital message can then be sent via Internet between sender and receiver (e.g. Facebook, SMS, ...).

In the second model, the card can be inserted to a stationary device called the "in-touch box" which is linked to the receiver’s computer. In fact the box has an opening where you can insert the "Interactive Postcard". Once the postcard is inserted it can communicate via Internet with the receiver and vice versa. In the future different cards could be connected and coordinated through a network where the sender can communicate with multiples receivers.
Figure 2: Connection of the pair of cards via antenna, Computer or Smart Phone.

Figure 3: Inserting of the card in the "in-touch box"

Figure 4: Connection of the pair of cards through the "in-touch box".
2.3 Design of the Interactive Postcards

The postcard as a responsive surface has an important role because it is designed to generate a haptic experience for the user. The electronics of each of the patterns of the postcard can be printed or combined with different techniques depending on the level of interaction and complexity of the output. The design of the interactive cards is based on three levels of interaction:

In the first level, from a low level of intervention the user can interact with simple and basic information, using light signals as actuators and a switch as an input, answering to predetermined questions like "Where are you?" or "Are you at home?" This first level applies in situations like travelling, or finding out somebody's location.

In the second level of interaction, the user can explore a tangible interaction with different kind of small activities. The user activates a function in a responsive touch panel. In this case the exploration produces a higher level of intimacy and can express more variable messages. This pattern is inspired by a situation where one wants to express feelings of love, friendship and so on.

The third level corresponds to the card as an object, which the sender and receiver can modify an elaborate in a small scale and transform from a plain surface to a 3D form.

2.4 Target group and scenarios

The post-and greeting cards are typically sent between friends and family, covering a considerable age range making the cards a universal product. In-touch interactive cards are a medium that is both conventional and alternative. The target group is focused in the users of regular postcards and greetings cards but also in communities such as pen pals and people using post-crossing [13]. This system contributes also to the use of traditional postcards and sending of non-digital cards. The experience of the interactive cards system generates different values for the user, which are described in the table below.
Table 1: Experience values of In-touch interactive Cards System.

<table>
<thead>
<tr>
<th>VALUE</th>
<th>CHARACTERIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting</td>
<td>Receive tangible messages from different places. The experience to be in touch with people. To learn different verbal (including written) and nonverbal codes from people from different parts of the world. A unique present from one person to another.</td>
</tr>
<tr>
<td>Tangibility</td>
<td>Sense the tangibility in the message. To send a traditional card nowadays has more personal value in comparison with electronic mails. Physical object that can be kept collected and displayed. It can be worn-out and torn from travelling.</td>
</tr>
<tr>
<td>Emotional Background</td>
<td>Choosing a specially designed card having the receiver in mind. The possibility to personalize and transmit a feeling through the interactive cards system. The experience to share a signal simultaneously with the other person.</td>
</tr>
<tr>
<td>Surprise Waiting</td>
<td>A surprise for the person who receives the postcard. The excitement of waiting for the sender.</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1 Prototype

The design of the interactive cards has embedded the circuits, the inputs and outputs and the electronic component integrated in each layer, which is explained in the figure below.

![Figure 7: Layers of the interactive cards.](image_url)

*Paper Substrate*

The basic material is paper as a substrate with a special treatment. This material should have good wetting properties to guarantee a high quality of the printed layers. The paper should be
chemically inert to prevent influences on the conductive material [14].

**Circuit board**

The circuit layout connecting the inputs and outputs can be printed with conductive inks on paper. This layer contains the printed electronics inside the circuit such as the OLEDs resistors and capacitors, pressure sensors and the RFID antenna [14].

![Figure 7: Conductive circuits layer.](image)

**Figure 8: Conductive circuits layer.**

![Figure 9: Samples of layouts 1, LED circuit board, high level which will be printed on the graphic of the card.](image)

**Integration of electronic components**

As actuators SMD LEDs as an alternative to the OLEDs can be integrated. The shape memory wire (SMA) is integrated in the folding papers. In fact the paper functions as a spring to increase the mechanical properties, in which they actuate to generate the movement to up and down. To integrate the SMA in the circuits crimps should be used because this wire cannot be soldered [9].

**Microcontroller and Programming**

In the first phase of the interactive cards system prototype the microcontroller ATMega 44/128 will be used to facilitate the understanding of programming. This type of controller can be found...
in the Arduino espora and Leonardo [15]. The number of pins is sufficient for the functions in the cards. In addition this version includes a USB system and connection. This microcontroller will be integrated in the circuit layout.

**Antenna and Internet Connection**

The antenna embedded in the interactive card establishes the connection with the computer or smart phone via Internet and consequently the sender and the receiver can exchange messages. If the in-touch card does not have the antenna, the signals will be sent through the In-touchbox, which is connected with the computer via USB. "The RFID reader transmits a modulated RF signal to the RFID tag consisting of an antenna and an integrated circuit chip. The chip receives power from the antenna and responds by varying its input impedance and thus modulating the backscattered signal" [17].

The layers of the cards will be developed according to the Design of interactive cards patterns mentioned above. In the following table the technical aspects of each pattern are illustrated.
<table>
<thead>
<tr>
<th>Graphic</th>
<th>Input</th>
<th>Output</th>
<th>Technical implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>First interactive card pattern</td>
<td>Contents -Cities and routes -General information about users mood</td>
<td>Switch (mechanic technic through the folding paper)</td>
<td>-Lighting: OLED and electroluminescent sheet -Integrated SMD LED</td>
</tr>
<tr>
<td>Second interactive card pattern</td>
<td>Contents in relation of the emotional and cultural meaning ex: -graphic of hands</td>
<td>Sensor: determined press sensor</td>
<td>Motion: the Use of shape memory alloy complement of folding structure</td>
</tr>
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<td>Third interactive card pattern</td>
<td>-3D object Generated of a foldable card -Alternatively can be combined with the in-touch box</td>
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<td>-motion: the use of shape memory alloy complement of folding structure in combination with other actuators like lightings integrated SMD LED</td>
</tr>
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4. Conclusions and Outlook

The work with a conventional medium and the reinterpretation of these techniques is an important contribution to the conservation of the printed media. In addition the design of the understandable technology integrated in media, permits that people can have access to another quality of interaction through the experience of sending a postcard [13].

The structural material, paper, comes from a natural background, and contributes to the development of sustainable and cultural products. The configuration of the postcard can be made of layers that permit huge possibilities to combine with different techniques and materials such as conductive fabrics, electroluminescence colors and sheets, print electronics and 3D prints. In the future the possibility of incorporating organic electronics among others permits that these products can be designed with high percent of eco-conscious.

The interactive cards should in the future be improved to arrange a communication without devices. This way one can explore a more direct and tangible interaction. This will be possible if the RFID chip is embedded in the card and the antenna can transmit the signals directly to other TCP/IP enhanced devices or objects.

This is meant in the sense that the postcard has the potential to develop more concepts in mobility and intimacy in long-distance relationships [1]. As a result the design of the interactive card motivates different kind of users and communities that are interested in a simple and tangible form of communication.

Acknowledgement

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Past meets present – concept for an interactive printed e-Book

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Abstract

Printing has become a mature industry, forcing printers to create new applications for their manufacturing process. One such application is printed electronics [1], a technology that uses printing methods to create electrical devices on various substrates. This new technology led to a design proposal of a "printed e-Book", a book combining classical printing technologies with functionalities of the e-book (Kindle, etc.) in a new interactive approach. The proposal focuses on children books. In existing research it is discussed whether new technologies such as e-books or others, are appropriate for this target group [2]. Nowadays, kids do not want to stay with old-fashioned books without any interaction. That might be the reason why they feel completely attracted to their parent’s expensive and complex new devices such as touch pads, smart phones and so on.

Keywords: interactive books, printed books vs. e-books, children, printed sensors

1. Introduction

The importance of children’s books in young people’s lives cannot be minimized. Books can help children to understand who they are, explore the world around them, and contribute to a child’s ability to be literate in today’s society [3]. After researching the subject, the advantages and disadvantages of printed books, e-books and other electronic devices allowing adults and kids to play and read were analyzed. Some interesting points that influenced the concept of the printed e-Book could be identified in the design process. Parent-child interaction around reading is an experience that is treasured. Parents had the experience of creating their literacy habits through a lifetime and these are happy memories. They want their children to have that warm, nurturing experience when reading books [4]. When traveling, more parents prefer reading e-books with their children than printed books [5]. About four of five parents who read e-books with their children say they "sometimes" or "often" give their children an e-book to read on their own if they are busy. But how safe are these kind of fragile and expensive devices in kid’s hands?

This is one smaller disadvantage that could be observed in the existing electronic devices. The idea of a new interactive and entertaining application specially designed for kids and their parents was the intention of this work. It lets children enjoy and play as they want to and when they want to.

2. Design Concept

2.1 Description of the projects concept

Typically the reading habit is established in childhood [6]. The experience of reading and playing with books as a child, normally remains present in peoples memories for their whole life. The fact of only looking at a picture has the potential to take readers to wonderful imaginary worlds.
Today, with the new generations the concept of a still image as a way of entertaining is, in my opinion, starting to disappear. Nowadays, with the advance of new technologies, it is difficult to see a kid without being surrounded by "intelligent" devices full of different kinds of interaction. Reading from an electronic screen is completely different than reading a conventional printed book. The idea of a printed e-Book is situated exactly in the middle of both of them. It should preserve the value of the material qualities of the paper and the illustrations and texts on it. At the same time it stays updated to the newest technologies in order to satisfy the requirements of the new generation.

My proposal consists of the revival of old children’s books. Keep the classic paper book, but adapt it to new technologies such as the printed electronics. Allow kids to play and interact with the printed e-Book even when their parents are not around.

Figure 1: The printed e-Book looks like a conventional paper book, but through the printed electronic components it works also as an electronic device communicating with its digital counterparts.

To better describe the application, I adapted the functions to one specific children’s book: Where Is Wally?/ Where Is Waldo? (a well-known "interactive" book where the reader has to find different characters and items).

Figure 2: Where’s Wally? - Where’s Waldo? -a series of children books created by British illustrator Martin Handford [7]
2.2 Planned application

As mentioned before, the device will be completely interactive, but it will keep the high value of being in contact with the realistic material qualities of paper and its texture, color, smell, etc. Through the printed electronic sensors, OLEDs, batteries and other components as well as the possibility of being able to communicate and interact with other electronic devices, the user will be able to experience a totally new way of reading from the beginning of the book until the end of it.

The advantage of being flexible, rugged and "tangible" provides the "printed e-Book" with the same meaning as a conventional paper book, which stores and communicate knowledge through reading and, at the same time, it makes it almost as interactive as an e-book or other electronic devices.

The printed e-Book will have different functions in order to enable the user to interact with it:

Timing: 
If the user stays longer than a couple of minutes the following actions take place on the same page:

- Make the character/item talk and the sound comes from the area where character/item is hidden to help finding it during the last seconds.
- If the reader can’t find the solution the character/item runs or moves to the next page.

Sounds:
- On the first page the reader is allowed to record his/her name in order to make it more personal. All characters will call the reader by his name in the following story.
- Before the story begins, the reader has the possibility to enable the characters via sensors to tell their own stories.
- Music could also be added to different stories in different chapters/pages.
- The on/off sound button will be available.

Sensors:
- Touch sensors: If the reader finds a character/item he/she can touch it. The reader can also find hints in the different chapters/stories by touching special characters/items
- Record and Play sensor: meant to let the reader record his/her own name.
- Light sensor: this device recognizes if there is few or no light in the area/room. The e-book will be put into night mode and be illuminated via OLEDs.

Light:
- In every page in the book there is the option of "night mode" set-up. It works automatically via light sensors and an on/off button is included in every page.
- When the user reaches higher "levels" in the book, there will be pages that could only be played if the lights are off. If the light is on the page will be white.

Connect the book to the Internet and other digital devices:
- Connect the book and sync it to other devices (computer, pads, smart phones, etc.)
- Create a link between the book story and an online app where the user can mix playing online and reading the book.
- Enable the book as multi-players/multi-readers and connect with other people that are also reading/playing at the same time and let them play/read together.
2.3 Description of the projects technical setup

To make the "printed e-Book" work, different sensors have to be printed. Many different stimuli can be sensed using organic electronics [8]. Touch-, light-, and sound-sensors will be included in this application, as well as printed loudspeakers [9], OLEDs [10], transistors [11], capacitors [12], batteries [13] and other electronic components. They will be printed on different reactive functional layers inside the book. All functional layers and components could be printed by means of gravure, flexo-, screen- and ink-jet printing [14]. Currently it is investigated if it is possible to include voice recognition on a low-tech level.

3. Conclusions and Outlook

The fact that the printed electronic technology promises to be an available and inexpensive technology, lead to the assumption that a printed e-Book could be very useful to improve the education of the young generation. These functions could be added to school books and inspire young people to learn in a more interactive way.

From our perspective a very important point is to keep the value of the material qualities since we live in a world that becomes less and less tangible. The idea of making an analog object with almost the same potential of interaction as an e-book, is something that is considered to be highly attractive. This new application could lead to the possibility of linking the analog to the digital world as well as the invention of other applications that could be customized and adapted to different types of already existing books.

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Abstract

N‘RUN uses printed electronics for the running industry to create electronic running devices which are almost immaterial – reducing their distraction while running to a minimum. The runner can focus fully on the feeling of the physical exercise and on his body signals. N‘RUN concentrates on three products for three target groups: professional runners, free time runners and social runners. INSERT‘N‘RUN is a shoe insole for professionals and free time runners. It enables the runner to read and improve his foot dynamics. The insole consists of a printed pressure sensor that shows different types of foot motion characteristics in form of different graphics. It is an easy way to check running styles and prevent the runner from long term injuries. BLAZE‘N‘RUN screens the runner’s vital and dehydration status while running. It mainly consists of an electrochromic ultra-thin arm patch, which is activated by body contact and fills up with colour while running depending on the vital status to prevent overexertion and muscle fatigue. Fully coloured it stands for hyperacidity in the muscle and shows the runner, that he has reached his own limit. It is an advice to slow down in order to reduce the risk of injuries. PLAY‘N‘RUN is a social-outdoor-guerrilla running game focussing on the competition between runners to push them farther to new highs combined with a fun factor. It works without the need of any social network or smartphone. The game is based on personalised stickers, which users can order online. These are activated before the runner starts his session. At the end of the run the personal sticker displays the time and distance and it can be patched anywhere so that the next player sees the sticker. The runners get in touch with each other only by their stickers, so they can challenge each other.

Keywords: running devices, body sensors, social-outdoor-guerrilla game, electrochromic display

1. Introduction

At the moment there are masses of different running gadgets to show people their running distance, time, pulse, energy level or their trail like Nike+, Nike fuel[1], Adidas miCoach breast strap, runkeeper and runtastic. They are meant to motivate but disturb at the same time. Many gadgets are only working in combination with a smartphone, so runners have to take their smartphones with on the run which is an additional ballast. Additional weight disturbs the runner in his dynamic. Gadgets are very fashionable in the sport scene to motivate the runner, support them and take them to a higher exhausting limit. The new possibilities of printed electronics can reduce the additional ballast on the run, to circumvent taking a smartphones on the run, which is an additional ballast too. Printed electronics have many advantages: devices made of printed electronics are very thin, the weight is minimal in relation to normal electronics and they are flexible so that they can be placed close to the body but are hardly noticeable. The possible applications are enormous. Yet, runners are not just doing themselves good by running, but they also risk negative effects. The most of running injuries are foot-related. The feet absorb the shock of running first. False foot positions can be caused or intensified by running.
printed electronic devices they can be monitored and actively intervened for identification or correction.

Especially young people, professional runners and free-time runners are users of existing running devices. This is also the target group of the new concept N'RUN.

N'RUN is a concept of reducing running sports of its essence: pure running and hearing the voice of the body. N'RUN unifies higher motivation, prevention of injury, training upgrade and liberation from gadgets.

N'RUN is split in three concepts, which concentrate on different aspects of running:

- INSERT’N RUN: the runner’s foot dynamics and false loading
- BLAZE’N RUN: the vital, dehydration or hyperacidity status
- PLAY’N RUN: the motivation and fun factor by competing with each other

2. Product Concept

N'RUN is a concept to innovate the running sports device market. N'RUN replaces disturbing and impractical support gadgets by ultra-thin and hardly noticeable films. The new printed electronic devices will increase the runners comfort and raise the effect of support. The products are designed to move and stretch with the body.

2.1. INSERT’N RUN

INSERT’N RUN is a printed electronic insole for running shoes, which enables the runner to read and improve his foot dynamics. Other products only allow measuring during standing or walking, since they require bulky electronics, which distract from running. Therefore real analysis of foot dynamics during running is only executed on treadmills by video analysis. However, these are not everyday conditions and require a well-equipped studio.

INSERT’N RUN enables everybody in their normal running environment to test and correct their foot dynamics. It is a single-use product with the purpose to create a comparability by collecting the insoles, so that the runner can watch the development progress. During the run sensors react to the pressure of the different areas of the feet. It also measures the course of pressure during touch-down of the foot. This information relating to the physiological roll-over of the foot is transferred into a graphic visualisation, that is easy to understand even without the help of an orthopaedist. The numbers, which appear on the insert at the end of the run, show the style of run. This allows the runner to correct his roll-over behaviour. The insert is the perfect alternative for long distance runners to bring the roll-over-style to perfection.

The colour gradient of the arrows and the number appearing on the insert depend on the pressure while running. A high number e.g. the number six mean high loading on the arch. This imprint usually indicates an overpronated foot. With the insert runners can prevent injuries caused
by overpronation. Typical injuries by overpronation are callouses, bunions, the widely spread runner’s knee and Achilles tendinitis. [2]
With the insert the runner can control his running manner and see improvements. And for all the information the runner needs only a pair of inserts, no other gadgets are needed.

2.2. BLAZE’N’RUN

The BLAZE’N’RUN function is a dehydration measuring instrument to optimise training sessions and protect from overloading and muscle over-acidification to reduce recovery phases. The patch can optimise hydration and minimise fatigue so the runner can focus on challenging the run. Dehydration can cause breathing problems, blackout or other muscle weaken symptoms.
There already exists a similar patch developed by the MC10 Inc, Cambridge [3] for athletes. This patch sends real-time hydration levels to athletes’ smartphones so they know exactly when they need liquid.
BLAZE’N’RUN works in an easier way: Before starting the run session the patch is transparent, only the battery is visible in the shape of the logo. The patch is stuck on the under arm like a normal plaster. It is activated by pressing a button on the battery. During the run, when the body starts to sweat, the patch starts filling up with colour and a pattern appears. When the pattern is filled up with colour, the runner has reached his physical limit and he runner should end his running session. His essential body processes are exhausted.

This patch trains runners to listen to focus the essential running instincts and develop a feeling, when they reach their personal limit. This patch is a lifestyle product and training support combined. Wearing a cool, non-disturbing BLAZE’N’RUN while running is motivating.

2.3. PLAY’N’RUN

The game PLAY’N’RUN is a non-internet outdoor guerrilla game based on a simple sticker system.
The idea of the game is to detach people from the connection of online games and take them outside. It is a motivation to go running, conquering the city and get challenged without taking a smartphone with you. An outdoor game motivates people to go outside and do sport with a fun factor at first-sight. To compete with each other without knowing the other runner is challenging. An additional fact is that the runner acts like a street-artist "decorating the city". The game has the potential to inspire a lot of people to start running. The game is like ‘catch me if you can’ only knowing the sticker, not the person. Street art is widely spread in big cities.
and it is quietly tolerated, being a street art runner sticking one’s own stickers around the city is fun.

The player creates a personalised sticker as his guerrilla avatar by choosing from different shapes and colours. So every runner has its own guerrilla identity, which can be ordered and reordered online.

The sticker structure is divided into three parts: the body shape, a black battery shape and an electrochromic cyclops eye, which displays time and distance after the run. The glue backside of the sticker is patched with a foil with gecko adhesion [4] properties, so that runner can easily fix it on his clothes. An integrated motion sensor and timer measure distance and time. The runner can put the sticker anywhere. The stickers are environmentally friendly, they dissolve after two weeks, which makes guerrilla street art legal.

3. Material and Technology

The N’RUN concept is based on very thin and light-weight materials to ensure that the runner feels like not wearing any devices and can focus on his own body perception during his run. All parts of the products, which belong to the N’RUN family, need little energy, are energy-autarkic and recyclable-the PLAY N’RUN would best be biodegradable.

3.1 INSERT’N’RUN

The insert consists of three different layers: the first layer contains the battery and a small processor and memory. The second layer contains the pressure sensor as produced by Peratech[5], which measures the data during running. The top layer displays the results using electrochromic ink like being developed by Acreo [6]. The graphics transfer the pressure results in an understandable picture, showing the runner, which part of his foot is overloaded and possible wrong foot dynamics.

3.2 BLAZE’N’RUN

Blaze N Run consists of three different parts: at first a battery like from the TU Chemnitz [7] in the shape of a logo, which also functions as the start button. It is connected with a biochemical
sensor and electrochromic ink. The biochemical sensor measures the chemistry on the skin. The ink starts boosting as higher the concentration of sweat and hyperacidity level gets. The structure of the patch is kept simple so that is not thicker than a hair.

3.3 PLAY’N’RUN

This product contains a battery, a motion sensor, a little processor and a bi-stable electrochromic segmented display. The first layer is made of a gecko adhesive, which allows the runner to stick the product on his sportswear. The sticker needs energy only for a limited time, so a small battery like the one from TU Chemnitz [7] to power the motion sensor and the bi-stable display, which retains the information even without battery power.
4. Conclusion

The N’RUN products use the advantages of printed electronics to enlarge the comfort for runners. Since all products are disposable and for one-time use only, they depend on further development concerning environmental issues such as biodegradability and concerning the price. Only by mass production in large volumes a reasonable price can be reached for this kind of product. However, the N’RUN products show a new approach to electronics in general. They present electronic devices, which seamlessly integrate and support rather than distract.

References

VISIBLIZER—A Tourist Guide with a flexible Display Making Use of Augmented Reality and a Navigation Bracelet

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Abstract

If you ever ask yourself, "What’s behind the walls of that building?", you need VISIBLIZER. This product enables tourists to discover a city in a new way using printed organic electronics. Holding VISIBLIZER in front of selected buildings, hidden insights are given of scenes that take or took place there by superimposing the view of the building with photographs, videos and information on a transparent screen. The feeling of being right in the middle of history makes the building much more alive and gives not just intellectual, but also emotional insight into the city, its people, stories and historic events. VISIBLIZER combines two devices: The first is a bracelet with an integrated navigation display guiding users to buildings with stories behind their walls. The second is a transparent rolled out OLED display that superimposes these stories when standing in front of the building.

Keywords: OLED-Display, rollable display, navigation system, augmented reality

1. Introduction

VISIBLIZER is based on the principle of augmented reality. "Augmented reality or mixed reality is a particular technology which allows adding sensations, images and information generated by a computer to the normally perceived reality. The user perceives the world like everybody, but with additional information: text, three-dimensional, static or moving images, with which they can also interact by means of simple devices." [1] VISIBLIZER is an augmented reality display that gives an emotional and visual view behind the walls by using short text information, pictures and videos. VISIBLIZER shows superimposed pictures and videos with the reality, so that the user gets the feeling of being part of the shown story. The target group of VISIBLIZER are tourists. Normally tourists discover a city by sightseeing tours, but also they want to experience other facets of a city in shortest time. Hence, they are also interested in how citizens live in that city. This is possible to find out with VISIBLIZER.

2. Product Concept

VISIBLIZER enables tourists to discover a city in a new way using printed organic electronics. The product is available in selected shops, especially tourist information and book shops, where tourists usually would buy a map or other guided tours. A short introduction is given here, when renting the VISIBLIZER. Also the language is set by the staff. Now the VISIBLIZER bracelet is worn on the right wrist and activated by pressing a main button. Wearing it on one’s arm provides complete freedom of hands and does not disturb during city exploration. The navigation system on the bracelet starts and VISIBLIZER guides the user to the selected buildings using an arrow in the shape of the logo. Next to a specified building the same logo appears as a big sticker.
This is the spot to stand on and look in the direction of the arrowhead. The user here simply pulls the display at the handle out of the body and holds it up to gain access to superimposed pictures and videos of what is inside the building or which historical events happened there.

Two examples for the city of Frankfurt: Even though often forgotten due to more prominent happenings in Berlin, Frankfurt was a centre of many Red Army Fraction activities and activists. The RAF, is commonly known as Baader-Meinhof Group and was Germany’s most prominent left-wing militant group after the second world war. In totally inconspicuous garages in Frankfurt Bornheim three activists – Baader, Meins and Raspe – were arrested because they planed a bomb-attack. VISIBLIZER users here see a picture of the activists’ arrest.

Another ordinary looking housing block right in the centre of Frankfurt is where the murder of a prostitute named Rosemarie Nitribitt took place. She was Frankfurt’s most famous prostitute in the 1950s. Her life never was easy. She came from a poor family and worked her way up to become a rich woman that consorted with Frankfurt’s high society men, like Harald Quandt and Gunther Sachs. VISIBLIZER shows a picture of her murder, where she’s lying dead in her apartment.

Three control buttons are integrated in the gripnext, back and pause buttonin order to stop or replay certain information. When finished, the user simply rolls the display back into the navigation bracelet, which leads the way to the next building.

It is also possible to stroll around the city without navigationhere one only has to watch out for the stickers in front of point-of-interest sites, which reveal hidden insights. By pressing the main
button twice, the navigation system will guide the user back to the place, where he rented the VISIBLIZER for return. VISIBLIZER can be charged for the next user - and occasionally be updated.

3. Materials and Technology

The VISIBLIZER consists of three main parts: the body, the navigation bracelet and the rollout display.

3.1 The Body

The body contains a rechargeable battery, memory, GPS, processor and socket for a docking station. It is made of a robust aluminum tube where almost the whole technology is cased. A main button on the top of the body is to be pressed to start and return the device. Inside the body the rolled in OLED display is hidden and protected when not in use.
3.2 The OLED Displays

The navigation bracelet as well as the rolled display make use of flexible and transparent OLED displays. These are being developed with great intensity by companies such as Samsung, LG and Sony. Sony already in 2010 revealed a very tight rollable OLED display [2]. LG has also just launched a flexible OLED screen [3] which meets the needs of VISIBLIZER.

3.3 The Navigation Bracelet

The navigation bracelet has a defined rounded but flexible form that can adapt itself to various wrist widths. The form of the bracelet display is a "V", so that it consists of two optimal separated parts. On one part a compass in form of the VISIBLIZER logo shows the direction of walking by the arrowhead of the "V". On the second part the distance is shown in meters. For more comfortable skin contact the bracelet has a soft textile underneath and a silicon frame around the navigation bracelet and a part of the body in form of small lines.

3.4 The Rolled Display

The VISIBLIZER display is extremely thin and possesses the characteristics of high flexibility and high durability. It provides images of high resolution and sunlight readability as well as a wide viewing angle to also view with two or more people. A thin edge of TPE is surrounding the display to make it more rugged and give it a better look and feel.

4. Conclusion

A transparent OLED display and the use of augmented reality used in the VISIBLIZER offer virtual storytelling for an emotional adventure. The advantages of printed electronics are that they can be lightweight, sustainable, flexible. Hence VISIBLIZER is that bright and of such good contrast, that it can be used outside when the sun shines on it. Furthermore the display is visible from all angles, so that even two people can view images displayed on the screen. Printed electronics are a useful technology to create a new kind of tourist guides, which uses augmented reality. In this case augmented reality is not invasive, because some attractions of the tour are historical events and people could also give their permission to let the user have a look inside their rooms. By looking through the display the user thinks he is right in the middle of the story and a part of it. For this reason VISIBLIZER is an attractive product for tourism. It perfectly extends tourism tours by another feature. But not only for tourism: Even local people, who want to get a different insight into their city can use VISIBLIZER. No instructions are necessary to use VISIBLIZER; the user can move freely in the city and can lead himself to where he wants to go and what kind of information he wants to experience. In the future the idea of VISIBLIZER
can be extended to an online platform, which allows anyone to reveal hidden insight—maybe just by showing their living room but maybe also by telling their stories about historical events and showing private photographs.

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Pimp your prototype

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Abstract

In this article we will give a short overview on the use of real physical models in different design domains and the role of materials like cardboard for the design process. The presented examples illustrate the way these models are made interactive at the current state for different steps of the design processes. The idea of an interactive cardboard-kit has to be seen in line with the diverse "do it yourself" toolkits in the field of interaction design and interactive tinkering. Such tool-kit could support the conventional development process of design or architecture and simplify the work on interactive questions in those domains even more.

Keywords: paper prototyping, cardboard model, interactive materials

1. Interactive environments and design

Already in 1991 Weiser forecasts the vision of "ubiquitous computing"[1]. The technological development over the last twenty years made possible that nowadays artificial systems could be interactive in different kind. At this juncture the technological development influences a lot of situations of our daily life and trends like the "maker community" will expedite this even more. One consequence of this technological development will be that in the future not only the new formed discipline of interaction design, but nearly all design domains like visual design, industrial design or architecture have to deal with the aspect of interactivity (see fig. 1.15 in [2]). During the last decades diverse digital tools and methods were introduced to the process of product development like computer-based sketches and photorealistic renderings, the modeling of virtual prototypes by computer aided technologies (CAx), the visualization of models by virtual and augmented reality technologies (VR, AR), the animation of processes and product use or even the diverse possibilities of rapid prototyping. According to their function as tools for demonstration, they can be classified concerning their application (1) as a medium for ideation and working, (2) as medium for communication and (3) as a medium for presentation [3]. Beside those new digital tools, sketching and modeling with real-world physical objects will probably be, although in the future, important basic skills for all design disciplines [4].

2. Models and materials in the design process

Prototyping is an essential tool for planning and communication in the design process for interactive environments [5]. Within this process cardboard-and paper-based models are well introduced in nearly all design disciplines [3]. At the present those materials are namely used in the early stages of the design process. But there are differences concerning the applicability of cardboard according to the function of the models [3]. In the field of media design they can be classified according to their degree of complexity (low- or high-fidelity). Low-fidelity prototyping plays an important role at the beginning of the design process [6]. In contrast high-fidelity-prototypes have to give the impression of the final application. These models are used for presentation to simulate the preferences of the interactive product or to allow the exploration of haptic and tangible, interactive or multi-sensory qualities.
The transitions are fluid, but usually the separation between low- and high-fidelity is also a division in physical and digital. Paper-based modeling as thinking tool supports the content-based analysis, such as Initial Idea Sketch, Thumbnail Sketching or Storyboarding. Using paper, cardboard, pen and glue enables the quick development of easy and alterable paper-prototypes, which focused on the functionality or rather on testing the conceptual understanding of an application. Unlike a static sketch the paper-prototype generates a modular framework to visualize the structure and encourage first ‘dynamic’ test runs through the based interaction concept. The playful use of varied paper grades is particularly attractive. So for example the using of tracing paper provides the opportunity to separate various basic elements in additional layers, e.g. the degree of abstraction or structural divisions of the interface (see fig.1a).

![Figure 1: (left to right) a), b), c): paper-prototyping [7]](image)

In contrast industrial design and architecture are focused on the development of three-dimensional shapes. In this context models are next to drawings important working and communication tools [4]. Therefore in those domains mostly cardboard is used to create at first a simplified, but three-dimensional impression of the sketched ideas. In contrast to sketches or computer-based models those models are the medium for thinking, self-reflecting, working and presenting in a real three-dimensional way. According to their purpose those models can be distinguished in idea models, working models and presentation models [3]. Idea models represent the first steps of the designing process. Working models deal with basic geometries and variations. Idea and working models are often quickly made installations of mixed materials including paper and paperboard and produced by the use of scissors, cutter, glue, pencils et cetera. Since they accompany the design process, they are raw, diffuse and open for interpretation. By contrast presentation models handle an illusion of the prospective product or building for clients and the public. They are made after the design process. Therefore materials with a certain degree of abstraction (e.g. plastic, cement, timber, metal) are used. These materials represent real materials. In architecture paperboard is often used for representing concrete walls. The use of paper or cardboard for presentation models is rather unusual. The following examples will illustrate the conventional use of these materials.

![Figure 2: Models in the process of designing architecture-Mercedes Benz Museum in Stuttgart (architects: UN-Studio) From left to right: idea and working models; virtual model; presentation model; building [8-10]](image)
As shown in the pictures above, product design models are often full-scaled cardboard mock-ups. Architecture models are usually scale-down descriptions of a potential built reality that consists of objects and their interspaces. 1:1 scale prototypes are rather unusual except for constructive details. Due to their three-dimensionality and their materiality models are compared to drawings more similar to the original they represent. In the course of introducing virtual models to architecture and design the contrast of drawings and models is vanishing. This different dimension influences the function of models in the design process. Whereas product design models could be used to evaluate the handling of the package and shape concepts in a simplified but direct manner, the information of architecture models is more abstract and had to be translated by the architect.

3. Intelligent paper-based surfaces

The advantages of paper and cardboard are that these materials are inexpensive, available almost everywhere and quick and easy to handle and modify. The combination of these materials with printed electronics opens new possibilities to use them as interactive modeling material within the design process. Just like normal cardboard even interactive cardboard models will be an advantage mainly for the early stages of the design process in the named areas. The following example shows an interactive cardboard model made by an ARDUINO board, conventional LEDs, micro-sensors and lots of wires, which had to be connected. Since designers and architects are busy with many tasks, the printed functionality should be very easy to handle like electronic labels from a roll. A simple cardboard-based developer kit or a print on demand service for interactive pattern may facilitate this electronic oriented process enormously. The pictures illustrate the contrast between existing solutions and possible new ones.

According to the design goals of the different disciplines such interactive cardboard models could be used for different objectives. Within the working process such quick access to interactivity can qualify working models. Architects and designers can develop a spectrum of different interactive
models in order to analyze diverse interaction concepts. Furthermore this allows integrating usability tests in the early stages of the design process. Herein the user might get basic but real feedback by light or sound directly on the paper-material or even in combination with different interaction devices like smartphones or tablets. Thus such models could also be used within these usability tests to measure and count contact points of the hand or of single elements of the object itself.

![Diagram](image)

**Figure 5:** Printed functionality as cut-out-sheets; (right): Electronic labels by the meter

According to the analogy between properties of paper and cardboard and architectural shapes there might be the possibility to introduce such material even in the context of presentation models. Printed functionality could be a part of presentation models so that the architectural models convert into miniature intelligent facades (see fig.5). Within a coalition of real and virtual models both concepts would support each other: Real models gain more flexibility and temporality; virtual models gain tangibility and materiality. In this way the different aspects could be implemented to the real three-dimensional presentation model itself more interactive and directly: Empiric virtual models visualizing the invisible (e.g. thermal bridges, solar input, forces) can be applied to real models. Presentation models can be enlivened with labels showing pedestrians, traffic, weather, light and movement. Varying solution for a facade according to geometries, proportions, materials or colors can be represented by only one real model. Presentation models can be qualified by visual markers which can be switched and appear as interactive models. Also in media design digital paper and cardboard expanded the range of these smart materials and offers a wider range of possibilities to support especially the drafting process for new forms of interaction.

Those perspectives may include a digital tool kit to support information architecture. Physical sticky notes will be transferred in a digital structure and representation (archiving, storage and collaborative work) or interactive paper into a digital wireframe model to support the translation of visual physical paper-based modular structured paper-prototypes (see fig. 6). Comparable to product design even in media design cardboard-based interface elements could simplify the record of the transitions and locomotion of test users in usability tests. Moreover the developments of such materials may include scenarios like paper computing, wherein printable interactive paper devices serve as low cost digital interfaces for small production quantities or individual fabrication.
4. Future vision - Interactivity by the meter

Current approaches of new interfaces, for example smart material interfaces "try to overcome traditional patterns of interaction and leaves behind the "digital feeling" [14]. The blurring of digital and physical space of interaction takes Weisers vision into account [1]. The enrichment of paper-based modeling with printed electronics reflects this shift – "how people, computational materials, and even traditionally non-computational materials are coming together [15]". Therefore interaction design changes into a form-giving discipline and has to detect the material nature of interaction”.

Interactive cardboard as new material for early prototyping as well as for presentation or evaluation will have some clear benefits: (1) Designers and architects may keep on working with familiar methods, tools and materials. (2) The different types of interactive models will enable to integrate the aspects of interaction with a potential designed reality in different stages of the process more directly. (3) By this way of interactive prototyping designers and architects may create a pool of different basic prototypes, including basic interactive elements, very quickly and with low expenses.

One first proposal to provide these new technologies for the process of modeling is a print on demand service. Here the designer should have in the first step the possibility to create suitable patterns and body-wraps of the three-dimensional basic object with common two-dimensional design software. In a second step then there should be the possibility to define the regions of the body-wrap with interactive functionalities like buttons, sensors, potentiometers or even LEDs and their connection by printed wires. In a third step the so-created interactive body-wraps have to be printed and mounted. A second alternative may be, to provide a paper-or cardboard-based model-kit with typical printed functionalities in different sizes for paper-prototyping. Such an interactive cardboard-kit can be used by designers and architects like the meanwhile well-known electronic prototyping platform around the ARDUINO. This could allow designers of different disciplines to build flexible models by using these interactive cardboards and connect the single components on the mechanical dimension with tape and glue and on the digital dimension with conductive ink pen.

Acknowledgement

We acknowledge the European Social Fund and the Free State of Saxony which supported the work in the named project (Project number: 100072525). We thank all students and advisors who participated in realizing the design cases presented in this paper.
References

"Micro-Thermoforming" by printing metal-based inks on thermoplastic substrates

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Abstract

Forming thermoplastic sheets by heating and vacuum within a solid mold is a common method for production of plastic parts that called "Thermoforming". The idea in this article is about a novel forming method of thin sheets of thermoplastic material, by printing the desired patterns using iron-based inks on the plastic substrate and warming up the printed pattern by electricity, thereby applying a magnetic field. The final result would be forming the plastic substrate in the shape of printed patterns. This could be used, for example, thin lines and fine details on the micro scale with respect to deepness and volume.

Keywords: Micro thermoforming, Metal-based inks, Functional printing

1. An introduction to "Thermoforming" and "Micro molding" processes

1.1 Thermoforming

Thermoforming is one of the most common methods for processing plastic materials. It is a very versatile method used to manufacture a wide range of products in different industries such as mudguards of cars, motorcycle windshields, boat hulls, blister packs, disposable food containers, cosmetic cases and packages [1]. In thermoforming process, a thick sheet is clamped in a frame and is heated to a temperature well above its glass transition temperature, so that it becomes rubbery and ductile. It is then placed over a mold and is stretched to take the contours of the mold, either by plug assist or a differential pressure (Fig. 1) [2].

![Figure 1: Schematic of the thermoforming process [2].](image-url)
1.2 Micro molding

Micro molding has been employed to fabricate a variety of polymer components. Most applications are in the field of micro optics and micro fluidics such as holograms which are affixed to credit cards, anti-reflective surfaces and capillary analysis systems but there are also some examples of micro electrical and mechanical devices.

Micro molding of thermoplastic polymers is one of the most promising fabrication techniques for non-electronic micro devices. There are five processes which are employed for micro molding of thermoplastic polymers: Injection molding, reaction injection molding, hot embossing, injection compression molding, thermoforming [3], and Rubber-assisted micro forming [4].

2. New concept: Micro-Thermoforming by printing metal-based inks

The new idea in this article is about forming a thin layer of thermoplastic sheet, e.g. a thin layer of PET, in a new way. First, the desired pattern is printing on the plastic substrate using dispersions of Nano- or micro scaled iron particles. After curing or sintering the ink, the border of substrate will be fixed on a frame. At the next step, by connecting the electricity to printed pattern, either by direct electrical connections or inductively by applying a high-frequency or microwave field [5], the printed lines are starting to warm up as electric resistors or heating filaments. Increasing temperature inside of these printed lines will cause to warm up the plastic substrate, at the same place that they were printed.

A permanent magnet under substrate attracts the printed lines of iron, steadily. This force causes to appear deformation in the structure of plastic substrate, as much as it is necessary to provide the final shape. Finally, by disconnecting electricity and cooling substrate, the surface forming will be fixed.

The final result would be forming the plastic substrate like the same patterns that printed on it before by iron ink such as thin lines and small areas in a micro scale of deepness and volume (figs. 2 and 3). Different linear and dot shaped structures would be like fig. 4.

Figure 2: The printed ink, works as a high resistance heating element
"Micro-Thermoforming" by printing metal-based inks on thermoplastic substrates

Figure 3: The printed layer starts to catch the form

Figure 4: Printed inks as dot-shaped and linear-shape
3. Process controllability

During this thermoforming process, the printed ink works as two different parts: First, it works like a resistive– heating element or inductive antenna to provide local deformity in plastic sheet, like printed pattern. Secondly, it provides the ability to interact with a dc magnetic field which creates the deformation forces instead of using molding parts.

The rate of magnetic attraction could be controlled by the thickness of metallic inks and the magnetic material. Also, shaping the plastic sheet depends on characteristics of printed inks like pattern layout, thickness, wideness, density, transparency and electro resistance of the inks would be controlled.

4. Benefits

In comparison of this method with conventional Thermoforming processes, one of most important benefits is the abundance of the "mold" from forming process. Other benefits like reduction of processing time and energy consumption would be expected as well. On the other hand, removing heating parts from machine and the reduction of process steps are considerable, too. In figure 5 (left) and 5(right), the comparison between different methods is illustrated.

5. Results

Using functional inks for printing the structures that work as deformation elements on thermoplastic foils would be a new concept for shaping precise structures in a reasonable price. This type of micro forming would be useful for making micro clichés or ink containers for e-papers based on electro wetting behavior. In compare with other methods, we can say it is a mold less process that uses printing instead of conventional molds.

References


Media
Optimisation of the lint camera system for analysis of lint deposits

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Abstract

This paper is a continuation of our work on the development of a lint camera system, which now looking at its performance optimization. To do this, we have analysed the role of camera exposure in determining the image quality as well as the impact of different ink colours that are used in the printing. A low exposure time with a fast moving press improves the clarity with which the lint objects can be observed. Lint is found to be easier to identify when printing using yellow and cyan ink compared to printing with black ink.

Keywords: linting, offset printing, image analysis

1. Introduction

During offset printing process, loosely bonded fibres, fines and other materials from paper surface come loose and can cause linting problem. These lint particles are removed by tacky ink when the ink film is splitting in the printing nip. The build-up of lint on the printing blanket reduces the quality of the printed image and can affect the pressroom efficiency due to blanket cleaning. Lint measurement is a challenge because of the dynamics of lint build-up, that is influenced by both paper and press variables. Many different methods, including both laboratory tests and printing scale trials have been used to estimate the tendency of linting in paper [1-6]. These methods, however do not give a good correlation with the behaviour of the paper in commercial printing. One reason for this uncertainty in the results is that laboratory tests often apply larger forces to the paper surface than offset printing, to remove large areas of the surface as lint. Printing trials were also run only to measure the lint accumulated on the blanket and do not analyse the transfer of the lint particles from the surface during printing. So far, only few people have done the studies on the dynamic measurement of linting [7, 8]. Wiik [7] developed a lint camera system to monitor the lint-build up on a blanket and measure the transfer of lint particles from the surface. The dynamics of lint particles during printing process can be described using two rate constants, $k_1$ the amount of lint which is transferred from the paper and $k_2$ the probability per copy of that an individual lint particle is removed from the blanket. Assuming simple first-order kinetics, the number of lint particles accumulated on the blanket, $L$ is: $L = (k_1/k_2) \times (1 - \exp(-k_2 \times n))$, where $n$ is the number of printed copies. In 2009, Hoc [8] did similar studies with an online measurement system (OLM). Both of the systems were able to measure the transfer of lint particles as effects of paper and press parameters. Unfortunately, there were still limitations in their studies. The original lint camera was not able to give reproducible results, while the OLM system was purposely tested with only a light-coloured ink that was matched with the blanket colour in order to produce visible lint [9]. In this study, we will extend our previous work on the development of lint camera system [10] to its performance optimization, by considering the effects of camera exposure in image quality as well as applying different ink colours in the printing trials.
2. Review of the development of a lint camera system

2.1 Early generations

Components

The original lint camera used during Wiik’s trials was a JAI CV-M40. This CCD camera has 1µsec shutter time but does not support asynchronous triggering, thus it was difficult to take an image at the same spot every time. For that reason, the second generation camera used a NET Electronics GmbH Foculus FO232SB. The lens is a NIKKOR AF Micro-Nikkor 60mm f/2.8D. To trigger the image capture, an optical sensor with polarizing filter and a special reflective tape are used. A 15V 150W halogen lamp was used as the light source, together with two lenses to focus on a small area on the blanket and a filter to shield the blanket and absorb the heat that is generated.

Mounting on the printing press

When setting up on a press, the original lint camera was mounted perpendicular to the blanket while the light source was angled. Both camera and the light source were mounted with movable arms from the side. This set-up was difficult and was not able to give reproducible results. The image quality was poor as shown in Figure 1.

![First generation of lint camera](image1.png)

Figure 1: First generation of lint camera is shown on the left side and the right image is the image result taken when the press is running [courtesy of Wiik and Norske Skog]

Since the movable arms were inconvenient to set-up, it was decided that a tripod would be used for the second generation of camera. The camera and lamp were attached to a plate on a tripod that supports all the components. With this system, the camera should be at 90° angle to the blanket cylinder and the light source should be angled. One major drawback from the system is the lighting from the side cast shadows and gave uneven illumination on the blanket, resulting a dark spot in the centre of the field of view (Figure 2).

2.2 Third generation

A new LED ringlight has been introduced to the system, replacing the halogen lamp. The ringlight is attached around the lens of the camera to improve illumination of the imaging area. LED gives a high intensity and distributes even illumination over a small area of the offset printing press blanket. When the ringlight is placed at the standard distance from the blanket (30mm), it can give 320 klux of illumination.

The camera set-up for the printing trials has also been improved for the third generation of lint camera. In order to eliminate the use of tripod, a bracket mounting has been designed to attach the camera directly to the frame of the press (Figure 3).
3. Printing trials and image analysis techniques

Printing experiments were carried out on a Heidelberg GTO-52 press, a sheet-fed single colour cold-set printing press with a maximum production of 8000 copies/hr. The paper samples used for the trials were standard 42gsm newsprint. A solid print density of 1 across the width of the print pattern was targeted for printing. Fountain solution used was 2% Aquarius AC. A compressible blue printing blanket (Seaga CMD2) was used in Heidelberg GTO-52 press. Three different ink colours were used in the experiments: a black ink with tack 12.5 from DIC, yellow and cyan inks from Toyo with tacks of 14 and 13.5, respectively. The plate was a standard A4 test plate consisting of solid, 40% tone at 150lpi and non image areas.

The lint camera was positioned in front of the blanket to capture images from a solid area. The dynamic images were collected every revolution during the printing runs. At the end of the run, the press was stopped and the static images were obtained for comparison with lint taken by the tape pulls.

The dynamic and static images taken by the lint camera were analysed using ImageJ. With the system, the photographed region has an area of 58mm$^2$. The captured images were already an 8-bit grayscale. Any uneven illumination was fixed by flattening the image background. After that, manual threshold is applied to identify the lint particles.

4. Camera exposure and its effects on image quality

The combination of aperture and shutter speed determines the amount of light that passes through the camera lens. It is thus important that the chosen settings are able to produce bright and non-blurred images. In practice, choosing the right settings has always been a challenge that
affects the image quality and possibly also the accuracy of the results.

![Image of shutter speed variation](image)

Figure 4: The image results from variation in shutter speed. (A) Shutter speed was 159μs; (B) Shutter speed was 120μs; (C) Shutter speed was 100μs.

Figure 4 shows dynamic images when the shutter speed is varied. As we can see, the higher the shutter speed, the longer the shutter remains open and the more light reached the image sensor. This results in brighter but blurry images. The lint objects seen in the image (A) are elongated in one direction due to the blurring. This will increase the measurement of length and area of the real lint particles.

With a fast moving printing press, lower shutter speed is preferable to reduce blurring and avoid the noise in the background. When shutter speed is reduced from 159μs in image (A) to 100μs in image (C), the appearance of lint objects is improved. There is still trade-off to be made between the aperture and the intensity from the light source to produce brighter image.

5. Lint identification

Identifying lint particles from the dynamic images taken by the lint camera depends on the ink colours used during the printing trials. When the press is running, the application of yellow and cyan ink in blue printing blanket will make the appearance of the lint particles brighter. Therefore, manual threshold is performed on light objects (Figure 5A and 5B). On the other hand, the use of black colour ink will make lint appear as dark objects thus, threshold is applied on dark objects (Figure 5C).

![Thresholded lint images](image)

Figure 5: The raw images from the lint camera system, taken during the press run and its thresholded results. (A1 & A2) When yellow ink is used; (B1 & B2) when cyan ink is used; (C1 & C2) when black ink is used.
In order to assess the validity of the system during printing run, the identified lint from dynamic images was compared qualitatively to the static images when the press is stopped and to the corresponding area from the blanket tape pulls. As we can see in Figure 6, the lint particles identified by the camera (dynamic and static) were similar to those lint particles in the tape pulls. However, many small particles that were picked up when looking at the tape pulls under the microscope were not visible with the camera, due to the lower resolution of the camera.

Figure 6: An example of lint particles analysis in dynamic image (A) during the printing run, static image (B) when the press is stopped and the blanket tape pull (C) at the end of the run.

6. Conclusion

The aperture and shutter speed determine the image quality. Lower shutter speed is preferable for fast moving press to separate the lint objects from the background. The lint identified by the camera (dynamic and static) show similarities to the lint removed by the blanket tape pulls, except that it does not pick-up small objects. Increasing camera resolution should improve the image details. An enhanced lighting source is required to improve the quality of the dark images generated by the use of black ink.

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References


Evaluating Consistency of ePub Document Reproduction Among Various Apps and Tablets

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Abstract

The .ePub format for digital books was designed with variable-format pages that adapt to various sizes and orientations of electronic eBook readers and tablet computers, while maintaining a constant font size that facilitates reading text-heavy documents. Notably the same .ePub document could look different, depending on the platform and eBook-reader app, the authors designed an EPUB test form, following the philosophy of the ink-and-paper press test forms developed by the Graphic Arts Technical Foundation (GATF, now Printing Industries of America, PIA) [1]. The form includes multiple character, paragraph, table, colour, image, and multimedia elements that can be used to assess the appearance and function of these elements on various eBook readers and apps.

Keywords: EPUB, iPad, eBook

1. Introduction

An eBook is an electronic version of a book that can be read on almost every digital device, including tablet computers, desktop and laptop PCs and mobile devices. In 2007 the International Digital Publishing Forum (IDPF) introduced the first version of EPUB. EPUB 3.0 is the latest standardized specification that was approved by IDPF in 2011 [2]. The main advantages of publishing digital books or eBooks, in the EPUB format are its ability to reflow text to different sizes and orientations of eBook readers and tablet computers, while maintaining a constant, easy-to-read text size. At the same time, designing reflowable pages can be difficult to adapt to for anyone who is used to designing for traditional ink-on-paper media, with fixed page sizes. Noting that the flow of text and graphics can be hard to visualize and that some formatting specifications are honored while various eBook readers and apps ignore others, the authors had the idea to design a test form for EPUBs. The EPUB Test Form that was created in Adobe InDesign includes samples of various text, paragraph, graphic, links and multimedia objects that could be used to test display capabilities and rendition on eBook readers, tablet computers, and apps.

2. EPUB Readers and Expectations

The EPUB test form was evaluated using Apple iBooks, eBookS Reader, eLibris, and AZARDI 20 on an Apple iPad (3rd Generation), Apple iPad Mini and Samsung Galaxy Tab 2 10.1. The test form was also tested on Barnes and Noble’s NOOK Simple Touch tablet.

Apple iBooks was used in the testing, as it is one of the most popular EPUB readers in today’s market. It is a free app that can be downloaded onto an iPad, iPhone or iPod touch with iOS 4 or later [3]. It supports EPUB 3.0, the latest standardized EPUB specification [4]. With its
popularity and proven functionality it will act as a benchmark for the testing process. eBookS Reader is a free German eBook Reader app. It supports EPUB, PDF and TXT formatted documents [5]. It uses a table of contents to skip directly to specific chapters of the eBook, which may suggest that it supports links well [5].

eLibris eReader is a free Finnish eBook Reader app. It also supports PDF and EPUB file formats. It is capable of cropping the margins and locking the screen position of an EPUB document, which may contribute to its formatting paragraphs well [6].

The AZARDI 20 reader was chosen because it is a desktop application with wide support of EPUB 3.0 features. As well it uses Gecko, an engine, to render pages while most other eReaders use WebKit. With this capability, the EPUB layout can be tested in several engines. For example, AZARDI 20 is the only application to support paragraph justification with alignment of the last line to the center. Readium, an official IDPF program, is another application with wide support of EPUB features. It runs, however, on the WebKit engine (as a Chrome plugin) and is designed to be used by developers as it supports almost all specified features but does not offer a user-friendly interface like other programs do. Readium was used to test the functionality of the test form.

Barnes and Noble’s NOOK Simple Touch uses Adobe EPUB renderer and is a popular eInk reader with native support of the EPUB format. Electronic ink-based readers are not expensive and are functional devices. The NOOK only supports EPUBs as e-book formats, therefore good support of the EPUB features are expected.

3. Results and Discussion

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*Chapter 2 Test Form  
**Chapter 2

iBooks was the most reliable EPUB reader compared to eBookS Reader, eLibris and the NOOK Simple Touch during testing of the character test form. The majority of the character styles
applied in Adobe InDesign were successfully exported into the EPUB file, showing up in iBooks. The only exceptions were ordinal numbers and varying fonts. These character styles did not show up in eBookS Reader, eLibris or the NOOK as well. The four tested EPUB readers translated all the specified fonts in the character test form into the default font of the program. These results were expected, as EPUBs do not support ordinal numbers or fonts that are not embedded within the document using HTML coding.

The character test form did not translate well into the eBookS Reader as all the character styles, with the exception of fractions, did not appear different. This result was contradictory to the testing of the Chapter 2 text in eBookS Reader, which did have the character styles appear differently. eLibris was even more unreliable than eBookS Reader as the character test form did not open. The Chapter 2 text did, but with missing text, and even less styles translated into the EPUB format. The character styles that did maintain their integrity were italics, font size and font colour.

The NOOK applied its user-defined character styles, which overrode the publisher’s styles regardless of the "Publisher Defaults" option being turned on in the Character Test Form. As with the other applications, the Chapter 2 text rendered more of its features than the Chapter 2 Test Form. Bold and italicized text did not display at all.

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<td>Drop Caps</td>
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AZARDI 20 proved to maintain the paragraph styles the best. This can be attributed to it using the Gecko rendering engine, which is almost fully compliant to CSS3, including justifying text with the last line aligned. The other eReaders supported most of the test form elements as well. Paragraph styling is a well-established part of the CSS standard and is well developed in HTML rendering engines.

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</table>

Cover - - - - -
The EPUB file format supports the following image files: GIF, JPEG, PNG and SVG. It is also possible to include non-core formats such as Flash. In this case it is necessary to provide a fallback file to be presented to the user with an eReader system that does not support the above mentioned non-core format. Images are included into EPUB files by standard HTML coding. Also the mention of image files in content.opf is obligatory. All of the tested eReaders supported image formats listed in the EPUB 2.0 and 3.0 specifications including vector SVG graphics, which is a part of the HTML5 standard. iBooks and AZARDI 20 displayed every image format supported by EPUB 3.0 specifications as well as HTML5 canvas elements. It also supports non-core formats such as embedded Adobe Flash animations.

<table>
<thead>
<tr>
<th>Standard HTML5 linking</th>
<th>iBooks</th>
<th>eBookS Reader</th>
<th>eLibris</th>
<th>AZARDI 20</th>
<th>NOOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linking inside of ePub container</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Link to Nth second of multimedia file</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

The majority of the tested EPUB readers proved effective in linking inside and outside of the document using standard HTML5 linking. eLibris was the only application that did not support this functionality. Among the additions, EPUB 3.0 has added a new flexible method of linking inside a document. This new method is called CFI (Canonical Fragment Identifier), which describes and unifies the functionality related to linking inside and outside of a document and even inside multimedia elements. It is still unsupported by most of eReaders with the exception of iBooks.

<table>
<thead>
<tr>
<th>HTML5 video embedding (H.264) function with controls</th>
<th>iBooks</th>
<th>eBookS Reader</th>
<th>eLibris</th>
<th>AZARDI 20</th>
<th>NOOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard HTML5 video embedding (VP8) function with controls</td>
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<td>No</td>
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<td>Standard HTML5 video embedding function with autoplay</td>
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<tr>
<td>SWF (Flash) format video</td>
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<tr>
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<tr>
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<tr>
<td>Audio overlay feature</td>
<td>No</td>
<td>No</td>
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</tr>
</tbody>
</table>
The audio and video elements were added according to EPUB 3.0 specifications and using HTML5 syntax. eReaders which use WebKit engine support VP8 video codec. Gecko based AZARDI 20 also supports it. eBookS Reader and eLibris have no support of most HTML5 features including multimedia files. The inclusion of Flash video as a non-core format is supported in AZARDI 20. The trigger (custom control) element enables the creation of markup-defined user interfaces for controlling multimedia objects, such as audio and video playback, in both scripted and non-scripted contexts. It is only supported by iBooks among all the tested devices. Audio overlay functionality allows adding audio narration to the text. To add audio overlay, a SMIL file (an XML format designed for applying overlays) has to be created. This functionality is not supported in any of the tested eReaders. Still it is supported in the official IDPF application, Readium. iBooks and Azardi proved to be the most reliable EPUB readers for supporting audio and video playback.

4. Conclusions and Ideas for Future Research

Apple iBooks eReader rendered the test form most accurately and consistently of all the tested eReaders. It can therefore be named as the application to best support EPUB features among the tested mobile devices thus far. The NOOK Simple Touch reader also provided good results considering the technical limitations of eInk technology. Unfortunately several important features in interactive reading, such as audio overlay and CFI linking are not yet well supported by eReaders.

The goal of this paper was to test the created EPUB Test Form. Similar to the GATF press test forms that underwent progressive iterations with user feedback, the authors consider the test form a "work-in-progress" that can benefit from user feedback and suggestions. Users are welcome to contact any of the authors with suggestions and ideas.

In future work the authors plan to further evaluate the test form and compile a greater checklist of what to look for when interpreting the test form on a specific platform.

Acknowledgement

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References

Determination of optimal distance from laser printer by measuring particulate matter concentrations

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Abstract

Due to drastic decrease of prices of laser printers and toners for laser printers compared to ink jet printers, as well as quality, durability and speed, in the last decade, more and more offices and homes use laser instead of ink jet printers. But often use of laser printer has some serious drawbacks. Recent studies have shown that considerable amount of particles are released to the room during printing with office laser printers. Other studies have found that inhalation of those particles can cause serious health issues. Aim of this study was to determine the optimal distance from printer that is safe enough from inhaling those particles. For experiment, three printers were chosen, considering date of production, to determine if the amount of released particles is smaller in newer printers which would implicate that manufacturers are making efforts to solve this growing problem. Second test was to determine the concentration of particles in the air on different distances from laser printer and with different speeds and quality of printing. In the end the optimal distance from printer was recommended.

Keywords: laser printer, pigment particles, occupational health

1. Introduction

In almost every industry, there is dust, whether it is used as a raw material, utility product, or created as intermediate product, waste material or finished product [1]. Dust, char and various gases mixed with moisture help carbon dioxide to create a cloud (buffer) above the ground, which causes the greenhouse phenomenon [1]. For occupational health purposes, the dust is classified by size into three categories [2]:

- Respiratory dust, diameter smaller than or equal to 5 µm, small enough to penetrate deep into the lungs (alveoli) in the neck, throat and upper respiratory tract.
- Inhalable dust, diameter size of 10 µm, which is usually trapped in the nose, throat and upper airways.
- The total dust, all airborne particles regardless of their size and composition.

Dust is present in graphics technology and the printing process, as well. In the process of laser printing, toner particles when activated through external influences, mixed with dust that is already in the printer, and the cellulose particles of dust that are created from friction between the paper and printer rollers under the influence of heat, form tiny dust particles that can remain in the air some time [3]. In such a floating state it is high likely that these particles penetrate the respiratory system and leave the consequences to human health. Extensive tests conducted by McGarry et al. [4] showed that workers in the office are constantly exposed to certain concentrations of particles. Most of them are in the ultrafine range, but majority of these particles is not emitted from the printer. Regarding the impact of ventilation to reduction of
the concentration of particles, it was determined that it acts with a delay, except in one case, when ventilation with rapid airflow was directed straightly to the printer and managed to reduce the concentration of particulate matter in the moment, but considering the typical flow rate of air and distance of ventilation from the printer, in general there is a lack of possibilities for the momental decrease of the concentration of particles emitted from the printer.

Morawska et al. [5] have been studying and comparing the high- and low-emitting printers in order to determine what is the crucial difference between them. They found out that main difference is the temperature instability of the heater during the short break between printing two pages. If the printer does not reduce the energy that causes the heating before the next paper is fed, the temperature rapidly rises until it loads a new sheet to absorb excess heat.

Vensing et al. [6] investigated the characteristics and the number of ultra-fine particles (UFP) emitted by laser printers and multifunction devices during operation. Results from test chamber confirmed that laser printers emit fine particles with aerodynamic diameters up to 100 nm. They showed that the test chamber is useful tool for physicochemical characterization, as well as for comparison of different printers under controled and standard conditions. They also concluded that a direct link between the results of the test chamber and offices with printers is very weak, due to the very different behavior of particles in them, as well as a long residence time in the indoor air of aerosols, especially in the case of poor air mixing or ventilation. In addition, they showed efficacy of commercially available filters on the reduction of the UFP concentration. They concluded that the installation of external filter does not automatically lead to a reduction in the concentration of UFP. To significantly decrease total emission of UFP by using an efficient filter is possible only if the air flow through the printer is designed so that most of the UFP is released out of the printer through a defined opening.

Koivisto et al. [7] have found a relationship between the measurements in the test chamber and the motion of particles in the room considering the ventilation system and based on that relationship, created a model of motion of printer emissions in the room. This model can be used in studies of internal sources of emissions, or as a tool for development and design of ventilation systems.

For these reasons it is important to determine the concentration of dust particles that is released during printing. In this paper, we tried to determine the impact of printer resolution, date of production of printer and the size of the room to the average concentration of dust particles in the air, in order to determine the safest way of handling the printer.

2. Experimental

The average concentrations of particles in the air during printing were measured using a device Microdust Pro, Casella (UK). This device can measure concentrations of particles in the following range from 0.1 to 2500 mg/m$^3$.

Results of measuring the concentration of dust in real time are shown as: TWA-average value of the mass concentration of total dust; ie. obtained value represents the average concentration from the moment of turning on the device and maximum reading, is the maximal concentration of dust.

First measuring was performed at the distance of 5 cm from the printers. The data was obtained for quantity of 1, 5, 10 and 20 sheets. For newer and older printer printing was done at 600 and 1200 dpi. For newer printer measuring was done in econo mode (mode for saving toner), as well. For newest printer, measuring was done in best, normal and draft mode.

Second measuring was performed at a distance of 1 m from printer.
3. Results

Fig. 1 presents results of measured concentrations of dust particles during printing of 1, 5, 10, and 20 sheets at a different resolutions of printing (a: Shows the influence of resolutions during printing on older printer (600 and 1200 dpi); b: Printing is done in the normal and econo mode with resolutions of 600 dpi and 1200 dpi, where higher resolution means that higher amounts of toner particles are applied to the printing surface; c: Printing is done on the newest printer in the best, normal and draft mode).

Figure 1: Influence of volume on the concentration of dust particles at different resolutions in a) older, b) newer and c) newest printer

Fig. 2 shows measured concentration of dust in real time during printing volume of 1 sheet with a resolution of 1200 dpi. From the Fig. 2 is observed that the maximal concentration reaches a
Concentrations of dust in real time during printing volume of 1 sheet

Figure 2: Concentrations of dust in real time during printing volume of 1 sheet

value of 3.37 mg/m$^3$ after 30 s and immediately after value drops to less than 0.5 mg/m$^3$. The average value of this measure amounted to 0.103 mg/m$^3$, which is significantly lower value than the maximal allowed value, which is 4 mg/m$^3$.

Fig. 3 shows measured concentration of dust in real time during printing volume of 20 sheets with a resolution of 1200 dpi. From the results of Fig. 3 is observed that the maximal concentration

Figure 3: Concentrations of dust in real time during printing volume of 20 sheets

is significantly lower than in the previous case and reaches a value of 0.464 mg/m$^3$ after 120 s. The average value of this measure is 0.013 mg/m$^3$, which is significantly lower value than the maximal allowed value, which is 4 mg/m$^3$.

Fig. 4 shows concentration of particles at the distance 1m from the printer.

Figure 4: Concentration of dust in real time during printing at a distance of 1m from printer
4. Discussion

At the beginning of printing, the average concentration of the particles was higher, in some cases, more than 1 mg/m$^3$ probably due to accumulated dust, that is activated when the printing is started and lifted into the atmosphere. During printing of 5 sheets, average concentration decreases to less than 0.1 mg/m$^3$. The average particle concentration and maximal particle concentration were greater at a resolution of 1200 dpi, probably as a result of greater activity of printer at 1200 dpi. Achieved concentrations are within tolerable limits of 4 mg/m$^3$. However, during longterm printing in a closed room it is possible that concentration of dust particles increases and crosses the limit. For this reason, as a preventive measure, a room containing a laser printer should be periodically ventilated.

Comparing the econo and normal mode, it can be seen that the average and maximal concentrations of dust during printing in econo mode are lower than the initial concentrations of dust when using the normal mode. After printing of 5 sheets in econo mode, dust concentration becomes higher than in normal mode, which indicates that the fixation of toner particles to the surface is weaker in the econo mode than in normal mode.

No particles in the range of 1 m is probably due to scattered movement of particles in all directions from the printer. That is why in the range of 1 m from printer, concentration of particles in the air is diluted to less than 0.1 mg/m$^3$.

5. Conclusion

In the industrial toxicology, where is necessary to adjust production and occupational safety measures, is important to know maximal allowed concentrations (MAC), ie. concentrations of a gas, vapor or dust to which employee can be exposed eight hours/five days a week for several years without any consequences to health. In this paper is shown that during the operation of a laser printer, a certain amount of dust is released in environment, which can have a negative impact on human health. Measured average dust concentration are within acceptable limits. Results of analysis in econo and normal mode the printer showed that the econo mode of printer releases greater amounts of dust compared to normal mode. Results of measured concentration of particles during operation of the printer in real time showed that the dust concentration is higher at the start of printing and decreases during printing. From results of measuring the concentration of dust at a distance of 1m from printer, it is concluded that 1m is optimal distance from laser printer, in which operator will be safe from inhaling potentially harmful amount of dust particles. Since in this paper is shown only the impact of the printing process on the emission of dust, further investigations will take into account the printing substrate. It is necessary to create a standard for measuring the concentration of particles in the air, and determination of MAC when working with printers and copiers.

Acknowledgement

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References


September 12, 2013
Functional printing IV
Printable magnetoelectronics

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Abstract

Printable electronics has emerged as a key research field to meet the requirements of modern electronics. The rise of this field is mainly indebted to huge efforts in materials science to fabricate cost-efficient versatile electronic building blocks such as transistors, diodes and resistors [1]. However, the fabrication of printable electronic sensors and contactless switches operating in combination with magnetic fields remains challenging, mainly due to the lack of appropriate sensing compounds at ambient conditions [2]. The printable magnetic sensor would act as a contactless switch in a complex printed electronic circuit. For this purpose, magnetic sensors with high sensitivity operating at room temperature have to be developed as inks, pastes or paints.

Metallic multilayers of alternating ferromagnetic and non-magnetic materials, i.e., Co/Cu exhibit a giant magnetoresistance effect (GMR). The use of these multilayer stacks revolutionised the field of magnetic sensors due to easy fabrication, high performance and remarkable sensitivity. Recently, the deposition of GMR stacks on bendable and elastic substrates has opened the field of flexible/stretchable magnetoelectronics [3]. Here, we demonstrate the first printable magnetic sensor that relies on the GMR effect. The developed multicomponent magnetic ink containing GMR flakes and nonconductive binder can be easily applied on various substrates, such as paper, polymer and ceramic. The fabricated sensor exhibits a room-temperature GMR of up to 8\%, which is sufficiently high to develop a complete printed electronic circuit that is able to respond to an external magnetic field, opening new application fields in the modern electronics [4].

Keywords: magnetic, sensor, flexible, resistance

References

Optical properties of thermochromic liquid crystal printing inks

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Abstract

Thermochromic liquid crystal inks (TLCs) reflect incident light in a rather narrow spectral region. This phenomenon is caused by selective reflection of light on chiral (twisted) molecular structure which changes its distribution with temperature. The reflected light produces iridescent colour which is continuously shifted from red to blue part of the spectrum with temperature, the effect which is known as "colour play". This research is focused on the optical properties of a water-based TLC ink. The ink was screen-printed over black and white matte uncoated paper. The temperature dependent iridescent colours are seen very clearly when the ink is printed over black background, while on the white substrate is hardly visible. The observed effects were quantified by spectral reflectances applying (45°:0°) and (8°:di) geometries in the 400-700 and 200-1500 nm spectral regions, respectively. The measured temperature dependent iridescent colours were analyzed.

Keywords: Thermochromic liquid crystal inks, optical properties, iridescent colours, reflectance

1. Introduction

Printing inks that changes colour under certain circumstances are known as chromogenic inks. There are various types of external impacts that can cause colour reaction of inks that contain chromogenic material, such as temperature (thermochromic), pressure (piezochromic inks), biochemical reaction (biochromic inks), light (photochromic inks), electric field (electrochromic ink) or pH value (halochromic ink). Thermochromic inks are most frequently applied and rather well known [1], [2].

There are two types of thermochromic inks, differing in the type of active material; liquid crystals (TLCs) and leuco dyes-based composites [2]. Most thermochromic composites with leuco dyes change colour reversibly from coloured state to discoloured one. The change occurs in more-or-less broad temperature region around activated temperature. Leuco dyes-based thermochromatic composites absorb the incident light which produces colour. The active material in TLCs do not absorb the light within visible, but reflect a narrow spectral region thus producing approximately monochromatic colour similar to colour of rainbow (i.e. iridescent clours). The continuous colour change is frequently named as "colour play" [3]. However, the effect is rather weak. Therefore, TLCs should be applied to black substrate which prevents the light scattered from the substrate to obscure the selective reflection. Under such circumstances, the iridescent colours could be seen [4]. The entire colour change occurs in a few-degrees wide temperature range, which ensures TLCs to be much more sensitive to temperature changes then leuco dyes. Thermochromic inks are finding increasing use in applications such as security printing, brand protection, smart packaging and packaging with added value, marketing and novelty printing [2], [4]. However, there are practically no research published on the properties of such inks and the
way how they can be evaluated. This was the aim of our research.

2. Materials and Methods

The TLC ink (SC-140-TC/0398, Printcolor, Swiss) in a water-based ink formulation was applied. According to the producer’s data the ink is activated at 25°C and develops the entire colour effect within 5°C temperature region. According to this data, when heated to 25°C the ink becomes red-colored and turns to green at 26°C and then blue at 30°C with further heating. Above 44°C it will revert back to clear. All colour changes in the ink are considered to be reversible. TLC ink was screen-printed over black and white matte uncoated paper (160 g/m²), with two layers of ink (wet over dry) using semiautomatic screen-printing machine, employing SEFAR® PET 1500 43/110-80W polyester mesh. The prints were dried trough a hot air tunnel at around 75°C. The temperature dependent iridescent colours are seen by naked eye very clearly when the ink is printed over black background, while on the white substrate the effect is hardly visible. This observed effects were quantified by spectral reflectance applying (45°:0°) and (8°:di) measuring geometries in the 400-700 and 200-1500 nm spectral regions, respectively. The X-Rite Eye-One spectrophotometer was used for the (45°:0°) geometry and Lambda 950 UV-VISNIR spectrophotometer (Perkin-Elmer) for the (8°:di) geometry. During measurements, the printed samples were heated on the Full Cover water block (EK Water Blocks, EKWB d.o.o, Slovenia) from room temperature up to 47°C in 0.5°C steps. The measured temperature dependent iridescent colours were then analyzed.

3. Results and Discussion

The reflectance spectra of samples on black and white substrates measured in both geometries are shown on Figs. 1-3. As expected, the effect is better obtained on the black paper and only hardly on the white one. In addition, the spectroscopic observation of the effect is strongly subjected to the applied measuring geometry. The (45°:0°) measurement geometry does not provide the full effect even on the black substrate (Fig.1a), and it completely disappears on the white substrate (Fig.1b). Contrary, it is nicely seen in (8°:di) measuring geometry, even on sample with white substrate (Figs 2, 3).

The reflectance spectra from figs 1-3 were used for colorimetric analysis, to calculate the dependence of CIELAB values on temperature. The results are shown on Figs. 4 and 5. As expected, the coloration effect is revealed very clearly applying (8°:di) measurement geometry, especially for the TLC layer on the black paper. The coloration effect is based on reflectance and not on the absorbance, therefore L* rises with temperature when sample is colored (Fig. 5). The optical feature produced by TLC ink was analyzed further directly from reflectance spectra in (8°:di) measurement geometry (Figs. 2 and 3). Each individual spectrum show single reflectance peak with typical Lorentzian shape (Fig. 2). This peak gives rise to narrow-band-width iridescent colour effect. Its position shifts exponentially with temperature towards shorter wavelengths (Fig. 6). Therefore, the red colour appears in a very narrow temperature region, while the blue appears on much broader temperature range, producing a long line in the (a*,b*) graph where the sample appears blue and this colour approaches very close to the negative b* axis to neutral. The reflectance peak becomes narrower when temperature increases (Fig. 6): the colors become spectrally confined when temperature rises. The effect could be describer also by stronger monochromatic effect.
Optical properties of thermochromic liquid crystal printing inks

Figure 1: Spectral reflectances of TLC ink printed over black (a) and white (b) papers (45°:0°) measured with (45°:0°) geometry

Figure 2: Spectral reflectances of TLC ink printed over black paper measured with (8°:di) geometry
Figure 3: Spectral reflectances of TLC ink printed over white paper measured with (8°:di) geometry

Figure 4: CIELAB ($a^*\,b^*$) (a) and $L^*(T)$ (b) graphs of TLC ink printed over black and white papers measured with (45°:0°) geometry

Figure 5: CIELAB ($a^*\,b^*$) (a) and $L^*(T)$ (b) graphs of TLC ink printed over black and white papers measured with (8°:di) geometry
4. Conclusions

Thermochromic liquid crystal inks provide special type of thermochromic effect: instead of selective spectral absorption, which is usual for all conventional coloured inks and also for leuco dye-based thermochromics the effect is based on reflectance of a narrow band within visible spectral region. The effect originates in selective reflection of light on specially ordered molecular structure. The studied sample show that the effect is best observable when the ink was printed on a black surface. Interestingly, collimated illumination and collimated detection does not allow recognizing the effect; the integrating sphere measurements are required to quantify the colour in dependence on temperature. The position of the reflectance band shifts exponentially towards shorter wavelengths when temperature rises. In addition, the reflectance band narrows exponentially with temperature.

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References


Surface engineering for printed biosensor applications

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Abstract

Surface energy manipulation, surface energy gradients and specific chemical functionalities play an important role in biosensor applications. \textmu PlasmaPrint is a novel digital printing technique that has the potential to address these important surface engineering challenges in biosensor manufacturing. In the present work the deposition of amine chemical functionalities has been investigated by means of this digital on-demand plasma printing technique. Fluorinated ethylene propylene (FEP) substrates have been functionalized using a precursor gas mixture of nitrogen and (3-aminopropyl)-trimethoxysilane (APTMS). The surface properties have been characterized by contact angle measurements and X-ray photoelectron spectroscopy (XPS). The measurements indicate that thin films containing a significant concentration of amine functionalities can be digitally printed by means of \textmu PlasmaPrint. The plasma deposited APTMS films exhibit a hydrophilic nature with water contact angles ranging from 10\textdegree{} to 44\textdegree{}, with increasing number of print repeats. The surfaces of the films contain amine (-NH\textsubscript{2}) concentrations ranging from 9.1\% for one print repeat to 4.7\% after 20 print repeats in the top 10 nanometers as determined from XPS.

Keywords: Surface engineering, biosensor, atmospheric plasma, \textmu PlasmaPrinting

1. Introduction

Among the growing number of functional printing applications, the production of disposable biosensors is identified as a field in which printing has the potential to become a cost-effective manufacturing technology enabling the commercial breakthrough of such sensors. Surface energy manipulation, surface energy gradients and specific chemical functionalities play an important role in biosensor functionality. [1,2]

One such promising printing technology is the InnoPhysics \textmu PlasmaPrint technique. \textmu PlasmaPrint combines the benefits of digital printing with the versatility of atmospheric pressure plasma processing. \textmu PlasmaPrint enables nanometer-scale surface modification, materials deposition and removal on glass and polymer substrates in a mask-less, digital pattern with a lateral resolution down to \textasciitilde{}100 \textmu m. [3,4] One example of a surface engineering solution for biosensor applications is printing of surface amine (-NH\textsubscript{2}) functionalities. Amine functionalities are able to bind specific biomolecules, biomarkers and/or proteins prior to analysis in the biosensor. [2] Most commonly wet chemistries based on organosilane molecules are used to create the amine functionalities. [1,5] Other methods to deposit amine functionalities are low pressure and atmospheric pressure plasma deposition. [2,6,7]

When patterns or local spots of functionalities are needed, the use of masking, lithography and/or etching is in general inevitable. However, from a production point-of-view, being able to print such functionalities in a single step, would therefore be more cost effective.

In this work we present the digital printing of amine functionalities onto fluorinated ethylene propylene (FEP) surfaces by means of \textmu PlasmaPrint using a nitrogen - (3-aminopropyl)-trimethoxysilane (APTMS) plasma gas mixture. The surface properties of the deposited films
such as wettability and chemical composition have been characterized by contact angle measurements and X-ray photoelectron spectroscopy (XPS).

2. Experimental Setup

2.1 μPlasmaPrint setup

The micro plasmas have been created by applying an AC voltage in the range of 1 to 10 kV peak-to-peak to a substrate carrier electrode (200 x 300 mm), which is covered by a dielectric medium. The FEP foil substrate is placed onto the substrate carrier. At a distance of one millimeter a printhead containing an array of 24 grounded needles is suspended on a XY-motion stage (InnoPhysics, μPlasmaPrint Station) [4] as shown in Fig.1.

![PlasmaPrint setup](image)

Figure 1: PlasmaPrint setup. The XY-Z motion platform hosts a 24 needle electrode print head. The print head is equipped with gas feed and exhaust and an inline camera system for plasma inspection during printing. The setup can run at print speeds up to 50 mm/s and print frequencies up to 400 Hz.

The μPlasmaPrint concept relies on Paschen’s curve. [8,9] Each needle electrode can be individually actuated, i.e., moved towards the substrate carrier and back. Consequently, when the spacing between the substrate and the grounded needle becomes small enough, the electric field between the needle tip and the substrate carrier becomes sufficiently large to initiate a discharge. When the needle is fully extended towards the substrate the spacing between substrate and needle tip is between 100 and 300 μm. Subsequently, when the needle moves away from the substrate again, the distance between needle and substrate becomes too large to sustain a discharge and, thus, the discharges quenches. The duration of one motion cycle is less than one millisecond during which the plasma ignites for no more than 500 microseconds.

Fig.2 shows a schematic illustration of the μPlasmaPrint concept. [3,4] By using this concept in combination with a digital print system the substrate can be plasma processed in a dot-wise manner based on a predefined digital pattern. The current printheads print at a minimum lateral resolution of 100 μm. The actual resulting feature size depends on the print settings and gas...
Surface engineering for printed biosensor applications

composition.
The type of atmospheric pressure plasma processing (surface modification, deposition or etching) is determined by the precursor gas mixture supplied to the plasma region in between the printhead and substrate.

![Figure 2: Schematic illustration of the working principle behind plasma printing technology: a plasma is ignited by varying the distance between a needle and the substrate behind which the counter-electrode is placed.](image)

2.2 Experimental details

Amine functionalities have been printed using the above described setup onto 75 µm thick fluorinated ethylene propylene copolymer (FEP) samples (Goodfellow) using a gas mixture of nitrogen and (3-aminopropyl)trimethoxysilane (APTMS, Merck).
The thin films, with a thickness ranging from less than a monolayer up to 100 nm, have been printed at 282 dpi. The 57 kHz AC voltage was set to 6.5 kV peak-to-peak and the minimum spacing between needle and substrate was 150 µm. In this study the total gas flow was 0.3 slm N₂ of which 0.1 slm N₂ was first passed through a bubbling system containing liquid APTMS at room temperature and mixed with 0.2 slm N₂ prior to the introduction of the gas mixture in the plasma region. The number of print repeats has been varied in order to control the film thickness and composition. In this study the emphasis is on the chemical composition of films rather than on the actual film thickness. Immediately after printing the samples are stored under vacuum conditions to suppress potential aging of the deposited films.

A K-Alpha Thermo Fisher Scientific X-ray photoemission spectroscope (XPS) has been used to measure the chemical composition of the thin film surfaces. The sample was irradiated by 1486.7 eV X-rays of a monochromated Al X-ray source. Photoemission spectra have been collected at 50 eV pass energy at an emission angle of 90°, at which the sampling depth is approximately 10 nm.

Surface energy measurements have been carried out using a home-built contact angle goniometer. To obtain both polar and dispersive components of the surface energy a common method is to measure the static contact angles of demineralized water and diiodomethane (CH₂I₂) and calculate the surface energies using the Owens-Wendt-Rabel-Kaelble (OWRK) method [10]. The contact angles and their standard deviation of both water and diiodomethane are determined by the average of three droplet measurements.
3. Results and Discussion

3.1 Surface energies

In Fig. 3 the contact angles for water and CH$_2$I$_2$ are shown on the left as a function of the number of print repeats. Zero print repeats corresponds to the blank FEP substrate, which has a water contact angle of $112^\circ \pm 1^\circ$, which reflects the hydrophobic nature of the fluorinated polymer substrate. For a single print repeat the water contact angle drops to $10^\circ \pm 5^\circ$, which indicates a good wetting behavior. When increasing the number of print repeats both the water and diiodomethane contact angles gradually increase from $10^\circ$ to $44^\circ$ and from $35^\circ$ to $44^\circ$, respectively. On the right hand side in Fig. 3 the calculated total surface energy as well as the polar and dispersive components are shown. The FEP substrate is non-polar, which is common for fluorinated polymers. After a single print repeat the polarity and dispersion of the surface has increased. With increasing number of print repeats the total, polar and dispersive surface energies show a gradual decrease.

![Contact angle analysis of APTMS films](image)

Figure 3: Contact angles of water (H$_2$O) and diiodomethane (CH$_2$I$_2$) on plasma deposited APTMS films as a function of the number of print repeats (left). The polar, dispersive and total surface energies have been calculated [10] from the contact angles (right).

The resulting thin films exhibit a hydrophilic nature. By controlling the number of print repeats local and/or patterned wetting on the surface of the deposited APTMS films can be controlled and, thus, the printability of water-based inks. The hydrophilic nature of the APTMS films is related to the polarity of chemical groups, in this case amino moieties, on the surface. In order to validate the presence of such polar groups XPS measurements have been carried out.

3.2 Surface chemical composition

In Fig. 4, the XPS results of carbon (left) and nitrogen (right) peaks are shown for films with 1, 5 and 20 print repeats. A reference measurement is shown of a cleaned FEP substrate without any plasma treatment. The peaks are fit with fixed peak positions ($\pm 0.1$ eV) to show the differences in film structure. The assignment of the different peaks to the specific environments of the atom, as shown in the insets of the figure, can be derived from literature. [7,11-13] Furthermore, in Table 1, the stoichiometry of the plasma deposited APTMS films is shown. In this table the concentrations of the different molecules, as well as the contributions of the individual peaks, are presented as percentages of the entire film. The results are compared with the APTMS monomer and the results of Borris et. al., who deposited APTMS films using a
Surface engineering for printed biosensor applications

Figure 4: The XPS measurements and fit results of the peak analysis of carbon (left) and nitrogen (right) for a various number of print repeats, including a reference measurement on a cleaned FEP substrate.

different type of dielectric barrier discharge. [7]
Both Fig. 4 and Table 1 show changes in the carbon and nitrogen peaks as a function of the number of print repeats. The C1 peak is much smaller than for the monomer, indicating a decrease in methyl groups. The C1 peak also decreases for an increasing number of print repeats, while the the C2 peak increases. Also the C3 peak slightly increases, while the overall carbon concentration in the deposited films remains constant for the deposited films; more carbon binds to oxygen and nitrogen, instead of to hydrogen and carbon.

A similar trend is observed for the nitrogen peaks. The amine peak (N1) decreases significantly below the monomer concentration for an increasing number of print repeats, while the amide peak (N2) increases with approximately the same amount. The overall nitrogen content in the film remained constant.

Results suggest that film growth occurs through removal of methyl groups, and that subsequent polymerization takes place at the aminopropyl chains, thereby decreasing the C1 and N1 peaks while increasing the C2 and N2 peaks. This deposition mechanism is consistent with the work of Borris et.al.[7]

4. Conclusions

μPlasmaPrint using a gas mixture of N2-APTMS results in the digital printing of amine functionalities. The plasma deposited APTMS films exhibit a hydrophilic nature with water contact angles ranging from 10° to 44°, with increasing number of print repeats. The surfaces of the films contain amine (-NH2) concentrations from 9.1% for one print repeat to 4.7% after 20 print repeats in the top 10 nanometers as determined from XPS. Amine functionality printing by means of μPlasmaPrint could be a viable alternative in (disposable) biosensor manufacturing either by creating hydrophilic surfaces to improve fluid transport in the sensors or as specific binding sites for biomarkers and/or specific enzymes. Future experiments will focus on identification and quantification of the surface amines by means of fluorescence microscopy imaging. The aging, i.e. the stability of the films over an extended period of time, will be investigated, as well as the influence of the precursor gas composition on the amine density.
Table 1: Atomic composition of the deposited films as determined by XPS. For both carbon and nitrogen, three peaks related to the different environments of the peaks are fit in resulting spectrum. Their concentration is also determined as a part of the film content. The atomic concentrations and environmental information of the APTMS monomer as well as the results from Borris et. al. are included for comparison. The marked result (\(\ast\)) is determined in a different manner: this result is derived from the ratio of the carbon content in the film and the concentration of amino functionalities as derived by chemical derivation XPS.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>N</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
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<th>Si</th>
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<td></td>
<td></td>
<td></td>
<td>66.5</td>
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<td></td>
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<td></td>
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Acknowledgement

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References


Low energy consumption e-ink display

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Abstract

To have a display that uses electricity only when refreshing the display is attractive. It’s today a reality. And the technology is fairly cheap. Such displays are e-readers such as the Kindle, the Kobo and many others. However we don’t have any choice in color, it is always black and white. Even if the E-ink Company has developed a new technology (Triton), it does not provide good contrast because of the way colors are generated (juxtaposition of pixels or use of filters result in only one third of the area display used for one color [1]). This paper has a double objective. First of all, it will give an overview of the state of the art and study the principle of electrophoretic displays, Gyricon’s technology, electrophoretic medium, particle stability, encapsulation and particle synthesis. It is necessary to understand limitations and technical constraints. Secundly, it will present an innovation to produce 4-color displays based on particles that use two different stimuli (electrical and magnetic).

Keywords: Display, E-paper, Electrophoretic

1. Introduction

The display market being in rapid expansion, it is necessary to develop different technologies to meet every customer’s needs. Some big companies like E-Ink or SIPIX lead the innovation since several years about displays. The first color displays should be created in 2011-2012 but it wasn’t really the case. We can nevertheless note the Triton technology developed by E-Ink, with low contrast as explained earlier. There are big challenges ahead especially to produce particles able to show 4 colors to enhance contrast.

One can find two main categories of media: non-rewritable media (such as printed paper) that are based on the reflexion of the light onto the media to see the information. Such devices allow a high visibility angle (180°) and a good comfort of use.

On the other hand, we have media that allow to update the information. They are emissive media, such as LCD or OLED displays. These technologies present some drawbacks: they need a constant electrical supply, have a (much) smaller visibility angle and are really expensive to produce because of their sensitivity to their environment during production and during their utilization (particularly OLED suffers from exposure to oxygen and moisture).

The idea to take advantage from these two ways of disseminating information came naturally. This is what we called electronic paper. Objectives are to produce a reflective display having the smallest possible energy consumption and contrasts comparable to the ones obtained on paper, the possibility to display information reversibly at low cost production, with a light weight and a high flexibility. Keeping in mind these objectives, this paper will present an overview of the state of the art and an innovation that makes a step to the so much desired 4-color display.
2. State of the art

2.1 Principle

The principle of a display is based on the migration of charged particles in a dielectric medium between two electrodes. The front side electrode is transparent so that the image can be seen and the backside electrode allows the addressing to all pixels independently. With a tension between the two electrodes, particles are attracted by electrostatic forces to one of the cell walls or the other according to their polarity. These pixels (white or black) finally form a visible image.

There are two kinds of electrophoretic devices: those made of particles containing a pigment diluted in a colored dye and those containing two different types of pigments with two opposite electrical charges diluted in a transparent dye. The majority of devices belong to the second category, for this technology made possible for a particle with more than two pigments to produce more colors.

The most important components of a display are obviously electrophoretic particles. They have a dramatic influence on performances. The fundamental properties of a display are its contrast, its time response (the shortest possible) and its stability at rest (without electrical supply).

2.2 Gyricon's heritage

Xerox made the first technical development with the Gyricon technology in the 70’s. This technology used "Janus" particles that have different properties between their two sides. Here, a material with a negative charge and a white aspect is applied on one side, whereas a material with a positive charge and a black aspect is applied on the other side. They move onto glass cavities and these cavities are encapsulated between two electrodes [2].

In an electrical field, particles turn over to reveal a white or black color according to their charge. Because of adhesion forces between particles and cavity walls, the electrical field needs to exceed a threshold to make particles move. This is one of the most important characteristics of electronic paper, because when the electrical field is removed, particles remain in their position and thus display information without any electrical supply. This is what we call a "bistable" display. Therefore, this property enables to produce low energy consumption displays. However, the Gyricon technology is not used anymore because of one limitation: spheres were not able to fully rotate because of a strong decrease, the electrostatic force at the end of each rotation [3], resulting in a low contrast.

2.3 Electrophoretic medium

Electrophoretic medium has a significant influence on performances and needs to respect two criteria. The first one is the non-conductivity. Indeed, an electrophoretic ink is a dispersion of nanoparticles divided in two groups with two opposite electrical charges. If the medium were conductive, part of the electrical charge would pass through the medium, thus decreasing the attractiveness of the particles to the two sides of the cavity. To compensate for this decrease,
one would have to increase the electrical charge, thus inducing a higher energy consumption. This is absolutely against what one is aiming at. The second criterion is the viscosity of the medium, which should keep an intermediate value not to slow down particles in movement but to slow down sedimentation. Several media exist and are used in the different companies using electrophoretic technology. Three main categories can be identified: iso-paraffins (E-Ink, Papyron), silicone-based fluids (Xerox) and tetrachloroethylene in the academic world (the latter being impossible to use at an industrial scale because of its toxicity). Their physical properties (density, dynamic viscosity, boiling point) are really different but they have similar dielectric constants and refraction indexes. It is also necessary to study their volatility in order to prevent the ink from drying on the spheres.

2.4 Particles stability

The stability of charged particles in suspension is really important because it is directly connected to their lifetime and performances. A dispersion of solid particles in a liquid phase does not keep a stable state. Without interface optimization, the system tries to minimize the energy by fusion or aggregation of particles. Because the dispersive medium is often non-polar, there is no electrostatic repulsion due to the absence of ions. This is why the only way to keep an electrophoretic ink stable is to use steric repulsion [4]. This consists in modifying the surface tension of the electrophoretic ink by using a surfactant. Physically, "hairy" particles are added to the surface to separate them and ensure a good stability between particles, thus minimizing surface energy between the particles and the medium.

2.5 Encapsulation

2.5.1 Microcapsules

The most commonly used technology to encapsulate electrophoretic inks are microcapsules. The latter may have different chemical properties and be produced by several polymerization or precipitation techniques in a heterogeneous medium. The capsule creation depends mainly on the interfacial tension between the oil phase and the aqueous phase. This relationship can be shown by adding surfactants [5]. When the interfacial tension is low, the oil droplets have a sufficiently low surface energy to remain stable in water. When the surface energy of the droplet is high, the polymer will be positioned on the droplets in order to decrease the interfacial tension. The type of surfactant used plays a significant role in the formation of microcapsules generation [6]. The ionic surfactants can inhibit encapsulation of the oil phase due to electrostatic interactions. Others may react with the reactive species. This results in a change in the surface microcapsules which can be roughened and therefore cause defects.

2.5.2 Pixellization

Another option, inherited from the packaging industry and especially corrugated cardboard, was developed by SIPIX [7]. A photoresist is coated onto a PET/ITO substrate which then undergoes embossing before being crosslinked by UV curing. Cavities are then formed. These are then filled with electrophoretic ink that contains UV-curable droplets. It will migrate to the surface and be crosslinked. The top electrode is then rolled on top.

2.6 Particle synthesis

This paragraph tackles with the active component of an electrophoretic display, that is to say the electrophoretic particles.
2.6.1 Requirements

As we have seen, the objective is to disperse one or several charged particles into a non-volatile and chemically inert medium. This one has to be non-conductive not to dissipate the electrical charge and to keep electrophoretic forces as long as possible. Particle size should be between 250 nm and 2 μm. Particles should have a good ability to diffract the light so that they have a good contrast to display information. Intense colored particles with good optic properties will be privileged. Thus we can find inorganic pigments such as TiO$_2$, organic pigments or dyes. Particles should be very stable within the medium to avoid sedimentation and thus improve the display time (the ability of the display to keep the image without electrical alimentation). Response time is essentially governed by the electrophoretic mobility, and thus by the electrophoretic ink.

2.6.2 Dispersion polymerization

Dispersion polymerization is characterized by the presence of a single phase containing the solvent and all of the reactive components. This results in the production of a latex type material. This technique provides a wide range of particle sizes (from 100 nm to 20 μm). Most of organic dispersions are free radical reactions. First of all, we produce initiators (by photochemistry, by heating the reaction medium or by redox reaction). Monomers then react with these free radical species. Oligomers are then produced. These will grow to reach a length of molecular chain from which will be called nuclei. They will then coagulate until the stabilizer, present in the medium, completely covers the surface. The reaction continues until a latex is obtained, consuming monomers diluted in the solvent and the polymer chains present in the medium. A copolymer is often used to stabilize the particles with steric repulsion forces. This technique (dispersion polymerization in a non-polar medium) proved to be able to produce in one step positive charged particles with two different inorganic pigments [8]. Using macroinitiators enables to cover metallic oxydes, giving them good stability to aggregation and decreasing their density. Several morphologies were obtained by varying the affinity between the polymer and the pigment surface. It was demonstrated that this technique works whatever the pigment. Thus, it is possible to produce inks of all colors. Nevertheless, it is much difficult to produce negative charged particles because of a lack of adhesion between the pigment and other components, even when macroinitiators are used. There are two ways of improving this situation: one can modify the surface of the pigment before it is integrated to the medium or can produce particles in a polar medium and then integrate species which allow their integration into a non-polar medium.

3. Innovation to the 4-color display

For the moment, all displays are black and white because we can only use electrical stimulus which offers only two possibilities (positive and negative). To produce a 4-color display, we need another stimulus. We can use a magnetic stimulus along with magneto-electrophoretic particles. Each magnetic material is coated by a pigment, and then encapsulated into a chargeable functional polymer (positive or negative charge). Thus, two particles are exactly as current electrophoretic particles, one being positive charged and the other one being negatively charged. Two others also have an opposite electrical charge but they have a magnetic core. Under an electrical charge $V^+$ or $V^-$, blue or red particles will move. To move yellow or black particles, we need a higher electrical load $V^{++}$ or $V^{-}$ to compensate for magnetic attraction forces. With this technology, each particle can show 4 colors. The entire display area is thus used for each of them, which significantly increases the contrast.
4. Conclusions

The display market provides many areas of research, particularly in regard to e-papers, since their low energy consumption is a drastic advantage over other technologies. Further efforts should be made to improve the performances of existing displays, including contrast, lifetime and response time, and to find new ways of development for color displays. However, e-papers, especially 4-color displays, will not compete with emissive displays but will share the market of very large posters for which the response time is a less important criterion.

References

Graphical Printing II
Analysis of life cycle impact assessment methods for products in the printing and packaging industry

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Abstract

Results of the life cycle assessment (LCA) are influenced by various parameters defined in the different phases of the LCA procedure: goal and scope definition, inventory analysis, impact assessment and interpretation.

In order to choose an appropriate method in the phase of ‘life cycle impact assessment’ (LCIA), this paper presents a comparative analysis of the LCIA methods CML2001, EDIP97 and EDIP03 for a specific product system in the printing and packaging industry: Polypropylene-based laminating film.

The study shows that these aspects could be responsible for the differences: (1) basic methodology, e.g. equivalence-oriented approach and no-effect concentration, (2) equivalency factors, (3) data sources and the state of knowledge.

The LCA results broadly vary in impact categories whose LCIA methods employ different basic methodology. Major differences were observed in the impact categories ‘photochemical oxidation’, ‘eco toxicity’ and ‘human toxicity’.

Keywords: Life cycle assessment, impact assessment method, CML, EDIP, polypropylene-based laminating film

1. Introduction

Sustainable product development with respect to the protection of humans and the environment is increasingly expected from society. Life cycle assessment (LCA) is an appropriate instrument to calculate the environmental burden of products. LCA results could point out potential for the optimization of materials and manufacturing processes to reach sustainable product development.

In the phase of ‘life cycle impact assessment’ (LCIA), inventory data are translated into potentials contributing to impact categories. Various impact assessment methods exist which consider information about the exposure of chemicals to the compartments ‘air’, ‘water’ and ‘soil’ in different ways. In accordance with the international standard DIN EN ISO 14040/44 [10, 11] towards life cycle assessment, the impact assessment phase could have a significant influence on LCA results.

Former research shows that the choice of an appropriate LCIA method depends on the product system investigated [1]. Thus, this paper presents a comparative analysis of the impact assessment methods EDIP97, EDIP03 and CML2001 applied on a product in the printing and packaging industry. A cradle-to-gate LCA study of polypropylene-based laminating film was conducted. The environmental effects on the impact categories ‘acidification’, ‘climate change’, ‘eutrophication’, ‘photochemical oxidation’, ‘stratospheric ozone depletion’, ‘eco toxicity’ and ‘human toxicity’ were calculated utilizing the EDIP97, EDIP03 and CML2001 methodology.
2. Method: Comparative Analysis

In this study the impact assessment methods CML2001, EDIP97 and EDIP03 are compared according to their characterized results in the impact categories ‘acidification’, ‘climate change’, ‘eutrophication’, ‘photochemical oxidation’, ‘stratospheric ozone depletion’, ‘eco toxicity’ and ‘human toxicity’. Therefore, the indicator results of a polypropylene-based laminating film were calculated. The data are referred to 1 m$^2$ laminating film, commonly used for coatings in the printing and packaging industry. The product system is described in [13]. To achieve a direct comparison, the impact assessment methods must be based on the same unit. Otherwise, the indicator results must be converted to the same reference to reach a comparative basis. (cf. Figure 1)

![Figure 1: Model for the comparison procedure of impact assessment methods](image)

Differences in the characterization results are explained below in detail. Therefore, the basic methodology, the equivalency factors, the data sources and the state were taken into account. The findings were transferred to the specific properties of the product system ‘polypropylene-based laminating film’.

3. Results

Generally, CML and EDIP (EDIP97/03) are both problem-oriented methods at midpoint level. Table 1 shows the indicator results of 1 m$^2$ polypropylene-based laminating film for various impact categories. All these categories were analyzed according to their methodology. Major differences are recognized in the categories marked: Photochemical oxidation, eco toxicity and human toxicity. For this reason, only these impact categories are described in detail in this paper.

3.1 Photochemical oxidation

The photochemical oxidation potential (POCP) considers all the substances, reacting sensitive to sunlight and ultraviolet light in the troposphere, e.g. ozone. These compounds are harmful to humans and ecosystems. In this paper, only the POCP approach for areas with high NOx concentrations is presented because it is the baseline recommendation of the CML method. The CML2001 and EDIP97 method are based broadly on the same data source. In some detail, the equivalency factors of substances considered in the LCIA methods are varying. The reason for these differences is that the EDIP97 approximated the equivalency factors for areas with high NOx concentrations based on investigations in regions with low NOx concentrations (Swedish...
trajectory model). Furthermore, the EDIP97 method defined equivalency factors for substance groups. In contrast, the CML method includes only specific substances. Hence, a difference between the indicator results of POCP exists. In an overall perspective on the environmental performance of polypropylene-based laminating film including several impact categories, the results of POCP will have only small influence because of a slight rate (cf. Table 1).

The EDIP03 method differentiates the subcategories ‘Impact on vegetation’ (m\(^2\)*ppm*h) and ‘Impact on humans’ (person*ppm*h). These values correlate with the C\(_2\)H\(_4\)-eq. values of the EDIP97 method mentioned in Table 1 [12].

### 3.2 Eco toxicity and human toxicity

In the toxicity potential, toxic substances are characterized regarding to their fate, effect and exposure to the ecosystem and to humans. The LCIA methods CML2001 and EDIP97/03 are based on different basic methodologies for the characterization: CML2001 uses a multimedia fate, exposure and effects model expressed in Dichlorobenzene-equivalents (g 1.4-DCB-eq.); EDIP97 and EDIP03 determine a no-effect concentration (m\(^3\)) based on a simplified approach [1,4]. Similar results are determined by applying the EDIP97 and EDIP03 method. Hence, the term ‘EDIP method’ is used synonymously for both the EDIP97 and the EDIP03 method.

In order to achieve a comparative analysis, the equivalency factors of the EDIP method is converted to the reference substance 1.4-Dichlorobenzene (cf. Figure 1).

#### 3.2.1 Eco toxicity

The impact category for eco toxicity is not specified in a single score but divided into some subcategories in both the CML method and the EDIP method. The EDIP method differentiates acute (short-term) and chronic (long-term) eco toxicity to water and soil through the compartments ‘air’, ‘water’ and ‘soil’. The CML method is focussed on chronic eco toxicity separated into ‘freshwater aquatic eco toxicity’, ‘marine aquatic eco toxicity’, ‘fresh water sediment eco toxicity’, ‘marine sediment eco toxicity’ and ‘terrestrial eco toxicity’.

<table>
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<tr>
<th>Impact category</th>
<th>Unit</th>
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<th>EDIP97</th>
<th>EDIP03</th>
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<td>Acidification, generic</td>
<td>g SO(_2) eq.</td>
<td>0.133</td>
<td>0.133</td>
<td>0.133 *)</td>
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<td>Climate change, GWP(_{100})</td>
<td>g CO(_2) eq.</td>
<td>42.3</td>
<td>42.1</td>
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<td>Eutrophication</td>
<td>g PO(_4) eq.</td>
<td>0.013</td>
<td>0.011 *)</td>
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<td>Photochemical oxidation, high NO(_x)</td>
<td>g C(_2)H(_4) eq.</td>
<td>8.79(\times)10(^{-3})</td>
<td>3.46(\times)10(^{-2})</td>
<td>3.46(\times)10(^{-2}) *)</td>
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<td>Stratospheric ozone depletion, steady</td>
<td>g CFC-11 eq.</td>
<td>3.75(\times)10(^{-7})</td>
<td>3.75(\times)10(^{-7})</td>
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</tr>
<tr>
<td>Aquatic eco toxicity, long-term</td>
<td>g 1.4-DCB eq.</td>
<td>4,002.02</td>
<td>12.39 *)</td>
<td>12.39 *)</td>
</tr>
<tr>
<td>Terrestrial eco toxicity, long-term</td>
<td>g 1.4-DCB eq.</td>
<td>0.025</td>
<td>0.315 *)</td>
<td>0.315 *)</td>
</tr>
<tr>
<td>Human toxicity, infinite</td>
<td>g 1.4-DCB eq.</td>
<td>4.04</td>
<td>3.80 *)</td>
<td>3.80 *)</td>
</tr>
</tbody>
</table>

*) indicator value converted
For the comparative analysis, the subcategory ‘chronic, in water’ of the EDIP method is compared with CML2001’s categories ‘marine aquatic toxicity’ and ‘freshwater aquatic toxicity’. For the terrestrial eco toxicity, EDIP’s category ‘chronic, in soil’ is matched to the ‘terrestrial eco toxicity’.

In Figure 2 and 3 the contribution of substances to the impact results for the aquatic and terrestrial eco toxicity potential are shown. The priority of chemicals in the characterization step is different in the CML and EDIP method.

![Main contributors to the aquatic eco toxicity potential](image1)

**Figure 2:** Main contributors to the aquatic eco toxicity potential for the product system ‘polypropylene-based laminating film’ applying the EDIP method and the CML method

![Main contributors to the terrestrial eco toxicity potential](image2)

**Figure 3:** Main contributors to the terrestrial eco toxicity potential for the product system ‘polypropylene-based laminating film’ applying the EDIP method and the CML method

### 3.2.2 Human toxicity

In the CML method, the human toxicity potential is aggregated to a time horizontal, single score, whereas the EDIP method is separated into the subcategories concerning to the compartments ‘air’, ‘water’ and ‘soil’.

For the comparative analysis, the subcategories of the EDIP method were converted and aggregated to one indicator value.

Figure 4 shows the contribution of substances to the human toxicity potential for the polypropylene-based laminating film. Generally, differences in the characterization factors in...
the EDIP and CML method are visible. For example, antimony is the main contributor in CML2001 but contributes to the human toxicity potential in EDIP only with a small rate (3%). However, the total results in the impact category of human toxicity applied by the EDIP method and the CML method are similar (see Table 1).

Figure 4: Main contributors to the human toxicity potential for the product system ‘polypropylene-based laminating film’ applying the EDIP method and the CML method

### 4. Conclusions and discussion

In this paper, differences in the impact assessment results for the product system of polypropylene-based laminating film were analyzed according to the methodological framework. Significant differences were identified in impact categories which are calculated based on different basic models, e.g. in the eco toxicity and human toxicity categories. The substances mainly contributing to these impact results are presented.

The authors of [1] also recognized major differences for these LCIA methods in the impact categories of toxicity investigating the product life cycle of water-based UV lacquer for the furniture industry.

According to the process knowledge in the product system of polypropylene-based laminating film, the main environmental impact was identified in the energy-related processes and disposal. Similar conclusions were made in [1].

In comparison to other LCIA methods at midpoint level, the method implemented in EDIP97/03 and CML2001 for the impact categories ‘global warming potential’ and ‘stratospheric ozone depletion’ are best practice. These are the findings in the long-lasting study initiated by the EC-JCR [2-4, 9]. In general, it is found that the choice of an appropriate LCIA method depends strongly on the impact category investigated.

### References


Innovative and promising future for the comics market

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Abstract

Although impacted by the hard economic context, the comics market seems rather more resilient than the general book market. Therefore, this demonstrates a tonic sector able to find new growth sources and to provide opportunities for new applications such as augmented reality or product personalization.

Indeed, have you ever wished to see your favorite comic strip characters coming to life and performing in the scenery? And who never dreamed of seeing one’s own name and personal facts of one’s life appear in the middle of a fiction?

This is now possible. Some books have already incorporated it, however, it is still too little developed and even unknown in comic strips.

Comics printing follows the same manufacturing process as book printing. Comic strips distinguish themselves by their unique content, including more pictures and less text. They are usually printed in conventional offset. With its ability to print long runs with high quality while maintaining a very competitive price, this process is mature and well adapted. However, with increasing quality and high speed printing for small runs (the comics rarely print large series), digital printing processes are direct competitors to offset lithography in this market.

Add to this augmented reality: superimposed layers of "virtual" information on what is physically seen. This technique, born in the 70s, requires a vector of information (webcam, etc.) and a software or an application. Combining a digital asset such as a webcam or smartphones and paper, we obtain new possible approaches to comics. The film adaptations of comics are a real success, why not move the animations into the book itself?

The objective of this work is to analyze and discuss the opportunities of combining digital printing and augmented reality on the very specific application of comic strip printing.

Keywords: Comic strips - Digital printing, Augmented reality - Personalization

1. Introduction

Even if the general economic context is in pain, the cartoon market seems to better resist the crisis than the rest of the book market. This sector confirmed its dynamism by having increased slightly its production for the 16th consecutive year. Application developments for new digital perspectives attest to the desire to anticipate and adapt to the technological revolution. Customization and creation of interaction between comic books and digital technologies by Extended Reality are examples of such evolution. Comics printing obey to the same process gears than book processes, with two main kinds of printing processes suitable for the product requirements: offset and digital printing processes. Superimposing digital data layers over tangible layers could be the future of comics printing. By combining the strength of digital technologies (smartphone, webcam) with the paper substrate, one could see an evolution full of promises. Such techniques have existed since the 70’s and require a data vector (such as a webcam) and software. This innovation could allow to enrich books’ content with teasing interaction (video, 3D animation).
2. Technical aspects

2.1 Offset lithography

Offset lithography is currently the most used process, with applications covering publishing as well as packaging. Its success is due to its high productivity, keeping a high quality and a low cost, with a print capacity going from several thousand copies to several hundreds of thousands of copies. Even if the comic books domain tends to multiple titles and lowers the number of copies, sheet-fed offset presses and even web-fed presses are still used, for their excellent colour rendering and the high productivity they allow.

This process is based on the double transfer of images: the first time from the plate to rubber blanket, then to the substrate. Offset-lithography is a planographic process using a printing form (the plate), unlike the digital processes where the printing form does not exist. Offset-lithography process relies on the physico-chemical phenomena: the repulsion between the fount solution and the ink: the fount solution is mainly composed of water, whereas the ink is mainly composed of non-polar hydrophobic elements.

The plate is formed by an aluminium base, which is grained and anodised to maintain water in the hydrophilic non-printable areas. This aluminium base is covered with a thin layer of hydrophobic polymer in the printable areas (PA). This polymer is photosensitive, which allows to degrade or to keep the areas needed by exposing the plate to appropriate light.

The fount solution is firstly applied on the plate cylinder to cover the NPA, and then ink is applied. A first transfer occurs from the plate to the rubber blanket, then from the rubber blanket to the paper which passes through co-rotating rolls, the second one being either a second rubber blanket cylinder (for two-side printing) or a counter-pressure cylinder.

2.2 Digital printing

Digital printing is the general term to describe different printing processes developed in the early 90’s. The common part of those processes is the uninterrupted flow between computers to copies, without intermediate form. In addition, the source of information can be reloaded for each copy, which permits to change texts or images on the fly without affecting the production speed. The modified information is called "variable data". Nowadays, two main technologies split the market: electrophotographic presses, pioneers in the black-and-white publishing market which has become a mature technology with a good quality, and inkjet presses whose productivity and print quality have been constantly increased during the recent years.

2.3 Inkjet

The inkjet process consists in projecting ink droplets on a specific position of the substrate from small nozzles. This very adaptable process is an obvious asset in publishing, allowing broad range of production quantities and remaining competitive in terms of cost, from 1 copy to thousands of copies. Two inkjet technologies exist: continuous inkjet and drop on demand.

The continuous inkjet technology is based on the use of disturbances to deviate drops, ejected at a regular frequency. Its main advantage is the high drop creation speed allowing higher production speeds even if, currently, the printed quality is lower than the one made by the drop on demand technology. The process stages are: (1) generation of droplets, (2) electrical charging of droplets, (3) deflection (some droplets reach the substrate while the others are recycled). Different types of deflection exist: binary deflection, multiple deflection, hertz deflection and magnetic deflection. In the drop-on-demand process, droplets are generated only if needed. Different types of droplet generation exist: (1) piezoelectric, (2) thermal, (3) electrostatic, (4) acoustic.

Regardless the head technology chosen, the ink contained in the tank forms a curved meniscus until a force grows higher than the surface tension and ejects the droplet (see Fig. 1).
2.4 Electrophotography

This process invented in 1938 is mainly used in printers and copiers. The principle is to remove with a local light exposure the electrostatic charges produced by corona effect of a photoconductive layer. This creates a latent image, ready to be developed. The charged toner (liquid or solid) is attracted onto the charged area cylinder. Then the toner is transferred, directly or via a blanket, onto the substrate, which could be charged. Finally, the toner is heated and pressed between rolls onto the paper, which ensure its adhesion to the substrate. Before a new cycle starts, the printing cylinder is cleaned and then charged again (Fig. 2).

2. Augmented reality

The augmented reality (AR) is more and more present in our current digital era. It allows overlying virtual elements upon 2D or 3D real objects. The first AR system appeared in 1968. Firstly used in military applications, then for medical research, AR interests now many other sectors. Its main advantage is its capability to enrich reality by adding information through a terminal equipped with an optical sensor, such as a mobile phone. Virtual elements could be images, sounds or even, in the future, odours. AR acts through a software, which allows users...
to obtain animations on a printed object, for instance. The most critical part is the software development. Indeed, this software should be able to detect the object printed on the substrate. Many studies are currently developing reliable fast and easy-to-use software.

There are plenty of benefits for publishers. In addition to answer to printed paper limits and issues, it develops new marketing ways and possibilities such as:

- Learn more about customers with collected data through the application
- Broaden the audience
- Generate new advertising profits.
- Attract and retain customers

3. Market study

Table 1 and Figure 3 underline the increase of the market, whereas most of publishing sectors are suffering from recession. Moreover, each subdivision in comics field (manga, comics and comic books) is experiencing a net increase.

<table>
<thead>
<tr>
<th>French market</th>
<th>Books</th>
<th>Comics</th>
<th>2009: about 2 million $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales: 4.3 billion €</td>
<td>Sales: 225.8 million €</td>
<td>8.5% of global sales</td>
<td></td>
</tr>
<tr>
<td>52% of the cultural market in France.</td>
<td>increasing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79,300 book titles published</td>
<td>+4.7% value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>632 million units produced</td>
<td>+3.5% volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December 2011: use by 0.1% the world population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011: rating 181.25 million $</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Figures about comics

Figure 3: Production of French comics (2000 to 2012)
With 38 million copies sold, which correspond to more than 416 million €, the comics market represented 12% of the French book market’s turnover in 2011. The number of titles published is also an important factor. Combining all categories, it represented 22% of the produced titles in 2012 in France. The diversity of contents, the formats, the enthusiasm for series, the rarity of originals (artworks), the reprinting of classics, the collector products, the creation of events (Festivals, meetings), the movies or TV adaptations, the development of the political cartoon satire, the committed comics fans which differ from others types of book readers, are boosting factors of the comics’ market (Fig. 4).

Figure 4: Titles product per category (2011)

Table 2 shows possible applications for AR and highlights the fact that the number of application fields has sharply grown for the last 30 years.

Table 2: Possible applications for AR

<table>
<thead>
<tr>
<th>Original applications</th>
<th>1980: Military → Pilots helmets - Dashboards aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990: Medical → Viewing ultrasound imaging data</td>
</tr>
<tr>
<td>Current applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advertising → Billboards</td>
</tr>
<tr>
<td></td>
<td>Car → 3D representation of prototypes</td>
</tr>
<tr>
<td></td>
<td>Museums - Sightseeing (Cultural visits)</td>
</tr>
<tr>
<td></td>
<td>Video games → 65% of sales</td>
</tr>
<tr>
<td></td>
<td>Stores → Displays/ Promotional terminals/ interactive packaging/ Virtual fitting clothes</td>
</tr>
<tr>
<td></td>
<td>Online sales → Hoe testing products</td>
</tr>
<tr>
<td></td>
<td>Teledmedecine &amp; Surgery</td>
</tr>
<tr>
<td></td>
<td>Disability Support → Assistance visually impaired(AR audio)</td>
</tr>
<tr>
<td></td>
<td>Comics:</td>
</tr>
<tr>
<td></td>
<td>→ La Douce</td>
</tr>
<tr>
<td></td>
<td>→ The first issue of the comics &quot;Star Wars&quot;</td>
</tr>
<tr>
<td></td>
<td>→ Volume 2 of &quot;Génération mal logée&quot; of Yatuu</td>
</tr>
</tbody>
</table>
AR applied in comics market promises interesting evolution possibilities with 732 millions $ of assessment by 2014, intending to be used by 1 percent of the world population within 5 years. In 2016, the market is expected to reach 5,15 billions $.

Newspaper and magazine publishers have already started to propose to their customers an access to AR content in their pages. One of the most recent examples is the free French daily newspaper "20 minutes". Since the 3rd April 2013, the daily broadcasts its AR version. With a smartphone and the "20 minutes" software, readers can activate the pictogram contained in the newspaper and enjoy the enriched content in live.

This application was created by the company RedShift which commercializes the PaperPlay solution. PaperPlay combines a management solution with a dedicated mobile application or an SDK, which must be integrated in an existing application. This solution allows publishers to integrate AR contents within pages.

4. Trends and developments

As already mentioned, the comics market presents many opportunities of development based on its strengths such as being the 9th art which attracts collectors searching for treasures of highly diversified formats and contents. Personalization possibilities by digital printing of the content is another strength, supported by the evolution of such processes. Moreover, the trend is to increase interactivity, to differentiate each product or its interaction with the owner. However, comics market also has weaknesses. The price of one copy is high compared to other types of books and cannot really go higher, whereas the cost of the raw materials (paper and ink) is still climbing steadily. At the same time, the market is more and more demanding for quality, which requires costly presses, and eco-friendly products. Environmental aspects need to be considered such as the deinking of digital-printed products remains difficult. Finally, the cultural aspect should not be neglected; the comics market is mainly a European may not expand. Anyway, European comics market is threatened by Asian mangas and American comics. It is also threatened by the poor reputation of paper and by the digital attractiveness. The new generation tends to replace traditional comics books by digital media such as tablets, computers or e-books.

5. Conclusion and possible future

To sum up and propose a vision of a possible future, the following scenario could be considered. Despite the "buzz" produced by e-readers appearance on the market, paper roots are deeply anchored in our societies. E-books are not yet able to satisfy the customers about colour rendition and variety of the format. However, the entry in the digital era has an impact. Demands of the readers have changed and the market has to adapt. Conventional processes have been caught up by digital printing processes, which became competitive for short runs and are perfectly adapted to the comic book market, thanks to the possibility of personalization. Customers could now discover their own personalized information (name, quote and even personal pictures) through each page of their album, directly onto the printed product or through display connected with the AR software. In partnership with software development companies, the first AR comic books are sold in bookshops. Other domains, seduced by the originality of the idea, extend the application field to other media such as newspapers and magazines.

Acknowledgement

We would like to thank Anne Blayo for her availability, her help and for her valuable comments. We would also like to thanks Lisa Flynn, Aurore Demeulin and Jocelyn Ruiz for their advice and their help. Thanks are also due to every person who gives us support directly or indirectly.
References

Waste Ink Management

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Abstract

Printing inks are heart of any printing job. Excess four color inks can be consumed in other jobs, but spot custom made inks cannot be re used as the color values may not match. Since no proper recommendations or regulations are available, the printers do not manage these inks properly and are usually sold as scrap or converted into black ink. With recycling technology the ink that would have gone to waste can be recovered and reused. The recycling process includes following steps -

1) Sorting - Categorization of the ink can be done based on color family and variations in shades. For example, maroon and bright red, light blue and dark blue.

2) Filtering - Two passes through a triple roll mill is necessary to remove impurities, both small and big.

3) Blending and Matching - the mixed ink can be used as raw material to prepare new ink as per specimen given by customer.

Once it passes the quality test, it can then be used as raw material to make new color shades as per Lab values. This has proved to be the best use of refurbished inks. In the extremely competitive world of printing, reducing ink wastes makes good business sense. The paper explores the economics of waste management and the cost benefit analysis has demonstrated that the potential market for recycled ink is promising.

Keywords: Printing Ink, Waste Management, Recycling, Economics

1. Introduction

In the printing industry a lot of ink is wasted (in terms of leftover) while printing a job. 4 color inks can be reused for other jobs whereas spot colors / special shades are custom made inks and can be re used for that job only. Hence once the job is printed the remaining ink becomes leftovers for the printers. (The left over ink is usually not utilized by the printer if the seal is broken). These printers do not know how to manage these inks and are usually sold as fuel supplement for industrial boilers and kilns or converted into Black ink [7, 8]. These inks can be refurbished along with necessary additives, to make recycled ink and sold in the market again to printers (commercial printers and in certain cases packaging printers). These refurbished inks can be used in conjunction with 4 colors or as a single color. Re processed inks can be added to the virgin ink to improve its physical properties [6, 7, 8]. Also these inks along with pantone bases can be used for matching purpose. The other parts of the inks like containers, blisters should be recycled properly.

2. Process

The process of recycling inks involve the 5 basic steps

1. Sorting and Categorization
2. Mixing

3. Filtration

4. Testing

5. Matching

Flow chart of the process is shown in Appendix (Fig. 1 Waste Ink Processing Flow Chart)

2.1 Sorting and Categorization [3, 7, 8]

The thumb rule is not to mix the colored inks unless it is a dark color. Sorting is done on the basis of

- Color family - Blue, Green, Red, Brown and also whether the color is light or dark.

- Shade - Very light shades can be used as mixing medium in a particular shade. Dark colors can be mixed to produce Brown or Black

- Batch Size - Small leftovers should be collected in different containers while a big size batch can be potted in same color shade container.

- The containers should be labeled on the basis of color family.

- Removing skin carefully before putting ink in the containers. Spraying anti oxidant on surface of ink will prevent extra skinning.

2.2 Mixing

After segregation the ink is mixed in the 20kg mixer. It is run at a high speed to heat the ink, as a result of which the flow will improve and help in filtration.

2.3 Filtration

Impurities in ink can be removed in 2 ways, passing the through Triple Roll Mill (TRM) or Filtering through aluminum mesh. Printers cannot afford a TRM; hence filtration using coarser 140 aluminum mesh and a finer 200mesh can be used. The process of mixing and filtration can be repeated till desired results are observed.

2.4 Testing

Test can be performed on recycled inks to determine the quality. These include, Tack, Viscosity and Yield value, Water pickup and Grind test [1]. The result can be compared to the original inks to arrive at a definite conclusion.

2.5 Matching

Inks can be utilized as raw materials to match colors as per clients specification. It was noticed (monitored for a year) that the shade of recycled inks was usually on dark color family like brown and blue as shown.
Table 1: Percentage of Color family of recycled inks

<table>
<thead>
<tr>
<th>Color</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Blue</td>
<td>25</td>
</tr>
<tr>
<td>Dark Green</td>
<td>10</td>
</tr>
<tr>
<td>Dark Red</td>
<td>16</td>
</tr>
<tr>
<td>Dark Brown</td>
<td>21</td>
</tr>
<tr>
<td>Black</td>
<td>8</td>
</tr>
<tr>
<td>Blue</td>
<td>4</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
</tr>
</tbody>
</table>

The data was collected from 375 batches of different sizes (ranging from 500kg to 30 kg)

3. Economic Evaluation

3.1 Fixed and Variable cost

The economic evaluation takes into account the capital and monthly operating costs of the recycling project and the results of cost benefit analysis are presented.

Table 2: Capital Equipment List (Fixed Cost)

<table>
<thead>
<tr>
<th>Major Equipment</th>
<th>Type</th>
<th>Qty</th>
<th>Cost Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td></td>
<td>1</td>
<td>25000.00</td>
</tr>
<tr>
<td>Mixer 20 kg</td>
<td>1</td>
<td>15000.00</td>
<td></td>
</tr>
<tr>
<td>Knives</td>
<td>6</td>
<td>5000.00</td>
<td></td>
</tr>
<tr>
<td>Filtration mesh</td>
<td></td>
<td>1000.00</td>
<td></td>
</tr>
<tr>
<td>Printing kit</td>
<td>2</td>
<td>3400.00</td>
<td></td>
</tr>
<tr>
<td>Weighing scale 30 kg</td>
<td>1</td>
<td>15000.00</td>
<td></td>
</tr>
<tr>
<td>200gm</td>
<td>1</td>
<td>20000.00</td>
<td></td>
</tr>
<tr>
<td>Container 20 kg</td>
<td>1</td>
<td>1000.00</td>
<td></td>
</tr>
<tr>
<td><strong>Office Equipment</strong></td>
<td></td>
<td></td>
<td><strong>130400.00</strong></td>
</tr>
<tr>
<td>Lighting</td>
<td>4</td>
<td>5000.00</td>
<td></td>
</tr>
<tr>
<td>Cupboard</td>
<td>1</td>
<td>5000.00</td>
<td></td>
</tr>
<tr>
<td>Locks</td>
<td>4</td>
<td>2000.00</td>
<td></td>
</tr>
<tr>
<td>Stationery</td>
<td>1</td>
<td>2000.00</td>
<td></td>
</tr>
<tr>
<td>Table &amp; Chairs</td>
<td>1</td>
<td>30000.00</td>
<td></td>
</tr>
<tr>
<td>Uniforms</td>
<td>4</td>
<td>1000.00</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>130400.00</strong></td>
</tr>
</tbody>
</table>
### Table 3: Variable Monthly Cost

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rent</td>
<td>20000.00</td>
</tr>
<tr>
<td>Container</td>
<td>1000.00</td>
</tr>
<tr>
<td>Cotton Rags</td>
<td>1000.00</td>
</tr>
<tr>
<td>Kerosene</td>
<td>6000.00</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1000.00</td>
</tr>
<tr>
<td>Salary</td>
<td>20000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>49000.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Salary / month</th>
<th>Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemist</td>
<td>10000.00</td>
</tr>
<tr>
<td>Blender</td>
<td>5000.00</td>
</tr>
<tr>
<td>Delivery</td>
<td>5000.00</td>
</tr>
<tr>
<td><strong>Total Salary</strong></td>
<td><strong>20000.00</strong></td>
</tr>
</tbody>
</table>

### 3.2 Cost - Benefit Analysis

#### Table 4: Recycling and Production Cost

<table>
<thead>
<tr>
<th>Recycling Cost</th>
<th>Rs</th>
<th>Time reqd min/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation cost</td>
<td>5.00</td>
<td>Separation 5</td>
</tr>
<tr>
<td>Filtration cost</td>
<td>10.00</td>
<td>Filtration 5</td>
</tr>
<tr>
<td>Blending cost</td>
<td>15.00</td>
<td>Blending 5</td>
</tr>
<tr>
<td>Cleaning time reqd * cost/min</td>
<td>5.00</td>
<td>Cleaning 5</td>
</tr>
<tr>
<td>Ant skinning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production cost / kg</td>
<td>35.00</td>
<td>Labor cost/min (Rs) 2.00</td>
</tr>
</tbody>
</table>

#### Table 5: Costing

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Type</th>
<th>Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Purchase / kg</td>
<td>30.00</td>
</tr>
<tr>
<td>B</td>
<td>Cost of prdn/kg</td>
<td>35.00</td>
</tr>
<tr>
<td>C</td>
<td>Final cost / kg</td>
<td>65.00</td>
</tr>
<tr>
<td>D</td>
<td>Sale price / kg</td>
<td>150.00</td>
</tr>
<tr>
<td>E</td>
<td>Profit</td>
<td>85.00</td>
</tr>
<tr>
<td>F</td>
<td>Container cost / kg</td>
<td>5.00</td>
</tr>
<tr>
<td>G</td>
<td>Variable cost / mth</td>
<td>49000.00</td>
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</table>
Waste Ink Management

Table 6: Cost Benefit Analysis (CBA)

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
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</thead>
<tbody>
<tr>
<td>Qty</td>
<td>Production</td>
<td>Qty</td>
<td>Purchase</td>
<td>Cost of</td>
<td>Final Cost</td>
<td>Sale Price</td>
<td>Gross</td>
<td>Net Profit</td>
</tr>
<tr>
<td>Purchase</td>
<td>Loss</td>
<td>kg</td>
<td>kg</td>
<td>Rs</td>
<td>Rs</td>
<td>Rs</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>kg</td>
<td>a*30%</td>
<td>a-b</td>
<td>a*purchase</td>
<td>a*B</td>
<td>d+e</td>
<td>c*D</td>
<td>f-g</td>
<td>h-(G+c*F)</td>
</tr>
<tr>
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<td>60</td>
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<td>6000.00</td>
<td>7000.00</td>
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<td>700</td>
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<td>35000.00</td>
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<td>40000.00</td>
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</tr>
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<td>450</td>
<td>1050</td>
<td>45000.00</td>
<td>52500.00</td>
<td>97500.00</td>
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<td>80000.00</td>
<td>24000.00</td>
</tr>
<tr>
<td>2500</td>
<td>750</td>
<td>1750</td>
<td>75000.00</td>
<td>87500.00</td>
<td>162500.00</td>
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<td>150000.00</td>
<td>175000.00</td>
<td>325000.00</td>
<td>525000.00</td>
<td>200000.00</td>
<td>133500.00</td>
</tr>
</tbody>
</table>

3.3 Summary

Sensitivity Analysis was conducted using the above formulation changing only the purchase and sale prices. SA was conducted for 5 scenarios as shown in the below table. Calculations for CBA for these scenarios are given in Appendix.

Table 7: Summary of Sensitivity Analysis

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Purchase Price/kg</th>
<th>Sale Price / kg</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>30.00</td>
<td>100.00</td>
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<td>-46000.00</td>
<td>-44500.00</td>
<td>-43000.00</td>
<td>-41500.00</td>
</tr>
<tr>
<td>2</td>
<td>30.00</td>
<td>150.00</td>
<td>-12500.00</td>
<td>24000.00</td>
<td>60500.00</td>
<td>97000.00</td>
<td>133500.00</td>
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<tr>
<td>3</td>
<td>30.00</td>
<td>200.00</td>
<td>-22500.00</td>
<td>40000.00</td>
<td>95000.00</td>
<td>170000.00</td>
<td>335000.00</td>
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<tr>
<td>4</td>
<td>40.00</td>
<td>150.00</td>
<td>-22500.00</td>
<td>40000.00</td>
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<td>170000.00</td>
<td>335000.00</td>
</tr>
<tr>
<td>5</td>
<td>50.00</td>
<td>150.00</td>
<td>-32500.00</td>
<td>-16000.00</td>
<td>5000.00</td>
<td>17000.00</td>
<td>335000.00</td>
</tr>
</tbody>
</table>

The summary shows that the project is not feasible for low sale price tag for the given volume. The minimum sale price tag has to be at Rs 150.00 to break even at 2000 kgs. If the sale price is increased to Rs 200.00 the project will self fund from starting and can be adopted at several places. In addition to the sale price, purchase price of the ink is very important to sustain the healthy profitability. As the purchase price increases form Rs 30.00 to Rs 50.00 the breakeven point changes from 2000 kgs to 3000 kgs and the margin shrinks as shown in the last column. The most lucrative option is Scenario 3 where the profits are maximized but in practical market situation Scenario 2 would be ideal.

4. Conclusion

Waste Management of inks is necessary as proper disposal is mandatory, failing which can lead to severe penalties. The CBA shows that the concept is feasible and can be adopted easily. Large scale printers from newspaper industry, commercial and packaging houses can set up a waste management facility in house. Medium and small scale industries can send the inks to service provider for recycling [1, 6, 7, and 8].
References


A. Appendix

A.1 Sensitivity Analysis for different Scenarios

Table 8: Scenario 2

<table>
<thead>
<tr>
<th>Purchase price / kg (Rs)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Sale price /kg (Rs)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qty Purchase (kg)</th>
<th>Qty Production (kg)</th>
<th>Qty Purchase Cost (Rs)</th>
<th>Cost of Production (Rs)</th>
<th>Final Cost (Rs)</th>
<th>Sale Price (Rs)</th>
<th>Gross Profit (Rs)</th>
<th>Net Profit (Rs)</th>
</tr>
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<tr>
<td>200</td>
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<td>325000.00</td>
<td>350000.00</td>
<td>25000.00</td>
<td>-41500.00</td>
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</table>

Table 9: Scenario 3

<table>
<thead>
<tr>
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</thead>
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<tr>
<td>Sale price /kg (Rs)</td>
<td>200.00</td>
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### Waste Ink Management

<table>
<thead>
<tr>
<th>Qty</th>
<th>Production Loss</th>
<th>Qty</th>
<th>Purchase Cost</th>
<th>Cost of Production</th>
<th>Final Cost</th>
<th>Sale Price</th>
<th>Gross Profit</th>
<th>Net Profit</th>
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</thead>
<tbody>
<tr>
<td>kg</td>
<td>a*30%</td>
<td>kg</td>
<td>a*purchase</td>
<td>a*B</td>
<td>d+e</td>
<td>c*D</td>
<td>f-g</td>
<td>h-(G+c*F)</td>
</tr>
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</table>

#### Table 10: Scenario 4

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<th>Purchase Cost</th>
<th>Cost of Production</th>
<th>Final Cost</th>
<th>Sale Price</th>
<th>Gross Profit</th>
<th>Net Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg</td>
<td>a*30%</td>
<td>kg</td>
<td>a*purchase</td>
<td>a*B</td>
<td>d+e</td>
<td>c*D</td>
<td>f-g</td>
<td>h-(G+c*F)</td>
</tr>
</tbody>
</table>

#### Table 11: Scenario 5

<table>
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<tr>
<th>Qty</th>
<th>Production Loss</th>
<th>Qty</th>
<th>Purchase Cost</th>
<th>Cost of Production</th>
<th>Final Cost</th>
<th>Sale Price</th>
<th>Gross Profit</th>
<th>Net Profit</th>
</tr>
</thead>
</table>
A.2 Process Flow

Waste Ink Recycling Process Flow Chart

Figure 1: Waste Ink Processing Flow Chart [1]
Let the people know that paper is an attractive, practical and sustainable medium

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Abstract

Paper is perhaps the most basic material on earth that people use every day. And yet, we are confronted to the difficulty of how to get the general public interested in the paper technology. Visiting a paper mill is not well suited for educational purposes since it is a large, loud and hot process. And here is the problem: people have false ideas about paper. In this study, we focused on developing educational tools that help to understand the paper industry. We collected evidences to prove that paper does not destroy the forest, we described how paper is made and we built a fully working paper machine model to enhance the learning experience. We present the results and approaches taken to develop these tools as well as the specificities of the model, which is, to our knowledge, the smallest working paper machine in the world.

Keywords: paper machine model, sustainability, education

1. Introduction

What would the printing industry be without paper? Paper is a common material used every day. And when it comes to production, few people actually know how paper is manufactured. Paper machines have become too large to understand their process by looking at them. From these observations, we face a wall, trying to catch the attention of the general public on the paper industry. Moreover, the lack of knowledge in the paper industry raised persistent stereotypes. Who has never heard “paper making destroys the forest”? Precisely let’s let the people know that paper is an attractive, practical and sustainable material. This study has 3 main objectives: facts, education and experiment. The first objective is to unveil the truth on paper and forests by having clear, complete and independent vision of the situation. The second objective is to enlighten the paper industry by demonstrating the simplicity of paper making. The third objective is to provide a tool that illustrates and helps people experience the paper industry, by showcasing a fully operating paper machine model, which is, to our knowledge, the smallest working paper machine in the world.

2. End the myth: Paper does not kill the forest

2.1 The myth

The forest, a primary resource, has a crucial position in life on earth. Forests are the home of most species, they absorb CO$_2$ and generate O$_2$, and are one of the most important human resources (energy, construction, furniture, paper). Two thousand years ago, forests covered 80% of the European surface. From the Neolithic age and until the 19th century (figure 1), deforestation increased, mostly to clear lands for agriculture, reducing dramatically the forest coverage, which became, during the 19th century, as low as 10% of the European surface[1]. At the same time, the paper industry started to use wood as material to supply fibers (paper industry was using...
rags; S.F. Gottlob Keller invented in 1843 a machine producing ground wood pulp suitable for paper making)\[2\]. The concern for forest sustainability was then founded.

2.2 Facts and figures

Today, the paper industry helps the forests grow. In 2013, 55% of the wood extracted worldwide is used for energy production, 21% is used by sawmills and only 16% is used directly by the paper industry\[3\]. Moreover, paper mills use mostly residues from sawmills, branches cut to maintain trees healthy and thinning out trees\[4\]. Paper is not responsible for deforestation, deforestation is the result of an uncontrolled development of farmland, grassland, of tropical wood for building or of energy harvesting. On the contrary, the paper industry plants trees. Paper manufacturers engaged in sustainable forest management ensure that 3 to 4 trees are planted for one tree cut\[5\]. European forests have grown and are today 30% larger than in 1950. With a growth rate of 700,000.00 hectares per year\[6\], 177 million hectares are occupied by European forests in 2008, corresponding to 42% of the EU27 surface\[7\]. 148,700.00 m\(^3\) of wood are supplied annually for the CEPI area (figure 2) with 80.5% coming from CEPI, 17.4% imported from non-CEPI Europe, and 2.1% from outside Europe. So since the European forests are growing and the wood used in Europe for paper pulp production is coming from Europe, we can say that paper doesn’t destroy the forests in Europe. Furthermore, the paper industry in Europe uses as much recycled paper pulp (48.4 million tonnes (MT)) as raw pulp (44.5 MT) with an annual paper production larger (95.0 MT) than the annual consumption (81.5 MT)\[8\].

2.3 Certifications and more about paper sustainability

FSC (Forest Stewardship Council) guarantees a wood coming from responsibly managed forests, PEFC (Program for Endorsement of Forest) guarantees the origins of the wood. Blue Angel, NAPM recycled mark, Nordic Swan, EU Flower are Eco-labels\[9\]. Paper manufacturing has an environmental impact as all activities have. However paper is one of the few products that is natural, renewable, recyclable and biodegradable and doesn’t alter the resources of the forests. So let’s continue our efforts in paper sustainability and stop believing in myths.

3. Learn about paper manufacturing

3.1 What is paper?

Paper is a conglomerate of cellulose fibers and is a porous and permeable material sensitive to humidity (figure 3). The paper industry produces paper with controlled properties at speeds
Let the people know that paper is an attractive, practical and sustainable medium.

Figure 2: From raw materials to paper, Cepi pulp and paper industry, CEPI key statistics 2011

beyond our imagination: 2,020 m/min on a 8,900 mm width[10] (Sept. 2010 world record, Myllykoski Rhein paper Hürt Germany Voith PM1).

Figure 3: Left: Section view of paper, Right: Top view of paper, bonded fibers, porous structure, Cerig, Pagora

3.2 How is paper made?

Paper is obtained by filtration, pressing and drying of paper pulp. Paper pulp is produced by the division of fibers contained in natural resources (i.e. wood). This separation can be obtained through a mechanical action (i.e. grinding, disk de-fiberig, (chemo-thermo-mechanical or extruding) or by a chemical reaction (i.e. alkaline sulfate, soda anthraquinone or acid bisulfite). Other treatments are then performed (refining, bleaching, purifying, etc.) to attribute specific properties to the fibers and thus to the paper. Starting from dispersed fibers in water at about 1% concentration, the process drains the water from the suspension, so that fibers start to tangle and form a mattress of fibers. This mattress is then pressed and dried to remove water. As water leaves the mattress, hydroxyl bonds (the cellulose affinity to bond with water or itself is given by its OH groups) start to link the cellulose fibers. At the end of the paper making process, cellulose fibers are bonded naturally to one-another and form a solid layer of tangled fibers called paper[11].
3.3 The paper machine

A paper machine does all the operations described above, online at high speed and with large widths. Supplemental operations are often added online, such as coating (i.e. applying pigments on the paper surface), size-pressing (impregnating the paper with additives) or calendaring (smoothening the paper). A paper machine can be divided into 3 sections (figure 4). First, the prepared pulp in aqueous suspension is pushed through the head box and is collected on the forming table, on which the pulp loses most of its water through gravity and vacuum suction, and fibers start to tangle. The paper enters then the press section, where more water is drained through pressing. Different press technologies are available and are associated to various purposes and with various efficiencies (i.e. a soft and a hard cylinder combination to increase the nip area, where pressing occurs). Then, the sheet enters the drying section where it is heated up progressively, so that almost all the water is evaporated, leaving a precise humidity level (essential for paper flexibility and strength). Then the paper goes through specific operations, is rewinded and slitted.

![Figure 4: Top: Large Paper machine Metso, Bottom: Fourdrinier paper machine, Danlei Chu, Michael Forbes.](image)

4. Experience the smallest working paper machine ever built

4.1 Sizing

To visit paper machines is not well suited for educational purposes. They are loud, large, hot, and mostly covered by fairings. This is why we built a small working model of paper machine. We started from zero with one idea and a lot of questions. Questions were asked to specialists and their answers were mostly associated with surprises, doubts and helplessness. Pierre Latécoère, a pioneer of aeronautics, stated: "The calculations from my engineers are formal, the project is not achievable. So all is left now is to build it". The legend pushed us to start building this machine we called m-MAP. Table 1 details the characteristics of the machine. To draw the sketches of the m-MAP, we copied at 1/10th every element of Pagora’s paper machine and then we made
Let the people know that paper is an attractive, practical and sustainable medium

several changes based on simulations and calculations to improve the design of the m-MAP. The goal was to build a simple machine that illustrates best the paper making process.

Table 1: Size of the m-MAP in relation to Pagora’s paper machine and to Hürt PM1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>m-MAP</th>
<th>Pagora paper machine</th>
<th>Hürt PM1</th>
<th>m-MAP in % of Hürt PM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (mm)</td>
<td>100</td>
<td>1000</td>
<td>8900</td>
<td>1.1 %</td>
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<td>Length (mm)</td>
<td>1300</td>
<td>13000</td>
<td>130000</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Speed (m/min)</td>
<td>4</td>
<td>100</td>
<td>2020</td>
<td>0.2 %</td>
</tr>
</tbody>
</table>

4.2 Simulating

We encoded a simulation, to verify that parameters chosen would work. We focused on the wet end of the machine. The simulation helped us set up regulatory parameters (figure 5). The machine is not fully automated today, but is due to future improvements. For now the pulp flow rate incoming in the head box is regulated by two precision valves, allowing to control the basis weight along the cross direction of the web. The pulp is pumped to a head tank, positioned higher than the head box, and an overflow outlet allows having a constant pressure distributed to the head box.

![Figure 5: Screenshot of the visual of the simulation encoded](image.png)

4.3 Building

We decided to standardize the size of the cylinders down to 3 different sizes: 17 cylinders of 18 mm diameter to support the web, 7 cylinders of 50 mm diameter to press and drive and 5 cylinders of 100 mm to dry the sheet. All cylinders are mounted on ball bearings to reduce
friction. Vacuum boxes are installed under the forming table to drain more water from the fiber mattress. Webs supporting the early paper on the forming table section and on the press section are reconditioned through continuous water washing and vacuum suction. There are two presses composed of four 50 mm diameters cylinders. Presses are brought to pressure by manual screw systems. The five 100 mm drying cylinders are heated in their core by five 400 W resisting elements. These elements are regulated by 3 dimmers, allowing a temperature ramp to smooth dry the paper. The speed of rewinding is automatically regulated as the diameter of the rewinding paper roll increases. A cylinder with constant diameter is pressed on the rewinding roll and drives the system. The rewinding roll speed decreases when its diameter increases (analog to a gearing system), keeping the rewinding speed matching the machine speed. The machine is driven by four motorized 50 mm cylinders, one for each section (forming, pressing, drying and winding), regulated individually. Driving cylinders are motorized with DC brushed motors equipped with epicycle gearings, reducing to 1/200th the speed of the motor, thus increasing the torque. On each section, one 18 mm cylinder (which can move vertically) allows to tighten the web manually and one 18 mm cylinder (which can move horizontally), driven by a servomotor, allows to align the web.

5. Conclusions and Summary

Learning about the paper industry is a theme of interest and if many people have revisited their biased position and ended their disbeliefs, it still remains a sensitive subject that associates lack of knowledge and stereotypes that harm the paper industry. The aim of this study was to prove some myths to be wrong, was to draw attention from a wider audience, was to provoke curiosity (raising questions and reactions) and was to stimulate interest for paper. The smallest working paper machine model ever built draws attention and provides education. The proofs gathered demonstrated that the myth was wrong. At the end, I hope that the reader that you are will be convinced, because let’s face it, paper rocks and rolls.

Acknowledgement

I would like to thank sincerely my institute, Grenoble INP Pagora, for their great help. Especially to Mr. Denis CURTIL, Mrs. Anne BLAYO, Mr. Bernard PINEAUX, my tutor Mr. Naceur BELGACEM and the technical staff of the school. I also would like to thank very much the company Sercom-France and namely Mr. Bernard VALLAT-EVRARD for his technical consulting and his equipment supply.

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[9] Eugropa (ed.): "Environemetal guide for pulp and paper production"  
Graphical Printing III
Donuts, Pinholes and other effects in flexographic printing

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Abstract

During the last years, the flexographic printing process has been closely investigated at the University of Wuppertal. Of particular interest is the process of the ink-splitting at the printing plate in the flexographic printing process which is producing special effects such as donuts and pinholes. For classifying these effects, several studies were carried out at the University of Wuppertal, intending to determine their correlation with parameters, such as printing speed, dot size, pressure, viscosity and others. These parameters are used for generating and verifying simulation models. This article should give an overview on this field of research at the University of Wuppertal and discuss several of the parameters.

Keywords: flexographic, donut effect, pin hole, viscous fingering

1. Introduction

The flexographic printing process uses a flexible relief plate for printing. This process generates effects that reduce the printing quality. Some of these effects are donuts, pin holes, the halo effect (squeezed edge effect) and dot enlargement, caused by ink-splitting. These effects are the subject of research at the university of Wuppertal. A study was carried out resulting in two master thesis from Wu[1] and Wang[2]. This article will present some result of the study.

2. Experimental Setup

The experiments carried out in the study all base on the same setup, in which a W&H Olympic 714 flexographic printing machine was used. The printing substrate was a 40μm thick PE-film. The used ink was solvent-based NC-Magenta, designed for flexographic printing. The ink metering was done by an anilox roll with various bands of line screen ranging from 220 to 460 lines per cm. The study of Wang[2] yielded, that the ink volume of the anilox roll bands decreases linear with the line screen. The machine run with varying settings for ink viscosity, engagement (distance between print form and substrate) and printing speed. The printed substrate was analyzed with an optical microscope and the dot size was measured in the images.

3. Investigating the Effects

3.1 Pin Hole

The pin hole effect is a change of the density inside a printed full tone area. In the full ton area the ink builds up a stripe-like structure, looking like a pin hole. Sometimes pin holes are only visible as a density fluctuation. Concerning this effect, Wang carried out a dedicated study. He measured the count of stripes in a defined area and the width of a stripe for two different printing
speeds. Fig. 1 shows the pin hole effect with respect to different anilox line screens. The results are shown in Table 1.

Apparently, the pin holes are increasing and the width is decreasing with the printing speed. The second result is, that a smaller ink volume results in smaller stripe size, which depends on the stripe count, since there is fewer space for the stripe to expand. The theoretical study from Vos [3] came to similar results.

Table 1: Pin Hole Effect Study Results: The pin hole effect study shows a decreasing stripe-count for increasing ink volume. Bigger stripes need more space, resulting in a lower stripe-count. (from [2])

<table>
<thead>
<tr>
<th>Anilox line screen (lower line screen results in a higher in ink volume)</th>
<th>400L/cm</th>
<th>400L/cm</th>
<th>340L/cm</th>
<th>300L/cm</th>
<th>220L/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printing speed</td>
<td>75</td>
<td>150</td>
<td>75</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>Count of strips per 660μm</td>
<td>7.5</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Width of strips [μm]</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td></td>
<td>66.3</td>
<td>60.7</td>
<td>81.9</td>
<td>75.5</td>
<td>102.8</td>
</tr>
</tbody>
</table>

3.2 Donut Effect

The donut effect is a missing or low density ink area in the middle of a printed dot. This effect is not to be confused with the halo effect, appearing at the edge of a printed structure in flexographic printing, if the engagement is too high. For studying this effect, a special print test form was developed. In this test form, the dots are surrounded by a full tone area, ensuring nearly similar pressure and vertical deformation for all objects on the printing form. Fig. 2 shows the dots with surroundings and the varying distance between the dot and the surroundings. Small distances result in low relief depth and are expected to reduce elasticity. Unfortunately, Fig. 3 shows that the distance has no effect on the donut.
Figure 2: Print test form used for experiments. (from [2]).

Figure 3: Donut effect with varying distance to the surroundings. This distance has no effect on the donut. (from [2]).

Figure 4: Donut effect with different anilox cell count and unvarying distance to the surroundings. The donut is decreasing with increasing ink volume (from [2]).
Fortunately, the ink volume has an effect on the donut effect. For high ink volume, this effect vanishes. Fig. 4 shows, that the donut effect is vanished for an anilox cell count below 340L/cm.

3.3 Viscous Fingering

The Viscous Fingering effect occurs at the halo effect of a printed dot. Fig. 5 shows the fingers situated at the halo around the dot. This effect seems to only occur for low ink volumes. Table 2 shows that the number of fingers is decreasing with increasing ink volume.

![Figure 5: Shows the viscous fingering effect at the halo on a printed dot with a donut in the middle. (from [2]).](image)

Table 2: Count of fingers for different anilox cell count at 150m/min printing speed. Apparently, the finger count is decreasing with higher ink volume(from[2]).

<table>
<thead>
<tr>
<th>Dot size</th>
<th>200μm</th>
<th>180μm</th>
<th>160μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>460 L/cm</td>
<td>21</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>400 L/cm</td>
<td>18</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>340 L/cm</td>
<td>12</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>300 L/cm</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>220 L/cm</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4. Results and Discussion

This article gives an overview of some well known and observed effects in flexographic printing and the influence of certain parameters on these effects.

The most important influencing factor is the ink volume, since most effects became only visible at low ink volume. A second key result is that the speed affects the pin hole effect. The number of stripes is increasing with speed. At least it was found out, that the deformation of a dot has no effect on the donut effect.

More extensive studies will have to be carried out, in order to get a deeper understanding of these effects. Thus, the theory of these effects has to be updated and confirmed by investigating
experimental data.
The next step will be the design of models for explaining and verifying these effects.

Acknowledgement

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Photocatalytically active printing ink based on the redox dye 2,6-dichloroindophenol

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Abstract

A photocatalytically active functional printing ink records exposure to UV light through reversible or irreversible change of colour. The change of colour can provide information necessary to protect ourselves against harmful effects of UV light by indicating the sufficient exposure to UV light in an easy recognizable and accurate way. In such inks chemically stable substances - redox inks - are in contact with photocatalysts; illumination by UV light may disintegrate organic substances and change the inks colour.

We have prepared and used such a photocatalytically active functional printing ink as a simple UV indicator. Ink was formulated applying hydroxyethylcelulose, photocatalyst (nanodimensional anatase), redox dye (2,6-dichloroindophenol), glycerol, some additives, and water as a solvent. The mixture was applied on cardboard, paper and foil, by the cube applicator. Dried samples were exposed to UV light and analyzed colorimetrically by spectrophotometer (CIELAB colour values were measured in dependence on exposure time). We found out that the pH value of the functional printing ink and the applied substrate crucially influenced on the colour of the samples. Additionally, the effect of amount of photocatalyst, reducing agent (glycerol) and UV radiation on colour change of inks were observed as well.

The results confirm that such a formulation of functional printing ink satisfies all basic demands of final application, i.e. screen printing of UV- or Sun-exposure indicators.

Keywords: functional printing ink, UV indicator dye, titanium dioxide, 2,6-dichloroindophenol.
Opportunities of EB vs. UV curing for printing inks

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Abstract

UV and EB (Electron Beam) are radiation-curing processes used for inks and varnishes. Although they appeared simultaneously, UV has been much more used than EB. The present work intends to compare these two techniques, on technical, economical and environmental aspects.

UV curing is based on the polymerisation of monomers and prepolymer, initiated by UV photons absorbed by suitable photoinitiators. The free-radical is the most common chemical mechanism. EB curing is based on free electrons, which are directly absorbed by the monomers, without any photoinitiator intermediate. The electrons are generated by metal wire, thanks to a very high potential in a vacuum chamber. Afterwards, they are accelerated, then cross a foil window. Finally, electrons are focused on the ink, triggering monomers crosslinking.

The limits of UV process are: (i) the thickness of the ink layer (less than 10 \(\mu\)m), (ii) the way photoinitiators absorption match the wavelengths emitted by the lamp and (iii) the nature and the pigment concentration. Indeed, the absorption of some pigments, such as carbon black or dark colours, can compete with the absorption of photoinitiators. These limits are pushed back with the EB process: in printing applications, the thicknesses are not limiting and the EB efficiency depends mainly on the density of the material.

For food packaging, photoinitiators in UV inks may be hazardous because of their possible migration into the material: their concentration in the food must be kept under 0.01 mg/kg. As they are absent from EB inks, the ensuing hazards are excluded.

Despite the reduction in size of EB equipment, it is still bulkier than UV lamps. Furthermore, the radiation required for the curing process represents a primary hazard. These specificities and the misunderstanding of this process still prevent its development. Initially used in offset, EB is also promising for flexography, particularly in food packaging because it allows in-line production without risk of contamination.

This study provides an overview of EB and UV processes, discussing their advantages and limits. This work proposes some promising applications for EB, as an alternative-curing mode, especially in the context of food packaging, where recent problems were generated by the migration of photoinitiators of UV inks.

Keywords: EB inks, crosslinking, food packaging, low migration inks

1. Introduction

Radiation curing processes are very interesting for industry because they allow to combine high printing quality together with high productivity. Actually two radiation curing processes exist: the first one - Ultra violet (UV) - is well known and largely used, while the second one - Electron Beam (EB) - is still seldom used, despite its undisputable advantages. Both processes appeared simultaneously in the late 70’s but only UV has been efficiently used during the last thirty years. Therefore, the question arises why the UV process knew such a rise compared to the EB and what is the potential of development of EB in the printing industry. In order to get a better insight into these questions, it is relevant to know about the formulations of the inks and equipment used in each process. This study will focus first on the technical aspects of both techniques, then
on a technical and economical comparison. As a conclusion, some applications where EB process is relevant or even more efficient than UV are proposed.

2. Radiation curing processes

2.1 Ink formulation

Both processes use radiation energy in order to convert liquid ink or varnish layers into solid films. Ink drying is based on the cross-linking of a blend of monomers and prepolymers, which constitutes the vehicle of the ink. For both UV and EB processes, these monomers and prepolymers are mostly acrylates. The main difference between the two processes lays in the way to convey the energy triggering the polymerization from the source to the ink. In UV, lamps emit photons whereas in EB, electrons are directly produced with an electron gun. The UV inks contain photoinitiators which absorb the energy of photons and create reactive species, whereas the EB inks are based on pigments and monomers and prepolymers only, which react directly with the electrons. This is an essential difference between the two processes, as explained below.

2.2 Equipment

UV equipment contains generally two principal items, mercury vapour lamps, and reflectors. The lamp is composed of a transparent quartz tube sealed by electrodes at either end. The tube contains inert gas such as xenon or argon and also mercury. An electric current is created between the electrodes, which involves an increase in temperature (600-800°C). Thus, mercury vaporises and emits photons in a wide spectrum of wavelengths. Reflectors focus UV rays on the printed materials, and IR rays are evacuated by a specific device. The reflectors can be semi-elliptical (focused beam of light), non focused or parabolic (parallel beam of light).

The EB equipment is more substantial. It is composed of an electron gun, which produces an electron cloud in a vacuum chamber. The vacuum is necessary to avoid the reaction between electrons and the oxygen in the atmosphere. The electrons are then shot out of the chamber because of a potential difference between the gun and a metallic foil window. This window is electrons permeable and keeps the vacuum. Finally, a shield is set behind the paper web in order to protect the operators from any possible X-rays emissions.

3. UV vs. EB

UV and EB inks are similar in composition. However, there are some interesting differences concerning technical issues and economical aspects.

3.1 Technical issue

First of all, UV inks contain photoinitiators contrary to EB inks. The formulation of UV ink is limited because the absorption wavelengths of the photoinitiators must match the wavelengths emitted by the lamps. Furthermore, UV is also limited in the choice of pigments. Indeed, some pigments such as carbon black, dark colours or metallic particles may create troubles in the UV curing process: these pigments may absorb photons and therefore provoke a competition of photons absorption between photoinitiators and pigments. Figure 1 shows the absorption peak of black pigments, TiO2 and some coloured pigments in the UV field (200-400nm).

There are also some differences between drying with UV and EB process. First the thickness of the ink layer can be a problem in UV curing. Photons cannot penetrate deeply into the ink layer, therefore cross-linking is not effective and the ink is not dried when the thickness is higher than 10µm. It is not the case for EB ink, the penetration depth of energy being larger. The
Opportunities of EB vs. UV curing for printing inks

Figure 1: Pigments absorbance as a function of wavelength [1]

The penetration of electrons is controlled by the energy voltage of the equipment, which allows curing of an ink film up to a thickness of 40 μm (see Figure 2).

Figure 2: Penetration of curing energy [3]

To sum up, Table 1 presents a comparison between UV and EB processes.
Table 1: Technical comparison between UV and EB processes

<table>
<thead>
<tr>
<th>UV Advantages</th>
<th>UV Drawbacks</th>
<th>EB Advantages</th>
<th>EB Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less bulky than thermal oven.</td>
<td>Ozone production</td>
<td>Less bulky than thermal oven.</td>
<td>Installation and working costs, X-ray production, Radiation can degrade packaging.</td>
</tr>
<tr>
<td>Ink</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Economic aspects

In order to take the economic aspects into consideration, the cost of each printing process was estimated. Some parameters such as the price of one litre of ink, the initial investment to buy a dryer and the operational cost are presented in Table 2. The values for heatset inks are quoted for the sake of comparison.

Table 2: Cost of Heatset, UV and EB dryers

<table>
<thead>
<tr>
<th>Dryer Type</th>
<th>Heatset investments (€)</th>
<th>UV investments (€)</th>
<th>EB investments (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ink’s Price (€/set*)</td>
<td>10 (offset)</td>
<td>45</td>
<td>65</td>
</tr>
<tr>
<td>Initial investment for the dryer (€)</td>
<td>15 000 - 40 000</td>
<td>2 500 - 10 000</td>
<td>230 000 - 600 000</td>
</tr>
<tr>
<td>Functionning cost (electricity + gaz) (€/year)</td>
<td>700 000</td>
<td>18 000</td>
<td>73 000</td>
</tr>
</tbody>
</table>

* set = 1 kg Process Yellow + 1 kg Process Magenta + 1 kg Process Cyan + 1 kg Process Black

At first sight, the ink and the equipment for an EB installation are more expensive than the UV counterpart. However EB technology becomes more money-making than the heatset drying in the long run. To determine the point where EB equipment becomes profitable, we took the example of a printing company consuming 11,000 kg of ink per year (http://www.colruytgroup.fr/). The worst situation is taken into consideration i.e. the heatset dryer was priced at 15 000€ and the EB at 600 000€.

According to these hypotheses, less than 2 years after the investment the EB equipment cost less than the heatset because of its low consumption of energy. However potential maintenance costs have not been taken into account because the information is considered confidential and not available.

Finally the UV technology remains the lowest initial price, the less energy-consuming and therefore the more profitable, compared to the two others.
4. Applications

The technical advantages of EB process can also be attractive for some applications such as food packaging, printed electronics and 3D printing.

4.1 Food packaging

The European legislation is very strict about the possibility of food contamination by the packaging components. First of all, the printed surface must not be directly in contact with food. It must have no staining and no ink marks. Besides, components of packaging must not migrate in goods according to the order of the Federal Department of Home Affairs about the objects and materials. There is migration when more than 0.01mg of constituent is detected in one kg of food. Moreover, different criteria of rejection must also be considered: all components classified as carcinogenic, mutagenic and toxic and all pigments and colorants based on antimony, arsenic, cadmium, chrome (VI), lead, mercury or selenium.

UV and EB processes allow fast and efficient curing. However, the advantage of EB inks is the absence of photoinitiators which may migrate into the food. This process represents a good opportunity for food packaging. In addition, EB inks do not create odours, contrary to vegetable inks. Thus the product is not contaminated. Finally, there are no volatile organic compounds with the electron beam process, which is eco-friendly. All those benefits make EB process an efficient alternative for food packaging.

4.2 Printed electronics

Given that the thickness of the ink is not a problem for the EB curing, it represents an important advantage in printing electronics. Indeed, the ink layer can be a decisive parameter for dielectric or semiconductor printed components, particularly to improve the resistivity. The maximal thickness required to cure with a UV dryer is roughly 10μm, while the ink film can be four times
thicker with an EB dryer. Furthermore, the efficiency of UV curing is decreased with the presence of metallic particles as explained before, whereas the latter do not prevent EB drying. Therefore, in the field of printing electronics, EB curing can be considered as a promising curing technique.

4.3 3D printing

With the development of 3D printing technology, it is interesting to know whether EB curing is really competitive, as it is less limited by the thickness of the ink than other processes. Although the creation of the 3D object must be considered layer by layer, the manufacturing will be faster with EB. This type of drying can then be effective considered for this application.

5. Conclusion

Electron Beam curing has many advantages, notably its lack of photoinitiators or its fast curing. The absence of solvent and consequently of volatile organic compounds is also a real advantage, as well as the fact that curing in depth is possible. Nevertheless, this technology is limited by weaknesses, such as the price of the equipment, X-ray generation or the necessity to have an inert atmosphere. Furthermore, it is threatened by the development of research on low migration UV inks and by the misreading compared to other printing process. Finally, EB curing remains the only drying technique that respects food packaging legislation and the rare curing process able to be used for 3D and electronics printing. Given the fact that the investment cost and the energy consumption are too expensive, using EB process is more profitable and pertinent for products with high added values.

References

Opportunities of EB vs. UV curing for printing inks


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1. Functional Printing
Requirements for electroluminescent printing inks

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Abstract

Electroluminescence is a photophysical phenomenon in which a material emits light in response to an electric current or to a strong electric field. This phenomenon is used in lighting and visualization applications. More precisely, it is the result of the recombination of electrons and holes in a material: the excited electrons release their energy as photons. In balancing current densities of electrons and holes, it is possible to obtain an intense emission of white or colored light even at a low voltage.

OLEDs (Organic Light-Emitting Diodes) are multilayer devices, using the electroluminescent phenomenon to produce light. The organic electroluminescent materials are introduced between two electrodes: an anode, which creates electron holes, and a cathode, which provides electrons. One of these electrodes must be transparent in order to let the light pass. These layers are deposited onto a substrate: glass, paper or other flexible material. In order to obtain an operational device, the thicknesses of these layers must be homogeneous over the entire surface. Vacuum evaporation techniques and spin coating are usually employed, but they have a low yield and are not suitable for continuous production. In this context, printing processes could offer a potential solution to manufacture OLEDs.

Inkjet printing is one of the most reliable processes to produce electroluminescent layers. This non-impact process allows printing on any kind of media without contact. The inkjet printing of OLEDs is already quite advanced. However, some difficulties still remain. For instance, the drop position is not always perfect and may cause shifts; satellite drops, filaments or a nozzle obstruction may also occur. Moreover, resolution, speed and size are not yet optimal for industrial production.

The objective of this short study is to present the specific requirements for inkjet printing of OLED, especially regarding the ink properties. A special focus is also made on the possible developments of OLED printing inks.

Keywords: electroluminescence, OLEDs, multilayer, Inkjet

1. Introduction

Nowadays, the incandescent bulbs are disappearing; the market is looking for lamps which consume less energy. For twenty years, research in organic electronics has grown significantly due to its innovative and varied applications. For example, the OLEDs (Organic Light Emitting Diodes) are more and more used. Indeed, the printed electronics market is in large expansion: by 2021, it will reach 44.3 billions USD. As to the OLED market, it will increase by 50% in 2015 [10].

This new technology has a lot of advantages: whereas new lamps must have economic, technical and aesthetic assets, the electroluminescent lamps meet these expectations.
2. Market research

2.1 Printed electronics market

The study illustrated in Fig. 1 shows how the market for organic and printed electronics is expanding: the global market will reach 44.23 billion dollars in 2021. OLEDs have a strong presence in the market today but only for display applications and not for lighting. In 2021, OLEDs for lighting applications will be more present and represent about 5% of the printed electronics market.

2.2 OLEDs market

OLEDs have already conquered the display market for small size mobile devices such as mobile phones, PDAs and digital cameras. The production of larger screens raises significant technical problems.

It is not surprising that this market knows a growth rate exceeding 50%. Beyond the display market, OLEDs should play a major role in lighting because they can be integrated on flexible substrates and are relatively energy intensive.
3. General Information

3.1 Electroluminescence definition

Electroluminescence is a photo-physical phenomenon in which a material emits light in response to an electric current. It is the result of radiative recombination of electrons and electron holes in a material, usually a semiconductor. The excited electrons release their energy as photons. Before recombination, electrons and holes are separated due to the induction in the material to form a junction (see Figure 3).

3.2 Materials used

Two main materials are used in the OLEDs: small molecules, that can produce electroluminescent films by vacuum evaporation, and polymers, used in solutions. These materials behave as semiconductors with a gap between 1.5 and 3 eV. The process using small molecules is more complicated but more efficient: it allows the deposit of successive layers with an accuracy of about one nanometer.

3.3 OLED mechanism

There are four main mechanisms involved in electroluminescence (Figure 3):

- Injection of electrons and holes, respectively by the cathode and the anode;
- Carriers of charges in the material by charged species called polaron (p + and p-)
- Recombining opposite charge carriers in a neutral excited state exciton
- Disabling the exciton and light emission

Figure 3: Schematic mechanisms of electroluminescence [9]
3.4 Simplified structure of an OLED

OLEDs are constituted of layers: a film of material (small molecules or polymers) is inserted between two electrodes of different chemical types:

- An anode (+) which creates holes (snatch electrons in the material), the most used today is the ITO (Indium Tin Oxide).
- A cathode (-) which provides the electrons.

One of these electrodes must be transparent in order to let the light pass.

The materials are deposited on the electrode, then the cathode is vacuum deposited on the organic material.

The different layers of an OLED are described on Fig.4.

![Diagram of an OLED](image)

Figure 4: Scheme of an OLED [1]

With an appropriate electric voltage, electrons and holes are injected in the emitting layer from the anode and the cathode. Electrons and holes are attracted by each other, then migrate through the luminescent material and combine themselves in the emitting layer in order to form excitons. Electrons must be snatched from one side and add up on the other side. Indeed, the luminous layer is sandwiched by two electrodes.

4. Technical specificities

4.1 Absorption spectrum

By absorbing a photon, the molecule reaches a higher energy level (arrow 1 in Fig.5), which gives an absorption spectrum in the visible wavelengths and therefore light.

The larger the gap size, the more delocalized and higher the electronic cloud gap size and the higher/larger the wavelength of absorption and emission. Then, the molecule goes down to level 0 of the excited state (arrow 2 in Fig.5). The lifetime of the excited state is in the nanoseconds scale. Finally, the molecule is de-excited, or de-energized (arrow 3 in Fig.5).

4.2 Specifications current/ luminance/ voltage density

Fig.6 shows that a threshold voltage Vth across the device is necessary for the passage of a significant current. From this threshold, an exponential increase in the current density and in the luminance can be observed. Given that the luminance is proportional to the current density,
Figure 5: Curves of potential energy of an organic molecule in the fundamental state and the first excited state [4]

Figure 6: Specification JV et LV (current and luminance density versus voltage) [4]
A small change in voltage across the diode causes a significant luminance variation. These results are very interesting: light can be created from a low current.

### 4.3 OLEDs efficiency

The external quantum efficiency in % is given by:

$$\eta_{\text{ext}} = \frac{\text{number of emitted photons}}{\text{number of injected electrons}} = \eta_r \cdot \chi \cdot \phi_{PL} \cdot \eta_{\text{ext}}$$

with:

- $\eta_r$ the recombination efficiency (formation of excitons)
- $\chi$ the proportion of excitons emitting light
- $\phi_{PL}$ the photoluminescence efficiency
- $\eta_{\text{ext}}$ the proportion of the outgoing device

The recombination efficiency is often close to 1 with a balance in the injection of positive and negative charges. $\chi = 1/4$ because 25% of excitons are singlets, $\eta_{\text{ext}} = 1/2n^2$, $n$ being the refractive index of the organic material. This efficiency can be optimized by using doping minimizes aggregation emitting molecules.

### 4.4 Sustainable development

Regarding sustainability, the main advantage of an OLED is its low energy consumption. As seen previously, the OLEDs can be used with a very low current. For instance, a 4V voltage will provide a 270Cd/m$^2$ luminance.

Another important aspect is the OLED lifetime. The end of life of an OLED is reached when its power declines under an unacceptable level. This can occur after a time varying from a few thousands to 50,000 hours. As a comparison, a normal bulb has a lifetime of 2,500 hours.

To conclude, an OLED is a sustainable device which may therefore replace other products for environmental purposes.

### 5. Deposition techniques

Commonly used techniques are spin coating and vacuum evaporation, but the printing processes bring benefits to OLEDs manufacturing. Gravure, screen-printing, flexography and especially inkjet printing can be used. These methods have their own advantages and limitations. However, offset lithography is not used: the viscosity of the ink is too high and ink formulations are too complex.

#### 5.1 Spin coating vacuum evaporation

Spin coating and vacuum evaporation are techniques usually used in organic electronics and micro-electronics, which allow to deposit thin layers. Spin coating uses the centrifugal force whereas the vacuum evaporation permits to deposit the material in a hermetic enclosure: the vacuum allows the particles to reach directly the substrate where they condense to solid state. These techniques are used in the laboratory and are not aimed at large productions. Moreover, they do not permit production line and despite their low performance, they involve a high price. Printing processes are therefore a plausible alternative.

#### 5.2 Gravure

Gravure printing has many advantages for the production of electronics compounds. Firstly, this process allows producing high volume with good repeatability using a high speed printing
technology. This high productivity is allowed by the long lifetime of the printing form. Then, the thickness of the deposited film is higher than with offset or flexography.

### 5.3 Flexography

The method is a flexographic relief printing method with a direct ink transfer. The ink is transferred from the anilox roll to a flexible plate and afterwards to the substrate. The main drawback of this method is the halo generation that could interfere with the functioning of OLEDs.

### 5.4 Screen printing

Screen printing enables to print a significant thickness of ink on various substrates. Some companies, such as ADD/Vision, already use screen printing to print OLEDs in order to obtain small displays such as smart credit card or speedometers.

### 5.5 Injekt

Inkjet printing is one of the most reliable processes to produce electroluminescent layers. This non-impact process allows to print on any kind of medium without contact and enables to produce at low cost. Inkjet printing of OLEDs is already quite developed. Numerous companies have chosen to print OLEDs thanks to the advances in inkjet technology. For instance, the Cambridge Display Technology Company (one of the leaders in the development of organic light emitting diodes) offers an OLED display of 14 inches, printed by 128 inkjet heads (Fig. 7). Inkjet resolution allows the reproduction of identical patterns with different colors and the layering of small patterns. This represents a significant advantage for printing multilayer devices such as OLEDs.

![Ink-Jet Heads](image)

**Figure 7:** Deposition of organic materials thanks to inkjet [4]

Regarding ink formulation, the requirements are strict physicochemical properties, corresponding to the needs of inkjet, namely: low viscosity between 2 and 10 mP.a.s and surface tension between 25 and 35 mN /m. The particle size should be less than one micrometer in order to avoid clogging of the printer nozzles.
6. Technique Issues

6.1 Linked to electroluminescence

The researcher’s aim is to optimize the electrons and holes recombination. For this, the emitting layer must have an equal number of electrons and holes. This balance is difficult to achieve in an organic material because the mobility of an electron is three times higher than the mobility of a hole.

Light emission occurs when there are singlet excitons. But because only 25% of excitons recombine as singlet excitons, there is a loss of performance.

Material degradation may cause different problems in the long run. Indeed, we can observe a decrease of the intensity of the light, a need for higher operating voltage, or the appearance of "black spots" due to ageing of materials.

6.2 Linked to Inkjet process

Inkjet printing is a non-contact technique, which implies a time of drop flight between its ejection and its impact on the substrate. During this flight, several problems may occur, such as shifts, satellite drops or filaments, which can adversely affect the properties of the printed layer and reduce its effectiveness.

In addition, resolution, speed and surfaces are not yet optimal for industrial production. Consequently, mass production is still a challenge.

The inks used must have a low viscosity and a particle size of less than 1 micrometer. If the formulation does not meet the conditions and requirements of the inkjet process, nozzle clogging may occur.

For applications of printed electronics such as OLEDs, a layer thickness between one and ten micrometers is needed, whereas classical inkjet printing allows only layer thickness between 1 and 2 micrometers, which may constitute a limitation for OLED layer manufacturing.

7. Conclusion

In a relatively close future, inkjet process can be designed to print lighting on larger scales: road signs, large advertising posters, ambient lighting, packaging. Such devices could be the future of our displays, replacing the plasma or LCD screens in television, mobile phones or other digital devices. Moreover, this generation of materials achieves very high luminous efficiency and brings the possibility to fabricate flexible devices.

However, there are still technological barriers and several problems to overcome in order to achieve the full development of this new technology. Improving the rheology and effectiveness of the inks used is especially required to reach acceptable performance. In addition, to compete with LCDs, production costs must be considered. However, a strong growth is expected in the coming years.

References

Requirements for electroluminescent printing inks


Synthesis and effect of graphene in PEDOT:PSS on conductivity for biosensor application

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Abstract

Graphene (G) is a very interesting material possessing excellent electrical conductivity and high electron transfer. It was prepared by chemical method following by sedimentation and centrifugation to separate graphene into three sizes: small, medium and large. It was found that the dispersibility of graphene in the PEDOT:PSS water based solution is limited. However, this problem can be overcome by a simple method such as sonication as confirmed by optical microscopy. The 50 µl of PEDOT:PSS/graphene (PEDOT:PSS/G) composite inks was casted onto the glass substrate (1.5×1.5 cm²) for primary morphology observation and electrical conductivity measurement. Moreover, the effect of casting method was also investigated. The electrical conductivity of three different patterns of composite inks showed significant enhancement compared with that of pristine PEDOT:PSS. Moreover, the surfaces of coated films observed by optical microscope and surface profiler showed higher surface roughness, which seem to be suitable for enzyme immobilization in biosensor application.

Keywords: PEDOT:PSS, biosensor, graphene

1. Introduction

Over the last decade, the disposable screen printed electrode has been interested in many practical fields such as medical, military, environmental and food detection. It can be mass produced by printing techniques, e.g., screen-printing, spin-coating and inkjet printing to obtain cheap electrodes with high substrate selectivity [1]. The electrode is a simple carbon-paste electrode and generally has poor potential for detection. Therefore, PEDOT:PSS has been used because of its outstanding properties such as high electrical conductivity and high stability. Many researchers improved the properties of electrode by incorporation of PEDOT:PSS into a carbon paste deposited on transducers surface [2]. Moreover, increasing surface working area can increase the electrochemical response and can also extend the detection limit and concentration-response due to the fact that enhancement of the electrochemically active area directly affects the electron exchange [3]. To increase the surface working area, PEDOT:PSS was incorporated with electrically conductive materials, such as nanogold and carbon nanotube particles, to obtain highly sensitive electrode to target substrate [4]. Among these, graphene is a very useful material owing to its prominent properties, particularly in terms of mechanical, thermal, and electrical properties [5]. From this reason, it has been used not only as reinforcing material in polymer matrix, but also to improve heat transfer and electrical transfer of material in electronic packaging [6]. Graphene can be produced by several methods, for example, micromechanical cleavage, chemical vapor deposition (CVD), epitaxial growth and so on [7]. However, these methods require
complicated instruments and produce small amount of graphene. Thus, the chemical method, which is a promising method to produce graphene from graphite, was selected in this work. Our present research shows the preparation of conductive ink by incorporation of graphene into PEDOT:PSS matrix. Also, the dispersibility of graphene in aqueous sodium dodecyl sulfate (2 wt% SDS), ethanol, and acetone was investigated. Preliminary preparation to study the properties of conductive inks was casting on glass substrates. Moreover, the casting methodology was also comparatively examined. The electrical conductivity and surface roughness were studied. For the further study, the modified conductive ink is expected to be applied for enhancement of the sensitivity of electrodes and for improvement of the surface working area and electron transfer for hydrogen peroxide detection of a screen-printed area. Then, PEDOT:PSS/graphene composite ink is screen-printed onto the electrode. Finally, the influences of surface area and roughness of the working electrode on the enzyme entrapment efficiency will be investigated.

2. Materials and Methods

2.1 Chemical reagents

For graphene synthesis, graphite powder (particle size ≤ 20 µm), hydrazine hydrate (5.51 wt%) were purchased from Sigma-Aldrich. Sulfuric acid (H₂SO₄), sodium nitrate (NaNO₃), potassium permanganate powder (KMnO₄) and hydrogen peroxide (H₂O₂) were purchased from Ajax Finechem. Hydrochloric acid (HCl, 5 vol%) was purchased from Merck. PEDOT:PSS (Heraeus, Clevios™ PH 1000) was purchased from Clevios. All organic solvents were analytical grade and used as received without further purification.

2.2 Instrument and analytical method

Compact High Speed Refrigerated Centrifuge 6500 was employed to separate the graphene oxide particles having different sizes. Chemical structure of graphene was characterized by Fourier transform infrared (FTIR) spectrometer (Perkin Elmer, Spectrum One) with a number of scan of 128 and a resolution of ±4 cm⁻¹. The ultrasonic processor (Hielscher-ultrasound Technology, UP200S, 200 W, 24 kHz) was used for improving graphene dispersion in organic solvents. Surface morphologies were observed by optical microscopy (Leica Microscope DM4000 M). The electrical conductivity of coated composite inks was collected by four-point probe measurements (Keithley). The average thickness was measured by a stylus surface profiler (Veeco Dektak 150 Stylus Profilometer) with standard scan at 0.5 µm/sample of resolution.

2.3 Experiments

Preparation of graphene

Graphite oxide (GO) was prepared from purified graphite powder according to Hummers method [8]. Filtration and centrifugation were done to separate the different sizes of graphene as displays in Fig. 1.

GO slurry was washed with DI water followed by filtration several times through PTFE membrane until the pH closed to neutral. The filtrated particles were freeze-dried for 5 days. GO was collected and further measured the weight: small (S; 0.168 g), medium (M; 0.228 g), large (L; 1.128 g). Dried GO (100 mg) was re-suspended in DI water (100 ml) for 45 minutes by sonication. Then, it was poured into a 250 ml one-necked round bottom flask equipped with reflux condenser and stirrer. Hydrazine (hydrazine:GO, 7:10, w/w) was filled into the suspension. After that, it was heated to 90 °C and stirred continuously for 10 hours. The reduction was taken place and the crude product was filtrated through a PTFE membrane and washed with DI water (100 ml × 3). The slurry was re-dispersed in 10 ml of DI water and dried in freeze dryer for 5 days.
Ink preparation and route of drop casting

Graphene (G) was dispersed in PEDOT:PSS, aqueous SDS (2 wt% SDS), acetone and ethanol at 1 wt% by being once post treated with an ultrasonic probe for 10 minutes for achieving a homogeneous dispersion. Furthermore, before drop casting with a micropipette the dispersions were placed in an ultrasonic bath for 10 minutes.

Two main casting methodologies were conducted. The first method is drop casting of 50 μl PEDOT:PSS/G mixed solution onto the substrate in an area of 1.5 cm × 1.5 cm. Another is drop casting of the individual graphene dispersions on the previous dried PEDOT:PSS layer (P/G), or on the glass substrate followed by drying and subsequently drop casting of PEDOT:PSS on top (G/P), 50 μl respectively in the same area. Drying was carried out on a hotplate at 60°C for 15 minutes. Overall, three drop casting test runs (run 1, run 2, run 3) were prepared and analyzed.

3. Results and Discussion

3.1 Synthesized graphene characterization (FTIR analysis)

The chemical structure of synthesized graphene was analyzed by FTIR as shown in Fig. 2. The broad peaks at 3435 cm⁻¹ appeared in all spectra that were assigned to hydroxyl groups and adsorbed water molecules (U\(_{O-H}\)), while weak signals at 2926 and 2855 cm⁻¹ were corresponded to the aliphatic CH\(_2\) and CH\(_3\) stretching (U\(_{C-H}\)), respectively. After oxidation, oxygen-containing functionalities occurred on GO as detected at 1716 cm⁻¹ of a strong carbonyl stretching (U\(_{C=O}\)) of carboxylic and ketone, at 1398 cm⁻¹ of O-H bending (δ\(_{C=O-H}\)) of carboxylic and carbonyl, at 1042 cm⁻¹ of C-O stretching (U\(_{C=O}\)) of carbonyl, and at 1217 cm⁻¹ of epoxy ring. Moreover, a peak at 1612 cm⁻¹ was also displayed, which is associated with the bands of carbonyl (U\(_{C=O}\)) and C=C stretching (U\(_{C=C}\)) of un-oxidized graphite. The spectrum of graphene exhibited a decrease in intensity of peaks at 1398, 1217 and 1042 cm⁻¹, indicating that the epoxy groups and hydroxyl groups were reduced with hydrazine hydrate. Furthermore, the absence of peaks at 1716 and 1612 cm⁻¹ and the presence of a new C=C skeleton vibration at 1632 cm⁻¹ indicated that graphene was successfully synthesized.
Figure 2: FTIR spectra of graphite, GO, and graphene

3.2 Characterization of PEDOT:PSS /graphene inks

3.2.1 Morphology of PEDOT:PSS /graphene thin films

In Fig. 3, microscopic images of drop casted and dried PEDOT:PSS dispersions are displayed for run 2. PEDOT:PSS (Fig. 3a) results in a homogeneous bluish layer. The PEDOT:PSS/G layer in Fig. 3c shows a relatively homogeneous distribution of graphene. The shining parts are arising from defects. The films from individual drop casted methods generally showed less homogeneous distribution of graphene. The P/G SDS (Fig. 3d) as well as G/P SDS layers (Fig. 3g) demonstrated darker and lighter areas depending on the graphene coverage. Spreading occurred over the entire area. The P/G acetone and G/P acetone dispersion led to very large agglomerations and a non-uniform distribution (Fig. 3e and 3h), whereas the agglomeration were even larger for P/G acetone (Fig. 3e). Agglomeration occurs due to the very fast evaporation of acetone directly after drop casting resulting in reduced spreading. Similar behavior is shown for the film obtained from ethanol-dispersion. The P/G ethanol layer (Fig. 3f) was comparable to the P/G SDS layer, and the G/P ethanol layer (Fig. 3i) was comparable to the G/P acetone layer. However, the best results were shown for direct dispersion of graphene in PEDOT:PSS or both preparation methods for the graphene in SDS and P/G ethanol.

3.2.2 Electrical conductivity measurement

The sheet resistance for all samples was measured from all three runs at three different positions. The results are given in table 1. PEDOT:PSS showed high surface resistance of $24018 \ \Omega/\square \pm 2541 \ \Omega/\square$. Pure graphene dispersion in SDS showed a sheet resistance of $15250 \ \Omega/\square \pm 1963 \ \Omega/\square$. The PEDOT:PSS/G mixture gave a sheet resistance of $2500 \ \Omega/\square \pm 471 \ \Omega/\square$, which identifies a significant decrease in sheet resistance of 90%. Best results were achieved for the P/G SDS and G/P SDS dispersions with $8 \ \Omega/\square \pm 1.41 \ \Omega/\square$ and $9 \ \Omega/\square \pm 2.33 \ \Omega/\square$, respectively. The P/G acetone dispersion resulted in $97 \ \Omega/\square \pm 23 \ \Omega/\square$, whereas G/P acetone resulted in $3037 \ \Omega/\square \pm 465 \ \Omega/\square$, similar to that of PEDOT:PSS/G. Furthermore, P/G ethanol obtained $8 \ \Omega/\square \pm 2.5$
Synthesis and effect of graphene in PEDOT:PSS on conductivity for biosensor application

Ω/□, which was close to those of P/G SDS and G/P SDS. The G/P ethanol layer resulted in 2643 Ω/□ ± 1245 Ω/□, which is analogous to G/P acetone and PEDOT:PSS/G. For graphene in SDS and P/G acetone for run 1 the sheet resistance was not measurable due to defects. These results are strongly connected to the graphene distribution in/on PEDOT:PSS. A homogeneous distribution resulted in lower resistances in which higher conductivity was observed.

Table 1: Measured values for the surface resistance of all three runs

<table>
<thead>
<tr>
<th></th>
<th>run 1</th>
<th>run 2</th>
<th>run 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEDOT:PSS</td>
<td>24765 ± 465</td>
<td>26102 ± 1086</td>
<td>21188 ± 1649</td>
<td>24018 ± 2541</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>3030 ± 129</td>
<td>2129 ± 35</td>
<td>2340 ± 516</td>
<td>2500 ± 471</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>10 ± 0.14</td>
<td>8 ± 0.74</td>
<td>7 ± 0.30</td>
<td>8 ± 1.41</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>12 ± 0.30</td>
<td>10 ± 1.08</td>
<td>7 ± 0.61</td>
<td>9 ± 2.33</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>3456 ± 637</td>
<td>2537 ± 421</td>
<td>3118 ± 161</td>
<td>3037 ± 465</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>11 ± 1</td>
<td>7 ± 0.30</td>
<td>6 ± 0.31</td>
<td>8 ± 2.50</td>
</tr>
<tr>
<td>PEDOT:PSS/G</td>
<td>4081 ± 553</td>
<td>1890 ± 113</td>
<td>1959 ± 35</td>
<td>2643 ± 1245</td>
</tr>
</tbody>
</table>

3.2.3 Surface profiles

The surface profiles in Fig. 4 were obtained from run 2. Each pattern was measured at five different positions. When comparing the profiles for the different positions inside the patterns as well as from run to run, no crucial difference could be detected. Pure PEDOT:PSS (Fig. 4a)
showed a relatively smooth surface profile without any noticeable hills. The average height is approx. 1.67 μm ± 0.39 μm with a surface roughness (Ra) of 0.05 μm. Pure graphene (Fig. 4b) displayed distinct hills of graphene clusters with an average value up to 15 μm and one peak of 25 μm as well as valleys down to the level of the substrate. The PEDOT:PSS/G layer (Fig 4c) presented a combination of single PEDOT:PSS and graphene. Here the average layer thickness is approx. 4.35 μm ± 1.21 μm, whose thickness was more than twice of that of PEDOT:PSS which could be due to the graphene particles distributed inside the PEDOT:PSS layer as well as larger graphene agglomerations. The P/G SDS and G/P SDS layers showed major average height thicker than that of PEDOT:PSS/G. Both films showed high surface roughness and fluctuations due to less homogeneous graphene distribution. The system with P/G acetone and G/P acetone showed the highest fluctuations. The system with G/P ethanol layers also showed high surface roughness, but slightly smaller fluctuations. The system with P/G ethanol is comparable to that with SDS. The surface profiles reflected either uniform or non uniform graphene distribution of the microscopic images (Fig. 3). A uniform graphene distribution gave best results for sheet resistance (Table 1).

![Figure 4: Surface profiles of varying PEDOT:PSS mixtures drop casted on glass](image)

4. Conclusions and Summary

The electrical conductivity of PEDOT:PSS inks was significantly improved by directly mixing 1 wt% of graphene in PEDOT:PSS. Using different solvents for dispersion of graphene and drop cast them on top of a dried PEDOT:PSS layer and another way around affected the surface morphology and the electrical conductivity of the dried layers. Aqueous SDS was the best solvent for both drop casting methodologies, while ethanol showed only well dispersion on PEDOT:PSS layer, but not on the glass substrate. Acetone was dried very fast causing problem in spreading
on the glass substrate and PEDOT:PSS layers as proved by surface profiles, resulting in lower electrical conductivity.

Acknowledgement

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References

Investigation of the relationship between conductivity and microstructure of inkjet-printed silver conductive tracks depending on the sintering process and the base substrate

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Abstract

A detailed study about the structural and functional characteristics of inkjet printed silver conductive tracks using a thermal sintering method is presented. This includes the printing of defined patterns and the analysis of the effect of diverse thermal sintering strategies, like varying the sintering temperature as well as the sintering time on the crystalline structure and therefore on the electrical performance. The printed silver structures are investigated qualitatively with the light microscope. Furthermore, the structures are examined by measuring the layer thickness as well as the building of surface profiles and finally by studying the crystalline structure with X-ray diffraction and a scanning electron microscope (SEM).

The aim of this work is a basic investigation of the relationship between changes in the crystalline structure, caused by thermal impact and the electrical characteristics of the printed silver tracks by measuring the resistance as well as calculating the resistivity. Next to this also a feasibility study for controlled micro three dimensional patterning is executed by the implementation of two basic printing strategies for multilayer patterning.

An overview of all the mentioned correlations and knowledge for further applications of printed silver conductive tracks and their use in printed electronics is provided. With the fundamental knowledge and findings given through this work silver structures can be printed with the basic requirements in electrical performance as well layer formation by changing defined parameters.

Keywords: Inkjet printing, thermal sintering, nanoparticle silver

1. Introduction

In printed electronics the functionality of the printed device plays the crucial role. This functionality of printed layers can be for example generated by a sintering process. For the printing technology particles are dispersed in solvents with additional additives. Both, solvents and additives have to be removed after the deposition onto a substrate. This is executed by a heating process referred to as sintering. Sintering in this case includes consequently the evaporation of solvents and additives as well as the fusion of the particles to a dense crystalline structure.

For this various sintering methods are common. Out of these methods photonic sintering, plasma sintering, chemical sintering and electrical sintering [1, 2, 3, 4, 5] are suitable for flexible polymer foils with a low melting point [6]. However, for rigid substrates with a higher melting point thermal sintering is an appropriate method because it does not require complex techniques.

Silver is an often used material for applications such as printed electronic devices, for example printed transistors [7, 8], radio frequency identification (RFID) [7, 9] tags and other circuit components [10, 11]. To date many researches deal with the investigation of printed silver tracks and the influence of varying parameters on the functionality [12, 13, 14, 15, 16]. What is missing
is a fundamental study of printed silver conductive tracks including the optical, electrical and structural nature and their dependencies on defined parameters like digital and printed pattern, thermal influences (sintering temperature and sintering time) and their relations among each other.

In the following sections, we investigate the morphology, the functionality and the microstructure by means of profile measurements with a profilometer, resistance measurement and resistivity valuation as well as X-ray diffraction and scanning electron microscopic images to show the relationship between the properties. The aim is to generate a basis for printing patterns with defined requirements.

2. Materials and Methods

The so called butterfly patterns consist of two contact pads connected by a bar (Fig. 1). The length of the bar varies with 250 μm for the square bar (Fig.1a) and 500 μm for the rectangle bar (Fig.1b). Printing was carried out with a Dimatix Materials Printer 2831 (DMP) line by line in printing direction (PD) starting from the print origin (PO) (Fig. 1a). The used inks are SunTronic Jet Silver EMD5603 [SunTronic] from Sun Chemical and Bayink TP S LT [Bayink] from Beyer. The used substrates are glass microscope slides (soda-lime glass, Paul Marienfeld GmbH & Co. KG) and polyimide foils (Kapton, DuPond). Sintering was carried out in an oven (Nabertherm 3000). Two sintering strategies were analyzed. The sintering temperature was varied between 150 °C and 300 °C at a fixed sintering time of 30 minutes [min] (strategy temperature) or the sintering time was varied between 10 and 50 minutes at a fixed sintering temperature of 200 °C (strategy time). Printing was done wet on wet. Here all layers were printed without any intermediate treatment on top of each other and post treated at the end of the whole printing process. A second printing strategy used for comparison is the wet on sintered strategy. Here each layer is post treated before the next is printed wet on top. All experiments were carried out on glass for both inks, SunTronic and Bayink. In a second test run SunTronic was printed for comparison on the polyimide foil.

3. Results and Discussion

3.1 Microscopic analysis

Figure 1c to 1f demonstrates the wet on wet printed and sintered (at 200 °C for 30 min) microscopic images for SunTronic printed in glass. The optical recognition indicated a relatively homogeneous pattern with one layer for square (Fig. 1c) and rectangle bar (Fig. 1e).

The patterns with three layers wet on wet showed for both bar dimensions a ripple formation starting from the edges to the center of the wings to end in a material accumulation in the center of the wings (Fig. 1d and 1f). Reason is seen in the high material amount of three layers, which stood wet onto the substrate until sintering in the oven took place and a material transport inside the pattern during sintering. In contrast to SunTronic the solvent of Bayink dried immediately after printing, which resulted in a wet on dry printing. Due to print direction and printing of 2 nozzles a line structure in printing direction for one layer and both bar dimensions could be observed (Fig. 1g and 1h). For printing several layers on top of each other shrinkage of the additional layers on the first one is visible for both bars (Fig. 1h and 1j). Same experiments were carried out on the second substrate, which was polyimide foil. In summary the same observation related to the material accumulation in the center of the wings with increasing number of layers for SunTronic and the line structure as well as the shrinkage of additional layers for Bayink could be made.

This optical recognition shows the first importance of the drying characteristics of various inks on the pattern formation.
Investigation of the relationship between conductivity and microstructure ...

3.2 Surface profiles and layer thickness

Profile measurements longitudinal over the whole butterfly pattern (wing-bar-wing) are presented in figure 2. SunTronic (Fig. 2a) showed for one layer a relatively homogeneous layer profile. A drastic increase in the height of the wings at a still very little thickness of the bar could be seen for two and three layers printed wet on wet, confirming the transport of material in direction of the wings during sintering.

Bayink (Fig. 2b) demonstrates a rough surface caused by the line structure and the measurement across print direction. No hill formation in the wings could be seen for printing several layers on top of each other, but a steady increase in the layer thickness over the whole butterfly pattern. Table 1 presents the measured layer thicknesses at the bar exemplarily for the sintering strategy of 200 °C for 30 min. By applying the strategy temperature and strategy time no significant change in layer thickness could be note. In the repetition of the experimental run on polyimide foil, besides general fluctuations, no significant change in layer thickness could be note.

Here the layer thickness did not change regarding to the applied sintering strategy, too. Surface profiles showed for SunTronic the same material accumulations in the wings as well as for Bayink the typical line structure. In summary basic behaviors were achieved for both inks independent on the used base substrate.
Table 1: Measured layer thickness for sintering at 200 °C for 30 min, both bars and inks.

<table>
<thead>
<tr>
<th>Ink</th>
<th>bar</th>
<th>1 layer</th>
<th>2 layer</th>
<th>3 layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunTronic</td>
<td>square</td>
<td>218 ± 21</td>
<td>285 ± 26</td>
<td>400 ± 25</td>
</tr>
<tr>
<td></td>
<td>rectangle</td>
<td>296 ± 17</td>
<td>417 ± 42</td>
<td>714 ± 61</td>
</tr>
<tr>
<td>Bayink</td>
<td>square</td>
<td>184 ± 34</td>
<td>357 ± 39</td>
<td>479 ± 49</td>
</tr>
<tr>
<td></td>
<td>rectangle</td>
<td>217 ± 35</td>
<td>412 ± 30</td>
<td>650 ± 46</td>
</tr>
</tbody>
</table>

3.3 Resistance measurement

In this section the two sintering strategies are analyzed regarding to electrical characteristics by resistance measurements (Fig. 3) as well as resistivity calculation.

![Graphs showing resistance measurements](image)

**Figure 3**: Resistance in dependence on sintering strategy and ink printed on glass.

A decreasing resistance with increasing sintering temperature as well as sintering time for both inks and both bars could be seen. Generally higher resistances were obtained for the rectangle bar. This identifies the dependence of the resistance on the channel length given by formula 1. With increasing channel length the resistance increases. Not demonstrated graphically is the dependence of the resistance on the height. With increasing height the resistance decreases, in the formula presented indirect proportional. The resistivity calculation indicates a decreasing resistivity with increasing sintering temperature for both inks exemplarily on the square bar printed on glass.

\[
R = \rho \frac{l}{w \cdot h} \quad (1)
\]

\[
\rho = \frac{R \cdot w \cdot h}{l} \quad (2)
\]

Finally at 300 °C a resistivity of 12*10^{-8} Ωm for SunTronic and 11*10^{-8} Ωm for Bayink were reached, compared to bulk silver with 1.59*10^{-8} Ωm.
3.4 X-Ray diffraction and SEM images

X-ray diffraction graphs are presented in figure 4a for SunTronic and figure 4b for Bayink printed on glass. For both inks the five characteristic peaks from bulk silver were present. Also for drying at room temperature the characteristic peaks for silver were already developed. An increasing intensity of the peaks with increasing temperature for both inks could be noted, especially for the (111) and (200) peaks at 300 °C. This intensity increase indicated a change in the internal structure with change in sintering temperature. More precisely it can be described as an increasing crystalline structure with increasing sintering temperature.

<table>
<thead>
<tr>
<th>300°C</th>
<th>200°C</th>
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<tbody>
<tr>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

Figure 4: X-ray diffraction and dependence on sintering temperature, a) SunTronic; b) Bayink.

The graphs for sintering time (not presented) identified the same basic behaviors, with increasing sintering time the peaks are increasing, too. Backdated to the results for the resistance in can be stated that increasing sintering time and temperature causes higher crystalline structures and interrelated to this smaller resistances. Furthermore with these results it can be summarized that the influence of the applied sintering parameters on the inside nanoparticle structure and the electrical performance (Resistance) is the same, independent on the used ink composition.

A detailed view on the crystalline nanostructures is given by SEM images at the cross section of the bar (Fig. 5).

Fig. 5a and 5b demonstrate three layers printed wet on sintered, each layer sintered at 150 °C for 30 minutes, for Bayink and SunTronic, respectively. Bayink (Fig. 5a) was high porous as well as the single layers could be detected by a slight border. The layer thickness is around 640 nm. SunTronic (Fig. 5b) seemed less porous than Bayink. Also here the single borders were slightly visible and the layer thickness is about 560 nm. In contrast to this three layers printed wet on wet and sintered at 300 °C for 30 minutes presented for Bayink (Fig. 5c) a dense structure with a high crystallization where the crystals and direction of the single crystals were clearly visible. Some gaps were present as well as a dewetting from the substrate. A high layer thickness of around 550 nm, due to the fast evaporation of the solvent and the wet on dry printing, could be still registered. On the contrary SunTronic has with approx. 240 nm only half of the layer thickness than Bayink. Reason was the wet on wet printing, which allowed intermixing of the single layers as well as the material transport into the wings, which led to the minor layer thickness in the bar between the wings (Fig. 2a). Also for SunTronic a higher crystallization with higher temperatures and printing wet on wet could be realized, but the structure showed
some disconnections. The SEM images demonstrated the influence of the printing strategy and the sintering temperature on the formation of crystalline structures.

Finally microscopic images and surface profiles of the sintering strategy wet on sintered for SunTronic and Bayink printed on glass are presented in Fig. 6. SunTronic showed no material accumulation in the center of the wings for two and three layers printed wet on sintered in the microscopic image (Fig. 6a) as well as the surface profiles (Fig. 6b). Compared to the results for the strategy wet-on-wet (Fig. 1d) an improvement in the layer formation by smoothening the profiles could be achieved with this printing strategy. Bayink showed no change in the surface profiles. The rough line structure was still visible in the surface profiles (Fig. 6d) and microscopic images (Fig. 6c). The only difference is that the shrinkage of additional layers is not occurring anymore (Fig. 6c).

4. Conclusions and summary

The influence of sintering temperature and sintering time on the electrical performance and crystalline structure for two inkjet printed nanoparticle silver inks was investigated. It was shown, that varying these sintering parameters has a high impact on the resistance and the crystalline structure. Higher sintering temperatures and sintering times caused lower resistances and higher crystallizations. Furthermore different drying characteristics of the two different silver inks showed a great impact on pattern formation. The strategy wet-on-sintered was carried out for both inks and presented a change in the structure and layer formation. The resistivity was evaluated dependent on the sintering temperature and showed with $12 \times 10^{-8} \, \Omega m$ for SunTronic and $11 \times 10^{-8} \, \Omega m$ for Bayink values in the same range. Furthermore by executing the same experimental run on a second substrate the same basic behaviors and conclusions were achieved. Based on these researches, patterns with defined requirements in layer thickness, surface profiles and resistances could be produced.
Investigation of the relationship between conductivity and microstructure...

Figure 6: Printing strategy wet on sintered: a) microscopic image SunTronic three layers wet on sintered; b) surface profile; c) microscopic image Bayink three layers wet on sintered; d) surface profile.

References


Inkjet Printed Silver Back Contacts for Flexible Amorphous Silicon Thin-Film Solar Cells on Glass Fiber Fabrics

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Abstract

The preparation of inkjet printed silver back contacts for flexible amorphous silicon thin-film solar cells on textile glass fiber fabrics is presented. The silver tracks were printed onto glass fiber fabrics that are stabilized with a polymer. The thermal expansion coefficient of the polymer is approximately 450 times higher than that of silver. To prepare the solar cell structure the following deposition steps (active material and top electrode) require temperatures of maximum 170 °C. Therefore, the main challenge was to avoid a cracking inside the silver layers since otherwise the functionality of the whole device will be destroyed by shunting due to shortcuts. By combining different low-temperature sintering techniques and therefore developing a special sintering routine, it was possible to produce smooth silver layers which are highly resistant against tensile and compressive stress and therefore can withstand the temperature cycling of the following deposition steps without cracking.

Keywords: flexible solar cell, print contact, thin-film solar cell, glass fiber fabric

1. Introduction

In times of "Green Energy"-solutions, solar cells as portable energy harvesters become more and more important. New approaches for integrating them for example into textiles are highly under development. For this purpose the substrates have to address a couple of properties which conventional solar modules cannot provide. In the case of amorphous silicon solar cells, glass fiber fabrics (Fig. 1a) are highly preferred as they provide the combination of high flexibility and drapeability, temperature stability, light weight and cost-effectiveness compared to conventional substrates (like glass panels, metal foils or polymer foils). Since it is a textile substrate, the design and therefore the shape and area transparency are totally free.

Several groups have developed solar cells on different flexible substrates like paper [1] and polymer foil [2]. A very futuristic approach is the use of single glass fibers as substrates [3]. Solar cells on those glass fibers could in principal be interwoven into textiles and therefore give clothing the possibility of energy harvesting. In fact, up to now cell efficiencies are in the range of \( \eta = 0.01\% \) requiring further investigation. Solar cells are also produced on glass fiber fabrics [4]. In order to stabilize the substrate, however lacquer or varnish coatings are used, which reduce the flexibility of the whole compound structure dramatically. To retain the flexibility of the fabric, in this work the solar cells are produced on small flat parts of the fabric only, without further stabilization (Fig.1b). Drop-on-demand inkjet printing as an upcoming technology is used to produce the silver back contact. Using this technology, different materials can be applied onto
various substrates under ambient conditions in an additive way. Therefore, no masking is required which makes inkjet printing a flexible and low cost process in contrast to standard lithography based processes. A silver nanoparticle dispersion is used since it is commercially available from different suppliers and therefore already well known for the formation of conductive features [5]. To sinter such metal nanoparticles, relatively low temperatures are necessary since the melting point of small metal particles depends on their size [6]. That means that the smaller the particles the more their melting temperature decreases from that of the bulk metal. Nevertheless, typical sintering temperatures of those printed metal nanoparticle tracks exceed 200 °C, which is not suitable for temperature sensitive substrates like most of the polymers. Therefore, different research groups investigated alternative sintering methods. Those include plasma sintering [7], microwave sintering [5], selective laser sintering [8], electrical sintering [9], and sintering using a pulsed broadband lamp [10]. In this work, a combination of plasma sintering and low-temperature thermal sintering is used to avoid cracking of the silver layers on polymer coated glass fiber fabrics.

2. Experimental Setup

For printing the electrode structures, a commercially available silver nanoparticle dispersion from Cabot Corp. (Cabot CCI-300) is used as ink. It is based on a mixture of ethanol and ethylene glycol and contains 20 wt% silver nanoparticles with diameters in the range of 30 nm to 50 nm. Printing is done with a piezoelectric printhead from Dimatix Inc. (DMP, nominal droplet volume 10 pl) using a desktop printer from Unijet Inc. (Omnijet100). The printer has a x-y-positioning system with an accuracy of 5 μm. The printer is placed in a laminar flow box to avoid particle contamination of the wet samples during and after printing. Polymer glued glass fiber fabrics from Vitrulan Technical Textiles GmbH are used as substrates. A short investigation of the temperature stability showed a color change of the polymer after 30 min at 170 °C indicating decomposition. At 150 °C all properties of the whole fabric could be retained, therefore 150 °C was set to the maximum processing temperature during printing and sintering. In order to remove big particles from the surface, the substrate was cleaned with nitrogen and isopropanol. The surface energy of the polymer is very irregular and at some parts too low to ensure good wetting of the ink, which leads to dewetting of some parts inhibiting the formation of a closed silver layer. To ensure an overall good wetting behavior, argon plasma activation was applied prior to printing. The plasma chamber used for the activation (Plasma Finish GmbH, Schwedt, Germany) is equipped with a 2.45 GHz RF generator. For the activation of polymers, normally a relatively low RF power and short activation times are necessary. In
this work, the samples were treated by a 100 W argon plasma for 60 s. The argon flow was set to 80 ml min\(^{-1}\) what leads to a chamber pressure of about 30 Pa during the activation. The silver back contact for the solar cells should totally cover the bars between the interconnections of the fabric (Fig.1b). Therefore, the printing layout was a simple bar structure. The printheads used are equipped with 16 nozzles and therefore allow short processing times by using multiple nozzles. In order to ensure constant and reproducible printing conditions, the ink was heated to approximately 35 °C directly before printing. To change the thickness of the resulting silver layers, the droplet spacing of the single printed droplets can be varied. Larger droplet spacings lead to thinner layers since less ink, and therefore less silver, covers the surface. From previous experiments on glass it was found that a droplet spacing of 15 μm both in x- and y-direction leads to layer thicknesses of around 250 nm of thermally sintered layers with electrical resistivities that are suitable for solar cell electrodes. Therefore, the spacing was taken over to the new glass fiber substrate. The electrodes were printed with a jetting frequency of 2 kHz. After printing, the electrodes were either thermally sintered at 150 °C for 60 min or selective argon plasma sintering was applied with a 2.45 GHz RF generator (Plasma Finish GmbH, Schwedt, Germany). Afterwards, a thermal treatment was carried out at 150 °C for 60 min. The plasma power was varied between 200 W and 600 W with typical sintering times of 15 min to 30 min. Table 1 shows the sintering conditions for the prepared samples.

3. Results and Discussion

To estimate their resistance against cracking, all samples were investigated under the microscope directly after plasma sintering and again after thermal treatment. The electrical resistivity was measured with an ohmmeter.

Table 1: Sintering conditions and specific resistivities of the samples after plasma sintering and thermal treatment. After plasma sintering all samples were treated thermally at 150 °C for 60 min. The used value for \(\rho_{\text{bulk}}\) was \(\rho_{\text{bulk}} = 1.6 \, \Omega\,\text{cm}\).

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Plasma Power [W]</th>
<th>Plasma Time [min]</th>
<th>(\rho_{\text{after plasma}}) [(\Omega,\text{cm})]</th>
<th>(\rho/\rho_{\text{bulk}})</th>
<th>(\rho_{\text{after thermal}}) [(\Omega,\text{cm})]</th>
<th>(\rho/\rho_{\text{bulk}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600</td>
<td>15</td>
<td>38.3</td>
<td>≈ 24</td>
<td>&gt; 5\times10^8</td>
<td>&gt; 3,1\times10^8</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>30</td>
<td>37.2</td>
<td>≈ 23</td>
<td>&gt; 5\times10^8</td>
<td>&gt; 3,1\times10^8</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>7875</td>
<td>≈ 4922</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>30</td>
<td>31.7</td>
<td>≈ 20</td>
<td>1025</td>
<td>≈ 640</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>2967</td>
<td>≈ 1854</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>30</td>
<td>30.8</td>
<td>≈ 19</td>
<td>24.1</td>
<td>≈ 15</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>333.3</td>
<td>≈ 208</td>
</tr>
</tbody>
</table>

To calculate the specific resistivity, an average silver layer thickness of 250 nm was assumed. Since the substrate surface has a micro roughness following the glass fiber direction and the silver is applied from a liquid via inkjet printing, trenches are filled with more material and therefore, the real silver layer thickness varies over the surface. The resistivities right after plasma sintering and after thermal treatment are shown in table 1. After plasma sintering a resistivity measurement was possible for the samples sintered for 30 min only. The electrodes are relatively large structures. Therefore, shorter sintering and drying times in the vacuum lead to not totally dried layers. As a special case and due to the high RF power, sample 1 was totally dried since it heated up during the sintering and therefore the evaporation of the solvent was enhanced. The high plasma power led to a very rough silver layer with only a few cracks inside (Fig.2a). Longer sintering times did not change the overall appearance and
resistivity, implying that the layers were fully sintered. Therefore, sample 1 and 2 showed the same resistivity in the range of 24 times the resistivity of bulk silver, what is sufficient for the intended application. However, many cracks occurred after heating the samples to 150 °C for 60 min (Fig. 2b), indicating that in the silver layers a certain stress (either tensile or compressive stress) was exceeded. Because of the number of cracks, there is no pathway for a current. Since the limit of the ohmmeter used (60 MΩ ≡ 5 × 10⁸ µΩcm) was exceeded, a resistivity was not measurable.

![Figure 2: Sample 1 after plasma sintering (a) and after thermal treatment (b). Large cracks occur after the thermal treatment which excluded the layer as possible electrode.](image)

Due to the short drying time for the samples 3 and 5 after plasma sintering and no drying of sample 7, a resistivity measurement was not possible before thermal sintering and treatment since all of them were still wet. Thus sintering could only take place during the temperature treatment. Like for the first 2 samples, many cracks occurred during the thermal treatment. The overall resistivity of the layers depends on the distribution of the cracks since then, the current path has a certain length. Therefore, the measured resistivities cover a wide range from around 30 Ωcm to 8000 µΩcm. Since cracks would lead to shortcuts in the planned solar cells, those layers are also excluded as possible electrodes.

The plasma sintering led to smooth, closed silver layers for samples 4 and 6 (Fig. 3a). Both had a resistivity in the range of 20 times of bulk silver, which is a suitable value for the intended application. After thermal sintering, sample 4 showed a few cracks and therefore the measured resistance of the layer increased. However, after the thermal treatment the measured resistance of sample 6 decreased to 15 times of bulk silver, indicating that the plasma could not fully sinter the silver layer due to the power or time. No cracks occurred (Fig. 3b), enabling the application of the sample. A possible reason is that layers with low porosity are produced during the plasma sintering due to the slow sintering. Faster sintering with 400 W or 600 W leads to fast solvent evaporation that induces large pores, leading to layers that are more brittle. Furthermore, compressive forces are induced in the silver layer during the 200 W plasma exposure. During temperature treatment, the larger expansion of the polymer surface of the substrate leads to a decrease of the compressive forces in the silver layer and even to tensile stress. Cooling down to room temperature causes compressive forces in the silver layer again. However, in that temperature range the stress did not exceed a certain value where cracks would occur. Therefore, these layers are preferred for further processing.

First solar cells are realized using the silver layers as back electrodes. An amorphous silicon layer is deposited on top by PECVD. The front contact is produced by sputtering transparent indium tin oxide (ITO) which is simultaneously used as an antireflection coating. Open circuit voltages up to 675 mV, short circuit current densities up to 2.4 mA cm⁻² and overall cell efficiencies of 0.26 % are achieved. The low efficiency is limited due to shunts. By improving the processes, maximum efficiencies of 5 % are expected, making the flexible module suitable for many applications.
Inkjet Printed Silver Back Contacts for Flexible Amorphous Silicon Thin-Film Solar Cells

Figure 3: Sample 6 after plasma sintering (a) and after thermal treatment (b). No cracks occur what makes the silver layer suitable for further processing.

4. Conclusions and Outlook

A large, crack free electrode pattern was successfully printed and sintered on a polymer glued glass fiber fabric. Sintering the samples was done with a 200 W argon plasma for 30 min and a following thermal treatment at 150 °C for 60 min. The produced silver layers withstand the tensile and compressive forces without cracking in a temperature range of 20 °C to 150 °C. Their specific resistivity is in the range of 15-times of bulk silver. With those properties, the layers are suitable for the following process steps and the use as back electrode for amorphous silicon thin-film solar cells on glass fiber fabrics. First cells with 0.26 % efficiency are produced.

Acknowledgement

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References


Viability of All-Inkjet-Printed Electronics in Textile Industrial Processes

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Abstract

Printed electronics represents an alternative solution for low-temperature and large area flexible electronics. In this context, the organic thin-film transistors (OTFTs) emerge as a critical component for the introduction of logic and data processing to printed electronics. Inkjet printing shows major advantages as compared to the other established printing technologies, mainly due to the reduction of the fabrication cost and simplification of the fabrication process. However, technological restrictions of the inkjet printing technology for printed electronics can hinder its application potential, namely when applied in industrial processes involving mechanical, chemical, and temperature treatments.

This work studies the viability of inkjet-printed OTFTs during the processing of semi-finished articles in textile industry. In this way, all-inkjet-printed OTFTs where fabricated with silver electrodes, UV curable dielectric, and 6,13-bis(triisopropylsilylethynyl) pentacene (TIPS-pentacene) for the active semiconductor layer. Thereafter, electrical characterization of the all-inkjet-printed OTFTs is made and elaborated a viability study when subjected to textile mechanical, chemical, and temperature treatment processes.

Keywords: OTFT; Printed Electronics; Organic Electronics; Inkjet Printing
Influence of different printing strategies on dielectric layer in inkjet printed capacitors

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Abstract

A compilation of morphological differences for the inkjet-printed dielectric layers has been brought to notice using time and process constrained printing strategies. A set of dielectric inks containing low solvent and ultraviolet (UV) based inks are herein used for fabricating the dielectric layers. These layers are cured either thermally or via ultraviolet (UV) radiation. Each driving source e.g. Thermal or UV can affect differently on the transition from the liquid to the solid state. When the droplets (mainly inks containing no evaporating solvent, UV based) from a printhead submit to the substrate collectively, they merge together and mostly they retain an identical rheological behavior. This forms the wet layer and when cured it hardens to form an already predefined morphology. On the contrary, if some selective droplets are rheologically controlled by producing an interfacial state between the solid and liquid then the lineation of the structure can be restricted, though the post treatment is not completely achieved. In this paper, we demonstrate this control as printing strategy. One example can be printing a UV based dielectric ink with certain number of nozzles and defined printing parameters. When one swath of the carriage is already advanced, corresponding number of lines are printed. These lines are then exposed to a UV radiation immediately for an exposure time of 0.10 sec at a certain distance from the substrate, as a result lines get pinned but not cured totally. This procedure is repeated throughout the advancement of the entire printed pattern. Finally, it is cured for 17 sec which completes the post treatment procedure. Therefore by accurately controlling the individual varying constraints which in this case are the time frame and energy dose for the driving sources can directly affect the pattern morphology of the dielectric layer and through this a morphological definition can be realized. A well defined morphology can affect linearly the functionality of a printed device e.g. capacitor where the quality of the dielectric layer becomes a prime factor for the electrical performance and its application.

Keywords: dielectric, capacitors, morphology, printing strategies

1. Introduction

Parallel plate capacitor is a very essential electronics building block for charge accumulation and dissipation in an electronic circuit. The capacity of charge accumulated can be defined in terms of a) active area and b) thickness of the dielectric layer, when the relative permittivity of the dielectric material is assumed to be constant. The capacitance can be defined by the following formula [1].

\[
C = \varepsilon_0\varepsilon_r \frac{A}{d}
\]

Where, \(C\) = capacitance, \(\varepsilon_0\) = permittivity of free space \((8.854\times10^{-12} \text{ F/m})\), \(\varepsilon_r\) = dielectric material constant, \(A\) = active area \& \(d\) = thickness of the dielectric layer.
In this paper, we attempt to vary the thickness of the dielectric layer with differently controlled post treatment procedures. These procedures affect the morphology of the printed dielectric layer which in turn affects the charge accumulation capabilities. In the next chapter, we exhibit a setup for the printing and post treatment procedure for already mentioned three different inks which contain no solvent (UV based, where polymerization is triggered by UV radiation), UV+Solvent (UV based with a fraction of solvent, where polymerization is triggered by the UV radiation and consecutively heat) and only Solvent (monomers are polymerized by a thermal cross-linking initiation).

2. Methodology

2.1 Materials

For the above mentioned investigations, following substrate and inks were used.

Table 1: Substrate and inks description

<table>
<thead>
<tr>
<th>Materials</th>
<th>Functionality/ Purpose</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>VWR glass slide</td>
<td>Microscopic glass slide</td>
<td>Substrate</td>
</tr>
<tr>
<td>(76 mm x 26 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SunChemical EMD 5603</td>
<td>Top and bottom</td>
<td>Silver ink</td>
</tr>
<tr>
<td>[Commercial ink], Nano-particle ink</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperion Prowet from Tritron [Commercial ink]</td>
<td>Dielectric ink</td>
<td>UV ink</td>
</tr>
<tr>
<td>Development ink from Altana Sigma Aldrich, Poly (4-vinyl phenol) as monomer (PVP)</td>
<td>Dielectric ink</td>
<td>UV+Solvent ink</td>
</tr>
</tbody>
</table>

Different layers were printed using the architecture of the conventional capacitor. Given below in Fig.1 and Fig.2 are the schemes for the two variants of capacitors. The stacked layers were deposited with the Dimatix Material Printer 2831 from Fujifilms Dimatix using the DMC development printhead and cartridge (nominal drop volume of 10 pL).

Figure 1: Cross-sectional view of a parallel plate capacitor

A defined set of an optimized printing parameter and post treatment condition was always followed to achieve the top and bottom silver electrode (in Table.2).
Due to inherent material property of the different dielectric inks, basic printing parameters and post treatment conditions were also varied accordingly. Following table shows the normalized optimal printing parameter and post treatment conditions for the different dielectric inks used (in Table 3). Possible improvisations were further performed using different printing and post treatment strategies to achieve higher capacitance value without inducing defects e.g. short cuts or electrical leakage etc. in the capacitor. The next chapter elaborates the different printing and post treatment strategies extensively.

Table 3: Printing parameters and post treatment conditions for different dielectrics

<table>
<thead>
<tr>
<th>Printing parameters</th>
<th>Post treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>Freq. (kHz)</td>
</tr>
<tr>
<td>UV ink (Hyperion Prowet from Triton)</td>
<td>21</td>
</tr>
<tr>
<td>UV+Solvent ink (Altana)</td>
<td>18</td>
</tr>
<tr>
<td>Solvent ink (PVP from Sigma Aldrich)</td>
<td>23</td>
</tr>
</tbody>
</table>
2.2 Experimental setup

**Printing and post-treatment strategies**

Printing and related post treatment strategies for the dielectric layer were determined according to the deposition of the UV ink. Then a condition is created under which the physical state of the deposited ink is either changed to solid (completely cured) or in between solid and liquid state (partially cured). In principle, the inkjet printing procedure advances in a manner that according to the number of nozzles and the DS selected, the printer’s carriage movements with the number of swaths are determined. Here an attempt has been made to create a setup for acquiring a time interval in which an intermediate UV post treatment could be performed during the pass of each swath. When the post treatment is performed prior to the complete print advancement and not during the individual swath then this strategy is termed as the normal curing strategy. An UV pulse of 17 sec at a distance of 4 cm from the substrate is sufficient to cure the wet layer completely. On the other hand, when a post treatment is introduced in between every single swath of the print advancement then this is termed as a strategy. Depending on the energy intensity and physical state of the ink, strategy is defined (solid or in between solid-liquid). If the layer is already cured then the strategy is defined as intermediate curing strategy (short UV pulse of 0.1 sec at a distance of 4 cm from the substrate), and when it is in between the solid-liquid state then it is called as the pinned strategy (short UV pulse of 0.1 sec at a distance of 10 cm from the substrate). Additionally in our investigation, we have included corona pretreatment for the dielectric layer in order to enhance the spreading behavior. Table 4 shows the compilation of all the strategies used for printing capacitors.

<table>
<thead>
<tr>
<th>Inks</th>
<th>Printing strategies</th>
<th>DS (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>Normal curing strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal curing strategy on corona pretreated silver layer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intermediate curing strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intermediate curing strategy on corona pretreated silver layer</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Pinning strategy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinning strategy on corona pretreated silver layer</td>
<td></td>
</tr>
<tr>
<td>UV+Solvent</td>
<td>Normal printing</td>
<td></td>
</tr>
<tr>
<td>Solvent</td>
<td>Normal printing</td>
<td></td>
</tr>
</tbody>
</table>

3. Results and Discussion

**3.1 Morphological and electrical analysis**

The morphology of the dielectric layer was characterized using the *Vecco Dektak 150* surface profilometer and *Leica DM4000* Light microscope. The capacitances for the fabricated capacitors were obtained with the *Agilent E4980A Precision* LCR Meter.

**a) Bottom silver electrode**

In Fig.3 and Fig.4 are the microscopic images and surface profiles of the silver layer which is untreated and corona pretreated. Corona pretreated silver electrode showed a lot of surface degradation when compared to the untreated. Also, the corona pretreated silver electrode produced relatively higher roughness compared to the untreated silver electrode.
Influence of different printing strategies on dielectric layer in inkjet printed capacitors

Figure 3: (a) Microscopic image of the untreated silver bottom electrode and (b) Sectional surface profile of the untreated silver bottom electrode

Figure 4: (a) Microscopic image of the corona treated silver bottom electrode and (b) Sectional surface profile of the corona treated silver bottom electrode
b) Dielectric layer

Fig. 5-12 shows the optical results from the setup which is already described previously. This depict the microscopic images and the surface profiles for the different printed and post treated dielectric layers for the purpose of morphological analysis and thickness evaluation.

**UV ink**

![Microscopic image and sectional surface profile of the dielectric layer](image1)

*Figure 5: (a) Microscopic image and (b) Sectional surface profile of the dielectric layer*

![Microscopic image and sectional surface profile of the dielectric layer](image2)

*Figure 6: (a) Microscopic image (b) Sectional surface profile of the dielectric layer*

![Microscopic image and sectional surface profile of the dielectric layer](image3)

*Figure 7: (a) Microscopic image and (b) Sectional surface profile of the dielectric layer*
Intermediate curing strategy on corona pretreated silver electrode

Figure 8: (a) Microscopic image and (b) Sectional surface profile of the dielectric layer

Pinning strategy

Figure 9: (a) Microscopic image and (b) Sectional surface profile of the dielectric layer

Pinning strategy on corona pretreated silver layer

Figure 10: (a) Microscopic image and (b) Sectional surface profile of the dielectric layer
From the results shown in Fig.5-12, it can be inferred that the normal post treatment strategy gave very smooth and uniform dielectric layers, although the layer at the central location was found unlevelled. This central location is the critical zone since this is the active area for the capacitor. The intermediate post treated dielectric layers showed two basic problems. Firstly, the morphology of the dielectric layer was very irregular and uneven at the central location and secondly the electrical insulation was deprived. On the contrary, the pinning strategy gave very smooth and uniform dielectric layers. The cured layers exhibited the presence of slight zigzag trajectory but the deviations were found to be minimal compared to the intermediate curing strategy. Electrical insulation was not achieved with the application of corona pretreatment on the printed silver electrodes. The reason was the degradation of the silver with the application of the corona pretreatment which produces random conductive spikes. UV+Solvent dielectric ink gave random and unpredictable morphologies. The thickness of the layer was also found to be high. The thinnest layer was achieved from the solvent based dielectric ink (approx. 1 µm) but with an evident coffee ring effect [2, 3]. The layer exhibited the characteristic coffee ring effect [2, 3] and this can be seen in the microscopic image (Fig.12 (a)) and the surface profile which proves to be advantageous due to the migration of majority polymeric material at the edge of the printed layer (convection flow). In Table.5, an overview of all the used printing and post treatment strategies has been presented with the obtained capacitances and the corresponding dielectric thickness. Among all the inks, Solvent based PVP ink gave the most optimal result.
Table 5: An overview on results obtained for different printing and post printing strategies

<table>
<thead>
<tr>
<th>Inks</th>
<th>Strategies</th>
<th>DS (µm)</th>
<th>Dielectric thick. (µm)</th>
<th>Capacitance (nF/sq.cm)</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>Normal Curing strategy</td>
<td>5.5 ± 0.08</td>
<td>0.64 ± 0.01</td>
<td>4.4 ± 0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal curing strategy on</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>corona pretreated silver layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intermediate curing strategy</td>
<td>6.6 ± 0.7</td>
<td>0.53 ± 0.03</td>
<td>4.8 ± 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intermediate curing strategy on corona pretreated silver layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinning strategy</td>
<td>6 ± 0.17</td>
<td>0.62 ± 0.01</td>
<td>4.7 ± 0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinning strategy on corona pretreated silver layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solvent+UV</td>
<td>Normal printing</td>
<td>30</td>
<td>6.4 ± 1.54</td>
<td>0.53 ± 0.03</td>
<td>4.4 ± 1.21</td>
</tr>
<tr>
<td>Solvent</td>
<td>Normal printing</td>
<td>20</td>
<td>1.1 ± 0.23</td>
<td>4.52 ± 0.15</td>
<td>6.2 ± 1.5</td>
</tr>
</tbody>
</table>

Also in Fig. 13 we can see the effect on capacitance when different strategies are employed for the UV based dielectric ink.

![Figure 13: Capacitance with respect to strategies used.](image)

4. Conclusions and Summary

Following conclusions were deduced from the above mentioned results:

- The morphology of the printed dielectric layer based on the UV ink could be controlled by printing and pinning strategy.

- The best post treatment strategy for UV based dielectric ink was found to be the normal curing.
• The intermediate curing strategy induced defects like pin-holes in the dielectric layer due to the irregularity and inability to form continuous layers.

• Corona pretreatment produced high peaks due to which the dielectric contained pin holes and this caused the electrical short-cuts.

• The best dielectric ink noted was PVP solvent based ink due to its least layer thickness and highest capacitance [4, 5]

• Coffee ring effect was found to be beneficial for making the dielectric layer thinner and getting higher capacitance.

References


Applications of Localized Tailoring of Ink-Surface Interactions through μPlasma printing

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Abstract

μPlasma printing is a novel technology combining dielectric barrier discharge (DBD) plasma with digital printing techniques. With μPlasma printing it is, among others, possible to change the wetting behaviour of materials like polymer films or glass substrates by either functionalization or deposition of materials on the surface of plasma treated materials. A big advantage of this technology is the ability to locally change the wetting behaviour without the use of masks, as used in other techniques, creating patterns with locally different surface energies. μPlasma print resolutions of approx. 100 μm are currently obtainable. With a hydrophilic treatment, the water contact angle (WCA) on polycarbonate changed from 85 to 45 degrees. With a hydrophobic treatment on glass, the WCA changed from 5 to 105 degrees. Future applications for this technology can be found in the field of e.g. inkjet printing of functional materials, lab-on-a-chip or microreactor engineering where localized tailoring of the surface can control the wetting behavior of inks or other liquids. In this investigation we focus on potential applications in which localized surface modification with μPlasma printing is used. QR-codes are commonly used in consumer advertising to show product specific information on websites when read using a smartphone. Invisible QR-codes were μPlasma printed on FEP-foil and subsequently visualized with a black marker pen. QR-codes down to 25 by 25 mm were still possible to be read with a smartphone. A second application is the development of a microreactor in which the flow channels are created using μPlasma printing. A combination of hydrophilic and hydrophobic tracks was plasma printed to direct liquid flow through canals within a microreactor. In both applications advanced μPlasma printing techniques were used to print both hydrophilic and hydrophobic areas.

Keywords: Dielectric Barrier Discharge, Surface modification, Plasma Printing, microreactor

1. Introduction

For several decades plasmas or electrical discharges are widely being used in a variety of industrial applications. Applications range from ozone generation, pollution control, lasers, lighting, flat large area displays and surface treatment. In recent years the use of dielectric-barrier discharge (DBD) plasmas made it possible to operate plasmas at atmospheric pressure in a controlled manner, thus creating the possibility to treat materials which cannot sustain heat or vacuum [1, 2]. Advances in DBD plasma technology have made it possible to treat entire polymer surfaces rapidly, continuously and uniformly. However, for patterned plasma treatment most current plasma technologies require masking techniques to achieve satisfactory resolutions. Exceptions are plasma jet or plasma pen, which scan the surface of the substrate and are capable of patterned plasma treatment with resolutions of approx. 1 cm in diameter. These are, however, relatively slow processes.
Recently, a new maskless plasma patterning solution, \( \mu \)Plasma printing, was developed by Innophysics B.V.. \( \mu \)Plasma printing combines atmospheric DBD plasma treatment with a digital printing platform (Figure 1). With the speed and accuracy of the printing platform, patterned plasma printing with resolutions of 300 \( \mu \)m, is possible without the use of masks [3-5]. Figure 2 shows an example of the maskless \( \mu \)Plasma printing capabilities. DBD plasmas are characterized by the presence of a dielectrical insulating layer between two metal electrodes in addition to a discharge gap [5, 6]. Atmospheric DBD plasma modifies the chemical structure of the top surface layer of a substrate to promote or demote adhesion or wetting, dependent on the plasma gas composition, without modifying the bulk layer. For instance the use of air as plasma gas functionalizes the substrate surface by incorporating oxygen containing groups on the surface. This increases the polar part of the surface energy of the substrate, thus improving the wettability creating a hydrophilic surface. By using silanized or fluorinated precursor materials in the plasma gas like e.g. hexamethyl-disiloxane (HMDSO) or perfluorohexane (C\(_6\)F\(_{14}\)), it is possible to deposit a hydrophobic layer on the surface [4, 7-9]. Combining "standard" atmospheric air plasma treatment and precursor plasma treatment with the patterned plasma capabilities of \( \mu \)Plasma printing offers the opportunity to develop new applications.

Future applications for this technology can be found in the field of e.g. inkjet printing of functional materials, lab-on-a-chip or microreactor engineering where localized tailoring of the surface can control the wetting behavior of inks or other liquids. In this investigation we focus on potential applications in which localized surface modification with \( \mu \)Plasma printing is used.

2. Experimental

For the plasma treatment, a Roth & Rau PixDro LP50 inkjet printer, equipped with an Innophysics POD24 \( \mu \)Plasma printhead is used (Figure 1). The principle of \( \mu \)Plasma Printing is described by Huiskamp and Brok [3, 5]. Table 1 shows the \( \mu \)Plasma print settings used for the
following experiments.

Two potential applications are investigated. The printing of an "invisible" QR-Code" and the printing of capillary channels for use in the construction of a microreactor.

Table 1: μPlasma print settings. A total gas flow of 200[ml/min] was used in all experiments.

<table>
<thead>
<tr>
<th>Plasma gas (ratio)</th>
<th>Print height [μm]</th>
<th>Print speed [mm/s]</th>
<th>Voltage [kV]</th>
<th>Resolution [dpi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>50</td>
<td>20</td>
<td>4.5</td>
<td>90</td>
</tr>
<tr>
<td>HMDSO:N₂ (1 : 4)</td>
<td>50</td>
<td>20</td>
<td>4.2</td>
<td>90</td>
</tr>
</tbody>
</table>

2.1 Printing of an "invisible" QR-code

A QR-code was digitally created as a bitmap image as shown in Figure 3(a). A modified version of the bitmap was also created with less detail, compensating for the relatively wide spot size (>0.3 mm) of the μPlasma printhead (Figure 3(b)).

![QR-Codes](image)

Figure 3: Example of QR-Codes used for μPlasma printing (a) original (b) compensated for plasma spot size.

The bitmaps were μPlasma printed on fluorinated ethylene propylene (FEP) film (GoodFellow, UK) with nitrogen plasma to create a hydrophilic area on the hydrophobic FEP film. Different sizes of bitmaps were printed in the range from 25 × 25 mm² to 75 × 75 mm² to test readability. After plasma printing, the QR-code is visualized using a marker pen. An iPhone 4S with the app "QR-reader" was used to test readability of the QR-code.

2.2 Printing of a microreactor

The microreactor consists of two glass slides (76×26 mm) positioned on top of each other. In between the glass slides adhesive tape (3M, thickness 90 μ m) is placed to create a space between the slides. A monolayer of dodecyl-thiclorosilane was applied on the glass slides beforehand to create a hydrophobic surface. The monolayer was made by placing the glass slides in a solution of 0.001 M dodecyl-thiclorosilane in toluene at 3°C for 30 minutes under a nitrogen atmosphere. After coating the glass slides were sequentially rinsed with toluene, ethanol and deionized water and dried with nitrogen. Next, on a set of two glass slides, two bitmaps (top and bottom) of the microreactor were μPlasma printed with N₂-plasma, thus removing the hydrophobic monolayer. Figure 4 shows two different designs of a microreactor to enhance mixing. The width of the meandering reactor (a) is 3 mm. The width of the mixer (b) path equals 3 mm, the obstructions 1 mm.

After plasma printing the bitmaps, the reactor was closed as mentioned above to create the hydrophilic capillary. To test the reactor, colored water was positioned at the opening of the
reactor. Under capillary force the water enters the reactor and fills the channel. The progress of the liquid flow through the capillary is filmed and analyzed.

3. Results and Discussion

3.1 Printing of an "invisible" QR-code

QR-codes were printed using the two bitmaps from Figure 3 at sizes ranging from $25 \times 25 \text{ mm}^2$ to $75 \times 75 \text{ mm}^2$ on FEP at 90.7 and 181.43 dpi. Figure 5 shows the result of a partial and fully visualized QR-code. This particular QR-code was readable with a QR-Code reader on an IPhone 4S.

![Figure 5: Examples of a µPlasma printed QR-code printed from figure ??a on FEP visualized with black marker. (a) QR-code partially visualized, (b) QR-code fully visualized and readable (size 75 × 75mm²)](image)

Smaller sizes $25 \times 25 \text{ mm}^2$ of the QR-code could also be read when printed with the corrected bitmap (Figure 3b) at 90.7 dpi. When printed at higher dpi values or the uncorrected bitmap, the plasma treated areas overlap and the QR-code could not be read.
3.2 Printing of a microreactor

Figure 6 shows the top and bottom glass slides for the two microreactor designs. For clarity the hydrophilic tracks are visualized with steam. Water droplets form on the hydrophobic area of the glass slides, while on the plasma printed reactor design the water droplets fully wet leaving a clear surface. On the mixer design (Figure 6b), the hydrophobic obstructions are still visible. This shows that narrow tracks with high difference in wettability are obtainable with μPlasma printing.

Figure 6: Top and bottom of two microreactor designs directly after printing. For clarity the hydrophilic tracks are visualized with steam. (a) meandering reactor, (b) Mixer with dual inlet and hydrophobic obstructions.

After μPlasma printing the microreactor designs closed to create the final reactors. After construction, in between the glass slides, a 90 μm opening existed over the full length and width of the glass slides. Droplets of colored water were placed at the entrance of the reactor. By capillary pressure only, the colored water enters the reactor, following the hydrophilic plasma printed track and avoiding the hydrophobic monolayer (Figure 7). In Figure 7b, two differently colored waters were used to show the mixing along the length of the microreactor. Due to the hydrophobic obstructions on the top and bottom of the capillary, the flow of the water is slightly restricted. This is visible by the gradient in the liquid flow perpendicular to the flow direction from left to right.

Figure 7: Visualization of capillary suction of the microreactor after final construction. Colored water is positioned on the left side of reactor. (a) meandering reactor, (b) mixer with dual inlet and hydrophobic obstruction.

The video data of the meandering reactor was further analysed to investigate the relationship between the distance the coloured water had travelled with the capillary as a function of time. According to the Lucas and Washburn equation this relationship can be described as [10]:

\[ x^2 = \frac{\gamma \cdot D_H}{4 \cdot \eta} \cdot t \]  (1)
with  
\[x = \text{distance water has penetrated into capillary [m]},
\]
\[\gamma = \text{surface tension of liquid [mN/m]},
\]
\[D_H = \text{hydraulic diameter of capillary [\mu m]},
\]
\[\eta = \text{viscosity of the water [mPa.s]},
\]
\[t = \text{time [s]}.
\]

Figure 8: Squared penetrated distance of liquid versus time for the meandering reactor. (\Delta) experimental data, linear fit equals: 
\[x^2 = 38.6.t \text{ cm}^2 \text{ with } R^2 = 0.9975.
\]

Figure 8 shows the square of the distance the liquid has travelled within the capillary. After 2.2 seconds the capillary is completely filled. The Lucas-Washburn equation is fitted over the experimental data, which result in the fitted curve 
\[x^2 = 38.6.t \text{ cm}^2 \text{ with } R^2 = 0.9975.
\]
Using literature values for water (\(\eta = \text{mPa.s} ; \gamma = 72.8 \text{ mN/m}\)) and the calculated hydraulic diameter of the hydrophilic track (\(D_H = 175 \mu \text{m}\)) a calculated constant of 31.7 cm\(^2\) is calculated. Taking into account measurement guesses of primarily the diameter of the capillary, the fitted and calculated values are in reasonable agreement.

Overall, this shows that \(\mu\)Plasma printing can be used to create hydrophilic tracks in between two hydrophobic surfaces. To work as capillary, the plasma printed tracks do not have to be closed on all sides, as the steep gradient in wetting between the printed track and surrounding area prevents leakage out of the printed tracks.

4. Conclusions

In this study, we showed two potential applications of localized tailoring of a substrate surface through \(\mu\)Plasma printing. Combining plasma technology and digital printing techniques, we were able to locally change the wettability of a substrate from hydrophilic to hydrophobic or vice versa. We showed it was possible to plasma print highly structured patterns, like a QR-code, on both hydrophobic and hydrophilic surfaces, swapping the wettability. Afterwards the QR-code was visualized and readable using a QR-code reader on a mobile phone. We also showed, it is possible to print hydrophilic tracks on hydrophobic glass slides, which combined, act as a capillary as the steep gradient in wettability prevents leakage. These capillaries can in turn function as part of a potential microreactor.

Acknowledgement

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Applications of Localized Tailoring of Ink-Surface Interactions through $\mu$Plasma printing

References


The Progress in Photoacoustic Characterization of Printed Functional Layers

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Abstract

The printed electronics is rapidly developing towards the industrial requirements, recently. This process is accompanied with the optimization of printed functional materials as well as the used printing technologies. For the process and material optimization and the future large scale production it will be necessary to control and monitor the properties of the printed layers. This work reports on the possible application of photoacoustic method for the evaluation and characterization of the printed functional layers. It involves the results of newest measurements of various functional materials (PEDOT:PSS, polyaniline). In case of PEDOT:PSS thin nanolayers with the thickness less than 100 nm were prepared and characterized by photoacoustics.

Keywords: photoacoustics, printing, thickness, functional layers

1. Introduction

The area of printed and flexible electronics has been significantly developed during the last decade. However, the quality of printed layers still needs to be improved for some applications. Since many new functional materials are now being developed as well, they must be further optimized for the desired applications. Some of the printing techniques and ink formulations do not provide sufficient quality of the layers so far. Also the future process control in production lines is of large importance. All the mentioned facts indicate the need for new methods of characterization. The main parameters of the printed layers, which should be controlled and evaluated, are the functionality (e.g. electrical conductivity or optical properties) and the layer thickness, structure and morphology. The thickness of functional layers can be evaluated by means of various methods but most of them suffer various drawbacks (e.g. measuring limits, inaccuracy, time elapsed for the measurement or they cannot be applied in R2R, etc.).

The photoacoustics has already been reported as a new optical method for the printed functional layer assessment [14]. The main advantages of the photoacoustic method consist in the fact that the basic principle of this method is based on the measurement of the heat, which is released by the sample after its irradiation by laser or other light source. This is in contrast to other optical spectroscopic methods where the photons are detected. The measured photoacoustic signal is represented by its amplitude and the phase shift. The photoacoustics has shown to be useful especially as an instrument for the functional layer thickness evaluation. Depending on the studied material and its thermal and optical properties, the change in the thickness or structure can be monitored by means of changes in the shape, slope and position on the y axis of the frequency curves in the amplitude or phase shift of the measured photoacoustic signal. Further, the photoacoustic spectroscopy ranging from the UV over VIS to IR spectral regions can be employed. The photoacoustic measurements are well suited for the evaluation of all kinds of
samples, including non-transparent or light scattering materials (e.g. polyaniline and aluminium electrodes in organic photovoltaic cells).

The first results on the evaluation of thickness were obtained for the bar-coated and screen printed poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) based layers (evaluation in the amplitude of the photoacoustic signal) as well as silver based conductive composite layers (evaluation in the phase shift of the photoacoustic signal) [1,3,4]. It was also proved that the assessment of transparent conductive polymer layers on the base of PEDOT:PSS is possible not only on the transparent glossy substrates, but also on rough non-transparent polycarbonate substrate [2]. Recently, further measurements have been proceeded to prove the capability of this method for the evaluation of other screen printed functional polymer layers (e.g. polyaniline [5]) and more complex structures such as multilayer systems (printed electroluminescent panels or spin coated photovoltaic cell) [6,7]. The possibility to monitor the change in the thickness and structure of the individual layers in the multilayered systems using photoacoustics was shown [6]. The photoacoustic spectroscopy can be used to spectrally evaluate the properties of the layers underlying the non-transparent electrodes in organic photovoltaic cells [7]. The newest results involve also the ultrathin printed layers of PEDOT:PSS prepared by gravure printing, having thickness lower than 100 nm [8]. This work shows the newest highlights of this promising evaluation method, such as high sensitivity and the capability of detection of changes in thickness and layer structure.

2. Experimental

2.1 Materials

For the new experiments with PEDOT:PSS, the commercially available Clevios™ S V3 from Heraeus was used. The dispersion was applied in diluted form (diluted with the solvent Clevios™ S T). The thinning ratio was 2 : 1 (Clevios™ S V3 : Clevios™ S T). Prior to the printing, the dispersions were stirred for 30 min using the magnetic stirrer.

2.2 Methods

The dispersion of PEDOT:PSS was applied by means of gravure printing test station IGT G1-5. The engraved roller with four different screen rulings was used (60; 80; 100; 140 cm\(^{-1}\)). The printing speed and force of the IGT G1-5 machine were set to 1.0 m/s and 1000 N, respectively. As the substrate, the transparent flexible PET foil Melinex® CW 400 was used (thickness of 100 m). After the printing, the samples were dried in the hot air oven (100 °C; 10 min).

After the printing, the layers were characterized by profilometry, electrically and by means of the photoacoustic method. The sheet resistance was measured using two point probe (with metallic silver paste contacts). The thickness of the prepared layers was measured by means of mechanical profiler Dektak XT. The amplitude and phase shift of the photoacoustic signal were measured in the modulation frequency domain in the range from 10 to 995 Hz (at laser wavelength of 532 nm).

3. Results and Discussion

3.1 Sheet resistance, roughness and thickness

The sheet resistance of the prepared PEDOT:PSS layers was depending on the printing conditions approx. 10 kΩ/sq. The results showing the relationship between the thickness, roughness and sheet resistance can be surveyed in Table 1. The Table 1 indicates that the dry film thickness, as well as the sheet resistance can be controlled by means of varying the screen ruling.
The Table 1 also shows that the roughness $R_a$ of the dry film is relatively high. In some cases, the roughness exceeds even 30% of the actual layer thickness value. Therefore, it is obvious that the thickness of the prepared films was not homogenous, which also contributes to the difficulties in the thickness evaluation by means of the profilometer.

### 3.2 Photoacoustics

The amplitude of the photoacoustic signal decreases with screen ruling of the engraved structures of the roller (Fig. 1). The photoacoustics can therefore be potentially used for the monitoring of the thickness (i.e. amount of transferred material) during the production. As shown in Figure 1, the change in the intensity of the photoacoustic signal can be observed at different frequencies of the intensity modulation of excitation laser light source, indicating the possibility to expand the range of modulation both to lower and higher frequencies according the nature of the examined sample. Further, the excitation wavelength can be chosen to better fit the needs of quality evaluation.

![Figure 1: The dependence between the amplitude of the photoacoustic signal and the screen ruling](image)

4. Conclusions

The review of recent progress in photoacoustic characterization of various functional layers intended for mass print production of different electronic devices was given. The results of the
measurement of ultrathin layers were reported. All the examined PEDOT:PSS functional layers deposited on transparent PET foil were successfully measured by means of photoacoustic method. The photoacoustic method has shown in all cases to be sensitive for the detection of the thickness and structure of the printed functional layers. Therefore its application as an evaluation method in organic and printed electronics can be suggested.

Acknowledgement

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References

Inkjet printing graphene-based materials for transparent conductor applications

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Abstract

We present a study of conductive reduced graphene oxide films produced by inkjet-printing for transparent conductor applications. The ink was prepared by dispersing graphene oxide in water with a stabilizing surfactant, Triton X-100 at pH≈ 10 by adding ammonia. This was subsequently reduced in solution-phase using hydrazine monohydrate. The inkjet-printed reduced graphene oxide films were heated at a temperature of ~250 °C for 10 min in air to remove the residual solvent and surfactant. By using a range of concentrations of graphene oxide dispersions and adjusting the number of printing layers films with electrical sheet resistance of 2 kΩ/□ and optical transparency of 98% could be achieved.

Keywords: Graphene, inkjet printing, sheet resistance, transparency

1. Introduction

Graphene has been attracting extensive attention not only for its exceptional electrical, mechanical, chemical and optical properties [1], but also because of the wide availability of graphite in the world, which is the base material for preparing graphene. This has made it attractive for low cost and large scale electronic applications, especially as a transparent conductor [2]. Graphene and graphene oxide (GO) can be dispersed in water or organic solvents to form graphene-based inks. These can be applied to large-scale manufacturing by printing processes. However, compared with continuous single layer graphene films produced by CVD, the conductivity of inkjet-printed graphene films are generally very poor because of the large sheet-to-sheet contact resistance and a higher density of defects or oxygenated functional groups within a fixed channel length. This is because the majority of the exfoliated graphene or GO flakes have sizes < 1 μm as a result of long prolonged ultrasonication and the harsh oxidation treatment during preparation of the graphene-based suspension [3]. In addition, to replace traditional transparent conductor materials such as indium tin oxide (ITO), the optical transmittance of graphene films should be higher than 85% in the visible spectrum [4], while providing adequate conductivity. Thus the thickness of graphene films should be limited to a few nanometers due to approximately 2.3% of white light absorption caused by each layer graphene [5]. In this work, we investigate the electrical and optical properties of inkjet-printed reduced GO films. Different concentrations of a solution-phase reduced GO ink and the number of inkjet-printed layers were used to adjust the sheet resistance and transparency of reduced GO films.

2. Experimental section

2.1 Preparation of graphene ink

Graphite oxide was synthesized from natural graphite flakes (grade 2369, Graphexel Ltd) by the modified Hummers method [6, 7]. As-synthesized graphite oxide powder (80 mg) was dispersed in deionized water (40 ml). The mixture was ultrasonicated for 40 minutes followed by centrifugation at 3000 rpm for 10 minutes to achieve a homogeneous GO dispersion (~ 1.8 mg/ml).
The lower concentration of GO dispersion (0.5 mg/ml and 1.0 mg/ml) was obtained by diluting the as-prepared GO dispersion with deionized water. This procedure results in a GO dispersion with the largest sheets \(< 3 \ \mu m^2\) (Figure 1), which is similar to that reported in earlier work [7]. In order to reduce the GO, dispersions (10 ml each) with a range of concentrations were mixed with hydrazine monohydrate (Sigma-Aldrich), at a dosage of 2 \(\mu l\) per mg GO, and 20 \(\mu l\) of ammonia solution (28 wt% in water, Sigma-Aldrich). To achieve a stable chemically reduced GO ink suitable for inkjet printing, 0.5 wt% of the surfactant Triton X-100 (Sigma-Aldrich) was added to the GO dispersion, followed by adding 0.1 wt% of antifoamer 204 (Sigma-Aldrich). The mixture was then stirred and heated to \(\sim 90^\circ\)C and held for 20 minutes at temperature to finish the reduction process.

The morphology of as-prepared GO sheets was characterized by scanning electron microscopy (SEM) (Philips XL30 FEG-SEM). The transparency of the inkjet-printed reduced GO films was measured using a UV-vis spectrophotometer (Perkin Elmen Lambda 25 spectrophotometer). In all cases, glass was used as the reference. The sheet resistance was measured by using a Jandel four-probe station equipped with Keithley 2182A nanovoltmeter and Keithley 6220 current source.

2.2 Inkjet printing

A Dimatix Material Printer (DMP 2800, Fujifilm Dimatix) was used to inkjet print the reduced GO inks on glass substrates using 10 pL printheads. The printer stand-off distance, substrate temperature and printed drop centre spacing were maintained at 0.45 mm, 50 \(^\circ\)C, and 30 \(\mu m\), respectively. The reduced GO films were printed as 10 mm \(\times\) 10 mm square patterns. After the printing process, the reduced GO films were heated at a temperature of \(\sim 250^\circ\)C for 10 minutes in air to remove the residual solvent and surfactant.

![Figure 1: Typical SEM image of as-prepared GO sheets (left) and area distributions of GO sheets (right).](image)

3. Results and Discussion

3.1 Characterisation of graphene films

The key parameters for a transparent conductor are its optical transmittance and electrical conductivity. Fig 2a shows the images of inkjet-printed reduced GO films on glass substrates with increased printed layers. Shown in Fig 2b are optical transmission spectra for a range of films with different layers. Typically the transmittance varies from \(\sim 98\%\) to \(\sim 72\%\) as the printed layers increases from 1 to 10 layers with a reduced GO concentration of 0.5 mg/ml. Fig 3 shows the comparing of optical and electrical properties between inkjet-printed reduced GO films with different number of layers obtained at different concentration of GO dispersions. As shown in Fig 3a, the transmittance of reduced GO films decreases with increasing number
Inkjet printing graphene-based materials for transparent conductor applications

of printed layers and GO concentration. At a concentration of 0.5 mg/ml, transmittance (550 nm) slowly decreased from \(~98\%\) to \(~80\%\) upon increasing the number of layers from 1 to 6. For a higher concentration ink of 1.8 mg/ml, transparency rapidly decreased from \(~81\%\) to \(~34\%\) with the same number of layers. This is because a greater quantity of the reduced GO was printed with a concentration ink. The sheet resistance of the reduced GO films measured after thermal treatment were decreased from \(~2 \times 10^7\ \Omega/\square\) to \(~8 \times 10^4\ \Omega/\square\), from \(~1.8 \times 10^5\ \Omega/\square\) to \(~8 \times 10^3\ \Omega/\square\), and from \(~2.4 \times 10^4\ \Omega/\square\) to \(~2 \times 10^3\ \Omega/\square\) for ink concentrations of 0.5 mg/ml, 1.0 mg/ml, and 1.8 mg/ml, respectively, as the layer number increases to a maximum of 6 layers.

3.2 Conductivity of graphene films

Fig 4a shows the optical transmittance (550 nm) as a function of sheet resistance. In general, for transparent conductive films, the relationship between the transmittance (T) and the sheet resistance (R_s) can be described with equation (1) [8]:

\[
T = \left(1 + \frac{Z_0 \sigma_{OP}}{2R_s \sigma_{DC}}\right)^{-2}
\]  

(1)
where $Z_0 = 377 \, \Omega$ is the impedance of free space, $\sigma_{Op}$ and $\sigma_{DC}$ are the optical and DC conductivity, respectively. The ratio ($\sigma_{DC}/\sigma_{Op}$) can be used as a figure of merit for transparent conductive films. Equation (1) can be fitted to the data in Fig 4a with a good fit obtained for reduced GO films when the transmittance of the film is lower than 80%. The fitted value of $\sigma_{DC}/\sigma_{Op}$ is 0.02, 0.08, and 0.11 for 0.5 mg/ml, 1.0 mg/ml, and 1.8 mg/ml inks respectively. We can also use equation (1) to evaluate the FoM, $\sigma_{DC}/\sigma_{Op}$, for graphene-based transparent conductive films prepared by different methods. In most cases high values of $\sigma_{DC}/\sigma_{Op}$ are always obtained with high annealing temperatures ($> 800 \, ^\circ C$), which is due to better reduction of graphene oxide and better sheet contact between the graphene flakes. However, for most transparent applications based on glass and plastic substrates, the processing temperature should be $< 400 \, ^\circ C$. Fig 4b shows the comparison data of $\sigma_{DC}/\sigma_{Op}$ of graphene films and reduced GO films prepared by different solution processes followed with different thermal treatment conditions [8-13]. We can see that the performance improves with increased processing temperature. Here, we have shown that our reduced GO films have high conductive ratio compared to GO-based films. This is due to our pre-reduction process using hydrazine monohydrate in solution-phase, which can obtain higher conductivity than post-treatment by hydrazine vapor for reduce GO films [14]. However, the $\sigma_{DC}/\sigma_{Op}$ of reduced GO films is lower than graphene films, which is because the higher contact resistance between reduced GO flakes caused by the defect and residual oxygenated functional groups in reduced GO sheets.

![Figure 4](image-url)

Figure 4: Transmittance (550 nm) as a function of sheet resistance for reduced GO films with different concentration of graphene oxide dispersions. The dashed line are fits to Equation (1) and are defined by $\sigma_{DC}/\sigma_{Op} = 0.02$, $\sigma_{DC}/\sigma_{Op} = 0.08$, and $\sigma_{DC}/\sigma_{Op} = 0.11$ for 0.5 mg/ml, 1.0 mg/ml, and 1.8 mg/ml, respectively. b) The FoM ($\sigma_{DC}/\sigma_{Op}$) versus treatment condition for graphene films (black squares) and reduced GO films (red dots) from the literature and our work.

4. Conclusions

In summary, we have demonstrated that transparent conductive graphene films can be prepared by inkjet printing using controlled concentrations of reduced GO dispersions and a mild thermal treatment without the need for further chemical reduction. The consequent electrical properties coupled with good transparency make these films attractive for transparent conductor applications. Comparing to GO films using the post chemical reduce process, the GO films obtained from the solution-phase chemical method has higher $\sigma_{DC}/\sigma_{Op}$. However, compared with graphene films, the reduced GO films show lower electrical ability. This is due to the higher defect contents and residual oxygenated functional groups of reduced GO flakes, which decreased the electron transport ability and increased the sheet-to-sheet resistance in reduced GO films.
We believe that such effect can be improved by using mild oxide process and larger sizes of GO flakes.

4. Acknowledgement

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References


Inkjet Printing Multifunctionalities on Microfluidic Chips for Biosensing Applications

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Abstract

Drop-on-demand inkjet printing is a digital printing technique that enables printing of different functional materials onto various substrates. It is a non-contact and mask-free technique, which makes it cost-efficient and flexible. In this contribution, inkjet printing is utilized as a deposition technique to integrate multifunctionalities such as heaters and light sources for biosensing applications on microfluidic chips. This paper discusses the heating homogeneity as well as heating and cooling rates of inkjet printed ohmic heaters in order to fulfill requirements of a polymerase chain reaction (PCR) application. As the detection of the concentration of analytes is also a key part for biosensing applications, a first step towards solution-processed OLEDs is demonstrated here.

Keywords: Inkjet printing; Heaters; OLED; Microfluidic chips

1. Introduction

Due to significant demands for low-cost and disposable biological/medical sensing devices, efforts are made to develop microfluidic lab-on-a-chip systems [2]. Microfluidic chips are miniaturized microanalysis labs fabricated on compact chip substrates, in which small fluid volumes can be controlled, mixed, and analyzed. In order to realize most of the basic functionalities needed for the analysis on a microfluidic chip without external components, functional units such as valves, pumps, heaters, fluorescent light sources, and detectors are required. Standard lithography with shadow masks is a conventional fabrication method to integrate conducting wiring structures like resistive heaters, which leads to high fabrication costs. Therefore, the goal for cheap and disposable polymer microfluidic chips is to easily integrate all functionalities by a low cost and simple fabrication technique. Inkjet printing is a drop-on-demand type digital deposition technique. By directly printing the functional ink onto various substrates like glass and polymeric chips, inkjet printing can integrate various functionalities using only small amounts of material under ambient conditions [8]. As no vacuum conditions and shadow masks are needed, inkjet printing provides a versatile manufacturing approach for low cost and simple microfluidic chips. Although fluorescent sensing is the most common analytical and diagnostic method in biological and medical applications [4], very few examples of fully integrated compact and low cost fluorescence sensing systems on microfluidic chips can be found. This is mainly due to the reason that widely used sensing units based on LASERs, LEDs, and silicon photodiodes have relatively large dimensions and can only be integrated by external bonding. In contrast, organic light-emitting diodes (OLEDs) can be easily integrated with simple fabrication methods like inkjet printing onto various substrates [7]. It holds the advantages of high luminous efficiency, full-color capability, low power consumption/driving voltage, low weight, and flexibility, which makes OLEDs...
a perfect optical source for portable and low-cost microfluidic devices on flexible substrates [6]. In the following sections, inkjet printing of ohmic heaters and a first step towards inkjet printing OLEDs for microfluidic chips are described and discussed.

2. Inkjet Printing Functionalities

2.1 Inkjet Printing Conducting Meandering Structures for Thermal Heaters

Compared with generating wiring structures by expensive lithographic technologies, the flexibility and direct writing advantages of inkjet printing enable a relatively easy and low cost fabrication of conductive structures such as electrodes and ohmic heaters [5]. In a microfluidic lab-on-a-chip system, a local heating component is necessary for certain chemo/bio-reactions within microfluidic channels. One important example is the polymerase chain reaction (PCR), which typically clones DNA sequences by thermocycling them between 60 and 95 °C. By inkjet printing ohmic heaters on top of microfluidic channels, a controlled heating of fluids is possible. Furthermore, by drying and partial sintering of inkjet printed silver nanoparticle dispersions, a controllable and relatively high resistance can be obtained, which eliminates using specific high resistance and expensive materials. The additive coating manner and digital structure design provides the possibility for low-cost fabrication. Nevertheless, there are two key requirements for microfluidic biosensing applications: one is to obtain controllable and homogeneously elevated temperatures over specific areas (normally a part of micro-channels) at relatively low driving powers; another requirement is to achieve high heating and cooling rates in order to fulfill chemo/bio-reaction requirements.

In order to investigate the influence of the geometry parameters on heating homogeneity, five different wiring structures with different line width and line spacing combinations but a same heating area (15 × 10 mm²) are inkjet printed using a silver nanoparticle dispersion (NPS-JL, Harima Chemicals, Inc.) on glass substrates. Fig. 1 and Table 1 illustrate the structure designs and line width and spacing parameters.

<table>
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<tr>
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<tr>
<td>5</td>
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Figure 1: Five different structural designs of meandering conductive heaters with a same heating area [1]

Table 1: Design parameters for design 1 to 5 [1]

After thermal sintering at 200 °C for 60 min, the structures reveal a conductivity of approximately
45% of bulk silver. According to Fig. 2a, different designs have different resistances mainly due to different numbers of meandering lines. With the help of an IR thermal camera, the thermal distribution on the backside of heater samples can be imaged and analyzed at elevated temperatures (see Fig. 2b). Therefore, by driving heaters at different voltages, the average temperature over the whole heating area vs. driving power can be compared between different designs. According to Fig. 2c, design 5 with relatively large line width and low resistance requires lower driving power to heat up to the same temperature, which is favorable for portable lab-on-a-chip systems. For measuring heating homogeneity, a channel size area (≈ 5 × 0.5 mm², parallel to meandering lines) is measured in the center, instead of the whole heating area and the standard deviations of temperature over the measurement area is calculated for all five designs. Although there are only very small differences amongst the five designs, design 5 still shows the lowest standard deviation of 0.47 K. All five designs show standard deviations of temperature below 1 K, which fulfills the requirements for biochemical reactions such as PCR.

![Figure 2: (a) Resistance comparison of samples with five different designs; (b) an example IR thermal imaging result; (c) average temperatures over whole heating area vs. driving electrical power for different designs][1]

In order to investigate the heating rate and cooling rate of inkjet printed structures, the best performing design 5 was selected for this dynamic investigation. 60 and 95 °C are chosen for the low thermal phase and high thermal phase for the PCR application. As depicted in Fig.3 (right), the measurement procedure is: first heating up the heater to 60 °C and wait until the temperature stabilizes; then shifting the driving current/voltage to a high level (P3) in order to increase the heating rate; afterwards reduce the driving current/voltage (P2) when the temperature is approaching 95 °C; after 10 min waiting, the electric input is switched off until the
temperature approaches 60 °C; finally a low driving level (P1) is used to maintain a temperature of 60 °C. The average temperature measured by the IR thermal camera is illustrated in Fig. 3 (left). The calculated heating rate is \(\approx 2.9\) K/s and the cooling rate is \(\approx 1.16\) K/s. Compared to the requirements of heating rate > 4.5 °C and cooling rate > 3.5 °C, the heating rate can be achieved by further increasing the heating power while fast cooling requires extra cooling components. As an option, Inkjet printed coolers are currently under investigation in order to achieve the required cooling rate.

Figure 3: The time dependence behavior of the average temperature generated by design 5 (left) at different driving conditions (right) for heating and cooling rate investigations

2.2 Solution Processing OLEDs

In microfluidic lab-on-a-chip systems, an optical source is essential for many sensing approaches to investigate the particular fluid composition characteristics and behavior under optical illumination with specific wavelengths [6].

As a first step towards a printed OLED for microfluidic applications, a proof of concept experiment by spin-coating OLEDs at ambient atmosphere was performed. For the purpose of bio-sensing, a light blue light-emitting polymer SPB-02B was purchased from Merck. The layer structure of the device (see Fig. 4a) is: Glass substrates//ITO anode (100 nm)//PEDOT:PSS hole transporting layer (\(\approx 40\) nm)//active layer (\(\approx 60\) nm)//aluminum (200 nm). At first, the ITO patterned glass substrates (purchased from Ossila) were ultrasonically cleaned in DI water and solvents. After oxygen plasma surface activation, PEDOT:PSS (Heraeus Clevios P VPAl 4083) was spin-coated on top of the ITO layer, forming a 40 nm thick hole transporting layer. After annealing on 150 °C for 10 min, a 10 mg/mL blue polymer in toluene was spin-coated and generated a 60 nm thick active layer. Finally an aluminum cathode (200 nm) was evaporated thermally on top of the active layer after a 10 min annealing at 180 °C. The device was encapsulated with epoxy and a glass coverslip (Ossila). The final device is illustrated in Fig. 4b. As shown in Fig. 4c, a working OLED can be successfully fabricated by solution processing in ambient condition plus cathode evaporation. The high driving voltage (14 V) is due to the missing part of the electron injection layer. And the small shiny spots are mainly because of particles on the substrate, which were not fully cleaned away. After proving the OLED manufacturing in-house, the next step is to improve the cleaning procedure and inkjet print organic layers instead of spin-coating.

3. Conclusions and Outlook

This paper describes that inkjet printing as a potential low cost and versatile fabrication technology can deposit multifunctionalities for microfluidic chips, in particular ohmic heaters and OLEDs.
Inkjet printing functional materials containing silver nanoparticles enable direct writing of meandering structures that can be used as thermal heaters. The printed heaters show good heating uniformities and provide less than 1 K temperature deviation at 90 °C within an example microchannel area. Besides, the heating rate of printed heaters provides the possibility to fulfill the requirements for PCR applications, while further printed cooling structures need to be investigated. Furthermore, printed organic light-emitting diodes as an optical source can be integrated on chips. For the initial proof of concept, a spin-coated blue OLED has been fabricated under ambient condition. With a blue OLED light source with a specific wavelength, the fluorescent light is able to be stimulated from the dyes labeled on the target analyte.

In the future, it is planned to combine fully inkjet printed organic photodiodes and optical filters with printed OLEDs as a sensing unit. Besides, fully inkjet printed actuators can be implemented as chip-integrated micropumps [3], which are required to control and mix fluids within the microfluidic channels. Consequently, with inkjet printing all the functionalities mentioned above onto a polymer microfluidic chip, a relative cheap, and portable monolithic lab-on-a-chip system can be fabricated for life science applications in the future.

Acknowledgement

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References


2. Graphic Printing and Media
Gutenberg murdered, Cross-Media get the charge?

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Abstract

How many of your friends do not own a smartphone or a computer? Probably none. Nowadays, most content is digitized: some magazines previously received in the mailbox are now available often solely on the web. In a way, the status of the print media is threatened. Is this a real drawback or a fantastic opportunity to bring interactivity into print? As shown in several studies, cross-media improves the efficiency of advertising campaigns: it allows publicists to monitor its impact and to add interactivity. If TV, radio or the internet are very efficient media regarding interactivity, leaflets or flyers grant permanence to information. This presentation examines how mixing both media allows creating high value products. But what are the technological prerequisites? Most relevant technologies come from computer sciences. Nevertheless the cross-media revolution has been made possible thanks to the digital revolution of print presses. Printing variable data through a continuous process is now possible. Advertisers need a link between media: QR codes, RFID chips and electronic printed devices. Consequently, printers’ mentalities have to similarly evolve. Printers have to learn processing variable textual and image data together or learn how to develop their activities in web-to-print. As emphasized in this report, this will ask them to acquire specialized knowledge issued from a wide range of domains. They will also have to acknowledge that printed material has become only the tangible part of a communication strategy. In this work, we demonstrate how printers can rise in the communication chain if they embrace the cross-media evolution. The new opportunities for printers are really exciting since new technologies and skills are involved. In the present work, a wide range of collected data is discussed, highlighting those issues: technologies, advantages and cultural changes brought by cross-media to traditional printers.

Keywords: cross-media, internet, communication

1. Introduction

Since the first "Macintosh" computer in 1984, IT has been democratized and documents which were before stored in paper format are now more and more entirely digitalized. In the same way, many advertising plans are now internet-based in order to carry their messages. Therefore, one could think that printers are doomed: the numeric revolution would change the world. It would make disappear any material information everything. However, the computer, if it became ordinary, still have limited impact so that to ensure their visibility, companies continue to trust the print media. Posters, canvas, clothes...paradoxically print is everywhere in our life, more than ever before. Furthermore, the world of graphic arts still evolves and proposes solutions for advertising and advertisers. One of the most ambitious and innovative one is to operate the fusion between those two worlds. The digital world in the one hand, the material one in the other. What is more interesting for a cultural organism than to be able to offer the customers a simple way to obtain more information about a representation?
This is one of the propositions of Cross-Media: duplicate the channels in order to create a rich and coherent environment. Even better, Cross-Media allows an old advertiser’s dream: to be able to monitor the impact of his communication plan. However, even if advances are spectacular, some even greater capabilities are yet to explore, and the printer will have to adapt. In order to keep on creating value, the printer should be able to propose solutions which allow to create beautiful designs, in which it will be still possible to incorporate variable data for example.

The main questions which can be addressed now are:

Which solutions can Cross-media propose to advertisers, publishers or simple users?
How the graphic arts can adapt to anticipate those evolutions?

2. Cross-Media, a proposal that makes sense

2.1 Impact on the audience

95.6 % of e-mails are spams, as the European Network and Information Security Agency shows. Furthermore, less than a recipient out of 5 takes the time to open all those mails.

On the other hand, printed mails are read or leafed down by 97 % of the recipients, read again and kept by 78 % of them [5].

This is also true for youngsters: according to a 2011 study from the TNS Sofres [3] agency, 51 % of the 15-34 prefer to receive information and advertisement on paper and 67 % like to receive addressed advertising e-mails with a colourful and illustrated envelope. Those young people prove the almost natural complementary between the Internet and paper: 62 % of them went already to an Internet website because of a received mail, in order to further inform themselves on an offer or a service, against 49 % for the totality of the population.

According to the Moonda agency who surveyed 5,000 French advertisers between November and December 2012, 13 % of them think that the "flyers" are the most "has been" media. But the same study reveals than 10 % of those advertisers had projected to use such flyers, and 24 % of them felt they had to use ads on paper media.

Indeed, for advertisers and clients, print seems to be inevitable. A flyer which enters a home is potentially read by all the family, an email may be opened by a unique person.

The printed mail addressed to one person in particular gives much value to the advertising message. It gives the feeling that the company has made an effort to contact the person, it tightens the link between the company and its clients, and furthermore it pushes the client to develop loyalty toward this company [6].

2.2 Economic Situation

The annual survey from an advertisers’ union[4] (Union des annonceurs, France) shows that in 2011 the communication market represented 31 billion euros, for France only. 10 % of this market was held by ads in the press, 30 % was printed mails (addressed or not). Therefore, communication on printed substrate represents 40 % of the communication market, which represents of 12 billion euros. Between 2010 and 2012 this market has decreased by 2 %.

In a parallel way, between 2010 and 2011, the advertisement market on the Internet jumped by 12 %. But this part of the market remains relatively small: indeed, in 2011, it represented only 5 % of the total advertisement market, representing 1.5 billion euros, 10 times less than the market of communication on printed substrate.

2.3 The situation of the print industries

According to a 2012 survey[1], covering year 2011, French printers produced 2.5 million tons of prints. The production of magazines has increased by 0.3 % between 2009 and 2010, while the
overall production of printed advertising decreased by 4.7 % (see Figure 1).
In 2000, there were 6000 printing plants in France. By 2010, they were just 3,700. This fall takes into account the shutdown of factories as well as fusions between companies. Since year 2000, the number of printing plants has dropped by 39 %. It is explained by the reduction in the demand for books and brochures. We can add the dramatic drop of sales of the newspapers. To summarize, the overall quantity of printed advertisement surfaces has decreased, in fact it has almost been divided by 2.
One of the specificities of the print advertisement market is its low added value. However this market represents 67 % of the volume produced by French printing plants, although it is just 42 % of the total volume [4]. One of the goals of the cross media would be to boost the added value of the print advertisement.
From a printer’s point of view, integrating the new possibilities offered by cross media is inevitable. The number of printers will continue to fall if they don’t catch up. The graphic industry will be more and more limited to packaging. However, the effort needed to integrate cross media will payback, for as we have seen, print is still a compulsory media for the advertisers. However, the print by itself is not a solution. Users are now used to connect to the internet to get more information. One of the goals of cross-media is to exploit this aspect.

3. The Cross-Media or the triumph of interactivity

3.1 Principle
The cross media technology lays on an IT structure which allows different media to communicate with each other.
The choice of the substrate is crucial. Indeed, it is the interface through which the consumer is exposed to the advertisement plan. The choice of a message, which perfectly suits the media, is an essential prerequisite for a successful advertisement. The media are:

![Figure 1: Inner ring: French printing industry production in volume in 2011, outer ring: global production consumed in France [1]](image-url)
There are two kinds of approaches:
The "Trans media" approach: the advertiser will use every medium as a point of entry for his/her advertisement plan. In the case of a movie for instance, a poster will propose to "flash" a QR code, which connects the user to a video. Thanks to an application on his/her smartphone, the user will also access to other material. Then, an Internet site will allow him/her to read some characters biography. All those elements help to construct a coherent universe, but all the media are complementary. This approach requires a lot of creativity to reach its full capacity.
The « Cross-Media » approach: the advertiser will just decline the same message on all media: the poster connects the user to a trailer. So does the application and the Internet site.
We can understand than the first approach is far more outsourced, while the second uses a stronger structure which is in the centre of the other media. However, in one case or the other, the prerequisites in terms of materials and infrastructures are:

- Servers to route the data
- Servers to host the media
- A database to personalize the user’s experience
- A development team for the applications
- A development team for the Internet site
- Graphic designers for the prints

But, this approach aims at making advertisement "funnier". One does not just sell the "brain time" of the clients, but the client becomes an actor at the very centre of the advertisement. When we personalize his experience, we add the possibility to touch him in what he is the most interested.

This is why interactivity revolutionizes cross-media: the data flow is not just descending. The consumer does more than just use time to receive, he also sends. He is an actor, plays and designs the communication as he wishes.

Furthermore, cross-media will allow recording the users’ connections to the network and will give the advertiser tools to quantify the impact of the communication plan. Tools such as Google Analytics give the possibility to measure the popularity of a page of the Internet site. Other tools such as Adobe Form Central will enable to measure the answer rate of a survey.

### 3.2 Variable Data Printing

Variable Data Printing consists in computing and printing data, which are all different. Every piece of data is in the same frame, but differs in its contents in order to adapt the plan to the targeted audience. The goal is not to diminish the speed of printing.

This technology has existed since the 90's. However a survey conducted in the USA in 2012 showed than 29 % of printers thought than this market was not attractive. This same survey emphasized that on the 50,000 printers in the world possessing a digital press, only 1,000 had the know-how to use the Variable Data.

This technology proposes true solutions for personalization and targeting. This goes from the simple addressed printed mails, to the targeting advertisement plan at a national level, using e-mails, mails and ads on the Internet pages.

For the advertiser, it requires a huge database, which could be built by the advertiser himself, or given by the client who wants an advertisement plan.

For the printer, this requires another form of investment. First he must buy software to link static data and variable data. Such software could cost up to several thousands of dollars and may require to re-design the entire prepress flow work and particularly the Raster Image Processor.

Furthermore, it is necessary to buy a digital press - inkjet or electrophotography - in addition to conventional presses - offset lithography, flexography, screen printing or rotogravure. This digital press must then be compatible with the print format that is used on the conventional presses.

If the variable data technology represents an investment and a large remodelling of the prepress process, it becomes necessary for all printers wishing to enlarge their market, develop their activity, create a real added value and thus increase their revenues.

### 3.3 Technologies

From a technology point of view, inkjet and electrophotography are equivalent because they all allow to change the data to print for each revolution.

From a software point of view, the ways to work are various:

- Autonomous software which collects the data from a data base and operates their fusion and their layout.

- Variable data printing fusion software which acts as a plug in of a pre-existing desktop publishing software such as Adobe Indesign or Quark Xpress
Furthermore, those software can proceed either before the RIP creation or during the RIP creation. The RIP can compute the data with variable data already incorporated, which is lighter to proceed. The other solution is to modify the RIP so that it incorporates the variable data, then sends information to the RIP.

This a non-comprehensive list of the existent software for the management of the variable data:

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4. Conclusions

There are thrilling opportunities for those who will evolve with technologies. The groundbreaking evolution of digital has changed our lives, just as Gutenberg and the printed media did five hundred years ago. After one of the toughest crisis of the century, cross media is an amazing asset for the printing industry, which is looking for new growth drivers.

It is a fact that people are still reading much more printed information than digital commercials. That’s why most advertisers are still sending paper mails instead of just e-mails. Moreover, with its long and rich history, paper is still a valuable medium for creativity.

Indeed, today there are tools to link real world and digital world through print. This is called variable data printing. Those tools are plugins for currently used software.

By building a two-sided flux, cross media repositions printers in the middle of the supply chain. Thanks to cross media, printers will become the architects of this brand new in tune with campaigns, and not just suppliers of leaflets and flyers for a very low wage. They can create value enabling to sustain their activity for the next century. Cross media is the opportunity that will deeply reshape the printing industry. Commercial printing will continue along the value-added printing. Cross media is the future of graphic industry, which is still moving ahead!

References

Gutenberg murdered, Cross-Media get the charge?


Digital Printing and the Influence of Printed Material Structure on Image Quality

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Abstract

Widespread digital printing is connected with the relatively low cost of print production at high efficiency. However, the cost of paper may increase significantly, due to the failure in work of individual components and mechanisms. The most common reason for equipment failure or distortion of the image in electro photographic digital printing is the mechanical wear of the surface layer of the drum due to the ingress of dust and paper. To increase its working cycle manufacturers recommend the use of special supplies and, in particular, the paper of the respective manufacturer [1].

Keywords: digital printing, paper, quality

1. Introduction

Digital printing making lottery printed with «digital» equipment. By understanding the digital equipment device print directly from digital files, are workstations. Conventionally, digital printing can be divided into several sub-types: Sheet digital printing is used to produce large quantities of promotional materials such as brochures, business cards, flyers, etc., a digital laser printing machines are mainly manufactured by Xerox, Konica-Minolta, HP Indigo, Canon, etc. The print can be both colored and in one color (only black ink, toner, such as Xerox digital press, or in any one paint (for example in the MTC HP Indigo)). Large format digital printing is used for the production of indoor and outdoor advertising, print width of these machines can reach five meters, and length – tens of meters in the machines using the principle of inkjet printing. The material used for printing – paper, banner fabric, mesh, special textile materials. The range of equipment manufacturers is very wide.

The problem of the study is that the choice of the substrate depends on the print color reproduction.

The aim is identify the most suitable paper for the office printing.

2. Research technique

To analyze the interaction of toner and various types of papers a test printing was made. Based on the test images and their changes a model of toner and paper interaction was built. Most significant paper quality indicators, that affect printed image were found.

3 Materials

The research was based on paper with different paper weight (see fig. 1) (Patent of the Republic of Belarus № 15509. A method for controlling print quality deviations from the nominal paper. Published 2012.02.28) [4].
The paper of following manufacturers was used: Color Copy, Mondy, IQ Economy, Xerox Premier TCF, Krasnokamskaya paper mill, ECF, Xerox Colotech +. Density is 70, 80, 100, 120, 140, 160, 200, 300 g/m$^2$.

The most commonly used in the Republic of Belarus is paper Xerox and Color Copy Mondy. Printing was carried out on a printing press KONICA-MINOLTA bizhub PRO S5501 [2].

With its unique combination of fast colour and b/w speed, extensive media flexibility, superior image quality and high durability the bizhub PRO C5501 helps reduce the pressure in busy print rooms. An impressive range of features and functionalities increases user convenience and facilitates the fast processing of jobs. Offering sustainable, reasonable running costs Konica Minolta’s highly dependable colour production system ensures competitiveness for CRDs and print providers that strive to produce perfect, high-quality results but need to protect their margins.

**Short specification:**

**Copy and print speed up to 55 ppm A4 (colour and monochrome)**

**Paper formats:** A5 SRA3

100 × 148 mm to 330 × 487 mm

**Paper weight:** 64–300 g/m$^2$

**Paper input capacity: Standard:** up to 1,750 sheets

**With optional cassette:** up to 4,250 sheets

Finishing (with options): Document feeder, Large capacity cassette, Booklet finisher, Staple finisher and Punch Kit.

This printing machine uses toner Simitri HD, designed particularly for the printing system of Konica Minolta bizhub PRESS C8000. Toner for laser printers that is produced with the help of mechanical grinding is called – mechanical toner and with the help of chemical synthesis – chemical toner. Mechanical toner has the cornerstones shape, which has an negative impact on the sensitive surface of the drum and accelerates wearout. Chemical Toner is much better comparing to the mechanical one. It has more rounded and fine granules, that allows to print a deep tone and saturation. Toner «Simitri HD» is a capsule protected ultrathin polymeric membrane. Image pellets toner «Simitri HD» is shown in Image. 1. Simitri HD has a low fixing temperature (125 °C). low-temperature fixation prevents twisting and bending sheet, thereby
improving the finishing. Just in the Simitri HD toner is included, which allows you to implement the concept of securing oil-free. [3]

![Configuration of Simitri HD toner](image)

Figure 2: Toner «Simitri HD» from Konica Minolta

Toner «Simitri HD» is specially designed for the printing of Konica Minolta bizhub PRESS C8000. In the production of toner «Simitri HD» CO2, SOx and NOx emissions are reduced by 40%, which speaks for its ecological advantages over the similar products. In addition, the production process of toner «Simitri HD» require less energy, which also has a beneficial impact on the environment.

The measurements were performed with a densitometer (X-Rite 500).

The changes that were important for the research are presented on a graph.

### 4. Results

Optical density

![Graph of optical density](image)
Printing uniformity

**Uniformity vertical print**

![Uniformity vertical print graph]

**Uniformity horizontal print**

![Uniformity horizontal print graph]
1. The highest color density CMYK color model are on paper of 140 g/m². It should also be noted that the lowest absorbance for all four colors have Krasnokamsk paper mill paper weight of 70 g/m².

2. Paper from Krasnokamsk paper mill again has the lowest and cannot compete with Xerox and Mondy for printing uniformity. Paper produced in Belarus has a paper weight of 65 g/m² and quite high index of uniformity both horizontally and vertically – 0.085 and 0.027, respectively.

3. Most clearly the contrast is transferred to the paper Xerox, with paper weight of 140 g/m². This allows good reproducibility of image details in highlights and shadows, which improves the quality of the displayed print. In contrast printing test Xerox paper is followed by Mondy paper with paper weight of 160 g/m².

4. Conclusions

As a result of the research can be concluded that Xerox office paper (with paper weight of 140 g/m²) dominated in all stages of the experiment and suites best of all for the office purposes, comparing to other paper brands.

References

Newspapers printing with digital processes

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Abstract

"Are digital processes suitable for newspapers printing?"

Today, the newspaper market is decreasing partly due to new media technologies, such as the internet, smartphones and tablets. The majority of newspapers are currently printed in off-set. A change in printing processes could be an opportunity providing new perspectives. For instance, digital printing processes, namely ink jet and electrophotography, offer many advantages: various formats, customization and short runs with the possibility of outsourcing the print production. Delocalization would reduce the problem of routing newspapers to isolated places. Transportation costs would be minimized. Furthermore, it is more environmentally friendly. These processes seem promising, but are they technically and economically realistic? Are digital processes suitable for printing newspapers?

Indeed, offset and digital processes are radically different. Offset newspapers require coldset inks, which are very viscous (10 Pa.s). Such inks "dry" by infiltration into the substrate which is very porous. The inkjet process requires very low viscosity inks (1 to 10 mPa.s) drying by evaporation of water, while electrophotography uses solid or liquid toners. With digital processes, the paper must have an excellent surface finish. For inkjet, the critical properties of the paper are: smoothness, intern porosity, sizing degree and dimensional stability towards humidity. For electrophotography, these properties are: dimensional stability (associated to the moisture content) and surface finish because the toner must be applied to the substrate.

The drying of digital printing processes generates mechanisms of adhesion onto the paper different from those involved in offset printing. Consequently, new deinking problems are expected, which can also be limiting.

The present work analyzes the various aspects of changing printing processes, on technical as well as economic issues. The study addresses the differences between offset and digital printing in addition to highlighting the specific requirements for the substrates used. The challenge addressed in this study is to show how to conciliate the newspaper reader’s experience with digital printing.

Keywords: digital processes, newspapers, economy, limits, substrat, opportunity

1. Introduction

Since 1843, the newspapers have been printed on offset presses. This process is largely used to print newspapers considering its high speed and production capacity. But nowadays, the newspapers market decrease requires questioning and searching new directions. Indeed, this decrease is partly due to new media technologies, such as the internet, smartphones and tablets. The new technologies are not the only reason explaining the smaller runs. Indeed, according to "Les Papier de Presse", the number of persons who read a daily newspaper decreases because people are less attracted by this information medium.

However, digital processes seem to have a place in the newspapers market as they allow innovation that could maintain the number of readers and even allow to find new clients. To what extent nowadays the newspaper market and digital printing can respond to its restructuring?
2. Technical part

2.1 Digital printing benefits

What is the purpose of using digital printing processes, namely ink jet and electrophotography, to print newspapers? The following part will develop the benefits of digital processes compared to offset lithography.

First, digital processes allow short runs: only several copies are enough for the process to be profitable, contrary to offset lithography. This offers the possibility of outsourcing. It might be a solution to newspapers delivery. Today, printing is generally centralized, and newspapers are not often delivered on time in the locations difficult to access. Relocation could reduce costs of transportation. Thus, printing would increase profitability and it would be more environmentally friendly as the CO$_2$ emission would be significantly reduced.

With digital processes, the number of manufacturing steps decreases, both before and after printing. The offset process requires a lot of steps: digital file treatment to adapt and decompose the colors in the machine, plate development and plate fixing on the press for each printing unit, even if this step is automated on most machines. Making the machine ready is also time consuming. In addition, after printing, plates and blankets must be cleaned up, the plates must be removed in order to set up new ones for the new run. On the contrary, the number of steps is reduced with digital processes, and they allow quick run changes.

Last but not least, the customization is the major asset of digital processes. Indeed, the customer feels more interest when his name is printed on the product. In addition, digital technologies allow printing in several languages, which is very interesting for touristic countries. For example, Malta already uses this possibility.

2.2 Printing processes

Digital processes bring many advantages that offset lithography cannot provide. Are thus digital processes suitable for newspapers printing?

The following part will be dedicated to the comparison of the characteristics of offset and ink-jet processes. The ink-jet process rather than the electrophotography was chosen, as our research showed that the printers who tried to print newspapers with digital processes chose ink-jet.

- **Presses** For a long time, the ink-jet process was not considered as a serious competitor for offset lithography, because of its low speed. This is no longer the case since today’s ink-jet printers are web-fed and can reach reasonable speeds. For example, the IPrint ink-jet press of Impika, which works with drop-on-demand technology, runs at a 15 200 m/h speed. Even if offset presses run at much higher speeds (45 000 rph), the ink-jet printer’s speed seems to be sufficient. In addition, digital presses are less cumbersome and less expensive than offset presses.

- **Inks** Offset newspapers require coldset inks, which are very viscous (10 Pa.s). Such inks "dry" by infiltration into the substrate, which is very porous. The inkjet process requires very low viscosity inks (1 to 10 mPa.s) drying by evaporation of water. This difference in viscosities can be explained by the nature of the ink composition (see Table 1). Indeed, coldset ink vehicles are made of mineral oils (viscosity: 0.9 Pa.s) and hydrocarbon resins. The coldset inks have a poor rub, while the digital inks anchor into the paper.

- **Substrates** For digital processes, the paper must have excellent surface finish, while the newspaper substrate printed with offset is very light, thin and very porous to allow the ink infiltration. For inkjet, the critical properties of the paper are smoothness, intern porosity, sizing degree and dimensional stability towards humidity.

To conclude, both processes are very different on a technical point of view, as well as on the characteristics of the raw materials used. This highlights the limits of the digital processes.
for newspapers printing. People often wish to keep the similar aspects from both products. Moreover, the drying of digital printing inks generates mechanisms of adhesion into the paper different from those of offset inks. Therefore it seems impossible to process the same mechanism of deinking for digitally or offset printed stock. Flotation mechanism, commonly used for offset printed papers, should be revised for digitally printed papers.

### 2. Economic aspects

In this part we analyze French newspaper market, and then the global market.

The first point is the analysis of the sales of newspapers in France. According to the French Minister of Culture and Communication, newspaper market is decreasing. In fact, within ten years (from 1999 to 2009), newspapers’ sales decreased by more than 20%. According to the same source, the turnover decreased by more than 25% during the same ten years. These data concern only the daily press of general and political information.

Regardless of the whole diffusion of daily press, a similar conclusion arises: in France, newspaper market is clearly decreasing. In fact, the global diffusion of the daily press has decreased by two percent between 2009 and 2010.

The trends are similar for several famous daily French newspapers. The data come from the Office of the Justification of the Broadcasting. Seven daily newspapers were randomly chosen. Four of them increased their sales between 2011 and 2012 and the three others decreased. However those which increased have increased by 1% on average. Those which decreased have decreased by 2.9% on average. According to these data, we can conclude that newspaper market is decreasing in France.

At a world scale, the situation is different.

Firstly, we analyzed the global broadcasting of newspapers. According to WAN-IFRA, the global broadcasting of newspapers increased by 3.5% between 2010 and 2011. We also analyzed the repartition between printed newspapers and digital newspapers. It is commonly stated that paper is progressively dying because of digital newspapers. In fact, today three billions of people daily read a newspaper. Among them, more 2.5 billions read the news on a paper. This data means that paper is still widely used compared to digital newspapers. Considering the problem at a world level allows getting a more precise and real analysis of the situation of the press. Indeed, in Europe, North America and Latin America, the printed broadcasting declines. But this decline is compensated by the sharp increase of the broadcasting of printed newspapers in Asia and in the Middle East. This increase is so strong that it allows the world broadcasting to progress. We can precisely determine this increase thanks to data stemming from WAN-IFRA. Indeed, broadcasting of newspapers increased by 3.5 % in Asia and by 4.8 % in the Middle East and in North Africa between 2011 and 2012. It has decreased by 3.4 % in Europe, by 3.3 % in Latin America and remained stable in Australsia (Australia + New Zealand). Concerning Asia we can add that South Korea and Hong-Kong are now among the first 10 countries of the world where the rate of newspapers readers is the highest.

Concerning the income at the world level, we can assert that the world press represents a turnover
of 200 billion dollars a year, which is more than 150 billions euros. The advertising income rose to 74 billions euros in 2011, which is a reduction of about 25% compared with 2007, when they had reached 98 billions euros. This reduction may be imputed to 72% in North America. Another issue is the development of new technologies, namely tablets which represent the main threat for printed newspapers. 60% of tablets owners use it to get information they previously get from a newspaper or from a magazine. Besides, more than half users of tablets assert that they read daily the news on their tablets and 30% indicate that they spend more time to read this information since the acquisition of their tablet. It is interesting to bend over what takes place in the United States regarding the on-line newspapers. Indeed, 7 Internet users on 10 assert consulting the Web sites of newspapers. However, only 17% of them consult them daily.

4. Conclusions

Through this study, our objective was to determine if the digital printing of newspapers was viable from a technical point of view but also from an economic point of view. Digital processes bring several advantages such as the shorter make-ready times, the possibility of personalization, lower cost of the press but also the innovation as the customization, the opportunity of relocate the print plant thanks to the profitability of digital printing with short editions. However, these processes create some limits, such as the level of requirement for the quality of paper, and the rise of new deinking challenges.

Acknowledgement

We thank everybody who allows us to achieve this project.

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Newspapers printing with digital processes


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Evaluating Camera Capabilities for the Purpose of Graphic Arts Education

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Abstract

This project tests the effectiveness of four different digital cameras for the purpose of teaching image capture techniques in graphic communications. The four cameras tested were the Pentax K-r DSLR, Sony NEX-F3 mirrorless, Canon S100 high-end point-and-shoot and Canon ELPH 300 entry-level point-and-shoot. The cameras’ capabilities were compared based on their usefulness in taking exposures common in the graphic arts, including copy, macro, product, still-life and portrait photos.

Based on the authors’ experience teaching image capture at Ryerson University using DSLR cameras (Pentax K200, Pentax K-r, and Nikon D90 DSLRs), a set of concepts were defined that students should know and be able to implement for an image-capture operation in the graphic arts industry. The essential concepts include learning about exposure setting, white balance, colour management and file formats including Camera Raw and JPEG.

Keywords: mirrorless camera, digital photography, premedia, DSLR

1. Introduction

In 2007 Ryerson University’s School of Graphic Communications Management began teaching digital photography as a replacement to scanning in its premedia curriculum. The first step was to identify what forms of photography would most commonly be performed in a printing, web design or electronic media production environment. The school also wished to distinguish production photography from a more aesthetic format, as taught in the Image Arts (Photography) curriculum. The faculty proposed that graphic arts productions most typically encompassed five types of photography: copy, macro, product, still-life and portrait [1]. Copy photography is the capture of flat work such as logos for tracing, documents, artwork for catalogs or original artwork for signed and numbered reproductions. Macro photography refers to close-up photographs of small products or parts, which are used in catalogs or instruction manuals. Product photography is photographs of individual products typically used for catalogs or web sites, including online auctions. Still-life photography is photographs of groups of related products for advertisements or flyers. Lastly portraits are photographs of individual or groups of people commonly used in annual reports or yearbooks.

Although expensive, medium- or large-format, high-megapixel digital backs are commonly used in production photography, the school felt that the cost of such cameras would be prohibitive and that the requirement of the camera to be tethered to the computer would limit teaching effectiveness. The faculty felt that important concepts and operations could be learned equally well from high-end 35-mm SLR cameras. The purpose of this study was to see if more recent forms of digital cameras, including mirrorless and high-end point-and-shoot cameras, could be as useful in teaching the important of this field.
2. Materials and Methods

The digital cameras used in this experiment were a Canon ELPH 300 entry-level point-and-shoot, Pentax K-r DSLR, Sony NEX-F3 mirrorless and Canon S100 high-end point-and-shoot (Fig. 1).

Figure 1: Cameras (left to right): Canon ELPH 300, Pentax K-r DSLR, Sony NEX-F3, Canon S100

The cameras were chosen based on their range of capabilities and functionality, with the Canon ELPH 300 being the most basic and the Pentax K-r the most advanced and professionally tested camera in this study.

Each digital camera was then used to photograph the five determined exposures common in the graphic arts: copy, macro, product, still-life and portrait. The copy and macro images were photographed upon a copy stand, while the product was photographed in a lighting cocoon. The still-life photograph was taken upon a photo stand and the portrait taken in front of a standard photographer’s background. The room was darkened with the exception of two standard photography lamps to light the scenes. All photographs were taken in the same lab at the School of Graphic Communications Management.

Before taking any photographs each camera was white-balanced using an industry standard grey card. An X-Rite ColorChecker Passport was also photographed after the camera was white balanced for colour management purposes. Each camera took three exposures (-1, 0, +1) of every item to ensure greater accuracy in achieving a correctly exposed image.

The photographs were then converted from Camera RAW to DNG (Digital Negative) using the Adobe DNG Converter. The conversion was made as DNG files provide an efficient workflow, especially as the files were from different camera models [2]. The converted files were then colour managed using a colour profile specific to each camera made from the X-Rite ColorChecker Passport photographs in Adobe Photoshop.

2.1 Camera Comparison

The cameras are compared based on tone reproduction, gray balance and the amount of colour correction needed in their photographs. Tone reproduction refers to image contrast and the amount of detail present in the highlight and shadow areas of the image. Gray balance pertains to the reproduction of images without colour casts and is achieved by white balancing the digital camera prior to taking photographs. Lastly colour correction of digital photography refers to
image editing and adjustment in an application such as Adobe Photoshop.

3. Results and Discussion

The Canon ELPH 300 was the easiest camera to handle, as it is the most basic. Its limited functions also contributed to it being the quickest camera to setup. The Canon ELPH 300, although a camera that all students of any level of familiarity with digital photography can use, is impractical in teaching basic digital photography theories. For example, the Canon ELPH 300 provides little control over shutter speed and aperture. Additionally it was inconsistent in taking close-up photographs, particularly of the macro and copy images. Multiple exposures were required to ensure an acceptable photograph was taken.

The Canon PowerShot S100 high-end point-and-shoot camera was also easy to handle, while having greater functionality then the Canon ELPH 300. Changes to the aperture or shutter speed were visible on the live-view LCD screen, which can be advantageous in teaching their effects on exposure. Similar to the Canon ELPH 300, the PowerShot S100 had difficulty focusing on the copy and macro images. It was unreliable taking these images, as it did not consistently focus on the image at the same height on the copy stand. Both Canon cameras did not provide sufficient close-ups for the macro photograph, as seen in Figure 2, compared to the other two cameras. The

Figure 2: Macro Photographs (from top left to bottom right): Canon ELPH 300, Canon PowerShot S100, Sony NEX-F3, Pentax K-r DSLR

Sony NEX-F3 is the only mirrorless removeable-lens camera tested in this experiment. Mirrorless cameras are more compact and light-weight compared to traditional DSLR cameras. This is the result of the mirror, prism and viewfinder being removed and replaced instead with a permanent "live view" on the camera’s LCD screen. The lighter-weight of the Sony NEX-F3 made it easier to handle than the Pentax K-r on the tripod and copy stand. The Sony NEX-F3’s lens is both manually and automatically adjustable which ensures the image is always in focus. The Pentax K-r has a manually adjustable lens, which proved to be problematic for learning photographers as photographs that appeared in focus, actually were not when the images were viewed in Adobe Photoshop. Although the Sony NEX-F3 had a macro lens for the macro photo, it was not able...
to get a closer shot of the stamp and coin as visible in Figure 2. This is not reflective of the lens’ capability but the camera was limited by the copy stand and how close it could get to the image. The Sony NEX-F3 produced images that were sharp and had great vibrancy. The Pentax K-r is a traditional DSLR camera that is presently used in the School of Graphic Communications Management’s curriculum; it provides a benchmark for commercial image capture. As it is a professional-grade camera, it can be intimidating to students who are unfamiliar with digital cameras as there are an overwhelming number of capabilities that are unnecessary for the requirements of the work for the curriculum. Its weight made it feel sturdy while on the tripod, but was also a hindrance when using the copy stand and lighting cocoon. This is the only camera that provided the option of both a viewfinder and a live view and having both was appreciated, as it provided more options for setting up the scene. The live view LCD screen provided more information in regards to exposure than the viewfinder, which was preferred. Unfortunately any changes in aperture or shutter speed did not show in the live view like the Canon PowerShot S100 or Sony NEX-F3. This can be problematic for students to understand these major photography concepts.

4. Conclusion and Summary

In completion of the study it was concluded that the Sony NEX-7F mirrorless camera proved to be superior in teaching image capture techniques compared to the other tested cameras. The Sony Nex-7F provided an approachability and ease of use for students of all levels of experience with digital cameras that the Pentax K-r DSLR did not. The entry-level point-and-shoot camera did not offer enough user control over exposure, white balance or colour management to be effective in teaching professional image capture concepts. The high-end point-and-shoot camera was easy-to-use and enabled hands-on teaching of exposure, white balance and colour management. It, however, was not capable of providing consistent image capture, specifically when taking macro or copy photographs.

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References


Main Tendencies of Packaging Design in Belarus

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Abstract

Packing industry in the Republic of Belarus is now intensively develops. Growth of output volumes on packing materials in comparison with previous years (increase of outputs of packing production makes \(\sim 15\%\)) is observed. At such surge of production it is necessary to give special attention to packing designs and packing materials. By construction it is possible to gate out some types of packing:

1) simple, when the standard squared shape without secondary members is applied;

2) the improved construction containing irregular shape with secondary members;

3) design, with unusual design and the shape.

Under production conditions to realize some design constructions is usual impossible owing to a heading the big share of muscle labor or application of special substances printing on which is complicated. Nevertheless, application of special substances, decoration, or finishing processes allows to raise attractiveness of the packing. The special substances applied in Byelorussia, are substances in decoupage technic, with a stamping, and with the special image beaten in ready packing. Creation of decorative elements is made on the basis of polymeric and fibrous materials on the equipment which is a less referring to polygraphic production. To finishing processes it is possible to refer the technics of plotting glitter, varnish coatings, a foil, and a raised impression. Survey of various "know-how" of the packing implemented at the factories of Byelorussia is in-process spent. The video clips showing the feature of playback of various packaging design are developed. Classification of packing production processes is spent out. Various packaging designs mostly spread in Byelorussia are resulted. Some design aspects of packing implemented in industrial conditions are developed.

Keywords: package, packaging design, materials, tendency

1. Introduction

Rapidly growing packaging industry in terms of production and the number of people involved in it currently competes with leaders of the world economy, as a military and the Industrial Agriculture. Tying together the most diverse areas of production, trade and consumption, it has become one of the most important parts of the global industrial infrastructure and evolving along with it. At the same time, and formed a new research area, designed to provide an effective solution resulting in the packaging industry scientific and technical and organizational problems, most of which are priorities: improving packaging materials and production technologies; Crate packing machinery; integrated automation of technological processes, the creation of high-capacity, design, standardization, logistics, marketing, environmental and other aspects of packaging production.

Today stamped boxes and boxes of wraparound are one of the most economical packaging options, as they are formed from a single sheet of corrugated cardboard and does not require the use of
complex equipment. Their blanks are shaped to assemble without the use of auxiliary materials (glue, tape, staples). Two or all of the walls and lid are so constructed that they are a continuation of the bottom.

Wraparound cartons used for packaging flat objects: cans, boxes, etc. Packaging is performed after installation of objects on the basis of the box, and is shut off by wrapping. Boxes wraparounds are the following types:

- simple wrapping boxes;
- Self-assembled box type with a hinged lid;
- box with end caps;
- Self-assembled type trays (vegetable, banana, etc.);
- trays rigid type (assembled with glue, tape or staples).

2. Experimental Setup, Materials and Methods

In this research, we used data on the possibilities of publishing house "Belarusian Printing House", as this company is one of the brightest on the market of high-quality packaging. Today, the publishing house "Belarusian Printing House" is ready to offer its clients a wide range of boxes wraparound.

The main materials are corrugated cardboard, coated and masked board.

3. Results and Discussion

Technical equipment today can make choices as simple and Self-assembled boxes, trays and rigid type. For boxes publishing "Belarussian Printing House" uses the following equipment: 2-ply micro corrugated with white and brown flat with coating layers produced in rolls and sheets on the vacuum corrugators, 3-layer micro corrugated produced on automatic laminating machine STM1450, for the construction of a cut boxes and packaging from 1 pc. we use software package EskoArtiosCAD and cutting plotter Kongsberg XL20, carving of packing is carried out on-stamping machine BOBST SP 102-E platen and cutting press ML1400, gluing packaging is carried out on a longitudinally-gluer machine «International» KJ. High quality offset printing on sheet fed printing machines MAN ROLAND 704 and 705. An additional finishing products - varnishing typographical, HP and UV varnishes, printing and pantone triadic colors, lamination, lamination finishing grades of cardboard, gluing windows, and etc [1].

In the study, we have determined that in the Republic of Belarus at the moment the most popular are simple wrapping boxes and boxes of wraparound, which have additional elements: the holes for carrying - handles, lock gates, latches.

The leaders of the sales today are five options boxes wrapping type [2]:

1. Box wraparound abutting valves. Wraparound box from one piece abutting outer and inner flaps. This option package is one of the most simple, but many companies choose exactly it, because such a package is ideal for the packaging of any flat objects and thus has the lowest cost Fig. 1.

2. Box wraparound with enhanced internal valves. Box wraparound from a single piece abutting the outer flaps and reinforced internal end flaps. This option package is also popular in Belarus, as it allows the transport of more fragile items through strengthened internal valves Fig. 2.
Main Tendencies of Packaging Design in Belarus

3. Folding carton, tray with cells. The tray consists of a single piece and glued. This embodiment of packaging is more complicated and expensive. But in Belarus, it is also often by businesses that are engaged in the implementation of most food products Fig. 3.

Pack of micro corrugated board - only at first glance a very simple thing, and unpretentious. In fact, cardboard boxes are a complex product development engineers, designers and other production staff. It is important to know those physical properties the micro corrugated board and understand the technical features and details that will maximize carton to protect goods during storage and transport.

Very important when choosing a package are the following indicators:

- Weight;
- Size;
• The value of the goods, products;

• Shipping and transport time;

• Climatic conditions of storage.

That’s why as part of this research work is the development of a new version of the package that allows for the storage most fragile things, but at the same time meet all the design requirements. The goal was achieved through the analysis of current packaging materials and their possible changes.

Corrugated cardboard, having an undoubted advantage in cost and the possibility of packing fragile items, has no opportunities to change the classical design. However, changing the outer shell by masking and joining decorative elements will undoubtedly increase the attractiveness of the box Fig. 4.

Coated board has high strength, it can be applied to high-quality images and warp greatly. Thanks to these properties, you can deviate from the traditional forms and convert into complex structural elements with curved edges Fig. 5.

Thick masked board can also be sealed, however, due to absorption of the adhesive compositions can be quite tough, which causes problems in terms of technology and sophisticated design can be difficult to realize. Fig. 3 shows the developed designs of packages from masked board.
4. Conclusions and Summary

Thus, in the paper analyzes the possibilities of printing equipment on the main enterprise of the industry, shows the use of different materials in package design. Works in this direction is continuing.

References

Thermal and mechanical properties of printed polylactide films

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Abstract

In order to solve the problem of solid wastes, and to reduce the consumption of fossil raw materials and emission of carbon dioxide into the atmosphere, scientific community gives a great deal of effort to the development and application of biodegradable polymers based on renewable resources. Polylactide (PLA) is a thermoplastic aliphatic polyester derived from renewable resources, such as corn starch or sugarcane. It is a biodegradable, compostable polymer material and one of the most promising biobased materials currently available on the market. PLA has similar properties to many polymers which are produced from the deficit fossil raw materials, and can be modified by adding plasticizers and fillers to enhance its properties or reduce the production cost. Polylactide films can be rigid and transparent with good barrier properties to aromas and the permeability to carbon dioxide, oxygen and water vapor. Some of the most common polymer films which are used nowadays in the food industry, may be replaced with this biodegradable polymer material. Because of many advantages, PLA is a promising candidate for the fabrication of biaxially oriented films, thermoformed containers and stretch-blown bottles. Printability and runnability of PLA films are comparable to standard petroleum based flexible packaging materials. The aim of this study was to observe changes in the properties of printed and non printed PLA polymer films. The main purpose was to research the influence of printing ink on thermal and mechanical properties of PLA polymer films. Inks for screen printing process were used for a printing of PLA films.

Keywords: polylactide, printing, mechanical properties, thermal properties

1. Introduction

Renewable resources of polymer materials offer an answer to maintaining sustainable development of economically and ecologically attractive technologies [1]. Polylactide polymers have gained enormous attention as a replacement for conventional synthetic packaging materials in the last decade [2]. PLA film has an excellent moisture transmission rate, high natural dyne level, excellent scratch resistance and high optical density. These features position this polymer material as a replacement for polypropylene or polyester in many applications. It is difficult for a new film to break into a market that has twenty or more years of established film lines [3]. PLA is printable with virtually all conventional printing processes. Clearly, PLA has the same carbonyl function group as PET (polyethylene terephthalate). PLA and PP (polypropylene) both contain a methyl group. These similarities may contribute to similar print qualities [4]. In this work polylactide films were printed with two different printing inks, with screen printing process. In this process it is possible to apply a very thick layer of ink, normal values are around 20-100 μm. The thickness of the stencil determines the thickness of the layer of ink [5]. For printing on plastic material composition of inks for screen printing are similar to composition of gravure and exographic inks [5]. The viscosity must be matched to the desired ink, layer thickness and
the neness of the mesh [5]. The main purpose of this study was to observe possible changes in
the thermal and mechanical properties of printed and non printed PLA polymer films.

2. Materials and Methods

For this investigation two different screen printing inks were used, HI-GLOSS VINYL 35.303 red,
producer Argon Manoukian (Italy), and Polyplast PY206 blue, producer Sericol (UK). Both inks
are dried by solvent evaporation and tack-free time at room temperature for HI-GLOSS VINYL
35.303 red is achieved in 15-20 min, and for Polyplast PY206 blue in 8-15 min. Polyplast PY206
blue is formulated free from lead and other heavy metals and is tested to comply with the EN71-
3:1995 Toy Safety Standard and do not contain ozone depleting chemicals as described in the
Montreal Convention.

Printing substrate used in this investigation was Earthfirst® PLA Tentered White Label film,
kindly supplied from Sidaplax (UK). Earthfirst® PLA film is a bioplastic film, made from Na-
tureWorks Ingeo™ resin. Technical properties of Earthfirst® PLA Tentered White Label film
are shown in Table 1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unit</th>
<th>Typical values</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>μm</td>
<td>50</td>
<td>ASTM D 4321</td>
</tr>
<tr>
<td>Yield</td>
<td>m²/kg</td>
<td>15.3</td>
<td>ASTM D 4321</td>
</tr>
<tr>
<td>Optical Density</td>
<td>O.D.</td>
<td>0.50</td>
<td>X-Rite 301</td>
</tr>
<tr>
<td>Gloss at 60°</td>
<td>Gloss units</td>
<td>30</td>
<td>ASTM D 523</td>
</tr>
<tr>
<td>Surface tension untreated</td>
<td>dynes/cm</td>
<td>38</td>
<td>ASTM D 5946</td>
</tr>
<tr>
<td>Coefficient of Friction COF (static)</td>
<td>-</td>
<td>0.4</td>
<td>ASTM D 1894</td>
</tr>
</tbody>
</table>

* Provisional technical data Earthfirst® PLA TWL

Thermal properties of the samples were investigated by differential scanning calorimetry using
DSC Q20 instrument (TA Instruments, USA). Hermetically sealed aluminium pans containing
printed and non printed samples of PLA films were prepared. All samples were heated in the
temperature range of 20-180°C with heating rate 10 °C min⁻¹.

Tensile strength and elongation at break tests were measured on a universal tensile testing
machine Instron 1122 according to the specifications of SRPS G. S2. 612 standard (ASTM
D882) at 25 °C. The sample sizes were measured by micrometer, and the crosshead speed was
set at 10 mm/min. After mechanical testing, the surface morphology of the breaking area of
printed PLA films was characterized with an optical microscope (Bresser, Germany).

3. Results and Discussion

3.1 Thermal properties

The glass transition temperature (T_g) of the polymer films is associated with a cooperative
motion of polymer chain segments, which may be hindered by the polymer-ink interaction. This
bond, formed between the ink layer and PLA film surface, is able to hinder the motion of the
polymer chains. Therefore, as expected, printed PLA films showed the higher glass transition
temperatures than the nonprinted PLA film, Fig. 1, Table 2.

Fig. 1 shows that the melting temperature (T_m) is decreased at printed PLA films. The slightly
decreasing of T_m of printed PLA films is probably the result of the low melting temperature of
pure ink which caused the lowering of thermal properties of PLA films.
3.2 Mechanical properties

Mechanical characteristic measurements of printed and non printed PLA films were carried out at 25 °C, according to the specifications of standard. This involved standard tube for investigation and measuring of five samples for each data point. Tensile strength and elongation at break were calculated according to following equations:

\[ \sigma_m = \frac{F_m}{A_0} \]
\[ \varepsilon, \% = \left( \frac{\Delta l}{l_0} \right) \times 100\% \]

where are: \( F_m \) - force measured at break, \( A_0 \) - cross section area (mm\(^2\)), \( l_0 \) the original length of an extension sample, \( \Delta l \) change in length.

The results of mechanical testing of printed and non printed PLA polymer films are shown in Table 3. From the obtained results it can be seen that ink layer decreased tensile strength of PLA film. This can be explained by mechanical deformation of substrate surface due to the pressure of squeegee during the screen printing process. Value of elongation at break of printed PLA films increased compared to the value before the printing process, which indicates that elastic ink layer increased flexibility of printed films. This also, increasing resistivity to cracking of ink layer which was confirmed by the optical microscopy (Fig. 3, a).

The optical microscopy was used to observe the surface of printed PLA films and the breaking...
Table 3: Mechanical properties of printed and non printed PLA polymer films

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Tensile Strength (σ MPa)</th>
<th>Elongation at break (%)</th>
<th>Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA film</td>
<td>56.41</td>
<td>9.48</td>
<td>50</td>
</tr>
<tr>
<td>PLA film HI-GL. VINYL 35.303 red</td>
<td>41.89</td>
<td>10.68</td>
<td>62</td>
</tr>
<tr>
<td>PLA film PY206 blue</td>
<td>40.09</td>
<td>10.76</td>
<td>70</td>
</tr>
</tbody>
</table>

area of samples after mechanical testing. It was confirmed that printed layers of both inks, HI-GL. VINYL 35.303 red and PY206 blue, were well adhered to the PLA film substrate (Fig. 2, a, b). This suggests a strong interaction between printing ink and PLA film, which was also confirmed by scratch resistance and abrasion resistance tests.

![Microscope pictures of printed PLA films, a) HI-GL. VINYL 35.303 red, b) PY206 blue.](image)

Figure 2: Microscope pictures of printed PLA films, a) HI-GL. VINYL 35.303 red, b) PY206 blue. The images show a region measuring 0.85 × 0.7 mm.

After mechanical properties testing, printed PLA films were analyzed in order to determine the degree of cracking and disordering of surface morphology. As shown in Fig. 3, after mechanical testing, in the printed PLA film are not observed the high level of surface damage, especially at breaking area (Fig. 3, a). From microscope picture of breaking area it can be seen that printed ink did not exfoliate from the PLA film, which indicates that ink layer has good flexibility. Outside of the breaking area printed layer retains almost unchanged morphology, what was expected (Fig. 3, b).

![Surface morphology at (a) and outside of the breaking area (b) of printed PLA film after mechanical testing.](image)

Figure 3: Surface morphology at (a) and outside of the breaking area (b) of printed PLA film after mechanical testing. The images show a region measuring 2.2 × 1.8 mm.
4. Conclusion

There is an apparent increase of research in the field of applications of polylactide as a material that can be competitive to traditional petroleum-based polymers. Polylactide has the potential to replace some of the most commonly used polymer films used in the packaging industry, but it is long and difficult process to introduce new material to already positioned market.

In comparison with other printing techniques, screen printing has the most varied range of application, and it can be used for printing on a wide variety of substrates. For the purpose of this study, screen printing was found out to be the most convenient for printing on PLA films. Two different types of inks were used, and thermal and mechanical properties of printed and non printed samples were investigated. Printed PLA films showed the higher glass transition temperatures than the nonprinted PLA film, because bonds formed between the ink layer and PLA film surface, are able to hinder the motion of the polymer chains. The slightly decreasing in the melting temperature of printed PLA films is probably the result of the low Tm of pure ink which caused the lowering of thermal properties of PLA films. From the results of mechanical testing of printed and non printed PLA films it can be seen that ink layer decreased tensile strength of PLA film, which can be explained by mechanical deformation of substrate due to the pressure of squeegee during the screen printing process. Value of elongation at break of printed PLA films increased compared to the value before the printing process. This can indicate that ink layer is flexible, what was also confirmed by the optical microscopy, by observing the breaking area surface of the obtained printed PLA films.

Acknowledgement

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References


Online book trading in Ukraine

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Abstract

The transformation of property relations, removal of administrative obstacles and barriers to domestic and foreign trade contribute to the development of competition in the trade area and make the search for new, more effective ways and forms of commercial activities more active, primarily the e-commerce. Publishing and printing industry in Ukraine is not an exception. Every year it opens up new online bookstores that indicate the transition of the industry to a new level of trade activity.

Keywords: book trade, payment systems, impacts, management issues, online bookstores, organization of logistics activities

1. Introduction

The development issues of e-commerce are reflected in the works of foreign scientific researchers as I.Balabanov, H.Bekker, D.Brachchi, H.Dunkan, D.Eimor, R.Imeri, A.Kantarovych, O.Kobeliyev, K.Kolley, D.Kozie, M.Mc-Neill, K.Peitel, A.Sammer, V.Tolstov, I.Uspenskiy, T.Hofman, V.Tsarov, and others. Significant theoretical potential for the organization and management of e-commerce enterprises in the market economy has been created by scientific works of national authors as A.Bereza, V.Huzhva, I.Kozak, B.Miziuk, M.Makarova, N.Medzhybovska, L.Ponomarenko, I.Svydruk, O.Shaleva and others. Among the recent publications on the organization of e-commerce enterprises we should note the works of O.Berezin, N.Hryniv, M.Katynska, M.Kindiy, M.Mahy, I.Yarova. At the same time, the study of the economic and organizational, technical and logistic support of functioning processes of e-commerce book selling enterprises requires further development, hence it causes the need and feasibility of this research.

2. Experimental Setup or Materials and Methods

According to the e-business experts, the book will become the most promising good of online shops. In today’s book market of Ukraine there are about 40 online bookstores. According to the sample survey we have formed ranking of online bookstores in Ukraine (Figure 1).

The survey showed that the majority of book buyers at online shops makes its purchase in shops "Book Club" (20.48%) and "Bookstore Ye" - (10.27%). Less popular stores are Yakaboo - 7.51%, "Bouklia" - 6.37%, "Chytaika" - 5.96%, "Buha" - 5.80%, "BookshopUA" - 4.98% and "Folio" - 4.69%.

In our opinion, the current network of online shops in Ukraine has been formed as a network of professionals in the book business, as those companies that did not keep the pressure of large retailers with their own online bookstores, disappeared from the market. At the same time, the tendency to increase the number of online bookstores is kept by opening of large retail networks, which for certain reasons could not get to the online market before or they got enough knowledge over this period in order to find the leading position in the market of book e-commerce now.
The problem of the quality supply of the online bookstores operation is the subject of the research conducted by the author. By means of respondents survey (professionals of operating e-commerce enterprises) we have evaluated the importance of processes of online shops and determined the state and problems in the functioning of book e-commerce in Ukraine.

The main factors that determine the efficiency of the online bookstore were grouped into the following groups: Web-page design, ease of use (navigation) of online shops, complete information on the supply of books, the range depth of goods offered, the level of goods prices compared to similar online shops, the level of goods prices compared to stationary retail network, the guarantee availability of goods in stock of online shop, the delivery cost of goods to customers, the delivery term of goods to customers, methods of payment for the goods.

The analysis shows the importance of certain aspects of the organization of online shops (Fig. 2), the experts have given the most significant place to the factor of level of product prices in e-commerce network as well as in stationary retail network.

The second most important group of factors consists of "the speed of delivery to the buyer", "the variety of the assortment of the offered goods" and "the cost of delivery of the goods to the buyer", the averages expertise values were respectively 11.48%, 10.53% and 10.05%. In our opinion, it is quite logical because the customers of online shops use their services not just because of curiosity, but because they try to find a) the product needed, which may not be found in their stationary distribution network, and b) in the maximum short time - no extra cost to the search for a specific product, and c) with the lowest overall level of costs on the purchase of this product. Therefore, the factors that determine the efficiency of the online shop, are connected not only with the goods supply (which requires good marketing and commercial work above all), but with its close contact to the customer by providing complex logistics operations, these factors identified the experts opinion on this problem.

Among other aspects of the online shop activity we can notice almost the same values of the importance factors such as "the information about the book", "methods of payment for the goods" and "the guarantee availability of the goods in stock of online shop", which average values have made 8.59%, 8.15% and 8.13% according to the survey. This can be explained by the fact that the national practice of e-commerce has often cases of improper description of the offered books and their quality, leading to the failure of buyers to purchase the delivered goods.
with low quality settings. Meanwhile, the organizers of online shops decreased significantly the problems connected with the payment for the goods that almost disappear with the development of modern payment systems in Ukraine.

To meet the requirements of goods buyers in online shops for the quick delivery, the pressing problem is the elimination of time delays between the moments of order processing and decision-making on the implementation of this order, on one hand, and the time of implementation of this order by selecting and sending the desired product from the online store - on the other side. That is why the expert high evaluation of importance factor of "the guarantee availability of goods in stock of online shop" determines the relevance of the system development of goods placement and management in the system of e-commerce.

Another important aspect of the goods delivery in e-commerce is the term of the orders. We have traced clear differences in the parameters of the virtual delivery of goods and the real delivery. As for the surveyed online shops (which carried book e-commerce of material nature), the duration ranged from 1 day (in some online shops in Kiev) to 30 days and the average value of this factor was 6 days. The duration of the period of orders implementation often increases due to temporary lack of goods offered in their catalog of online shop, in the company store. It should be noted that many of the online shops (about 60%) have no special storage facilities for the goods storage and accumulate them directly in the office of online shop.

3. Results and Discussion

The study has showed that the domestic online shops often use the following ways to organize the goods delivery (Figure 3):

Typically, online bookstores offer the types of delivery, which are most common among e-commerce. This is confirmed by our study, as often offered method of delivery is the use of transportation companies (28.67%) and the post in Ukraine (24.67%). Online bookstores often offer their own customers to come directly to the storage (if any) (20%). They rarely offer to the customers to use their own courier service (13.33%) and "Books by mail" (6.67%).

One of the features of the delivery organization in e-commerce in Ukraine is the location of
products supply mainly in the capital and several regional centers. According to the survey, Kyiv has about 24.0\%, regional centers (including Donetsk, Dnipropetrovsk, Kharkiv, Luhansk, Lviv, Odessa and Kiev) have 58.0\%, other places have 18\% of supply. This location allows the use of the different types of public transport, as almost 81\% of online shops have access to railways, system of "Autolux", "New Mail", "Night Express", EMS, Ukpost. Cargo delivery systems provide opportunities to reach consumers who live outside of major population centers. In particular, express delivery "New Mail", ASD ensure delivery of goods outside regional centers, although the possibility of such delivery is limited to economic factors. Consequently, the cost of delivery of purchased books in online shops to the buyer, who lives at a distance of 40 km from the regional center, increases in $1,7 - 2,4$ times and is comparable to the price of the product itself.

To a large extent this factor determines the limit group of buyers in online shops of Ukraine. The study has showed that the majority of customers residing in the central (40.88\%) and Western (26.81\%) regions of Ukraine. The rest of the customers are from the Northern (16.27\%), Eastern (11.24\%) and Southern (4.79\%) regions of Ukraine.

In carrying out the payment for goods, online bookstores offer their customers the following methods of payment: COD, payment by courier, payment via bank transfer, payment via plastic card, systems Webmoney, PayCash, etc. (Fig. 5).

The cash payment is more popular than cashless. This can be explained by the fact that Ukrainian consumers have not changed the culture of the goods purchase, so the fact of paying...
cash on delivery remains the highest priority for 59.14% of customers of online bookstores (including 32.79% customers who prefer "payment by courier" and 26.35% - by COD). The payment via credit card was done by only 13.28% of the buyers.

The experts survey of e-commerce professionals revealed major problems in the management of books selling via online shops for functional processes: the selection of software, the organization of the collection and processing of orders, the organization of customer service, the organization of payment for goods, the organization of goods delivery, the organization of communication of the online store with the producers (publishers and printers) (Fig. 6).

The experts believe that "the organization of delivery" (28.57%), "the organization of the collection and processing of orders" (21.57%) and "the organization of customer service" (21.42%) are the most crucial problems that arise in the management of online bookstores. At the second level, they distinguish "the organization of payment for goods" (14.29%). Less important issues are "communication system with publishers and printers" (7.14%) and "software selection" (6.68%). To a large extent these problems are reflected in the efficiency of online shops, so they require
management decisions to minimize the negative impact.

4. Conclusions and Summary

The study confirms the high level of costs and the existence of significant problems for the organization of book e-commerce, which determines the necessity of the measures implementation for the goods delivery to customers on the basis of the formation of integrated logistic chains involving so-called third parties to the implementation of delivery process - logistics intermediaries (transport-dispatch companies, resellers, agents who work primarily on a simplified system of taxation).

The overall efficiency of e-commerce systems is largely determined by the efficiency of goods movement from sale places to the consumer, however, these processes are closely related to the organization of material (primarily - commercial) provision of the companies, which determines the necessity to use the tools to improve logistics level of working with suppliers, customers on the integration of production and transport and trade systems and optimize the commercial-technological processes occurring in the field of e-commerce and goods promotion. Therefore, further studies should be conducted in developing methods of implementing this idea.

References

Hardware and software of the risograph printing intelligent module on the basis of model operation

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Keywords: risograph, intelligent module, software

1. Introduction

The aim of the study is to improve the quality of digital image printed on risograph RZ370 using a mathematical model in Matlab based on the functions of Image Processing Toolbox package. The research subject is the development of the risograph printed model based on IPT package functions and on automatic choice of the risograph printing profile. Today most of the original models are produced with the personal computers and with the transfer of the image by connecting the risograph to a computer via the interface. The advantage of this method of printing is obvious, as it allows to get the best print quality through the use of the program risograph model. The interface greatly simplifies the producing of circulation: it makes possible to process the image and the text for the best print results on the risograph. Enlarged algorithm of the mathematical model in Matlab is shown in Fig. 1.

![Diagram of the mathematical model in Matlab](image)

Figure 1: Enlarged algorithm of the mathematical model in Matlab

2. Experimental Setup and Methods

Some experiments were carried out to use the developed program module for printing images of different types on risograph RZ370. The tested images were a photo (a), a text (b), a drawing (c) and an outline drawing (d). Fig 2a, 2b, 2c, 2d show pattern structures at printing with type 1 of driver RZ 370: grain-touch and to half-tones. Fig 3a, 3b, 3c, 3d present pattern structures at printing with driver RZ 370 type 2: grain-touch, to halftones and to stress text. Fig 4a, 4b, 4c, 4d present pattern structures at printing with driver RZ 370 type 3: screen-covered,
**to halftones and to stress text.** Fig 5a, 5b, 5c, 5d present pattern structures at printing with type 4 driver RZ 370: **grain-touch, tone level 30% and to solid-lock.** Fig 6a, 6b, 6c, 6d present pattern structures at printing with type 5 driver RZ 370: **screen-covered, tone level 30% and to solid-lock.** **Grain-touch:** various tones of photo images are reproduced by changing the number of dots in an area according to original density. The printed-out photo images will have grain-touch appearance. **Screen-covered:** various tones of photo images are reproduced by changing the size of dots according to original density. The printed-out photo images will be covered with a dot screen. Though the wide range of tone levels in original photo images can be kept in this style, their fineness will be lowered. **To Halftones:** the color difference of texts and line-art images can be reproduced as tone difference on prints. **To Solid-look:** the color difference of texts and line-art images is not reflected on prints and all images are to be reproduced as solid ones there. **Fine Lines - To Stress Text:** you can sharpen the outlines of texts, especially small characters, by selecting this option.

After the comparative analysis of under mentioned pictures the following may be recommended: for photo 3 profile; for text 2 profile; for graphic 1 profile and for out-line drawing 4 profile.
Hardware and software of the risograph printing intelligent module ...

Figure 2: The result of the print settings and increase the points structure
Figure 3: The result of the print settings and increase the points structure
Figure 4: The result of the print settings and increase the points structure
Figure 5: The result of the print settings and increase the points structure
Figure 6: The result of the print settings and increase the points structure
3. Result

Three basic types will be considered: 1 «Document», 2 «Photo», 3 «Graphic» or «Outline Drawing». Further we will consider the application of these types for printing of images «Document», «Photo», «Graphic» or «Outline Drawing» on the risograph. To automate printing, a program on the MATLAB developed; the program defines the type of the starting file.

A method of finding the text in the image will be used as an algorithm. If the text occupies less than 20% of the image, the image should be classified as «photo», if the text occupies from 20% to 80%, the image should be classified as «Graphic» or «Outline Drawing», and if the text occupies more than 80% of the image, we will classify the image as «Document». The analysis of the image type in the program module is based on the method of finding the text fragment. The program recognizes the image type from types «Document», «Photo», «Graphic» or «Outline Drawing» and then chooses the type with the corresponding patterning method. The text of the program to select the profile is presented below.
Program module in a functional Matlab for image analysis:

```matlab
function F=detectText2(path)
num_char=30;
def_size=24;
porog_black=70;
max_size=42;
min_size=8;
porog_compare=0.6;
porog_text=0.8;
porog_graphic=0.2;
Isrc=imread(path);
figure; imshow(Isrc);

[folder, name, ext] = fileparts(mfilename('fullpath'));
Itemplates = cell(num_char,1);
for i=1:num_char

Igray = imread(fullfile(folder, templates, fullfile num2str(i) '.bmp'));
Igray = imresize(Igray,[def_size def_size]);
Itemplates{i}=double(255-Igray);
end;
I = rgb2gray(Isrc);
Ilogic = I(:,:)<porog_black;
figure; imshow(Ilogic);
Ilabel = bwlabel(Ilogic,8);
Idata = regionprops(Ilabel,'Image','BoundingBox');
Iblack=Ilogic*255;
sum_area=0;
for i=1:length(Idata)
    if (Idata(i).BoundingBox(4)<min_size && Idata(i).BoundingBox(4)>max_size)
        bound = floor(Idata(i).BoundingBox);
        subI = imcrop(Iblack,bound);
        subI = imresize(subI,[def_size def_size]);
        minc=255;
        for j=1:num_char
            A = abs(subI-Itemplates{j})/255;
            c=sum(A(:))/(def_size*def_size);
            if (c<minc)
                minc=c;
            end; end;
        if (c<porog_compare)
```
39 sum_area=sum_area+Idata(i).BoundingBox(3)*Idata(i).BoundingBox(4);
40 x1=int32(Idata(i).BoundingBox(1));
41 y1=int32(Idata(i).BoundingBox(2));
42 x2=int32(x1+Idata(i).BoundingBox(3)-1);
43 y2=int32(y1+Idata(i).BoundingBox(4)-1);
44 Isrc(y1:y2,x1:x2,1)=Isrc(y1:y2,x1:x2,1)+uint8(Ilogic(y1:y2,x1:x2)).*(255-Isrc(y1:y2,x1:x2,1));
45 Isrc(y1:y2,x1:x2,2)=Isrc(y1:y2,x1:x2,2)-uint8(Ilogic(y1:y2,x1:x2)).*Isrc(y1:y2,x1:x2,1);
46 Isrc(y1:y2,x1:x2,3)=Isrc(y1:y2,x1:x2,3)-uint8(Ilogic(y1:y2,x1:x2)).*Isrc(y1:y2,x1:x2,1);
47 end; end end
48 [h w]=size(Isrc);
49 sum_area=sum_area*15;sum_area=sum_area/(h*w);
50 if (sum_area>porog_text)
51 disp('document');
52 elseif (sum_area>porog_web)
53 disp('graphic');
54 else
55 disp('photo'); end; figure; imshow(Isrc);
Fig 7 shows the type of the program interface and the basic profiles for a manual choice.

![Program Interface and Basic Profiles](image)

Figure 7: The program interface and the basic profiles for a manual choice.

In the interface the following controls are used:

- **Button OPEN** is used for open images;
- **Button Type File** to determine the type of the loaded document;
- **Button Conversion** is for converting color image to grayscale;
- **Button CLOSE** is for closure of the image;
- **Button INFO FILE** opening the file information;
- **Unit Type Image** contains four types of setting for image processing: **photo**, **text**, **graphic** and **outline drawing**.

- **Choice filters** the use of filters for image processing.

- **Save** save the processed files.
- **PRINT** sending print.

4. Conclusions

The program of referring the type of the printed file to the classes «Document», «Graphic» or «Outline Drawing» and «Photo» developed. It is possible to process the image with standard filters of the library Image Processing Technology (IPT) toolbox of the environment MATLAB. The experimental research shows that the ba-sis of imitation model makes it possible to improve the quality of rizograph printing using the automatic choice of type print and standard filters in MATLAB environment.
References


Colour Image Processing and Analysis of Transformations in Consumer Digital Cameras

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Abstract

The objective of this study is to interpret and analyze the image processing that takes place in a digital camera, and compare it to the processing that can be done in Adobe Camera Raw. An analysis is performed on the results from the in-camera processing, and then reverse engineering of this data took place in Adobe Camera Raw, in order to gain an understanding of the colour behaviour in the colour-processed photos.

This was examined by photographing a classic 24-patch X-Rite ColorChecker in three different ways: using a RAW image and a JPEG image with two different assigned profiles from the camera. Then, the characteristics of the photos, in terms of lightness, saturation and hue are examined.

The study concluded that, although in-camera and Camera Raw computer processing should be expected to produce comparable results, they in fact do not. Therefore, manual steps were required in order to improve the accuracy of colour management.

Keywords: Digital Camera, Colour Management, ICC Profile

1. Introduction

Colour management of digital cameras is an important part of the digital imaging process, and can be particularly difficult due to constantly changing lighting conditions. Colour management can be defined as the "communication of the associated data required for unambiguous interpretation of color content data, and application of color data conversions as required to produce the intended reproductions" (Green, 2010). The International Color Consortium (ICC) has become the universal standard for colour management, with the goal of "promoting the adoption of cross-platform colour management systems" (International Color Consortium, n.d.) through the use of ICC profiles. This means that ICC profiles are meant to provide its users with a comprehensive colour management system that works with all software and operating systems. Having a profile is necessary to achieve accurate colour, because they "allow the correct interpretation of image data" (Sharma, 2004).

In recent years, colour management systems have converged towards using colorimetric models as opposed to densitometry or indexed colour mapping. This is based on the well-established Commision Internationale de L’Éclairage (CIE) system. Moving towards colorimetric models means that device-independent colour spaces such as L*a*b or XYZ are used.

The function of a colour profile is to provide the transformations that need to be applied to the image, by using a Profile Connection Space (PCS) and a Colour Management Module (CMM). In most cases, a standard ICC profile is used such as sRGB or Adobe RGB (1998). The AdobeRGB colour space is able to represent "about 35% more color ranges than sRGB is able to" (Sutton, 2013). Despite the larger colour gamut that the AdobeRGB colour space offers, sRGB still remains the most common choice because of its simplified workflow and because it can display directly to the web without requiring any conversions. These factors should be considered when setting AdobeRGB or sRGB in-camera. AdobeRGB would be more suitable for printing due to the larger gamut, and sRGB would be more suitable for web applications.
Manually deferred formats such as RAW are also used frequently in digital imaging, especially in professional photography. This proprietary file format has no colour profile applied to it, but it is intended to be subsequently rendered. This "digital negative" file is archived for future use, where it can be rendered again.

A photo captured in RAW file format must be processed through computer software, as opposed to a JPEG, which is processed in-camera. This means that a RAW photo remains unprocessed and uncompressed until it in imported into the computer software, in this case Adobe Camera Raw, and that it is a lossless method of capturing photos. In other words, "the complete data from the camera's sensor is stored within the photo" (Darren, 2006).

As previously stated, within the JPEG file format there are two options for colour spaces, AdobeRGB and sRGB. "JPEG images can contain up to 16.7 million colors, and different color spaces allows for you to use a broader or narrower range of those 16.7 million colors" (Sutton, 2013), this is why there are the different colour spaces to choose from, to give the user control over which part of the gamut will be used.
2. Experimental Setup

2.1 Materials & Software used

- Nikon D90 digital camera
- X-Rite Classic ColorChecker 24 patches
- 18% grey card
- Adobe Photoshop CS5.5
- BabelColor PatchTool
- CHROMiX ColorThink

The Nikon D90 digital camera was selected as our capturing device. The Macbeth ColorChecker was used as a colour calibration target. The purpose of photographing the test chart is to gather spectral reflectance data that can be referenced back during the test; this is helpful in determining how well the digital camera reproduced colours. The 24 patches found on the ColorChecker are a variety of colours intended to mimic those in nature, such as skin tones, green grass, sky blue, etc. The 18% grey card was photographed in order to set the white balance of the digital camera. This is an important step in the digital imaging process, as the grey card allows for consistent image exposure across the whole series of photos.

In terms of software, Adobe Photoshop CS5.5 was used to open the RAW images and render them into the TIFF file format (with the appropriate colour profile applied). It was also used to gather colorimetric data from the patches by using the histogram tool and recording both the RGB and L*a*b values. In addition, Photoshop was used to modify the neutral patches of the photos, due to its comprehensive photo-manipulation abilities.

BabelColor PatchTool was employed to extract the target values of the photos using the average pixel value of each whole patch. PatchTool also created text files with the data, which was useful in the research project.

Finally, CHROMiX ColorThink was used to gain a visualization of the colour behaviour by viewing individual points representing each patch, and by mapping vectors showing the $\Delta E$ between two points. This was a useful tool during the process of manually adjusting the photos, as it was easy to identify what exactly needed to be modified, such as the lightness or darkness of a patch, or if there was a colour cast, for example.

2.2 Procedure

A classic 24-patch X-Rite ColorChecker was photographed using a Nikon D90 digital camera in three formats: RAW, AdobeRGB JPEG, and sRGB JPEG. Prior to shooting, the camera was set to an F-stop of 5.6 and the exposure value to 0, then the 18% greycard was shot in order to set the white balance.

The RAW photos were then converted to the TIFF file format, due to its lossless processing, once with the AdobeRGB profile assigned and once with sRGB, in Photoshop CS5.5. These files were then put into BabelColor PatchTool software, which extracted the target RGB and Lab values using the illuminant D50, the relative colorimetric rendering intent, no black point compensation and 8-bit RGB encoding. The values for the in-camera processed photos and Photoshop processed photos were then compared, using the DE2000 formula.

After assessing the results of the $\Delta E$ between the photos, manual adjustments were made in Adobe Camera Raw in order to reduce the $\Delta E$ between the photos. Furthermore, the photos were also compared in CHROMiX ColorThink in order to gain a visualization of the colour behaviour in terms of lightness, saturation and hue angle.
3. Results and Discussion

The resulting L*a*b values of the test targets colour patches under both the in-camera and Photoshop processing were expected to be similar, since one method applies the profile directly to the photo in the camera, and the other method applies the same profile to a completely unprocessed RAW photo in Photoshop. However, when the RGB and L*a*b values were compared, they yielded dissimilar results. As demonstrated in Table 1. In order to understand the colour behaviour within the photos, reverse engineering of the colours took place in Adobe Camera Raw, in efforts of trying to reduce the $\Delta E$ between the photos. The first step to this process was in reducing the $\Delta E$ within the neutrals, with the hope of an overall improvement of the photos. This was done by adjusting the: highlights, lights, darks, shadows, points in the midtones, brightness and contrast.

Table 1: $\Delta E$ comparison between the colour test target patches under in-camera and Photoshop processing

<table>
<thead>
<tr>
<th></th>
<th>Average $\Delta E$</th>
<th>Maximum $\Delta E$</th>
<th>Minimum $\Delta E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AdobeRGB</td>
<td>8.27</td>
<td>16.15</td>
<td>2.12</td>
</tr>
<tr>
<td>sRGB</td>
<td>7.55</td>
<td>13.9</td>
<td>1.32</td>
</tr>
</tbody>
</table>

By reducing the $\Delta E$ in the neutrals to less than 2, the overall colour quality of the image improved. Prior to modification (Figure 3), the colour behaviour was inconsistent between the two photos, meaning that there was variation in the lightness, saturation and hue of the colours. However, after modifying the neutrals in Photoshop, the issue remains predominantly in the saturation of the colours, as seen in the straight vectors of the $\Delta E$ in Figure 4.
After

Figure 4: ΔE comparison between in-camera AdobeRGB JPEG and modified Photoshop AdobeRGB TIFF, presented in CHROMiX ColorThink.

Table 2: ΔL Comparison between in-camera AdobeRGB JPEG and modified Photoshop AdobeRGB TIFF

<table>
<thead>
<tr>
<th>AdobeRGB</th>
<th>Average</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>5.5</td>
<td>10.76</td>
<td>0.78</td>
</tr>
<tr>
<td>After</td>
<td>0.75</td>
<td>3.75</td>
<td>0.03</td>
</tr>
</tbody>
</table>

The steps taken in Adobe Camera Raw to reduce the ΔL are as follows:

Table 3: ΔL Comparison between in-camera AdobeRGB JPEG and modified Photoshop AdobeRGB TIFF

<table>
<thead>
<tr>
<th>Adobe Camera Raw Setting</th>
<th>Value Changed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast</td>
<td>+25</td>
</tr>
<tr>
<td>Brightness</td>
<td>+50</td>
</tr>
<tr>
<td>Highlights</td>
<td>-20</td>
</tr>
<tr>
<td>Lights</td>
<td>-18</td>
</tr>
<tr>
<td>Darks</td>
<td>+32</td>
</tr>
<tr>
<td>Shadows</td>
<td>+28</td>
</tr>
<tr>
<td>Midtones</td>
<td>Input: 128, Output: 135</td>
</tr>
</tbody>
</table>

*Please note: Lights and Darks affect the whole photo, while Highlights and Shadows only affect the lightest or darkest points*

Based on the steps taken in Adobe Camera Raw to reduce the ΔL between the photos, it is apparent that the Photoshop processing produced highlights that are too light and shadows that are too dark, in comparison to the in-camera processing of the photos.
4. Conclusions and Significance

This study has provided an understanding of the processing that is done in-camera compared to in Photoshop. It has been concluded that although the same profile is being applied in the camera and in Photoshop, the results differ in terms of lightness, saturation and hue angle. It has also been determined that by adjusting the neutrals in Adobe Camera Raw, the remaining inconsistencies between the colour lie mainly in the saturation. In other words, by reducing the $\Delta E$ between the neutrals, the $\Delta L$ and $\Delta H$ (hue angle) have been improved in the colours, with the $\Delta C$ (chroma) remaining an issue.

The purpose of this research project was to gain an understanding of the colour processing done inside the digital camera, compared to computer processing such as in Photoshop. One challenge faced with colour management for digital cameras is the lack of consistent lighting, which creates an issue when integrating photos in a digital prepress workflow. This project aims to mimic the in-camera processing using Adobe Camera Raw, in order to identify and control the problematic areas of the photos. Once the colour characterization of the camera manufacturers processing has been determined, a profile can be made to correct these issues in order to attain a more colour-accurate photo.

Acknowledgement

I would like to acknowledge Dr. Reem El Asaleh and Dr. Abhay Sharma for their guidance and input. I would also like to acknowledge Dr. Richard Adams for his help with the software and for problem solving. Lastly, I would like to acknowledge the chair of the school of Graphic Communications Management, Ian Baitz, for his continued support in our research project.

References

3. Printing Future Days Design

Please note: In this section only those full papers are published which were presented as an interactive poster. Further contributions about the topic ‘Printing Future Days Design’ are found in the respective session on Wednesday.
Design Concept for a Model Airplane with Solar Energy

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Abstract

The intention of the following concept is a model airplane, which is able to fly independent of external energy supply with a small electronic motor. Most of its functional electronic energy supply parts should be delivered through printed photovoltaics on the wing. Low prices ensured by the mass production process make the plane affordable and allow the production as a children toy.

Figure 1: Schematic of the airplane model

Keywords: photovoltaic, toy plane, printed organic electronics

1. Introduction

The focus is on producing a flat cut-out plane model for a children toy with independent energy supply. It is important to use parts and materials of low weight. On the other side it is very important to produce a low cost toy because the target group is looking for a cheap and uncomplicated alternative to the bigger models that are available on the market. Manufacturers of toys and model makers developed some interesting airplane-model kits controlled by radio. One of the interesting customers is the Plantraco company. The Plantraco Micro Flight "Classroom Fighter" [1] proves that it is possible to build a flat cut-out model of an airplane from Styrofoam which is controlled by radio and able to fly. In the market of micro model building one can easily access small motors, geardrives, receivers, actuators, servos, batteries and propellers. An important part for radio controlling is an RC receiver. Plantraco developed a very small Receiver to control the airplane named micro9 [2]. This state-of-the-art technology is available on the model builders market.
2. Materials and Methods

2.1 Concept

The intention is to develop a flat model of an airplane, which parts are 80% printable and that is able to fly without external energy supply or batteries. We suggest to use the printed paper photovoltaics 3PV technology [3] to print a photovoltaic supply on the main wing of the airplane. For the flight control we want to use a smart phone, a tablet pc or a radio remote control.

2.2 Technical Setup

The model consists of three printable parts - the body, the main wing and the rear wing. The different parts of the model should be blanked out of Styrofoam, which is coated with printed paper. All wiring will be mounted during the printing process as printed lines. Electromechanical parts, like the motor and the control unit, could be mounted by plug. Connections should be established without additional mounting parts or adhesives.

Figure 2: Main wing with photovoltaic and power plug.

The independent energy supply will be ensured by photovoltaics printed (3PV) on the main wing. The major advantage is that time-consuming recharge of batteries or capacitors will be obsolete. These normally consume a lot of time and reduce playful experiences. The avoiding of energy storage should save enough weight for the assembly of photovoltaic. Weight and space saving RC-Technology enables the integration of antennas, receiver and controls in the body of the model.

The whole control technology is available on market as DIY- variation or pre-build parts like the micro9 RC module. Its weight of 0.95g makes it perfect for micro engineering. This state-of-the-art technology is fully integrated in the market of model makers. For remote control it is possible to use a smart phone or tablet PC. To translate the movements to data you can use the gyroscope sensors by the mobile device. So it is possible to look at the flying model while handling the controls.

For directing the model you can use a magnetic actor at the tail of the plane. The HingeAct Magnetic Actuator 0.23 g [4] with its weight of 0.23g has enough power to steer the model into the left and into the right. For the electronic drive I use a motor with a gearbox. In table 1 you can see different types of them.

<table>
<thead>
<tr>
<th>Motor type</th>
<th>ASize</th>
<th>Weight</th>
<th>current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor 7mm 1,7 Ohm</td>
<td>7mm × 16,5mm</td>
<td>2,9g</td>
<td>1,28 A</td>
</tr>
<tr>
<td>Motor 7mm 3,3 Ohm</td>
<td>7mm × 16,5mm</td>
<td>2,9g</td>
<td>500 mA</td>
</tr>
<tr>
<td>Motor 6mm 4.5 Ohm</td>
<td>6mm × 12mm</td>
<td>1,3g</td>
<td>NA</td>
</tr>
</tbody>
</table>
2.3 Planned application

Many people are looking for a cheap airplane model that is easy to use. The printed model airplane is an easy way to play with a high performance toy. I think about two ways for distribution:

- Buy the model kit at a shop

  It is easy for everybody to buy the model airplane in a special shop or an online shop. The advantage is to buy all parts at the same time. You don’t need special tools or much knowledge for electrics and handcrafting. After downloading the mobile application for your smart phone or tablet you can begin to play.

- Distribution by Magazine

  You buy a magazine with all parts included. This could be published once a month with different designs. Parts like the motor could be re-used.

3. Result and Discussion

3.1 Prototype

There are many different airplane models on the market. They are expensive and hard to use. You need a lot of know-how and experience to build these models. The printed Airplane does not need a special workspace or expensive tools. You can build the model easily. Its very interesting for model makers because you don’t have to charge batteries or other external energy supplies.

3.2 Application

The focus is on the photovoltaic wing for independent energy supply. That is new on the model builders and toy market. It is a chance to distribute printed photovoltaics to a new target group.

3.4 Conclusions and Outlook

It is possible to build a flat cut-out model of an airplane with a photovoltaic integrated on the main wing. With the state-of-the-art technology it is possible to let them fly and to control his flight by radio remote control. For the future questions like the weight and the size of the wings and the body of the toy have to be addressed indetail.

4. Acknowledgment

I would like to acknowledge Plantraco Microflight for the great development of flat models of airplanes and their whole technology. Thank you to Prof. Dr. rer. nat. Reinhard Baumann and his team from the Technical University Chemnitz. Thanks to Prof. Jens Geelhaar and the Bauhaus-University Weimar.

References

Navigation Concept using printed RFID in Public Transport

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Abstract

In public transportation travel routes often change during the journey due to train delays or platform changes. The following concept makes use of printed electronics to help passengers find their way in public transit systems. To achieve this, the project suggests to integrate printed Radio Frequency Identification (RFID) tags into train tickets purchased at vending machines. The information connected to the RFID is the passenger’s destination. Small devices installed at train stations and on trains will read the tag on the ticket. The fastest route is calculated and a connected screen displays the relevant travel information to the passenger making it easy to find connecting trains. The information displayed is adjusted to the passenger’s location as well as to route changes.

An alternative to installing reading devices is using printed Near Field Communication (NFC) tags to communicate the passenger’s exact location. The passenger’s smart phone serves as the reading device, displaying the relevant travel information.

Keywords: Public Transport, Navigation, RFID, NFC

1. Introduction

Train stations in larger cities may have more than 20 platforms, located on different floors or in different buildings. According to the German railway company more than 160 million passengers change trains at Munich station each year. It can be assumed that this includes a large number of people who do not use the national transit system on a regular basis. Passengers may derive from countries all over the world and are used to differently organized transit systems and different signage. In spite of well-designed wayfinding systems at train stations passengers often face difficulties when their travel routes change spontaneously due to delays, platform changes or technical difficulties.

In 2012 20% of all German nationwide express trains were delayed for about 15 minutes average [8]. This makes it likely for the passengers to miss connecting trains especially if the route requires changing trains more than once.

Most transit companies offer a service to calculate individual travel routes for national train lines. These services can normally be accessed by customers online via the company’s web page, in applications for mobile devices or at vending machines. The service offered by the German railway company Deutsche Bahn (DB) already includes train delays and platform changes [4]. At vending machines these travel routes can be printed to take on the journey. If the route changes during the journey however the paper becomes obsolete. The same calculation can be done in mobile apps. This requires that the passenger possesses a certain mobile device and the corresponding app has to be installed beforehand as well. The user is also required to speak a certain language and to be in reach of a stable Internet connection that is usually not the case during train travel. Neither conventional printed schedules nor mobile apps are sufficient for easy wayfinding in case the travel route changes, the passenger is short in time, new to the country or does not own a smart phone.
The following concept mainly addresses passengers who use a public transit system. In particular tourists, visitors to a fair or conference attendees who are not frequently using the train system. The first approach uses printed RFID tags in combination with installed reading devices. The second concept uses NFC as an alternative to RFID and is also shortly introduced.

2. Materials and Methods

2.1 Concept description

The concept suggests that each train ticket purchased at a vending machine or a ticket counter contains an embedded printed RFID tag. This way each ticket will have its unique ID. When the passenger buys the ticket, the information of the desired destination is connected to the RFID tag's ID on the ticket.

Small RFID reading devices should be installed at train stations and on trains. The device is connected to a small computer with access to the transit company’s database and is attached to a small screen. Passengers can push their tickets to the reading device - which will then read the tag and immediately knows the corresponding destination. The device will call existing routines to calculate the fastest route for the passenger. These are the same routines that are already used at the purchase of a ticket. The computed information is displayed on the screen attached to the reading device. The screen will only display the most relevant information such as departure time, platform, and train number. Passengers should be able to grasp the information as quickly as possible so they can immediately look for their train. Once on the train the traveler can check the route again at another device. At that point the information is already updated and the next connecting train’s information is displayed. This can be repeated as many times as necessary. If a connecting train is late, canceled or departing from a different platform than initially planned the information is updated so that the passenger does not have to worry about how to find the way at the next station.

![Figure 1: Sketch of an RFID tag printed on a train ticket.](image)

As the idea presented above requires a large number of devices being installed at stations and trains, using NFC technology can be considered as an alternative. NFC tags printed or installed at different spots within a transit system (e.g. timetables on stations, railroad maps on trains, vending machines) can communicate the exact location of the passenger. An NFC-equipped smart phone is meant to serve as the reading device. The relevant information is then collected from the database and can be displayed on the phone screen.

2.2 Technical Setup description

The RFID tags should be printed on the same paper that is used in ticket vending machines at train stations. In many cases this is a certain security paper including features like holographic bands that take multiple steps to manufacture. During the manufacturing process the RFID
tags should be printed in certain intervals on the paper. Later the paper is stored on a reel in the vending machine. At the purchase the paper has to be cut in a way that each ticket contains one RFID tag. At the same moment, the identification number on the tag is linked to the travel details of the passenger, mainly the travel destination. This information is stored in a database until the passenger has reached his or her destination.

Figure 2: (a) Sketches of reading devices and display at train station and (b) on train.

The devices that should be installed consist of three parts:

- A device which reads the RFID tag on the ticket when it is pressed to the reading unit.
- A small computer with connection to the transit system’s database to gather information concerning the calculated route.
- A small screen that displays the relevant information to the passenger.

The devices have to be installed in sufficient numbers and at easily accessible spots. The device is of no use if passengers have to cue in a long line to take a short look. Transit systems might already have screens installed in trains to display general information. Interregional trains of the German railway company have two screens installed in each wagon. In theory these screens can be connected to an RFID reading device and serve as display for the individual route information of the passenger (Figure 2b). As soon as the passenger removes the ticket from the reading device the regular information will appear again.

The NFC concept works the other way around, NFC tags are installed at stations and on trains and the passenger carries the reading device in form of an NFC-equipped smart phone. When on a train the tag will send the train’s identification number. As this approach requires a stable internet connection it is advised for the transit company to provide a free wireless LAN connection on trains. The phone will use an existing service of the train company to calculate the route, displaying the relevant information on the phone screen. Some transit systems already use NFC for ticket purchase so this functionality could be added. This alternative is much more limited in terms of the target group as it requires owning an NFC-equipped phone.
2.3 Planned application

The goal of the RFID-based concept is to help all passengers where signage systems are limited in their possibilities to guide the people on their individual route. While the service at vending machines allows customers to choose between different routes, the concept introduced here will only display the fastest route. If passengers select certain stations as breakpoints when purchasing the ticket, this can be included in the calculation. For the sake of simplicity and speed no selection is possible at the introduced device, it is only for displaying information. A glance no longer than three seconds must be sufficient to grasp the content. Even if a passenger has merely a few minutes to catch a train, he or she is able to take a look at the device and assure him/herself of the right direction.

Passengers using the service for the first time do not have to read a manual. A simple symbol on the device will indicate where to put the ticket to get an effect. There is no menu to browse, just one screen of information, unambiguous and clearly legible. It is usable for passengers of all ages including those who are not used to browsing through digital menus. Apart from holding the ticket to the device the only other interaction that could be added is a language selection. Although the only language-specific word is platform, a language selection might be useful for people who use different scripts as Arabic, Chinese, Japanese, or Korean.

At the moment there are three ways to buy a train ticket: At a vending machine, at the counter, or online. The concept of printed RFID tags in tickets currently only works with the first two ways as online tickets are printed at home. However it would be possible to give passengers the opportunity to additionally print their online tickets at a vending machine.

3. Discussion

3.1 Display

A key aspect of the concept is to only show the absolutely relevant information to the passenger. Figures 3 to 8 show different ways of how the information could be distributed. From top to bottom the information is displayed in the following order: Departure platform, departure time, train number as well as a list of all stations that require changing trains plus the final destination. This list should show the passengers the way of their journey if they have time for a second glance. The train number and destinations are presented in a different hierarchy, distinguished by background color and type size. It must be obvious for the viewer which information is most relevant [6]. Updated information can be indicated through the use different colors (Figure 3).

![Figure 3: Different approaches for displaying relevant information to the passenger.](image-url)

The information is desired to be easily accessible in the user’s perception. Thus the information has to be displayed legible and clearly structured. Any additional information or element that is not necessary at this point can be confusing. The viewer will not be able to focus on more than
three pieces of information at the same time [1]. To find the ideal arrangement of information a user survey is needed in which members of the target group are exposed to situations where they need to gather the information as quickly as possible. Different color schemes, typefaces, and distribution of space have to be tested in order to transmit information the best possible way [9].

The proposed screen designs also work for the NFC alternative. Here the layout is displayed on the phone screen (Figure 4).

![Figure 4: Displaying information on NFC-equipped phone.](image)

Figures 2a and 2b show proposals for reading device designs. While the proposed device in figure 2b uses an existing screen, the device in figure 2a has a screen attached. Using existing screens has the advantage that only the RFID reading device has to be added. Installing a new device has the advantage of simplicity as it is only used for one purpose.

### 3.2 Application

Comparable existing applications are not suited as a quick wayfinding reference as they are built for other purposes. Either to buy tickets, choose between connections, or to inform the passenger about services offered on the train [4]. The concept suggested is not meant to replace these applications but to add to them by providing a clearly understandable help in navigation. A lot of useful concepts have been developed for navigation in public transport. Among the most interesting ones are a flexible transportation card including a display [Chen, 2013], and mobile terminals navigating the passenger by using a personalized database [7]. The disadvantage of these concepts is that the passenger needs a special device that he or she has to carry and from our perspective thus is not really suitable for people who do not frequently use public transportation.

### 3.4 Conclusions and Outlook

Using printed RFID technology is a useful way to make wayfinding in public transportation easier. Especially passengers who do not frequently use public transit might benefit from additional navigation as long as it is self explanatory and easy accessible. Printed RFID tags on tickets
F. Wittig

may offer a simple solution to put up with train delays and route changes during the journey. It is yet to be determined if the cost of printed RFID tags on every ticket makes sense also from an ecological and economical perspective.

The next step would be to set up a user survey to determine how the target group perceives the concept. A survey will help to define how the travel information should ideally be distributed. The NFC-based concept has the advantage of being less costly but using RFID-tickets might be more convenient for a broader target group as it does not require the passenger to fulfill any special requirements.

References

Chameleon - Interactive Smart Phone Cover Design Concept

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Abstract
This project addresses the aesthetic conformity of existing mobile handy covers and proposes a design for a new interactive smart phone cover. The inspiration for this design comes from the chameleon. A color sensor embedded in the smart phone cover allows users to interact with colors in the real world. The sensor can detect the colors of objects in the real world and changes the appearance of the smart phone cover to a similar color. The smart phone cover mainly consists of a color sensor, solar cell and transparent layers and an OLED. For the output of colors we will use flexible electronic OLED. By using printed electronics technology it allows us to make the handy cover as thin as possible.

Keywords: chameleon; color sensor; printed electronics; OLED

1. Introduction

Printed electronic is a set of Printing methods used to create electrical devices on various substrates. Printed electronics promise various kinds of sensor circuit labels, for applications in distributed sensing and monitoring, which can be manufactured by using traditional printing tools at very low cost [1].

An OLED (organic light-emitting diode) is a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compound, which emits light in response to an electric current. Flexible OLED Displays have started to appear in a variety of applications. This new display technology consists of two parts: a front plane that contains the imaging component, and a back plane that controls which pixels are on. For a display to be fully flexible, both parts need to be flexible. While dozens of companies are competing to provide back planes, two front plane technologies have taken the lead [2].

The disadvantage of existing smart phone covers is their aesthetic similarity and conformity. When using a new smart phone cover this can be chosen according to the mood and specific style of their owner. The target group for the Chameleon smart phone cover is:

- Young people owning a smart or mobile phone
- People who are interested in fashion and fresh design
- People who like to use changing accessories

The main goals of the design are to make a smart phone cover with flexible design appearances, to make the smart phone cover as thin as possible and to add interactive functions, so people can have more fun when they use it.

A related project is the chameleon ball. The chameleon ball can detect the colors of objects in the real world and emit similar colors. It consists of multiple color I/O units, a main board, a lithium ion battery, and expansion modules. Each color I/O unit consists of input devices - a color sensor, an infrared reflection sensor and a white LED - for detecting the color of an object.
that has been touched, and output devices - full-color LED’s for displaying colors. The main board consists of a microcomputer and circuits to control the above devices [3]. Another project that is related to this proposal is the chameleon scarf. This scarf is capable to change color to match the outfit using the Flora color sensor and 12 color-changing LED pixels diffused by a ruffle knit scarf [4]..

2. Design Concept

2.1 Concept description

The inspiration comes from the chameleon. People associate changeability and flexibility with a chameleon. This is exactly the aim this design concept. To realize this project the main task is the recognition of color and the output of color. Therefore, this smart phone cover will work like a color I / O device. With the development of technology and the use of different sensors the products become more and more diverse. In this case the color sensor will play a central role as a recognition unit of the real color in the world. Another aim of this project is to make the handy cover as thin as possible. This goal will be achieved through the use of printed electronic technology. Printed electronic technology allows us to print electronic components in thin layers. The sensor and solar cell should both be printed.

2.2 Description of the technical setup

The main parts of the handy cover are the color sensor, a transparent layer, a solar cell and an OLED display. The transparent layer will be used as a substrate to print electrical devices on it. The printed solar cell will work as the power supply in this case. The color sensor will be used for the recognition of color. The OLED display works without a backlight. Thus it can display deep black levels and can be thin and light. In the current market there is one existing color sensor called Flora Color Sensor-TCS34725. It has been used in the chameleon scarf project that we mentioned above. The TCS34725 is a Color Light to Digital Converter with IR Filter, which has RGB, and Clear light sensing elements. An IR blocking filter, integrated on-chip and localized to the color sensing photodiodes, minimizes the IR spectral component of the incoming light and allows color measurements to be made accurately. The filter means you’ll get much truer color than most sensors. The high sensitivity, wide dynamic range, and IR blocking filter make the TCS3472 an ideal color sensor solution for use under varying lighting conditions and through attenuating materials [5].

2.3 Planned application

The workflow can be divided into four steps. First the user points the smart phone cover close to a colored object. Then the inside color sensor will recognize the color and convert it into a digital signal. The next step is the digital transmission. Finally the color will be displayed through a flexible OLED.
3. Results and Discussion

3.1 Prototype

Actually in this project the most important part is the interaction process between the handy cover and the real world. From a marketing perspective the smart phone cover can achieve product diversification through this process. The intention of this design concept is to give the users a joyful experience.

3.2 Application

About the product application we can also combine it with the handy functionality. For example, when the phone receives a call or a text message, the handy cover will change its color in order to achieve the reminder function.
4. Conclusions and Outlook

Currently the project is in an initial creative phase. The work done so far is related to the explanation of the product’s functionality and an introduction to a potential technical implementation. The realization of the product will be the main focus of future work. In addition the product’s functionality will also be a major issue.

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References