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To meet the need for a high quality scientific publishing in its research fields of interest, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries (iarigai) publishes the peer reviewed quarterly Journal of Print and Media Technology Research.

The Journal is fostering multidisciplinary research and scholarly discussion on scientific and technical issues in the field of graphic arts and media communication, thereby advancing scientific research, knowledge creation and industry development. Its aim is to be the leading international scientific periodical in the field, offering publishing opportunities and serving as a forum for knowledge exchange between all those scientist and researchers interested in contributing to or benefiting from research in the related fields.

By regularly publishing peer-reviewed high quality research articles, position papers, survey and case studies, the Journal will consistenly promote original research, networking, international collaboration and the exchange of ideas and know how. Editors will also consider for publication review articles, topical and professional communications, as well as opinions and reflections of interest to the readers. The Journal will also provide multidisciplinary discussion on research issues within the field and on the effects of new scientific and technical development on society, industry and the individual. Thus, it will serve the entire research community, as well as the global graphic arts and media industry.

The Journal will cover fundamental and applied aspects of at least, but not limited to the following fields of research:

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- ◇ Printing on biomaterials
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Contents

A final word from the Editors

Nils Enlund
Editor-in-Chief

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This issue of the Journal of Print and Media Technology Research closes its third full year of publication. It also marks the end of my period as Editor-in-Chief. After having successfully established the Journal of Print and Media Technology Research as a high quality scientific journal in the broad field of print and media technology and seen it develop during the first busy years, I now feel that it is time to pass on the responsibility into younger, fresher hands.

We have succeeded in finding an excellent successor in Dr. Gorazd Golob at the University of Ljubljana. He will take over as Editor-in-Chief on January 1, 2015. At the same time, the responsibility for editing the Topicalities section will be assigned to Dr. Markéta Držková at the University of Pardubice.

At first, very little will change. The e-mail address journal@iarigai.org will remain but will be assigned to Dr. Golob instead of to me. The stated mission of the journal and the broad variety in its contents will remain unchanged. But, as time goes by, I am certain that Dr. Golob and his team will implement many changes and improvements to the journal.

I wish the new editor and his staff many exciting hours and inspiring experiences in producing the journal, while serving the entire research community and related industries. I trust that all authors and journal readers will continue to support the new editorial team as you have supported me and the current team.

For my part, I would like to sincerely thank all of you who have made this journal possible: the authors, the reviewers, the Scientific Advisory Board, my colleagues on the Editorial Board, the publisher, iarigai, and its Management Board, our former Associate Editor Dr. Raša Urbas, and finally our untiring Executive Editor, Professor Mladen Lovreček. Thank you all for your enthusiastic cooperation!

Mladen Lovreček
Executive Editor

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Launching a new peer-reviewed journal was an unprecedented experience and challenge, especially in fields that have not been adequately covered with too much publishing opportunities.

A number of interesting high quality papers, that have been presented on iarigai conferences, but also scattered in other different publications, many young, ambitious and capable researchers that emerged throughout the years, all this indicated the need of offering a completely new publishing channel to the research community.

It took more than three long years from the first decision of the Board of iarigai until the first issue of JPMTR was presented in Budapest, in September 2011. It was a period of considering and creating the scope of the new journal, designing its pages, gathering a team of editors and reviewers, resolving many expected problems and anticipating the new ones. Many barriers had to be overcome - external as well as internal - before the first issue was ready for the public.

All this would not be possible without full support of the members and the Board, and of course, without the financial resources of the Association. We believe that his support will remain as firm and undisputed as it was during our tenure.

Although published by iarigai, from the very beginning JPMTR was intended as a journal for wider audience, not only the members. Following the highest standards of scientific editing and publishing, as well as ethic standards, JPMTR has established itself as a reliable source of scientific information. We are sure that it will continue to develop in this way under the new Editor-in-Chief and his team.

Finally, behind each successful project are not only good ideas, enthusiasm, positive aims and possible results, but much more than that, people, just as it was Professor Nils Enlund - not only the enthusiastic first Editor-in-Chief, but also a good spirit of the journal.

It would be a long list of those who contributed in one or another way to the initial success of JPMTR, and our appreciation goes to each of them. The doors are now open wide for the new and better future of a journal.

Helsinki-Zagreb, December 2014

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Developing a high throughput printing technology for silicon solar cell front side metallisation using flexography

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Abstract

Most crystalline silicon solar cells feature a front and rear side metallisation which is usually applied by flatbed screen printing. Rotational printing methods represent a highly interesting alternative approach to realize the front side metallisation with a considerably higher throughput. Particularly flexographic printing has proven to be well-suited for fine line contact fingers down to 25 μm width on textured silicon wafers. Within this work, flexographic printing has been applied for a seed layer front side metallisation of silicon solar cells. Three silver based inks with varying viscosity have been prepared for the experiment. Printing tests have been carried out to investigate the impact of printing pressure, material tolerances and ink viscosity on the printed contact finger width. A considerable impact of material tolerances on the printing result has been observed. It was further found that a variation of the ink viscosity did not significantly influence the finger width. Fingers down to a minimum width of 32 μm have been achieved by applying the optimum process parameters. Fully functional solar cells have been produced by reinforcing the flexo printed seed layer metallisation with silver light-induced plating. The solar cells revealed very promising results with a maximum conversion efficiency of $\eta = 18.8\,\%$.

Keywords: flexographic printing, rotational printing, silicon solar cell, solar cell metallisation, seed layer, seed and plate, light induced plating

1. Introduction

Reducing the costs per Watt peak is currently the predominant goal of the solar cell industry. The manufacturing costs, especially for the metallisation of silicon solar cells is one of the major cost-drivers in the production process (Fischer, Metz and Raithel, 2012).

To date, flatbed screen printing is the standard printing technology for solar cell metallisation. Currently, screen printed contact fingers are in the range of 50-70 μm in width and 10-15 μm in height (Hannebauer et al., 2013; Burrows, 2013). Although this technology is well proven and highly developed, screen printing features significant drawbacks regarding throughput and the ability to transfer small amounts of cost-intensive silver paste.

Rotational printing methods represent a very promising approach to address these drawbacks. In contrast to flatbed screen printing, these printing technologies have the potential to transfer very small amounts of ink with a very high printing velocity onto the substrate. Rotational printing methods are well-suited for a so-called two-step seed and plate metallisation process. In the first step, a silver-based fine line seed layer grid is printed onto the solar cell wafer using a high-throughput rotational printing method. Subsequently, the printed seed layer is sintered (fired) to form the contact between metal and semiconductor. In the following, the sintered seed layer is reinforced by depositing silver or other materials using light induced plating (LIP) (Bartsch, 2011).

Previous work demonstrated technological advantages of a two-step metallisation using LIP such as an improved contact to highly doped silicon and enhanced conductivity of the front side grid (Pysch et al., 2009). Yet, this approach primarily promises significant economic advantages compared to screen printing (Kamp et al., 2011; Lorenz et al., 2013) as it enables replacing cost-intensive silver by plated nickel as a diffusion barrier and copper as a cheaper and equally conductive alternative to silver. Tin, silver or organic surface protection (OSP) is used as capping layer (Bartsch et al., 2013). Among other potential printing technologies for seed layer deposition, several methods such as inkjet (Ebong et al., 2011) and aerosol jet printing (Mette et al., 2007) have been investigated to realise seed layer front side metallisation. None of these technologies has been implemented in industrial production yet due to inadequate reliability or limited throughput. Among rotational printing methods, flexography is particularly well-suited for the deposition of a seed layer on the front side of silicon solar cells. The printing process itself is comparatively simple and reliable, well-proven on all types of substrates and particularly suitable to transfer fine line structures on very rough substrates like textured silicon wafers. Several investigations on laboratory scale printing machines with small area samples have reported that flexographic printing is able to transfer fine line seed layer grids on textured silicon (Frey et al., 2011; Thibert et al., 2012; Thibert et al., 2013). Cell efficiencies up to η = 18.0 % on Czochralski-grown silicon wafer material (Cz-Si) with 156 mm edge length have proven the concept on industrial full scale solar cells (Lorenz et al., 2013).

Developing flexographic printing for solar cell front side metallisation requires a deep understanding of both printing parameters and electrical parameters of the solar cell. From a printer's point of view, printing pressure (respectively engagement) (Bohan et al., 2003), printing speed (De Grâce and Mangin, 1984), anilox roller (Bould et al., 2007), printing plate (Claypole et al., 2008) and plate deformation (Bould, Claypole and Bohan, 2004), plate substructure (Kilhenny, 2007), substrate properties (De Grâce and Mangin, 1984), ink splitting (Griesheimer and Dörsam, 2012) and ink viscosity (Megat Ahmed et al., 1997) are known to be important parameters for ink transfer, dot gain (and thus line width) and uniformity of the printing result using flexography.

Regarding the electric performance of the front side metallization, shading of the front side grid (Woehl, Hörteis and Glunz, 2008), contact resistance of the metal-semiconductor contact (Mette et al., 2007), lateral grid resistance (Mette et al., 2007) and uniformity of the contact finger width (Rommel et al., 2011) are important influence factors which affect the conversion efficiency η of the solar cell (see section 2).

The present contribution investigates two of the mentioned influence factors - printing pressure and ink viscosity - on the printed contact finger width. It will be shown that an adequate printing pressure is of significant importance for the realisation of narrow contact fingers. Furthermore, uniformity of the printed contact fingers across the entire wafer area is examined and causes for variations are discussed. Solar cells are produced by reinforcing the printed seed layer with Ag-LIP. The electrical parameters of the fabricated cells are measured and compared. Finally, future approaches for further optimisation of the flexographic printing process for silicon solar cells are discussed.

2. Important parameters for solar cell metallisation

2.1 Principles of solar cell metallisation

In order to extract the photo-generated current flow, silicon solar cells require metal front and back side contacts (Figure 1) which are usually applied using screen printing technology. Typical p-type crystalline solar cells, also referred to as *aluminium back surface field solar cells* (Al BSF) have a rear contact consisting of aluminium paste with a layer thickness of approximately 20 µm which usually covers the entire rear surface except for local openings, where solder pads are printed beforehand using aluminium-silver paste.

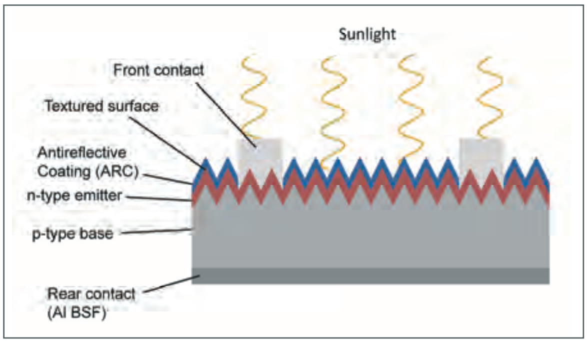

Figure 1:
Schematic drawing of an Al BSF solar cell

On the front side, a fine line contact grid is applied using silver paste. This contact grid usually consists of 70-100 narrow lines (referred to as *contact fingers*) with a width of 50-100 µm and three to five *busbars* for cell interconnection featuring a width of 1.2 to 1.5 mm (Figure 2).

Figure 2: Schematic drawing of an Al BSF solar cell

The grid should cover as little area as possible on the front side to maximise the active cell area for the incoming photons. Thus, reduction of the contact finger width is of particular importance.

2.2 Loss mechanisms related to solar cell metallisation

2.2.1 Loss mechanisms

Focusing on the front side metallisation of solar cells, optical and electrical losses have to be considered. In order to increase the *conversion efficiency* η of a solar cell, these losses have to be minimised. In the following, the fundamental loss mechanisms and electrical parameters related to front side metallisation are explained briefly. Detailed information about the impact of the front and rear side metallisation on the electrical performance of solar cells can be found in (Mette et al., 2007).

2.2.2 Optical losses

The incident light is reflected or absorbed in the areas, which are covered by the front side metallisation and therefore lost for current generation within the cell. This so-called shading effect reduces the generated current, called *short-circuit current density* j_{sc} and thus the *conversion efficiency* η of the cell (Goetzberger, Knobloch and Voss, 1998).

Usually, the coverage fraction of the metallisation is about 5-7% of the total front side surface area. Depending on the number and width of contact fingers and busbars, 2-4% of the total area is shaded by the contact fingers and approx. 3% by the busbars. Reducing the contact finger width is therefore a major goal to optimise the front side metallisation.

2.2.3 Electrical losses

According to the commonly used two-diode model for solar cells (Goetzberger, Knobloch and Voss, 1998), electrical losses are caused by the s*eries resistance* r_s and parallel resistance R_p. The *parallel resistance* R_p is governed by parasitic junction leakage currents between emitter and base and should be as high as possible. *Series resistance* r_s consists of several resistance contributors which are related to electrical properties of emitter and base, contact resistance between metal and semiconductor and the lateral resistance of the front and rear side metallisation. r_s affects the so called *fill factor FF* of the solar cell and should be as low as possible to get a high *FF* and thus obtain a high *conversion efficiency* η. Regarding the impact of the front side metallisation on *series resistance* r_s, two main influence factors have to be considered: *Contact resistance* R_c (also expressed as *area-weighted* or *specific contact resistance* ρ_c) between metal front grid and emitter is the first factor. The second one is the contribution of the lateral resistance of the front side grid to *series resistance* r_s which is referred to in the following as *grid resistance contribution* r_{grid}.

Specific contact resistance ρ_c is affected by paste or ink formulation (i.e., glass system), the front side emitter and contact firing conditions. *Grid resistance contribution* r_{grid} depends on the lateral resistance of the printed and plated contacts on the front side (fingers and busbars). In order to reduce series resistance losses related to the front side metallization, *specific contact resistance* ρ_c and *grid resistance contribution* r_{grid} have to be minimised. From a printer's point of view, the challenge is to realise contact fingers with a high aspect ratio (height-to-width ratio).

Increasing finger height (and thus cross-section area) leads to a lower lateral resistance and thus reduces r_{grid}, while narrow fingers reduce shading losses and thus increase j_{sc}. In case of a two-step metallisation approach, the printed seed layer contact fingers have to be particularly narrow, as the finger width increases considerably during the plating step. Yet, the plating process generates very dense contact fingers without pores. Thus, the lateral resistance of plated fingers is usually lower than (porous) screen printed fingers, even if the finger width (and thus cross-section) is smaller.

3. Experimental methods

3.1. Experimental setup

As discussed in section 1, a variety of parameters influence the geometrical and electrical results of flexo printed contact fingers.

Within this work, the influence of printing pressure and ink viscosity on flexo printed seed layer contact fingers has been examined. Therefore, an adequate experimental setup has been arranged (see Table 1). Experiments No. 1 and 2 comprised investigations about the influence of printing pressure on the flexo printed seed layer finger width. Furthermore, the uniformity of the finger width across the entire wafer area is examined.

Within experiment No. 3, three silver ink formulations with varying viscosity have been prepared to evaluate a possible relation between viscosity and printed finger width. Within experiment No. 4, solar cells have been fabricated from cells of experiment 3 by reinforcing the seed layers using Ag-LIP.

Electrical cell parameters of all solar cells have been measured using a Manz industrial cell tester and sorter with Halm CetisPV IV-measurement device.

Table 1: Experimental setup

Exp. No.	Objective	Varied parameter	# of samples	Characterisation
1	Influence of printing pressure	Substrate holder position (nip)	21	3D Microscopy
2	Uniformity of finger width	-	1 (Opt. result from Exp. 1)	3D Microscopy
3	Influence of ink viscosity	Viscosity	30	3D Microscopy, Celltester, SEM
4	Comparison of solar cell results	Ink formulation	30	Cell Tester, TLM

3.2 Wafer material

As base material for all fabricated solar cells, state-of-the-art *p*-type Cz-Si precursors (industrially pre-produced cells up to anti-reflection coating) with an edge length of 156 mm have been used. The precursor material had a *p*-type base resistivity of ρ_{base} = 1-3 Ω cm and a *n*-type phosphorous doped emitter with an nominal sheet resistance of $R_{sh,nom}$ = 90-100 Ω/sq. The front side has been textured by alkaline wet chemical etching and coated with SiNx anti-reflection coating (ARC) by plasma-enhanced chemical vapour deposition (PECVD) in order to minimise losses due to back reflection. The emitter on the rear side has been removed by wet chemical etching in order to ensure an adequate parallel resistance R_p (see section 2.2.3).

3.3 Screen printed rear side metallisation

The metallisation on the rear side of all cells has been screen printed using an Asys flatbed screen printing line for solar cell metallisation. Industrially available aluminium paste has been used for the Al BSF and silver paste for the solder pads.

3.4 Ink preparation and characterisation

Three silver based seed layer inks with an adequate viscosity for flexographic printing have been developed in-house. The formulation of all inks is based on a metallisation ink developed at Fraunhofer ISE (Hörteis et al., 2007; Kalio et al., 2011) and contains silver particles for metal-semiconductor contact formation, lead glass as a sintering additive, high-boiling solvents (Butyl Carbitol), dispersants (Byk) and synthetic resin SK to adjust printability and viscosity.

The ink has been prepared by blending defined amounts of solvent, dispersant and synthetic resin using a precision scale. The synthetic resin has been pulverized beforehand by a manual mortar.

Subsequently, a defined amount of silver particles and lead glass dissolved in solvent has been added. After intense mixing, an additional treatment using an ultrasonic unit has been carried out. Finally, the ink has been dispersed and disagglomerated using an Exakt three-roll mill. Inks 1, 2 and 3 have been prepared using different amounts of resin which strongly influences the resulting viscosity.

The viscosity of all ink formulations has been determined using an Anton Paar MCR 101 rotational rheometer with a cone-plate setup (d_{cone} = 50 mm, a = 1°). The applied shear rate has been varied between = 0.01 and 10 000 s^{-1}.

All prepared ink formulations are listed in Table 2.

Table 2: Prepared seed layer ink variations

Indication	Viscosity η (shear rate = 1000 s^{-1}) in [mPa·s]	Silver content	Resin	Glass
Ink 1	135	60 wt%	-	Lead glass
Ink 2	155	60 wt%	Standard	Lead glass
Ink 3	339	60 wt%	Double amount	Lead glass

3.5 Flexo printed front side metallisation

The front side seed layer metallisation has been realised with flexographic printing method using a Nissha Angstromer roll-to-plain flexographic printing machine (Figure 3). This printing machine has a vacuum substrate holder to fix the wafer during the printing process which allows smooth vertical distance adjustment of the substrate holder position. The used anilox roll had a dip volume of V_{Dip} = 8.5 cm^3m^{-2} and a screening of 120 lcm^{-1}.

The ink has been applied by a pipette directly on the anilox roller. Excessive ink has been removed by a metal doctor blade. A photopolymer printing plate (Flint group nyloflex® ACE, nominal hardness 62° Shore A) with an H-pattern solar cell front side grid with 3 busbars (1.5 mm width) and 84 contact fingers (nominal finger width 25 µm) has been fabricated using a high-resolution UV image setting process with 4000 dpi resolution (Figures 4 and 5).

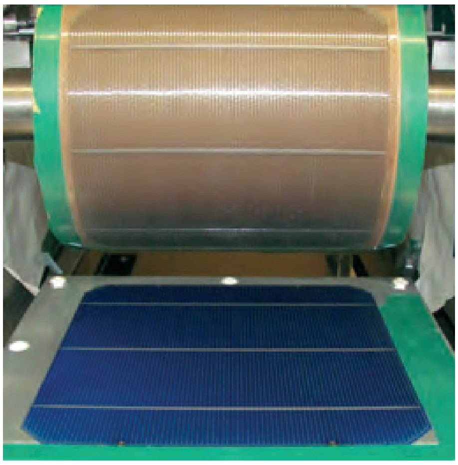

Figure 3:
Test platform for flexographic solar cell metallization

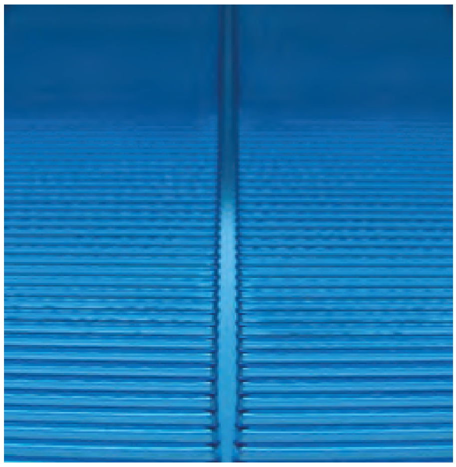

Figure 4:
Photopolymer flexo printing plate (cliché) for front side metallisation

The elongation of the printing form (Anon., 1985) has been compensated within the digital data beforehand. The printing form has been mounted onto the printing cylinder using a cushion foam tape (Lohmann Duploflex 5.1) and double side adhesive tape (thickness 100 µm) as substructure. All printing tests have been carried out at a printing speed of v_p = 0.3 m s^{-1} (fixed printing speed of the machine). Apart from experiment No. 1 where printing pressure has been varied systematically, the optimum printing pressure (respectively the optimum z-position of the substrate holder) has been adjusted and kept constant. All solar cells have been dried in a Heraeus cabinet drier at T_{Dry} = 200 °C for 2 minutes directly after printing. A firing variation has been carried out in an industrial fast firing oven (FFO) at three peak set temperatures (T_{FFO1} = 900 °C, T_{FFO2} = 910 °C, T_{FFO3} = 920 °C) to identify the optimum contact firing conditions.

The firing process takes approximately 1 minute and passes three phases: During phase 1, the temperature increases moderately to approximately 550 °C to burn out organic components within the ink. Within phase 2, the temperature rises rapidly to the peak set temperature followed by a moderate cooling-out phase. All cells have been fired at T_{FFO3} = 920 °C which has been found to be the optimum peak set temperature. The printed and fired front side seed layers on the cells of experiment No. 3 have been reinforced using Ag-LIP with 85 mg Ag within experiment No. 4.

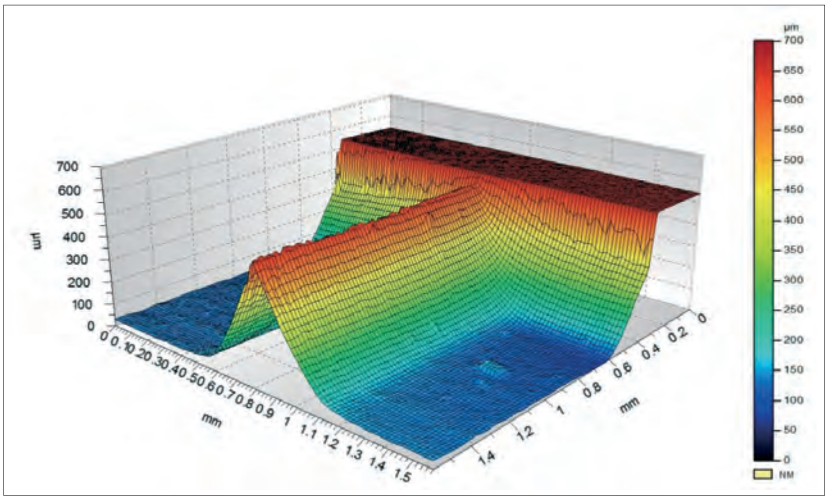

Figure 5: 3D microscopic image of a busbar-finger intersection on the printing plate

3.6 Geometrical characterisation of contact finger width

To determine a statistical average of the flexo-printed seed layer contact finger width w_s, two defined finger positions on 10 cells per experimental group have been measured using an Olympus Lext confocal microscope (amplification factor 500x). To allow an objective evaluation and comparison, all finger widths have been quantified using image analysis algorithms which have been developed at Fraunhofer ISE (Strauch et al., 2014). The statistical average of 20 individual finger widths per group has been calculated. After Ag-LIP, plated finger width w_p (which is relevant for shading) has been measured at the same positions on the same wafers and the statistical average has been calculated.

3.7. Electrical characterisation

The fabricated solar cells of experiment No. 4 have been measured on a Manz industrial cell tester and sorter with a Halm CetisPV IV-measurement device after Ag-LIP. The measurement has been carried out at an irradiance E = 1 000 W m^{-2} and a flash duration of t_f = 145 ms. Specific contact resistance ρ_c has been determined using *transfer-length-method* (TLM) (Goetzberger et al., 1964; Berger, 1972) from two cut-out samples of one representative cell per experimental group. In order to determine adequate positions, the space-resolved series resistance of the selected cells has been visualised beforehand using the C-DCR method (Haunschild, 2012).

4. Results and discussion

4.1. Experiment No. 1 - Influence of printing pressure

As mentioned in section 1, printing pressure is known to be a predominant influence factor for dot gain respectively line gain of contact fingers. Bould, Claypole and Bohan (2004) reported that small elements on the plate such as small dots or fine lines are particularly deformed with increasing printing pressure due to *dot* or *line barrelling* (Figure 6). Furthermore, extension of the dot/line surface and ink spreading has been identified to contribute to dot/line gain.

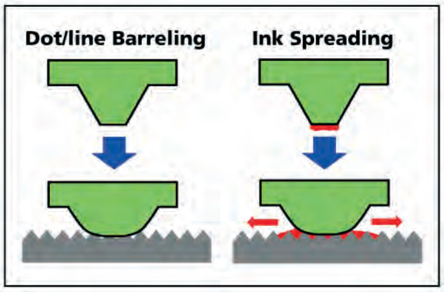

Figure 6: Schematic of dot/line barreling and ink spreading effect of fine elements on the printing form under compression

These findings are also relevant for solar cell contact fingers which represent fine line elements on the printing form. Within experiment No. 1, the impact of printing pressure on the contact finger width has been investigated.

On the machine used, the printing pressure between substrate and printing plate (on the printing cylinder) is set by adjusting the vertical position of the substrate holder perpendicular to the axis of the printing cylinder.

For this experiment, the axis perpendicular to the axis of the printing cylinder has been defined as *z-axis*. A certain position z thus indicates the z-distance of the substrate holder from the starting position z_0. For z_0, the so-called *kiss-print-level* has been chosen. Kiss-print-level is generally defined as the lightest possible impression that transfers ink to the substrate. Printing plate and substrate are just in contact at this point. The printout at *kiss-print-level* allows a precise visual analysis of the print uniformity over the entire wafer area. Starting from kiss-print-level z_0, the substrate holder has been traversed in 5 µm-steps until position z_{max} (Figure 7).

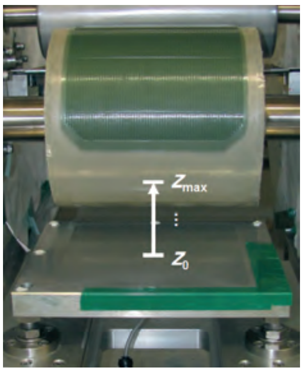

Figure 7: Adjustment of substrate holder along the z-axis

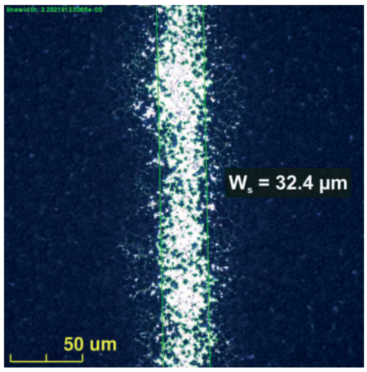

Figure 8: Microscopic image of a flexo printed contact finger (32 µm width)

Figure 9 shows the impact of the substrate holder travel distance Δ_z from *kiss-print-level* z_0 on the average printed finger width w_s. The smallest finger width has been determined at position z_{min} with $w_{s,min}$ = 32 µm (Figure 8). At position $z_{f,opt}$, the printing pressure has been identified as adequate for a completely un-interrupted printout of all contact finger elements. However, busbars still showed missing areas due to inadequate printing pressure at this z-position. Increasing the printing pressure by adjusting the travel distance to position $z_{BB,opt}$ led to the minimum required pressure for a completely homogeneous printout of finger and busbar elements. From Figure 9 it is obvious that the z-position of the substrate holder and thus the applied printing pressure has a strong effect on the printed finger width. Over the whole z-range, the average seed layer finger width w_s varied between $w_{s,min}$ = 35 µm at level z_{min} and $w_{s,max}$ = 83 µm at maximum substrate holder position z_{max}. This represents a total increase of Δw_s = 48 µm (137 %) over the whole z-range. However, it has to be considered that the determined finger widths are associated with a relatively high degree of uncertainty (percentage standard deviation of w_s at positions z_0 to z_{max} between $\sigma_{ws,min}$ = 0.5 % and $\sigma_{ws,max}$ = 12 %).

The considerable variation of the measured finger widths prohibits a distinct statement about a linear or non-linear behaviour of the curve. Interpreting the findings of Bould et al. (2011), a non-linear behaviour of the contact finger line gain with increasing pressure might be possible as fine line elements on the plate usually show a finite compression with increasing pressure.

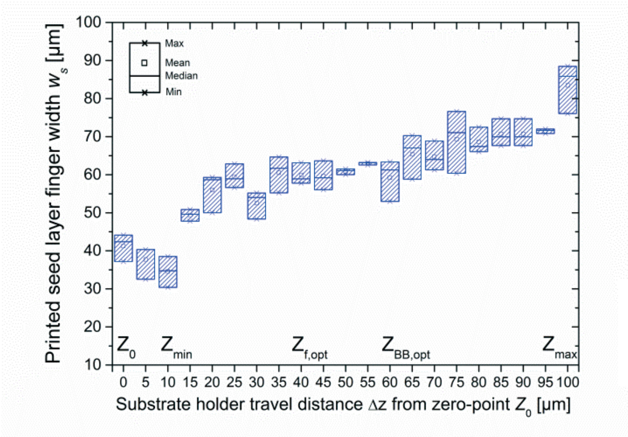

Figure 9:
Impact of printing pressure respectively Δ_z-distance of the substrate holder on finger width w_s

Printing forms for solar cell front side metallisation comprise both fine line elements (contact fingers) and solid area elements (busbars). From a printer's experience it is known that solid area elements on flexographic printing forms require a significantly higher printing pressure than fine line or dot elements to ensure a uniform printout. This considerable difference of the optimum pressure becomes apparent when comparing the optimum z-positions for a uniform printout of contact fingers ($z_{f,opt}$) and busbars ($z_{BB,opt}$). The difference of Δ_z = 20 µm between these two z-positions underlined that the busbar elements require a considerably higher printing pressure to ensure a homogeneous printout (Figure 10), while a lower printing pressure is optimal for the fine line contact fingers.

Adjusting the printing pressure to the optimum level $Z_{BB,opt}$ for a completely uniform printout of both elements therefore resulted in an additional, considerable line gain of the fine line contact fingers.

Hence, it can be concluded that realising narrow contact fingers below w_s = 50 µm by printing contact fingers and busbars on one printing form is very ambitious without further modifications. To solve this problem, contact fingers and busbars could be printed in two separate printing steps. This would require a machine with a series arrangement of two printing units and an axial and lateral register accuracy of approx. +/- 50 µm.

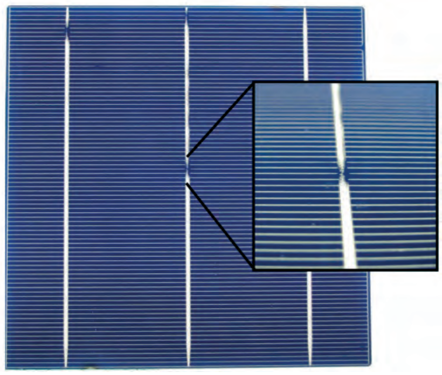

Figure 10: Missing areas in busbar element at level $z_{f,opt}$

As the wafers have to be removed and repositioned manually on the machine used before each printing step, ensuring such a register accuracy is hardly possible. Yet, such a process sequence could be easily realized on an industrial machine with two printing units.

Another possible solution to avoid a second printing step could be the realisation of contact finger elements with an undercut in relation to the busbar level (Figure 11).

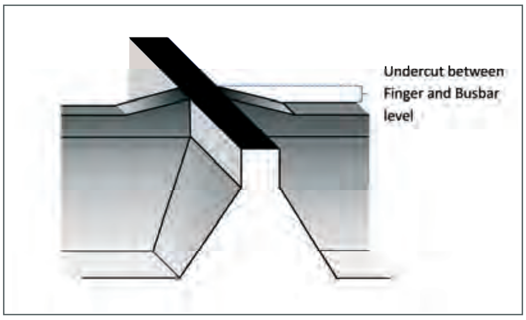

Figure 11: Schematic of a busbar-finger intersection with undercut

In summary, it has been demonstrated that contact fingers down to $w_{s,min}$ = 32 μm and less can be realised using flexographic printing, if printing pressure is adjusted precisely and problems related to different pressure requirements of finger and busbar elements are solved by modifications of the printing form or printing sequence.

4.2 Experiment No. 2 - Uniformity of finger width

The results from experiment No. 1 demonstrated that a small variation of the printing pressure can lead to a considerable variation of the printed finger width. Thus, thickness tolerances of printing form, sub-structure or substrate might have an impact on the finger width. Within experiment No. 2, the variation of the printed finger width at 16 defined positions across the entire wafer area is determined and quantified.

The most effective method to visualise such tolerances is a *kiss-print* (see section 4.1). Using this method, variations of the effective local printing pressure can be immediately seen by missing areas within the printout (Figure 12).

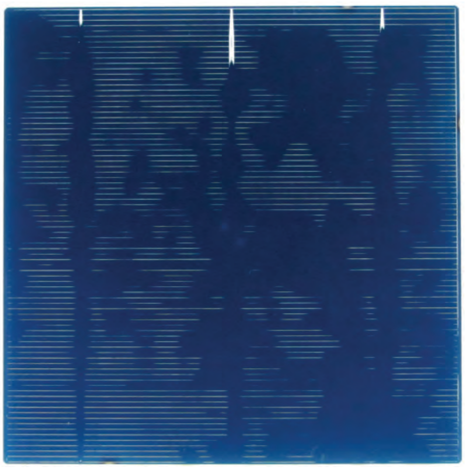

Figure 12: Visual result of the wafer printed at kiss-print-level z_0

To quantify the impact of such tolerances on the finger width w_s, the z-position of the substrate holder has been adjusted to position $z_{BB,opt}$, which has been identified previously as the minimum z-position for a complete printout of fingers and busbars. The local finger width has been measured at 16 defined positions across the entire wafer area (Figure 13).

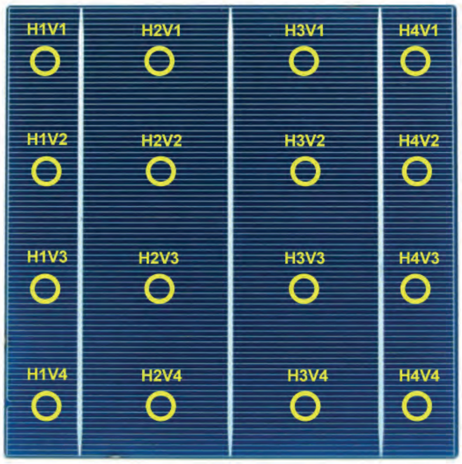

Figure 13: Measurement positions of the local finger width on solar cell printed at $z_{BB,opt}$

The average of all 16 finger widths has been determined with $w_{s,avg}$ = 55.8 μm and the standard deviation with σ_{ws} = 4.8 μm (8.6 %). The range between minimum and maximum finger width $R_{f,max-min\gamma}$ = 19.1 μm is considerable and shows that it is absolutely necessary to minimise tolerances related to materials and process. An illustration of the determined local finger widths underlines the considerable variations (Figure 14).

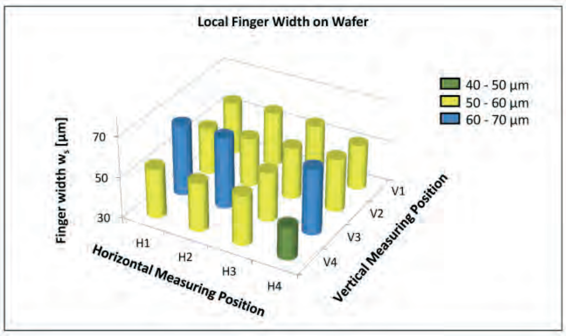

Figure 14: Local seed layer finger width w_s at 16 measuring positions across the entire wafer

The causes for these significant variations are most likely cumulative local tolerances of the plate substructure (adhesive foam tape), the printing plate and the wafer substrate which have an impact on the local printing pressure and thus lead to broader fingers.

To investigate the tolerances in detail, additional measurements of the local thickness deviation have been carried out on printing plate, adhesive foam tape and wafer material used for the experiment. As the measurements could not be carried out on the original material which has been used for the experiment, identical materials have been chosen for the evaluation. Thus, the results cannot be directly related to the detected finger-widths which are shown in Figure 14.

However, the results give a good idea of the impact of plate, tape and wafer material on the total cumulative tolerances. The local thickness has been determined at the same positions (as described in Figure 13) on all three materials.

Figures 15 to 18 show the deviation from the minimum measured thickness on 16 positions of the three materials.

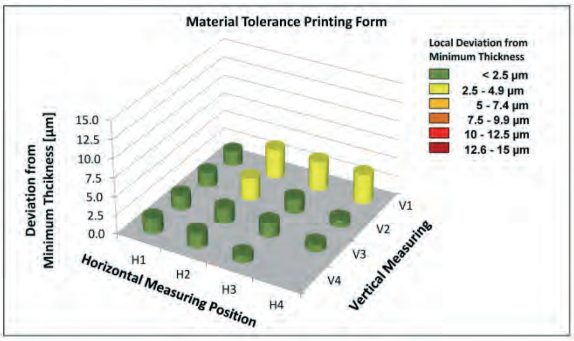

Figure 15: Thickness deviation of the printing form related to the minimum thickness

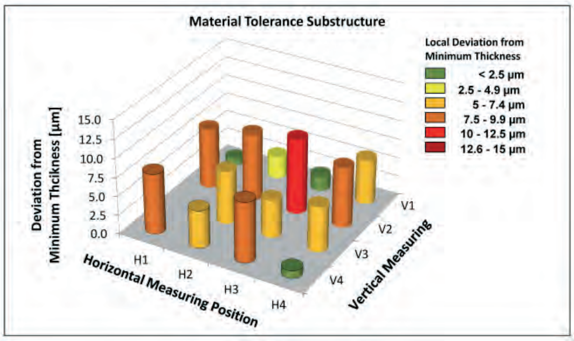

Figure 16: Thickness deviation of the sub-structure related to the minimum thickness

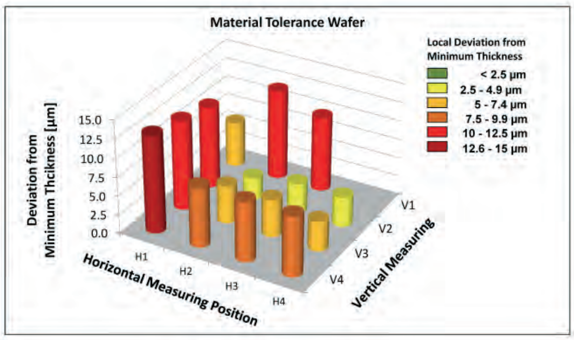

Figure 17: Thickness deviation of the wafer material related to the minimum thickness

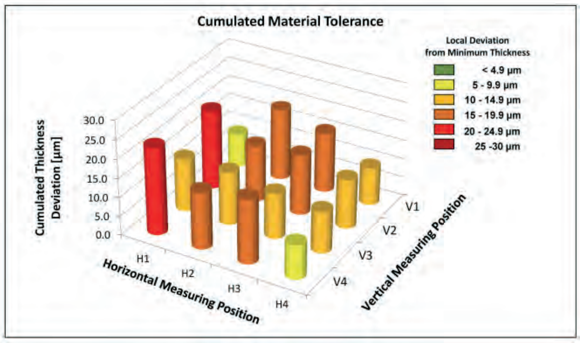

Figure 18: Cumulated thickness deviation of all three materials related to the minimum thickness

While the printing form revealed only minor thickness tolerances (Figure 15), the used adhesive foam tape (Figure 16) and particularly the wafer material (Figure 17) varied considerably in thickness. The cumulated tolerances of all three materials are considerable and underline the necessity to reduce material tolerances (Figure 18). While the tolerance of the wafer material cannot be avoided and has to be taken into account, tolerances of the substructure and the printing plate have to be minimized.

Such an approach to avoid tolerances of the substructure can be the usage of a half-shell with defined thickness which is mounted onto the printing cylinder.

4.3 Experiment No. 3 - Influence of ink viscosity

Experiments No. 1 and 2 revealed the importance of an adequate and homogeneous printing pressure throughout the printing process. From literature, ink viscosity is known to be another important parameter for ink spreading and thus dot/line gain of the contact fingers. Previous work reported that dot gain decreases with increasing viscosity of the flexographic ink (Megat Ahmed et al., 1997).

Within experiment No. 3, three seed layer inks with varying viscosity have been prepared. Viscosity of the inks has been measured by applying shear rates between $\gamma_{min} = 0.01\ s^{-1}$ and $\gamma_{max} = 10\,000\ s^{-1}$ in order to determine the shear-related viscous behaviour of the inks. As shown in Figure 19, all three inks revealed a similar viscous behaviour with increasing shear rate. All inks showed a strong shear-thinning behaviour up to a certain threshold shear rate γ_1. Above γ_1, a near-Newtonian behaviour could be observed, meaning that the viscosity stays nearly con-stant with increasing shear rate. As the surface velocity of the printing cylinder and the lateral velocity of the vacuum substrate holder are equal, a shearing of the ink in the printing nip is only caused by compression. Thus, the effective shear rate in the printing nip might be significantly smaller than γ_1. On the used machine, this shear rate γ_{nip} has been estimated with 0 to $100 s^{-1}$.

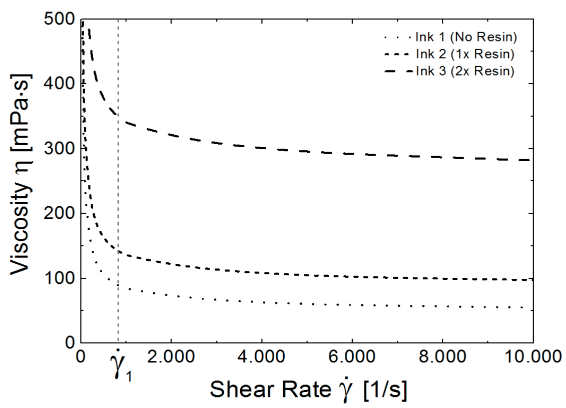

Figure 19: Viscosity in dependence of the applied shear rate (inks 1 to 3)

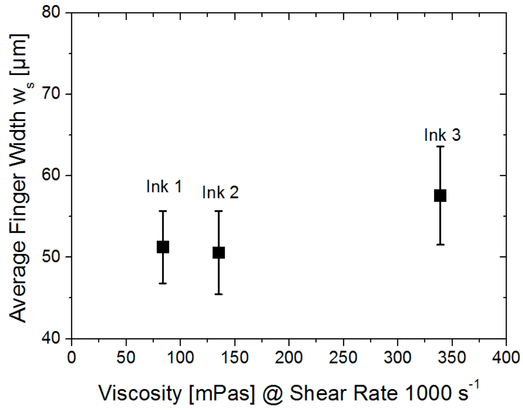

Figure 20: Printed finger width w_s of ink 1,2

The viscosity of the prepared ink formulations has been adjusted by different amounts of added resin. As expected, a higher viscosity could be observed with increasing amount of resin. Contrary to our expectations, the printing tests using inks 1 to 3 did not confirm the presumption of smaller contact fingers with increasing ink viscosity. The finger width w_s stayed in the same range for all three inks despite of different viscosities (Figure 20). However, below the threshold shear rate γ_1, the viscosity of the inks depends very much on the actual shear rate γ_{nip} in the printing nip. At very low shear rates, the viscosity difference of the inks decreases significantly which might explain the comparable printing results of all three inks. Another possible explanation could be the fact that the used solvent showed a very good wetting behaviour on the textured SiNx coated surface. Visual observations and SEM analysis showed that the solvent seemed to be "extracted" out of the ink dispersion shortly after printing while silver particles seemed to spread much less, possibly due to surface adhesion phenomena (Figures 21 and 22).

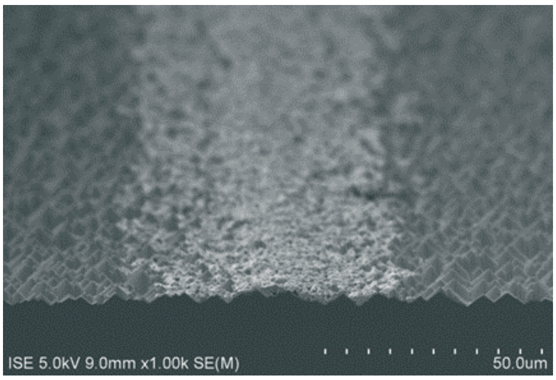

Figure 21: SEM image of a flexo printed seed layer contact finger

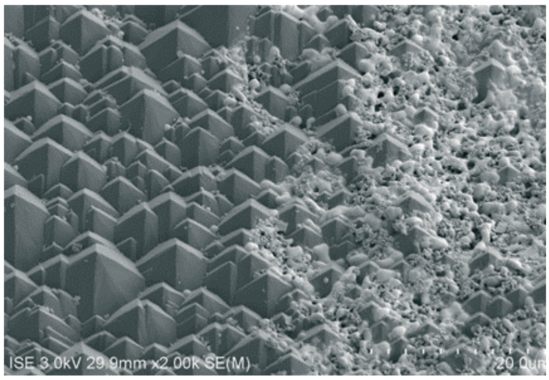

Figure 22: SEM image of the finger edge

The relatively tall pyramids (5-10 µm height) in comparison to the ink layer thickness (approx. 2-4 µm) might also prevent extensive spreading of the silver particles on textured silicon surfaces (Figures 21 and 22). Spreading of metal-filled inks on textured silicon surfaces is governed by a complex interaction between surface micro-structure, wetting properties of ink and substrate, rheological characteristics of the ink and printing parameters. An interesting approach to investigating the spreading behaviour of different components within the ink could be thin-film chromatography (Schwedt, 2007). Ink spreading on textured silicon has to be analysed in much more detail to understand the formation of the final finger geometry during the printing process.

4.4 Experiment No. 4 - Solar cell results

Within experiment No. 4, the cells with flexo printed seed layer front side grid from experiment No. 3 were reinforced with 85 mg Ag using Ag-LIP. The electrical results of the solar cells have been measured on a IV-measurement device as described in section 3.7.

The electric results provide important information about the electric performance of the front side metallisation. As explained in section 2.2.1, j_{sc} plays an important role to evaluate the shading losses due to the front side metallisation. *Fill factor FF*, series resistance r_s and - for a deeper analysis - *specific contact resistance* ρ_c and *grid resistan-*

ce contribution r_{grid} are the most important parameters with respect of the front side metallisation (see section 2.2.2).

Looking at *series resistance* r_s of the measured cells, all groups achieved results between $r_{s,min}$ = 0.7 and $r_{s,max}$ = 0.8 Ω cm² which is in a comparable range to screen printed cells (Figure 23). *Fill factors* of the experimental groups were determined between $FF_{avg,min}$ = 78.6 % (Ink 2) and $FF_{avg,max}$ = 79.2 % (Ink 1) which is also comparable to state-of-the-art screen printed cells (Figure 24).

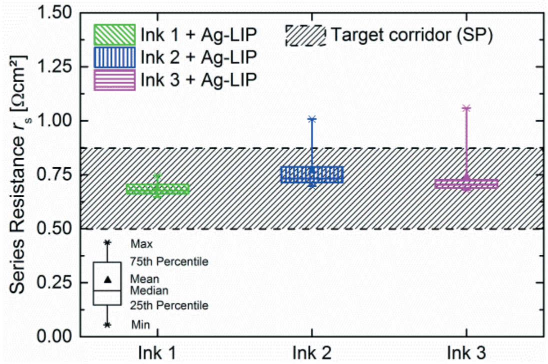

Figure 23: Series resistance r_s of all experimental groups after Ag-LIP

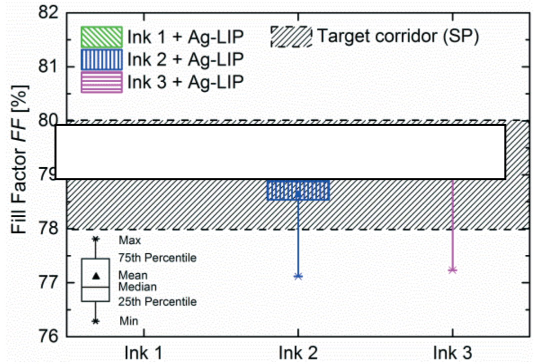

Figure 24: Fill factor FF of all experimental groups after Ag-LIP

Yet, solar cell results could be slightly improved by a further reduction of r_s, resulting in a higher *fill factor FF* and thus higher *conversion efficiency* η. Concerning the front side metallisation, r_s can either be reduced by improving the metal-semiconductor contact and thus reduce specific contact resistance ρ_c or by improving the lateral conductivity of the front side grid and thus decrease grid resistance contribution r_{grid}.

Looking at the specific contact resistance ρ_c of the cells, results between $\rho_{c,min}$ = 3.3 mΩ cm² (Ink 2) and $\rho_{c,max}$ = 4.7 mΩ cm² (Ink 1) were obtained. Latest industrial screen printing pastes achieve lower specific contact resistances down to 1.5 mΩ cm².

In order to compete with state-of-the-art screen printing pastes, the formulation of the flexo seed layer inks should be optimised in respect of contact formation to lowly-doped emitters. Varying the amount of glass or changing the glass system within the seed layer ink could be a path to achieve this goal. Regarding the grid resistance contribution r_{grid}, results between $r_{grid,min}$ = 0.24 Ωcm² (Ink 1) and $r_{grid,max}$ = 0.27 Ω cm² (ink 2) were achieved. These results are comparable to screen printed solar cells. Yet, the j_{sc}-results reveal the predominant potential for further optimisation. Average finger widths between $w_{p,min}$ = 70.6 µm (Ink 2) and $w_{p,max}$ = 85.6 µm (Ink 3) were determined after Ag-LIP (Figure 25). Due to increased shading, this led to comparatively low j_{sc}-results between $j_{sc,min}$ = 37.2 (Ink 2) and $j_{sc,max}$ = 37.3 mA cm⁻² (Ink 1 and 3) (Figure 26). Screen printed cells typically achieve finger widths between 50 and 70 µm and short-circuit current densities j_{sc} between 37.5 and 38.0 mAcm⁻² on this material (shaded area).

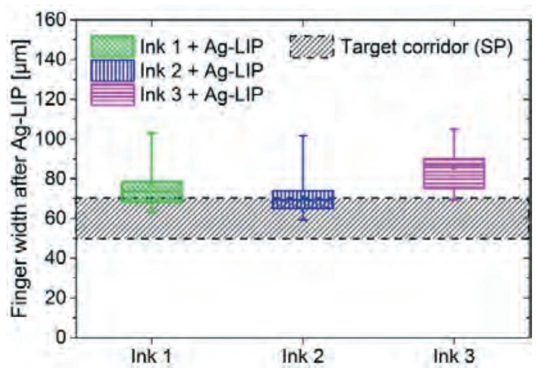

Figure 25: Finger widths w_p of all experimental groups after Ag-LIP

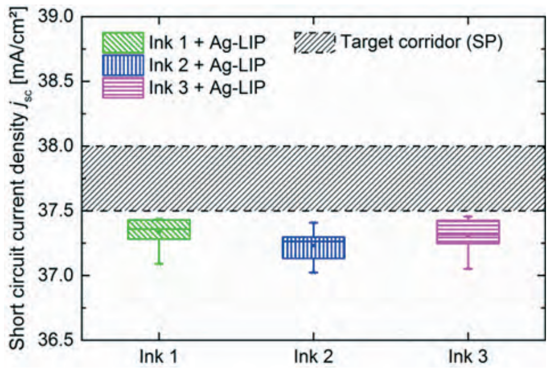

Figure 26: Short-circuit current density j_{sc} of all experimental groups after Ag-LIP

Figure 27 shows the conversion efficiencies η of all experimental groups. The best cell results using flexography and Ag-LIP were achieved with Ink 1 with η = 18.7 %, FF = 79.2 %, V_{oc} = 632 mV and j_{sc} = 37.3 mA cm⁻².

The best individual cell within this group obtained an efficiency of η_{max} = 18.8 %. Screen printed cells on the same material typically reach conversion efficiencies between 18.7 and 19.2 %

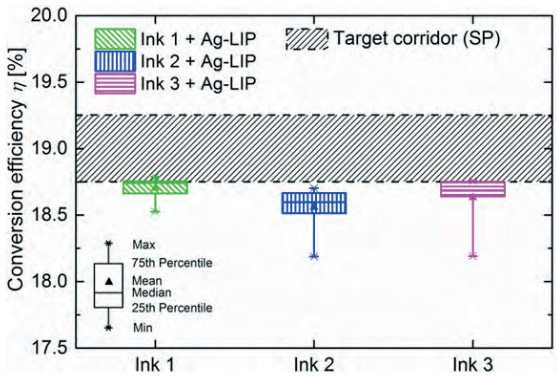

Figure 27: Conversion efficiency η of all experimental groups

5. Conclusions

Experiment No. 1 showed the impact of printing pressure on the printed seed layer finger width w_s. Adjusting the travel distance Δ_z of the substrate holder (and thus increasing printing pressure) by Δ_z = 100 μm in positive *z*-direction led to a considerable contact finger line gain of Δ_{ws} = 48 μm (137 %). This result clearly showed the impact of printing pressure as a key parameter to control the flexo printed finger width. Finger widths down to $w_{s,min}$ = 32 μm could be realised under optimum conditions. This underlines the great potential of this technology to realise narrow contact fingers and thus reduce shading losses considerably.

Experiment No. 2 focused on the uniformity of the printed finger width over the whole wafer area. A considerable variation range of the finger width of $R_{f,max\text{-}min}$ = 19.1 μm has been detected which is critical in respect of a homogeneous subsequent plating step. These variations could be traced back to local thickness tolerances of the wafer material, the used adhesive foam tape and - to a small extent - the printing plate. While the tolerances of the wafer material cannot be avoided, it is essential to use other materials with less thickness variations as substructure.

Experiment No. 3 addressed the influence of the seed layer ink viscosity on the printed finger width. Contrary to our expectations, no significant influence of the viscosity on the finger width could be observed. A possible explanation is the presence of alkaline textured pyramids on the wafer surface which possibly prevent the spreading of the silver particles within the ink.

Within experiment No. 4, solar cells have been fabricated from all wafers processed in Experiment No. 3 by reinforcing the printed seed layer grid using Ag-LIP. The best cell group using flexography and Ag-LIP obtained promising solar cell results of η = 18.7 %, FF = 79.2 %, V_{oc} = 632 mV and j_{sc} = 37.3 mA cm^{-2}. The maximum efficiency of an individual cell within the best group has been determined with η_{max} = 18.8 %.

The results demonstrate that front side metallisation using flexography and Ag-LIP can compete with state-of-the-art screen printed cells. Future approaches will primarily focus on a significant reduction of the flexo printed seed layer finger width to reduce optical shading losses after Ag-LIP. The path to achieve this goal is an absolutely precise adjustment of printing pressure, new concepts regarding the printing form (i.e., realising contact finger areas with undercut), substructure material with less tolerances, as well as a profound and systematic optimisation of further influencing factors like anilox roller, seed layer ink and printing process.

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List of symbols

Symbol	Description	Unit
E	Irridiance (IV-measurement device)	[W m²]
FF	fill factor	[%]
j_{sc}	short circuit current density	[mA cm⁻²]
R_p	parallel resistance	[Ω m⁻²]
r_s	series resistance (area-weighted)	[Ω cm⁻²]
R_c	front side contact resistance	[Ω]
$R_{f,max-min}$	range between minimum and maximum finger width	[μm]
r_{grid}	series resistance contribution of front side grid (line resistance)	[Ω cm²]
$R_{sh,nom}$	nominal emitter sheet resistance	[Ω /sq]
T	temperature	[°C]
T_{Dry}	drying temperature of cabinet dryer	[°C]
T_{FFO}	firing temperature of the fast firing oven	[°C]
t_f	flash duration (IV-measurement device)	[s]
V_{Dip}	dip volume of anilox roller	[cm³ m⁻²]
v_p	printing speed	[m s⁻¹]
V_{oc}	open circuit voltage	[mV]
w_s	seed layer finger width	[μm]
w_p	finger width after plating	[μm]
z_0	starting position of substrate holder / kiss-print-level	[μm]
z	distance differences of substrate holder from position z_0	[μm]
γ	shear rate	[s⁻¹]
η	viscosity	[mPa·s]
η	conversion efficiency	[%]
ρ_{base}	base resistivity of silicon wafer	[Ω cm]
ρ_c	specific contact resistance	[mΩ cm²]
σ_{ws}	standard deviation of seed layer finger width	[μm]

List of acronyms

Acronym	Description
Ag	Silver
Ag-LIP	Light-induced plating of silver
Al BSF	Aluminium back surface field
ARC	Anti-reflection coating
Cz-Si	Czochralski-grown silicon wafer
C-DCR	Coupled determination of Dark saturation Current and series Resistance
FFO	Fast firing oven
LIP	Light-induced plating
OSP	Organic surface protection
PECVD	Plasma enhanced chemical vapour deposition
SEM	Scanning electron microscopy
TLM	Transfer-length-method

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Performance optimization of fully printed primary ($ZnMnO_2$) and secondary (NiMH) batteries

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Abstract

Printed batteries, based on nickel/metal hydride and traditional zinc/manganese dioxide chemistry, were manufactured as single cells in stacked configuration by screen printing. To identify the performance limiting elements of the printed rechargeable battery, a printed Ni/MH battery equipped with a Zn-probe was assembled. The printed batteries were electrochemically analyzed by means of electrochemical impedance spectroscopy in two-electrode configuration and by chronopotentiometry. It was demonstrated that the cathode is responsible for the limitations on battery performance. The influences of the limitations of the cathode inks were examined and new water-based electrode inks were developed. The improvement of the electrode inks decreased the overall impedance and raised the value for the open circuit voltage as well as the operating voltage for the primary battery chemistry. In addition to the electrode optimizations, a printable electrolyte/separator paste, equal in its performance to a conventional electrolyte saturated polymer fleece, was developed, enabling a fully printed battery system.

Keywords: printed battery, electrochemical impedance spectroscopy, probe cell, printable electrolyte

1. Introduction

In recent years, many companies, universities and research laboratories worldwide have started to work in the field of thin and flexible printed energy storage devices (Hilder, Winther-Jensen and Clark, 2009; Willert et al., 2009; Ho, Evans and Wright, 2010; Wendler, Krebs and Hübner, 2011; Janoschka et al., 2012). These devices can be used in low power applications such as RFID chips, medical strips and smart sensor systems. Primary and secondary batteries based on zinc/manganese dioxide, zinc/air, lithium-ion, nickel/metal hydride and, recently, organic radical chemistries can be partially or completely manufactured using printing technologies (Hilder, Winther-Jensen and Clark, 2009; Ho, Evans and Wright, 2010; Wendler, Krebs and Hübner, 2011; Janoschka et al., 2012). This means that all functional elements of a battery, i.e., electrodes, current collectors, electrolytes and separators can be printed. However, at present the performances achieved by these printed electrochemical energy-storage devices are far below those of corresponding conventional batteries, such as button cells. Changes in the distribution of the overvoltage the device are believed to be responsible for this. The overvoltage of a battery can be subdivided in:

- Ohmic resistance, e.g., from the current collectors, active materials and the electrolyte,
- Overvoltage caused from activation polarization in the charge transfer reactions (the actual charge/discharge reaction),
- Concentration polarization (diffusion) caused by charge transfer (Jossen, 2006; Linden and Reddy, 2001, chapter 2.2).

For this reason, further research aiming at optimizing the different elements of printed batteries in order to improve the overall battery performance is required.

Compared to conventional coin cell manufacturing processes, printing technologies provide highly flexible and inexpensive manufacturing processes for short runs as well as for mass production of such batteries. In this paper, the process used for producing several printed primary (Zn/MnO_2) and secondary (Ni/MH) batteries is exclusively flatbed screen printing. The layer thicknesses of the electrodes are up to 150 μm and the coarseness of the particles in them is in the range of 25 μm to 75 μm. Thus, only the screen printing technique is suitable for applying these materials.

Screen printed secondary batteries based on traditional nickel/metal hydride (Ni/MH) chemistry, all containing the same amount of active materials, were investigated in this work.

Furthermore, screen printed primary zinc/manganese dioxide batteries were used as testing system for electrode optimization. As primary non-rechargeable batteries are ready to use after cell assembling, no time consuming cell formation and charging processes are necessary.

The electrochemical performance was evaluated by means of electrochemical impedance spectroscopy (EIS) and chronopotentiometry (CP). EIS is a direct technique to study electrode processes by measurement of changes in the electrical impedance. As an AC impedance technique, EIS can distinguish between electronic and ionic sources of the internal resistance of a battery, thus EIS is an ideal analysing technique for battery development and optimization (Linden and Reddy, 2001, chapter 2.63). Galvanostatic cyclization (for Ni/MH) and galvanostatic discharge (for Zn/MnO2) at constant current (CC) are chrono-potentiometrical measurement methods for measuring the ampere-hour capacity and the cell cyclability.

The purpose of this work was to identify the performance limiting factor of these printed batteries and to optimize them.

2. Methods

The battery design which was used for analysis is a single cell in stacked configuration as schematically shown in Figure 1.

Stacked batteries are typically constructed by the consecutive deposition of layers. The charge transfer in a stacked cell runs through the thickness of the electrolyte/separator layer perpendicular to the electrode layers and is approximately constant. Printed accumulators, based on the nickel/metal hydride chemistry using potassium hydroxide solution (KOH) as electrolyte and printed batteries based on traditional zinc/manganese dioxide chemistry using zinc chloride ($ZnCl_2$) as electrolyte, were manufactured at the Media University (HdM) Stuttgart, Germany.

The substrate, current collector, sealing-layer and the cell assembling process are fixed parameters in this work and will be briefly discussed for the sake of completeness.

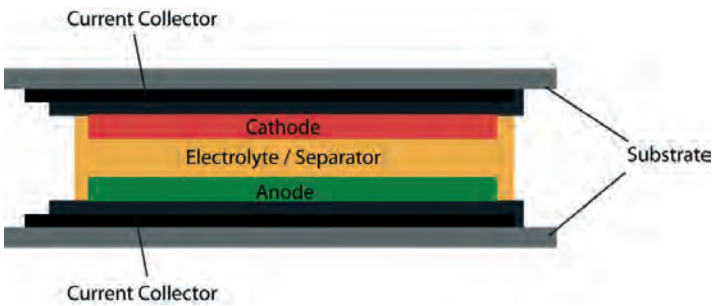

Figure 1: Schematic illustration of a stacked battery design

The barrier properties of the substrate used for batteries are very important. Because the electrolyte must be kept humid, the cells must be sealed. In the case of the alkaline Ni/MH system, it is important to block the diffusion of carbon dioxide into the cell. Otherwise, the carbon dioxide will be carbonizing the alkaline electrolyte, following the reaction in Equation 1.

$$CO_2 + 2\ KOH \rightarrow K_2CO_3 + H_2O \qquad [1]$$

This would lead into an irreversible deterioration of the battery performance because of the increasing electrolyte resistance (Jossen, 2006). For this reason, high-barrier foils are used as a substrate.

In this work, a composite material made of a 15 μm thick layer of aluminium sandwiched between two layers of PET was used for both battery chemistries.

The different functional layers were consecutive applied, using a semi-automatic sheet fed screen-printing unit E2 from EKRA, Germany. In a first step, the current collectors were printed side-by-side on the insulating substrate (Figure 2).

The current collectors consist of commercial silver ink (Electrodag PF050 from Henkel) overprinted carbon ink (Electrodag PF407A from Henkel).

Since silver is not electrochemical inert, it would take part in the electrochemical reaction. The carbon layer serves as a protection layer. The first layer is printed of silver. This is due its good conductivity. The silver ink is ready to use, and consists of 68.5 w% of solid content and has a viscosity of around 17.5 Pas. The silver ink is sheer thinning during printing. After drying in a batch oven (FDL 115 Binder, Germany) at 120 °C for 15 minutes, the thickness of the silver layer is about 8 µm.

One component ready to use is the carbon ink used for silver shielding. It consists of about 35 w% of solid content and its viscosity is around 30 Pas. After drying for 15 minutes at 120 °C, the applied dry coating thickness was about 10 µm. In principle, the current collectors could be made from a single carbon layer. However, this would result in a much higher electrical resistance and would negatively affect the battery performance.

When manufacturing printed batteries, one of the greatest challenges is the leak tightness. Especially the sealing of the collector contact areas is very problematic. This has been solved by printing a sealing layer around the collectors and electrode areas. The sealing layer consists of printable polyurethane hot-melt adhesive, as shown in Figure 2, that gets activated by heat application.

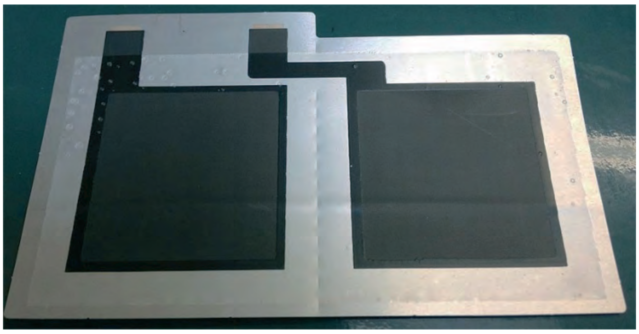

Figure 2:
Printed current collectors with printed hot-melt adhesive as a sealing layer

The active electrode ink materials were provided as powder formulations from VARTA Microbattery GmbH, Ellwangen, Germany. The detailed powder formulations are the intellectual property of VARTA and cannot be described in detail here.

Inks for the Ni/MH chemistry are based on nickel(II)-hydroxide as the active cathode material and metal hydride as the active anode material and were formulated to contain a high amount of active particles, 80 w% for the cathode and 85 w% for the anode ink.

The anode inks were composed of an AB5 hydrogen storage alloy for Ni/MH chemistry and battery grade zinc for the primary cells, mixed with carbon ink (PF407A, as above) and 1-methoxy-2-propylacetate ($C_6H_{12}O_3$) as solvent. Due to its better electrical conductivity, no additional conducting agents for the active powder formulations are needed. The hydrogen storage alloy is based on nickel and rare earths such as lanthanum (La), cerium (Ce), neodymium (Nd) and palladium (Pd) (Jossen, 2006). The cathode inks were also made up of active powder formulations mixed with carbon ink and 1-methoxy-2-propylacetate ($C_6H_{12}O_3$) as solvent (as above). The cathode powder formulation for the Ni/MH system contains nickel(II)-hydroxide (NiOOH) as the electrode active material and nickel-metal powder, cobaltoxyhydroxide (CoOOH) and cobalt-metal powder as conductive agents, due to the poor electrical conductivity of the nickel(II)-hydroxide. The active materials for non-rechargeable Zn/MnO_2 batteries are manganese(IV)oxide as the cathode material and lead-free battery grade zinc for the anode, dispersed in PF407A using the same solvent as above. After drying at 100 °C for 10 minutes, the electrode layer thicknesses achieved in printing are about 80 µm and 70 µm for the anode and cathode inks, respectively.

The active materials for the optimized water-based inks are the same as for the solvent-based ink formulations. In contrast to the 1-methoxy-2-propylacetate solvent-based inks, the newly developed water-based inks are based on a completely different binder formulation. Due to the use of the same printing screen (PET 1500 48/123-55 Y), the layer thicknesses, after drying at 80 °C for 5 minutes, of the printed elec-trodes are in the same range as for the solvent-based inks.

The optimized electrodes contain less than 5 w% of binder in the dry layer. To increase the compaction of the highly porous electrode layers, a mechanical post-treatment process is required. A manual lab-scale super-calender was used to flatten the electrode surfaces. The surface topology was measured using the Focus Variation incorporated in the Alicona microscope. The analyzed area was about 8x2 mm. As a surface roughness parameter, the S_a value was chosen to rate the impact of electrode calendering on the electrode surface. S_a is a 3D parameter expanded from the 2D roughness parameter R_a. It expresses the mean of all measured roughness values of the analyzed surface, with no distinction between peaks and lows.

When conventional electrolyte soaked polypropylene fleece was used after electrode calendering, the separator and the electrolyte were manually placed in-between the electrodes before cell assembling. For manufacturing the batteries using printing processes only, a printable electrolyte/separator-paste has been developed and patented (Wendler and Krebs, 2011). The main ingredients of this paste are 33 % potassium hydroxide solution (for Ni/MH chemistry) respectively 25 % $ZnCl_2$ (for Zn/MnO_2 chemistry), water-soluble sodium salt of carboxymethylcellulose as thickener, and solids which act as a kind of spacer for the electrode separation. The printable separator/electrolyte paste is printed on top of both electrodes before flipping one side on top of the other and laminating the folded cell at 110 °C.

A set of printed Ni/MH batteries equipped with a Zn-probe was assembled to identify the performance-limiting element of the system. As Zn-probe, a small Zn-sheet was applied manually in the separator layer, electrically insulated from the electrodes with regard to the electron flow, right before the lamination process. EIS measurements on fully assembled cells, equipped with a Zn-probe, enables measurement of the anode and cathode separately against the Zn. A great advantage of the probe-cell testing is that these measurements are taken under real conditions. This means that the cells have passed through the lamination process, the quantity of electrolyte is reduced and corresponds to real conditions and the cell forms an internal gas pressure during cyclization, which may influence the overall battery performance. A printed battery, equipped with a Zn-probe is schematically illustrated in Figure 3.

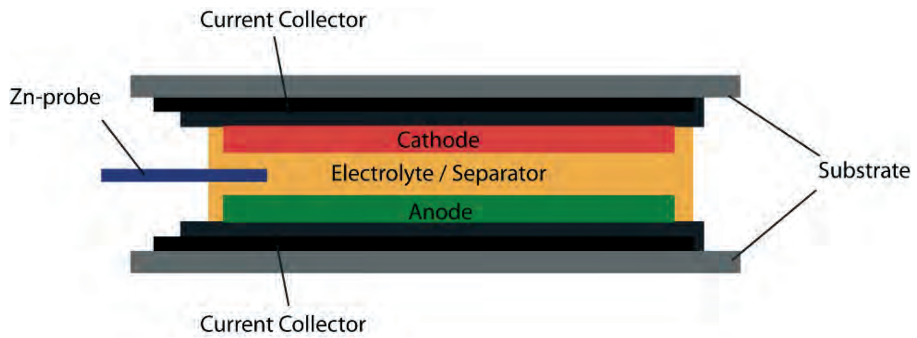

Figure 3: NiMH testing cell equipped with a Zn-probe

The printed batteries were electrochemically analyzed by electrochemical impedance spectroscopy (EIS) in a two-electrode configuration in a frequency range from 10 mHz to 100 KHz.

In addition to EIS, galvanostatic cell cyclization with a 2 mA constant current (CC) for the rechargeable system, as well as galvanostatic discharges of 1 mA CC for the primary batteries, were used.

All electrochemical measurements were performed using a Bio-Logic VMP 3 Potentiostat (Bio-Logic SAS, France) at VARTA Microbattery GmbH in Ellwangen, Germany.

3. Results

3.1 Three experimental steps

The experimental findings will here be provided in three main parts. At first, the identification of the performance-limiting elements of the printed rechargeable Ni/MH batteries was carried out.

The results of these investigations were used to optimize the electrode inks. The study was completed by a performance comparison between a printable electrolyte formulation and a non-printed conventional electrolyte saturated polymer fleece.

3.2 Identification of the performance-limiting element

The printed rechargeable solvent-based Ni/MH batteries were analyzed using galvanostatic cell cyclization with a 2 mA constant current, for up to 100 cycles. The polarity reversing limits were set at 1 430 mV for end of charge and 1 000 mV for end of discharge. Figure 4a shows an example of cell cyclization where the cell contains 0.09 g of active cathode material and about 0.21 g hydrogen-storage-alloy. The amount of active material of the cathode is defining the capacity of the whole system. The mass ratio between the electrodes is not coincidentally chosen. If the accumulator gets overcharged, the cathode produces oxygen. To prevent the cell against overpressure, the anode is oversized to absorb the oxygen.

The theoretical mass specific capacity for NiOOH is about 292 mAh g^{-1}. The theoretical capacity of this cell is 26 mAh (Linden and Reddy, 2001, chapter 1.11). As can be seen in Figure 4b, the cell performance in the case of a charge acceptance with only 1.2 mAh, as well as a discharge performance with 0.5 mAh is unsatisfying. To identify the performance limiting battery elements, EIS measurements on printed Ni/MH cells equippe with a Zn-probe were performed.

In Figure 5 the probe-cell and the test setup for the measurements is shown.

The results of electrochemical impedance spectroscopy measured on a probe-cell containing solvent-based electrodes are depicted using Nyquist-plots. Nyquist-plots are used to visually represent the real versus the imaginary components of the impedances, measured from high (100 KHz) to low (10 mHz) frequencies, in a complex plane.

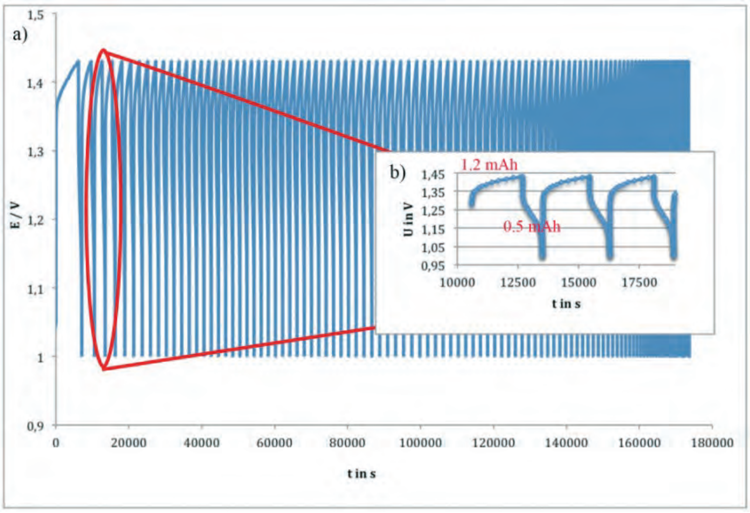

Figure 4: Cell cyclization at 2 mA
a) for 100 charge/discharge cycles and b) three cycles in detail

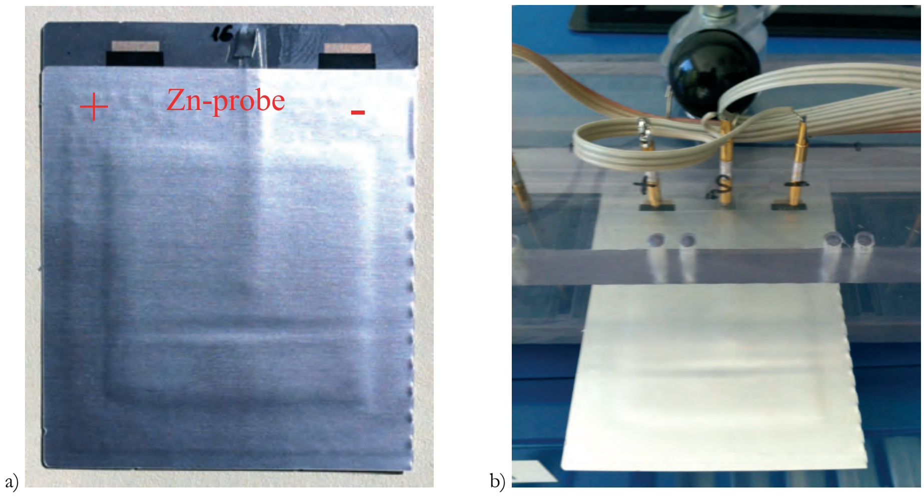

Figure 5: Printed Ni/MH-probe-cell
a) integrated in the measurement setup b) for EIS measurement

As can be seen in Figures 6a-d, the majority of the overall cell impedances were caused by the cathode. Especially Figure 6d shows that the cell impedances at low frequencies are clearly dominated by the cathode. By comparing Figures 6b-c, it can be clearly seen that the imaginary part of the cell impedances for the cathode is about 14 times higher than for the anode. The EIS measurements for the Ni/MH probe-cell have shown that more than 90 % of the overall cell impedances are caused by the cathode.

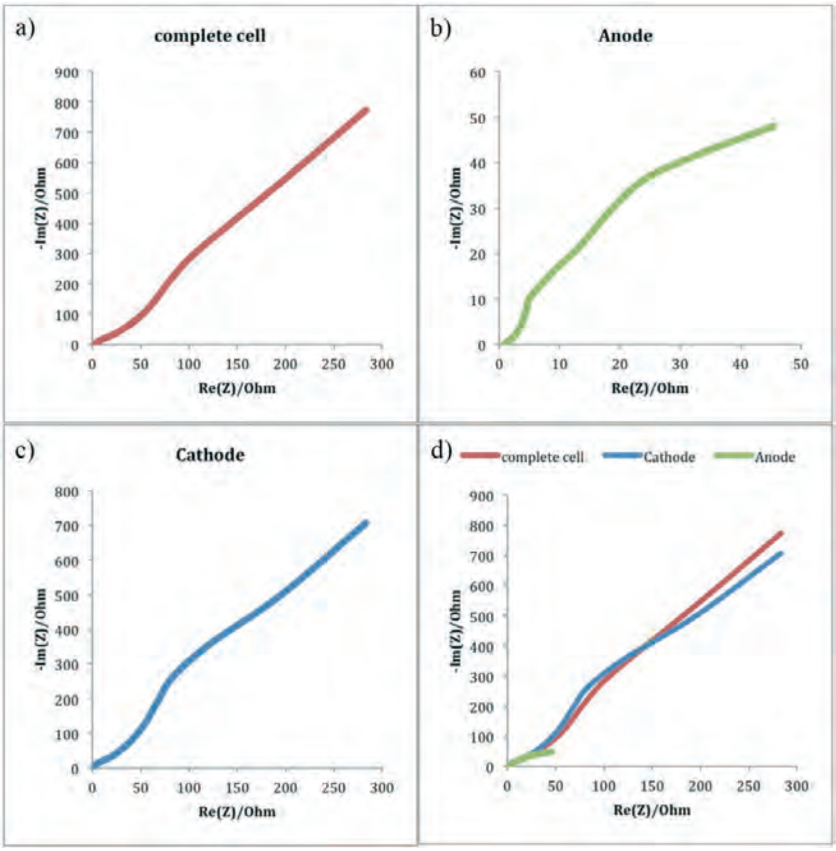

Figure 6: Impedance spectra measured on a Ni/MH probe-cell. Depicted are impedances for the complete cell a), for the anode b), for the cathode c) and a comparison of the three plots in d)

When Zn/MnO_2 chemistry was used as a testing system in the development process of printable electrolytes during the cathode ink mixing, using 1-methoxy-2-propylacetate as solvent, an exothermal reaction occurred. An exothermal reaction during ink preparation for the Ni/MH cathode ink was not noticed in our experiments. However, NiOOH was discoloured from greenish to black when adding 1-methoxy-2-propylacetate - an indication of a chemical reaction. This discoloration was initially not recognized due to the amount of conductive carbon black in the PF407A. It was assumed that the solvent used for electrode ink synthesis causes chemical side reactions and negatively influences the cathode performances. For this reason, a complete re-design of the electrode inks was necessary.

3.3 Re-design of electrode inks

3.3.1 Ink development

The organic solvent 1-methoxy-2-propylacetate was substituted by distilled water. Different latex-based binders in combination with thickening agents, which are typically used for manufacturing conventional battery electrodes, were used for the newly developed printable electrode inks. The exact ink formulation cannot be described here, due to intellectual property restrictions set by VARTA Microbattery GmbH.

These newly developed electrode inks are fundamentally different in their binder composition compared to the formerly used Electrodag 407A.

Nevertheless, the printability of these newly developed inks is comparable to that of the earlier solvent-based ink formulation, as can be seen at the printed Ni/MH cell in Figure 7.

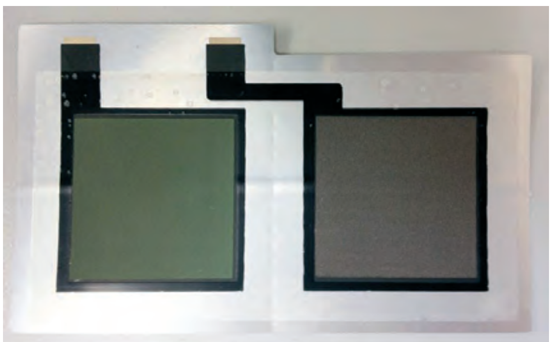

Figure 7: Printed water-based Ni/MH electrodes before electrolyte printing

On the left, the cathode with its typical greenish colour is shown. The printed electrode has a sharp contour and the surface is homogeneous with zero defects.

3.3.2 Mechanical electrode post-treatment

As described in section 2, the optimized electrodes contain less than 5 w% of binder in the dry layer. To increase the compaction of the highly porous electrode layers, a mechanical post-treatment process is required. A manual laboratory scale supercalender was used to flatten the electrode surfaces. The surface topology was measured using the Focus Variation incorporated in the Alicona microscope. Sample results of electrode calendering are shown for the MnO_2 cathode in Figures 8a-d.

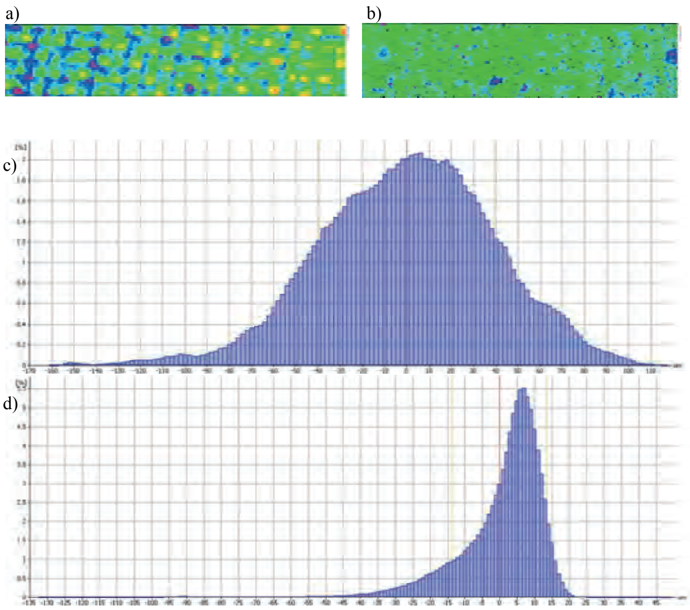

Figure 8: False colour representation of the (a) un-calendered surface and (b) calendered surface. Corresponding surface topology histograms for the (c) un-calendered and (d) calendered electrode

The mean electrode thickness was reduced by 30% to 47 µm and the S_a value as the mean of all measured roughness values, with no distinction between peaks and lows, was reduced by 71%, from 31 µm to 9 µm.

To evaluate the influence of the mechanical post-treatment process from an electrochemical point of view, EIS measurements of primary Zn/MnO_2 batteries, activated with 25% $ZnCl_2$ aqueous electrolyte using a conventional polypropylene separator fleece, were performed. Figure 9 shows that the mechanical post-treatment process significantly reduces the overall battery impedances, in particular the charge transfer resistance.

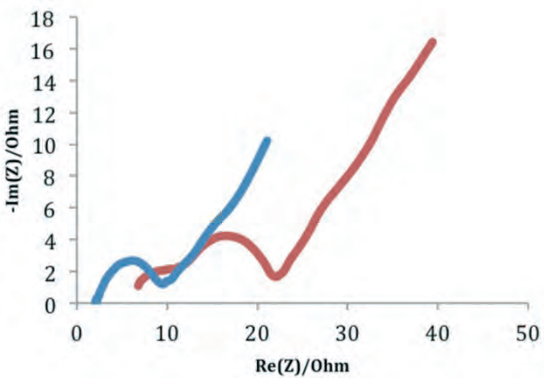

Figure 9: Influence of mechanical post-treatment on battery impedances, (blue) battery with post-treated electrodes and (red) without calendering

3.3.3 Performance of optimized primary electrodes

The primary Zn/MnO_2 system was chosen as a testing system for the water based electrode ink system. If a rechargeable system would have been chosen, a time consuming cell formation would have been necessary. As expected, no heat development during the ink mixing was detected, a first indication of the absence of chemical side reactions. Printed primary Zn/MnO_2 batteries, constructed with solvent-based and water-based electrodes, were discharged at a constant current of 1 mA. Figure 10 shows representative discharge profiles of the different electrode ink formulations.

The plateau shape of the discharge profile for batteries using the solvent-based ink formulation (shown in red), corresponds to a two-phase discharge. This effect is typical for systems with chemical side reactions, causing changes in the reaction mechanism and potential in active materials. The discharge profile for the optimized primary battery (blue) shows a flat one-phase discharge, where the effect of change in reactants and reaction products is minimal until the active materials are nearly exhausted (Linden and Reddy, 2001, chapter 3.3).

The ampere-hour-capacity of both cells is nearly identical. The specific charge density would be 1.9 mAh cm^{-2} for an assumed active electrode area of 9 cm^2. The open circuit voltage (OCV) of about 1.4 V for the unoptimized battery is far too low for an electrochemical system with a nominal voltage of 1.5 V. In contrast, the OCV of 1.65 V and the discharge profile of the optimized cell is according to the literature (Linden and Reddy, 2001, chapter 8.1).

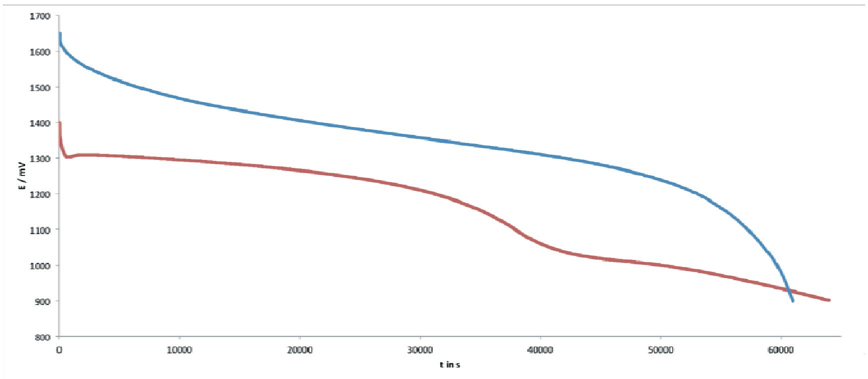

Figure 10: Discharge profile at 1 mA of representative optimized (blue) and un-optimized (red) printed primary batteries

3.3.4 Ni/MH probe-cell analysis of the optimized electrodes

The positive experience with the water based electrode ink system can be reproduced in the Ni/MH system. EIS measurements on Ni/MH probe-cells, based on the newly developed water based electrode inks, were performed according to section 3.2 in this paper. The results are depicted in Figures 11a-d and show a massive drop in the overall cell impedances compared to the probe-cell containing the unoptimized electrode formulation.

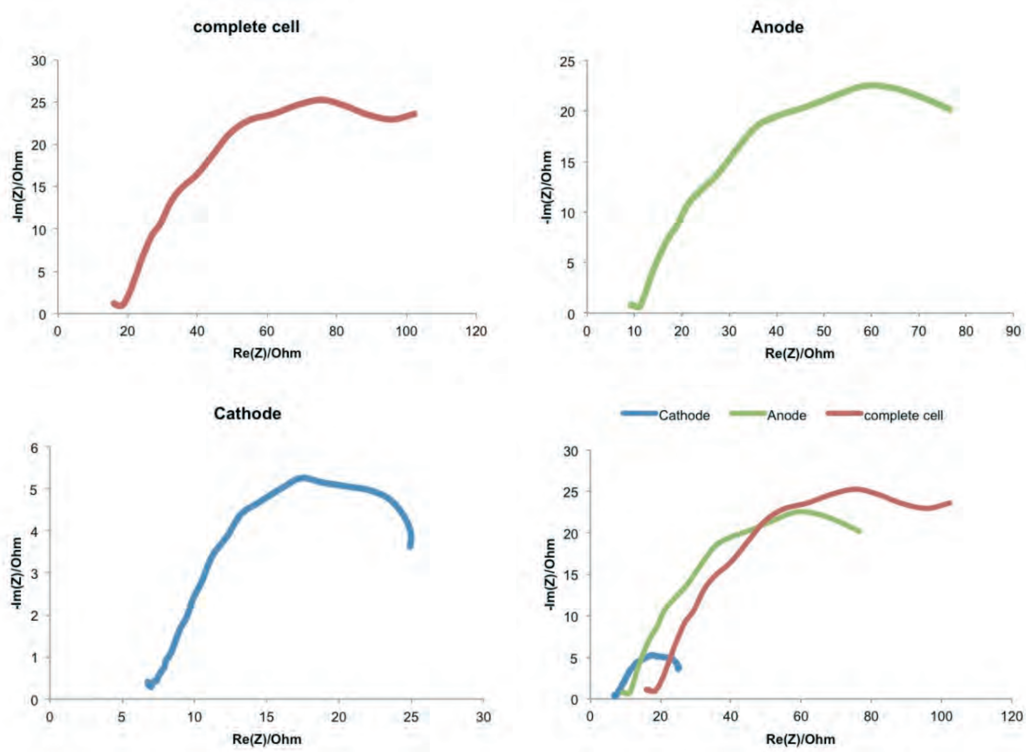

Figure 11: Impedance spectra measured on an optimized Ni/MH probe-cell. Depicted are the impedances for a complete cell a), for the anode b), for the cathode c) and a comparison of the three plots in d)

The reduced imaginary part of the impedances for both electrodes indicate that the electro-active materials are better wetted in the optimized cell than in the solvent based one. This means that the electrolyte saturation of the electrodes has increased, thus a higher amount of electro-active surface takes part in the reaction and the diffusion resistance is decreased. Especially the cathode benefits from the electrode optimization. The real part of the impedances for the NiOOH electrode is decreased by one order of magnitude compared to the old cell.

3.3.5 Cell cyclization of optimized Ni/MH batteries

As can be seen in Figure 12, the impedance spectrum of the printed Ni/MH battery without optimized electrodes shows significant higher impedances than a battery with improved electrodes.

The charge transfer resistance can be extracted from the Nyquist-plots in Figure 12. The optimized battery shows a charge transfer resistance of about 20 Ω compared to about 45 Ω for the unoptimized version.

The significantly reduced cell impedances suggest an improvement of the cell performance. Therefore printed rechargeable batteries were cycled with a 2 mA constant current. The amount of electro-active material used in these cells is comparable to the cell in section 3.2, therefore a capacity of about 26 mAh was expected. As and example, cell cyclization over a period of 220 hours is shown in Figure 13. A drastic decrease of discharge capacity, after the first six to eleven discharge cycles, can be seen.

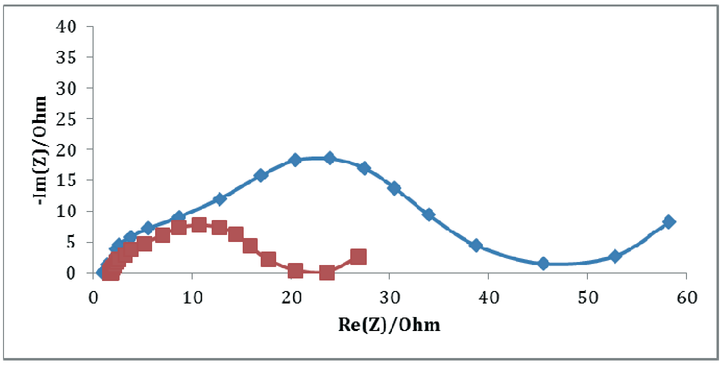

Figure 12: Nyquist-plots of the impedance data, measured on fully printed rechargeable NiMH batteries after 13 hours of cell formation: (blue) un-optimized battery, (red) optimized battery

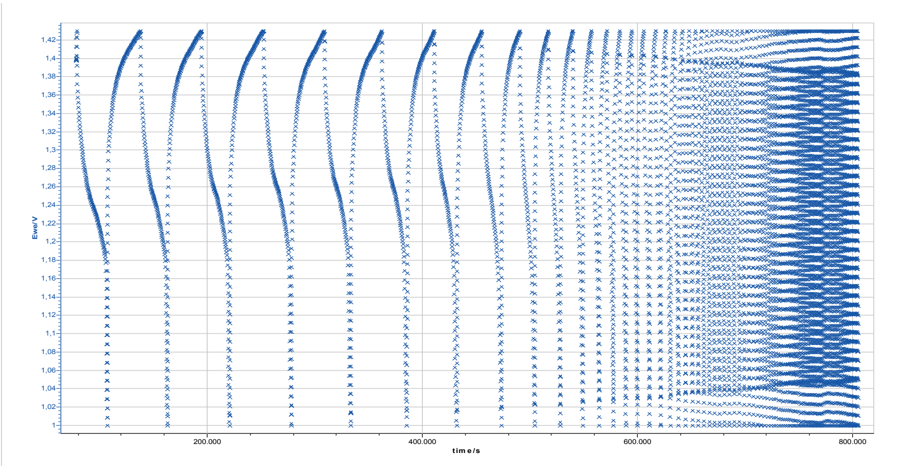

Figure 13: Cell cyclization of a water-based fully printed Ni/MH battery over a period of 220 h

This effect is clarified by comparison of the charge/discharge capacities [Q] of the first 20 cycles as illustrated in Figure 14.

The achieved discharge capacities decrease from 15.5 mAh at the first to 5.2 mAh at the 11th cycle before they stabilize at about 2 mAh after the 19th cycle.

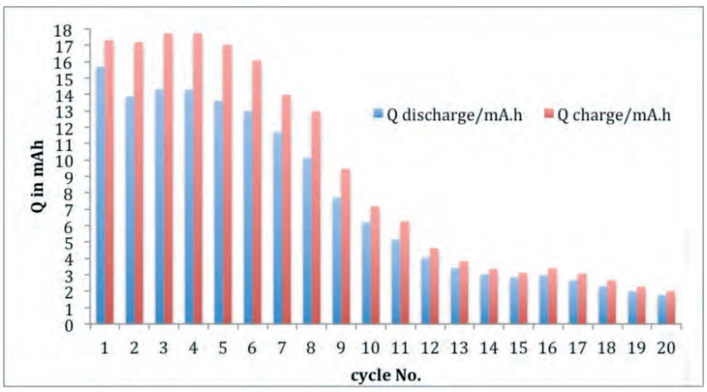

Figure 14: Comparison between charge and discharge capacities of a fully printed Ni/MH battery

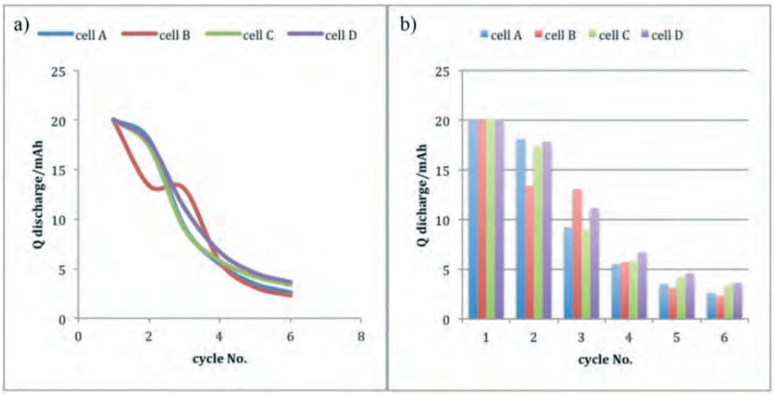

Figure 15: Drop of discharge capacities of four different printed Ni/MH batteries as a line chart (a) and a bar chart (b) presentation

Four more cells were cycled under same conditions, but due to time constrains, only for six cycles. In Figures 15a-b, the achieved discharge capacities, with the same effect as shown above, are illustrated. As can be seen, the starting capacities for these four cells are nearly identical at about 20 mAh before the values fall steadily to under 5 mAh at the sixth cycle.

3.4 Printed separator

One of the major problems in manufacturing thin flexible printed batteries is the handling of the electrolyte/separator. In conventional battery manufacturing, the separator is a polymer-fleece material soaked with electrolyte placed onto the electrodes. For manufacturing batteries using printing processes, a printable electrolyte/separator-paste has been patented by VARTA (Wendler and Krebs, 2011). The main ingredients of this paste are 33 % potassium hydroxide solution for Ni/MH chemistry, respectively 25 % $ZnCl_2$ for Zn/MnO_2 chemistry, water-soluble sodium salt of carbo-xymethylcellulose as thickener and solids which acts as spacer for the electrode separation. The printable separator/electrolyte paste was printed on top of both electrodes, as shown in Figure 16, before flipping one side on top of the other and laminating the folded cell at 80-100 °C.

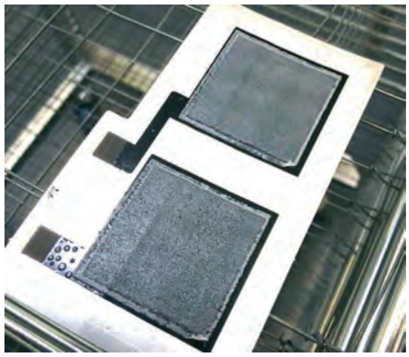

Figure 16: Screen printed electrolyte/separator (whitish layer) paste on top of electrode

In a Nyquist-plot, the intersection of the real part of the impedance (Re(Z)/Ω), where the imaginary part of the impedance (-Im(Z)/Ω) is zero, indicates the solution (electrolyte) resistance R_s at high frequencies (kHz). Figure 17 shows a comparison of a printed Ni/MH battery with conventional (non-printed) electrolyte/separator and a cell with a fully printed electrolyte/separator layer.

Highlighted in the red box are the values of the electrolyte resistance, with 0.95 Ω for the non-printed electrolyte compared to 0.98 Ω for the fully printed one.

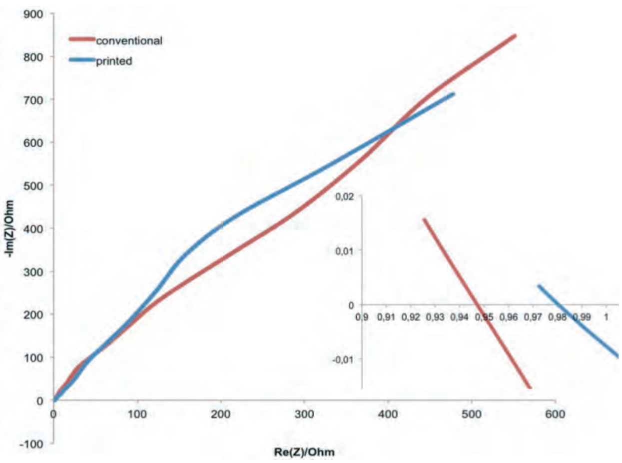

Figure 17: Nyquist-plot of the impedance data, measured before cell formation: printed Ni/MH battery with conventional electrolyte/separator (red); fully printed Ni/MH battery (blue)

4. Discussion and conclusion

The achieved capacities of the printed Ni/MH batteries are too low in comparison to the theoretical values corresponding to the printed active masses. EIS measurements of the Zn-probe equipped testing systems have shown that the cathode is the essential determinant for the overall impedances. It has been demonstrated that the organic solvent used for electrode ink formulation is responsible for the limitations of the cathode materials. Newly developed water-based electrode inks were tested using non-rechargeable Zn/MnO_2 chemistry. The improvement of the electrode inks decreased the impedance of the battery and raised the value for the OCV as well as the operating voltage for the primary batteries.

In addition to the electrode optimizations, a printable electrolyte/separator paste, comparable to a conventional electrolyte saturated polymer fleece in its performance, was developed and was shown to enable a fully printed battery system.

The capacity of the optimized rechargeable batteries was drastically improved for the first cycles of cell cyclization compared to the un-optimized cells.

However, the cyclability of the printed Ni/MH batteries is unsatisfying and further research is needed to identify the reasons for the deficiencies in cell cyclization.

Acknowledgements

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Increased performance of printed electroluminescent devices using a transparent conductive laminate

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Abstract

The paper describes the development of a novel thick film top emission electroluminescent (EL) lamp which displays excellent performance and is fabricated without an ITO film and is encapsulated for safe use. The conductive adhesive laminate can be applied to low cost opaque substrates such as paper. The development utilises a commercial contact adhesive which has been blended with a PEDOT:PSS solution to form a liquid which can be coated onto a conductively micro-structured PET film. This PET film can then be applied under minimal pressure to the EL lamp, to provide a laminated top electrode. An optimization of the material formulation and deposition thickness was required in to order the balance the primary requirements of the coating; namely adhesive tack, conductivity (lateral and through film) and optical transparency. For example, a pure adhesive layer would achieve excellent adhesion but would not be conductive while a pure PEDOT:PSS layer would provide the necessary conductivity but lack any adhesive properties. Non-optimised light output achieved 88 % of that of conventional glass devices and this could be further optimised through manipulation of the PEDOT:PSS concentration and film thickness to create devices with an output of 96 % of that of conventional devices. The optimum balance was found to be a 15 µm film with a 1.25 % concentration of PEDOT:PSS in the adhesive. This material and specification is screen printable, thus the entire material stack can be manufactured using a common single low cost printing process. In order to examine whether silver could be replaced in the manufacture, lamps were manufactured on an aluminium substrate. These achieved 87 % of the light output of conventional lamps although they showed a variability which was associated with the fragility of the substrate and its subsequent variation in flatness during lamp manufacture. The work has shown that EL lamps can be printed that are self-encapsulating and possess a performance close to that of conventional bottom emission lamps.

Keywords: electroluminescence, transparent conductive, adhesive

1. Introduction

There is now a range of options for flexible printed light emitting devices. The two most popular options are AC electroluminescence (EL) and Organic Light Emitting Diodes (OLEDs). While the two technologies both emit light, they differ in the way the emission is produced. OLED devices work by the principle of injection of electrons and holes near a p-n junction to emit light and are current devices. EL devices emit light by the acceleration of electrons in a high electric field causing excitation by impact (Mauch, 1996).

This principle of operation gives them some fundamental disadvantages over OLEDs, such as high operation voltage, lower operational lifetime and limited brightness. Typically, EL lamps operate at 100-150 V AC, the brightness half life is 1 000 hrs and the lamp output has a maximum of 200 cd m^{-2}.

Notwithstanding these limitations, printed EL (in a top emission structure, Figure 1a) is now considered a mature technology with many applications in back lighting, promotional displays, emergency lighting (Hecker, 2009) and their characteristics are widely reported (Allieri et al., 2002; Ciez et al., 2007).

In contrast, there are few, if any, OLED commercial applications where liquid deposition is the manufacturing process - commercial OLED exploitation being dominated by vacuum deposited small molecule materials.

An issue affecting both types of devices is that they commonly use inherently expensive ITO/FTO (indium tin oxide / fluorine-doped tin oxide) metal oxide coated substrate and / or vacuum deposit contacts at some stage during their fabrication. While metal oxides still provide the highest transparency and conductivity, their lack of easy processing and their high cost has led to them becoming the barrier to success for many printed electro optic devices technologies (Kirchmeyer and Reuter, 2005). The most common printable alternative is poly-(3,4-ethylenedioxythiphene): poly-(styrene-sulfonate) (PEDOT:PSS), (Elscher et al., 2010). This has been shown to be a suitable replacement in organic photovoltaics (OPV) (Winther-Jensen and Krebs, 2006; Aernouts et al., 2004), polymer-dispersed liquid crystal (PDLC) devices (Kim et al., 2008) and also OLED (Jabbour, Radspinner and Peyghambarian, 2001).

The increasing maturity of the technology has now led to commercially available PEDOT:PSS formulations for a wide range of applications including light emitting devices. Past studies have showed that PEDOT:PSS can be used in EL devices where the ITO coated substrate is substituted for a less expensive bottom opaque substrate such as paper (Jewell, Claypole and Gethin, 2012; Kim et al., 2010) as well as on other substrates such as polycarbonate (Weigelt et al., 2012). This "top emission" mode of operation has the PEDOT:PSS coated as the upper layer, with the light now being emitted through the PEDOT:PSS, Figure 1(b).

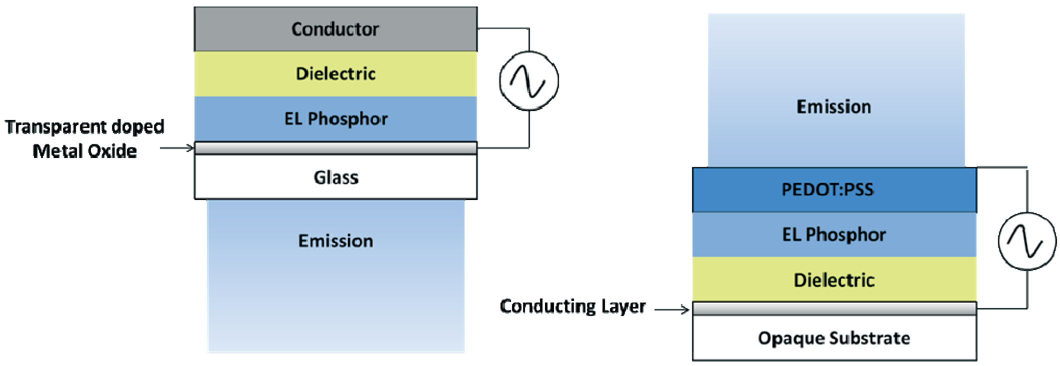


Figure 1: Cross section schematic of (a) a conventional bottom emission EL device using a doped metal oxide coated glass and (b) a top emission device using PEDOT:PSS and an opaque substrate

However, top emission EL lamps manufactured using PEDOT:PSS only gives a performance of 50% when compared with a conventional structure and the reason for this has been attributed to incomplete coverage of the phosphor particles by the thin PEDOT:PSS layer (Jewell, Claypole and Gethin, 2012). It also requires a form of encapsulation / lamination for safe operation as the upper surface is at high voltage. A recent technology which may overcome the limitations associated with lower output and an accessible high voltage electrode is a Transparent Conductive Adhesive (TCA) laminate. This is manufactured when PEDOT:PSS is mixed with an acrylic based adhesive (Bryant et al., 2014), and is subsequently applied to a plastic substrate into which a nickel mesh has been embossed. This proprietary substrate possess 5 µm conductive structures at 30 µm spacing below the plane of the substrates (Epigem, 2013). The mesh provides high macro lateral conductivity (nominally 1.2 Ω /□) while the TCA provides the lateral conductivity between the nickel mesh strands.

The TCA / mesh structure was predominately developed for dye sensitised and perovskite solar cells allowing ITO-free cells with an efficiency of 15% to be manufactured (Bryant et al., 2014). The advantages of this technology development are: ITO is eliminated, it can be cured separately making it applicable to low temperature curing systems, the soft nature of the adhesive makes it conformal to a wide range of geometries, it can be applied to flexible barrier materials, and it provides a single step conductive layer/ lamination process. In addition, for EL applications, it provides an insulating layer to prevent user access to the high voltage top electrode. The authors will present a way in which, when used in conjunction with the embossed grid, a TCA /mesh structure can be used to form a transparent conducting contact to an EL device by lamination.

A further commercial obstacle to EL is the silver required as the base electrode. In addition to the demonstration of an EL using the TCA, an additional aim was to develop an EL device fabricated on aluminium metal using the TCA-laminate set-up. Aluminium has many advantages over silver materials in that it is low cost, widely available, has excellent barrier properties, and can be made in a variety of different thicknesses depending on the application. In addition to this, aluminium is already coated by a continuous roll-to-roll process and coating of an EL device and lamination is applicable without significant additional cost. The aim of this investigation was to show firstly that a TCA-laminate can be utilised within an EL device and study how the properties of the TCA influences lamp emission, and secondly how this could enable devices to be fabricated on aluminium.

2. Methods

A TCA-laminate was fabricated using PEDOT:PSS (EL-P3145, AGFA) within an acrylic based adhesive matrix (F46, Styccobond). Conventional devices were fabricated by bar casting a 45 µm wet height each of phosphor-dielctric-silver ink (Luxprint, DuPont) onto a piece of FTO coated glass (Tec-7, NSG-Pilkington) with drying at 140 °C between consecutive depositions. This processing technique provides a film thickness which is comparable to screen printing but was chosen as the material quantity required for the studies was significantly lower. Given the variations in the properties of the materials used in the study, the quantity wasted during screen clean up in screen printing would have been significant. FTO coated glass was used as the transparent conductor in the study in place of ITO coated PET. The glass provided a more thermally robust substrate and is readily available in the sheet resistance specified (7 Ω/□). This is a lower sheet resistance than that which is usually specified for EL lamps (typically 15 - 150 7 Ω/□) and thus provides a sterner test for the TCA material. In the results, the concentration of PEDOT:PSS is quoted as the value of PEDOT:PSS within the dry film which varied in the range 1 - 1.75 %.

The TCA-laminate devices were prepared in the same way as conventional devices only the layer succession was dielectric - phosphor - TCA-laminate applied using hand pressure, with no additional heating step following the TCA-laminate application. An aluminium substrate was also used which was exchanged directly for the silver coated substrate construction. A schematic of the TCA-laminate devices manufactured is shown in Figure 2. The active lamp area in all devices was 6.25 cm².

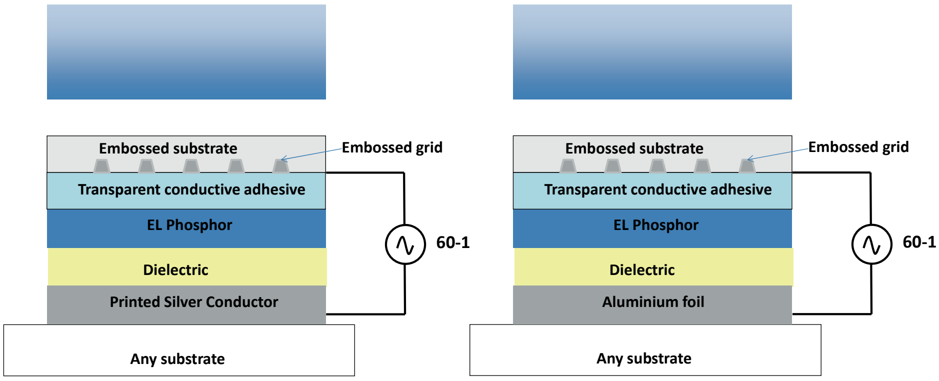


Figure 2: Schematic cross section schematic of a top emission device using a TCA-laminate on (a) printed silver and (b) Aluminium

Transmission measurements were conducted on a Perkin Elmer Lamda 750s with a 60 mm integrating sphere. The lamps were driven by a sinusoidal voltage produced by an EL specific power supply (LM30, Light & Motion) with the excitation frequency fixed at 400 Hz and with applied voltages of 75, 100, 125 and 140 VAC. Luminescence was measured using a spectrophotometer in emission mode (Spectrolino, Gretag-Macbeth) with a spot size of 4 mm. The measured lamp outputs are shown as a percentage of the output of Tec-7 conventional build lamps.

Measurement of adhesive "tack" was carried out in accordance with international standards (ASTM International, 2003). In this test, a rolling ball is given a fixed speed by an incline and traverses across the adhesive layer. The tack value is then measured as a linear distance, with lower tack producing increasing distances.

3. Results

An initial top emission EL device made with a TCA-laminate with a 1 % PEDOT:PSS concentration was found to emit around 88 % of that of a conventionally built lamp with an FTO glass electrode at an applied AC voltage of 140 VAC (Figure 3). As the applied voltage is decreased, the output of the two lamps become more alike until at 100 VAC they are the same. Figure 3 also shows that an EL device made with a laminate that contained a 0 % PEDOT:PSS concentration had no emission. Thus, the conductive mesh without any transverse conduction between the grid lines is unable generate the field required for light emission. Figure 3 also shows that the TCA-laminate technology can be applied to the manufacture of EL lamps, but that there is a penalty compared to the standard material set. The remainder of this study examines how this technology could be optimised to improve the light emission, processing and performance.

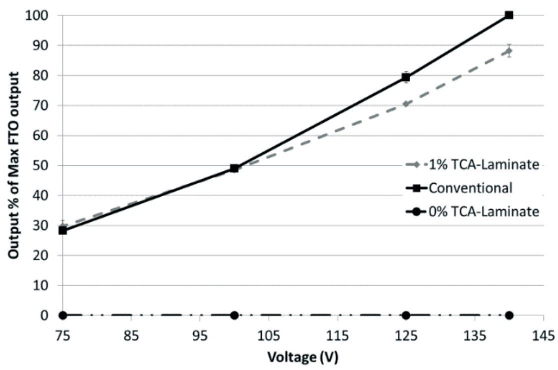


Figure 3: The performance of a 1 % TCA - laminate top emission EL device compared to a conventional EL device

In optimising the process, primary factors such as PEDOT:PSS concentration and film thickness must be balanced so that the maximum through and lateral conductivity is achieved without sacrificing the transparency or the adhesive properties. The influence of the PEDOT:PSS on the dry film transmission is illustrated in in Figure 4 where transmission spectra of the layers of FTO glass and TCA-laminate can be seen. These correspond to the layers which the emitted light would travel through and shows that at 490 nm the TCA-laminate's transmission is lower than that of Tec-7 with 76.5 and 84.1 % respectively. Thus, even a small increase in PEDOT:PSS concentration can cause a significant change in transparency.

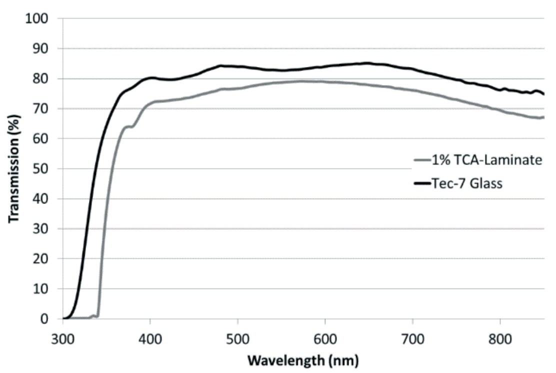
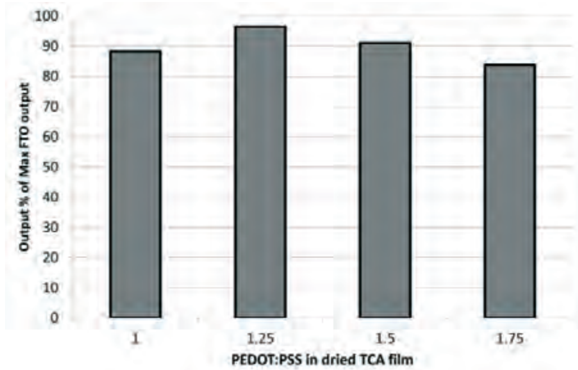


Figure 4: UV-Visual transmission spectra for a 1% TCA-laminate and Tec-7 glass at 300-850 nm

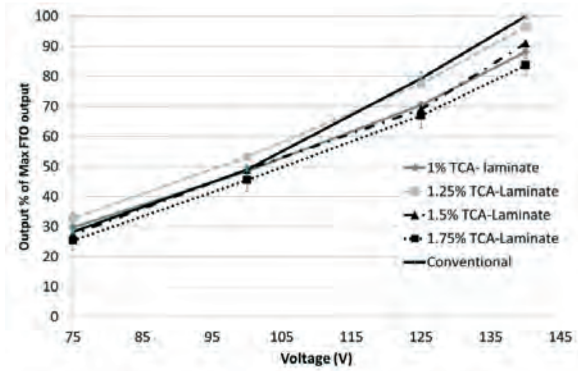
When the PEDOT:PSS concentration was increased from 1 % to 1.75 %, the emission increased to 96 % at a concentration of 1.25 % and then subsequently decreased to 91 % and 84 % as the concentration increased to 1.5 and 1.75 % respectively (Figure 5a).

This result is consistent across the applied voltage range, apart from 1 % at 140 VAC (Figure 5b).

Thus, while increasing PEDOT-PSS concentration increased the conductivity of the TCA, the net light output is reduced as the transparency of the coating diminishes.



(5a)



(5b)

Figure 5: Performance of EL devices made with TCA-laminates using varying % concentrations of PEDOT:PSS in the dried film at (a) 140 VAC and (b) a range of VAC

The concentration of PEDOT:PSS in the coating also has an effect on the adhesive qualities of the film and this is clearly illustrated in Figure 6.

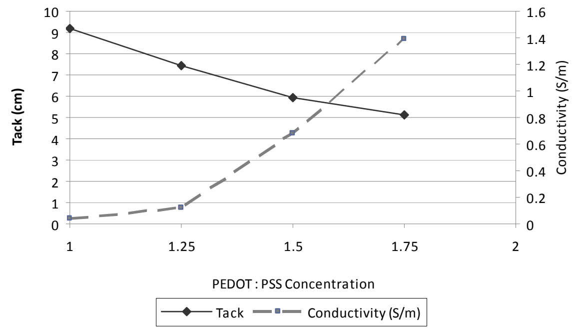
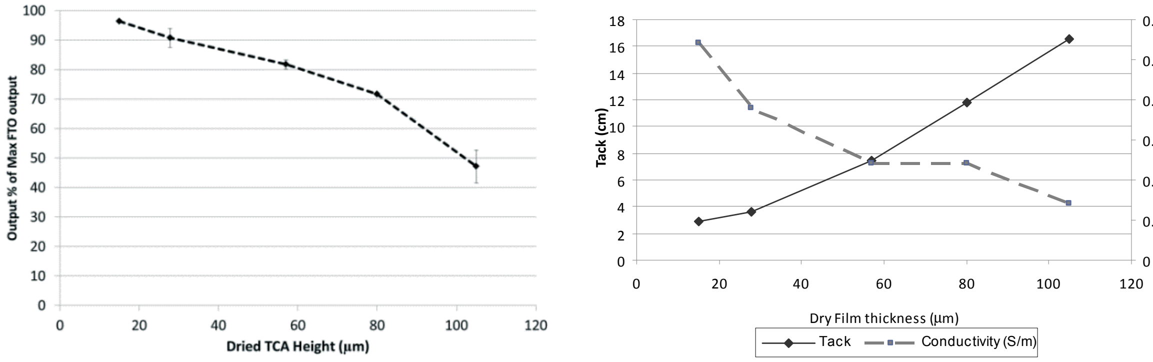


Figure 6: The impact of PEDOT:PSS concentration on the tack and conductivity of the TCA

The contradictory requirements of maintaining good conductivity and adhesion must be balanced to produce a material which meets electrical and mechanical performance requirements. There is a reduction in tack of approximately 40 % when the PEDOT:PSS concentration is increased by 0.75 % while the conductivity increases by a factor of approximately 20 over the same range.

A PEDOT:PSS concentration of 1.25 % was therefore selected and held constant whilst the film thickness of the TCA was varied from 15 µm to 105 µm. It was postulated that while a thinner film would improve the film transparency, it could potentially reduce the film conductivity by limiting the PEDOT:PSS network structure that could be created in the film. This would subsequently reduce lateral and through film conductivity. This range was chosen as it represents the typical wet film thickness range of screen printing, the process of choice for EL manufacture. The highest light emission is obtained with the thinnest layers (Figure 7a) with approximately a 50 % reduction in output over a 100 µm range. The only benefit of increasing the film thickness is to increase the adhesive performance of the TCA (Figure 7b). As well as reducing light output, the increase in film thickness also reduces the film conductivity as it provides a greater through film resistive path length.



(a) EL output (b) Tack

Figure 7:
Comparative performance of EL devices using a 1.25 % TCA-laminate of different TCA dry film heights

This systematic study has shown that it is possible to optimize the light output in order to produce top emission ITO-free encapsulated lamps with an output of 96 % of conventional bottom emission lamps. The optimum is obtained with a thin film which is manufactured with a 1.25 % PEDOT formulation. In order to establish whether such devices could utilise an alternative low cost metal substrate, an optimized TCA with a PEDOT:PSS concentration of 1.25 % and a cast height of 15 µm was selected for cells being fabricated on an aluminium substrate with the TCA laminate as the upper surface. The TCA laminate and aluminium emissions are 96 % and 87 % of top emission devices, respectively (Figure 8). Thus, it is possible to manufacture EL lamps without the use of silver or ITO whose performance is close to that of lamps which contain both these high cost materials.

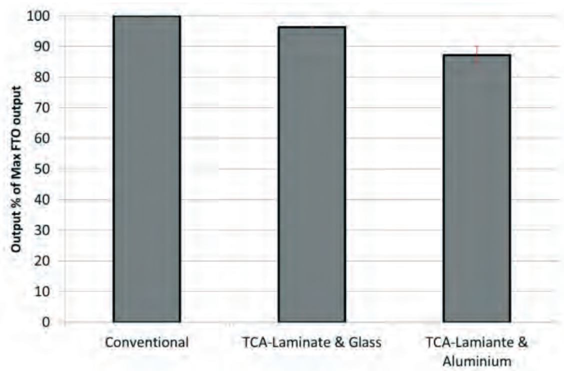


Figure 8:
Relative light emission for different EL devices: conventional (top emission), using the TCA-laminate (bottom emission), and aluminium substrates (bottom emission)

4. Discussion

The highest emission achieved for an EL device made with a TCA-laminate was 96 % of that of a conventional device. This is higher than the previously reported 50 % acheived with an EL device where PEDOT:PSS was coated directly onto the phosphor (Jewell, Claypole and Gethin, 2012). The improvement over the previous work can be attributed to the soft TCA-laminate conforming to the rough phosphor layer ensuring complete electric field coverage of the particles, as a SEM cross section shows (Figure 9).

The net effect of the TCA-laminate technology is significant in that it provides improved illumination and provides an encapsulated system for the high voltage electrodes.

When EL devices were made on an aluminium substrate, their mean emission lagged 13 % behind the total emission of conventional FTO illuminated devices, although there was a variation of +/- 4% between the samples. The drop in output between devices made on FTO and aluminium substrates can be attributed to a number of factors. The fragility of the aluminium material leads to variations in flatness during handling and processing of the aluminium substrate and this had a subsequent effect on the printing of additional layers. This is shown to manifest itself as the large error seen in Figure 8. This highlights the importance of handling the thin aluminium substrate. With the correct bonding to a more rigid substrate, this effect should be minimised.

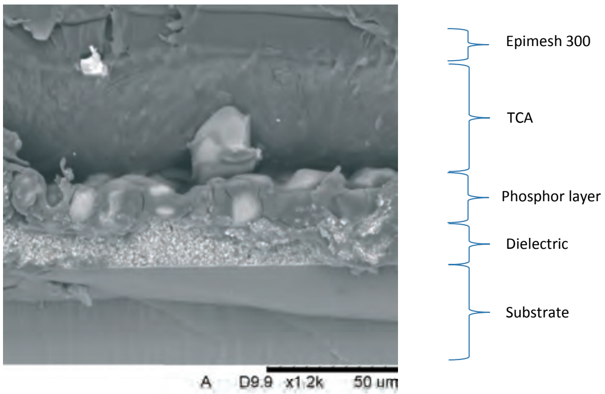


Figure 9: SEM micrograph of a cross section through an EL device made with a TCA-laminate showing the conformity of the TCA layer to a raised phosphor particle

Although silver has a higher bulk conductivity than aluminium, printed particulate ink films generally have a conductivity between 1 and 2 orders of magnitude lower than that of bulk. As the aluminium displays near bulk conductivity, the differences associated with electrode conductivity were discarded as a possible reason for the reduction in output. The use of aluminium as a substrate offers the possibility of using traditional decorative cold / hot foiling techniques as a means of depositing the base electrode. The foiling process usually produces a thin aluminium layer covered by a polymer film, but since EL is a field device, the polymer film, provided that its intrinsic dielectric constant is not too low, should not have a significant effect on the functioning of the lamp. The use of EL using hot foil techniques will be examined more fully in future work.

In order to assess the economic benefits of the technology, a bill of materials (BOM) cost analysis of the product components was performed (Table 1). The values were calculated from commercial retail prices and wet film weight measured when individual layers were deposited. The net reduction in cost when considering the top emission lamps compared to the conventional build is highly dependent on the lamp coverage as a proportion of the total substrate size (Figure 10).

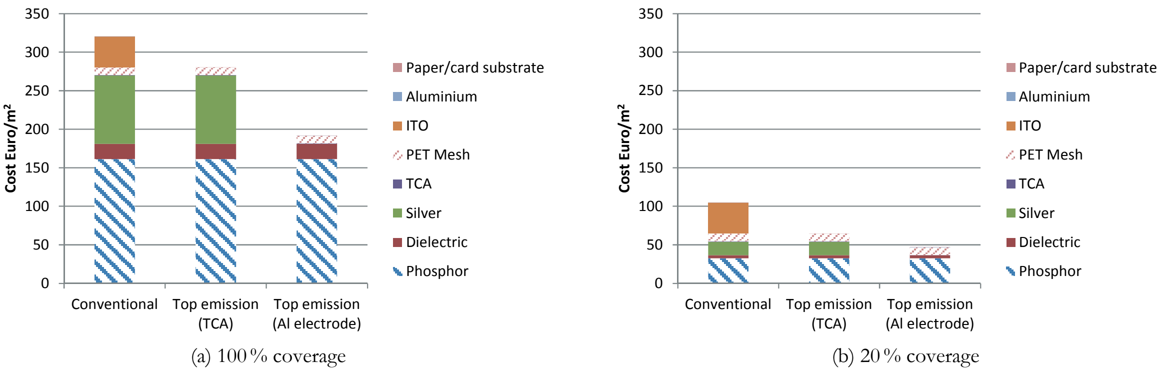


Figure 10: Cost analysis for lamp coverage levels

There is a minimal reduction in lamp output when the entire image is covered (typical for backlighting) but at a lamp area coverage of 20 % (more typical for signage and iconic displays), the reduction in cost is more appreciable with bill of material costs being around 70 % of the conventional build. These costs are likely to be more pronounced as the mesh material costs diminish as volumes increase, while the cost of ITO increases. The dominant factor in the BOM remains the phosphor ink in all scenarios and there is likely to be little movement in this unless new material suppliers or manufacturing processes enter the market.

The removal of the silver from the from the lamp design has an appreciable effect, although the current study has identified that this is at the expense of lamp performance.

Table 1: Base material costs used for BOM calculations

	Cost (Euros/m^2)
Phosphor	61
Dielectric	20
Silver	89
TCA	0.40
PET Mesh	10
ITO	40
Aluminium	0.10
Paper/card substrate	0.10

At present, the TCA has been used in conjunction with a commercial embossed nickel grid material. This provides a more durable and lower cost alternative to ITO but remains a premium cost product. It may be possible to utilise a truly printed grid structure on a generic PET film using flexography (Deganello et al., 2010) or gravure (Søndergaard et al., 2013).

This would potentially allow lower cost substrates to be used as well as allowing patterning of the high conductivity lateral grid. In order to achieve this, the chemical compatibility of the TCA and nano silver as well as the adhesion of the PET/nano silver when subjected to the separation forces induced during the screen printing process would have to be established. This is the aim of ongoing work where nano silver inks are being screen printed to provide a low profile, high conductivity macro mesh.

Although the TCA was bar cast onto the substrate, the TCA blend has subsequently been shown to be screen printable through a variety of polyester meshes. Work is ongoing on relating the dry film thickness to the screen specifications such that a recommended mesh range is provided in the recipe for lamps printed wholly by the screen printing process.

This study has shown that the combined conductive / lamination adhesive process is capable of producing lamps which are safe, easily manufactured and capable of an output which is nearly identical to that of ITO based devices. This provides both a cost and a manufacturing advantage

5. Conclusions

A parametric study has been undertaken to examine the use of a transparent conductive adhesive for the manufacture of lower cost printed EL lamps.

Through a process of optimization, top illuminated electroluminescent devices made with a TCA-laminate have been shown to achieve 96% of the emission of a conventional FTO glass illuminated device. The method was also shown to be viable when the substrate was changed to aluminium, creating a vacuum free, silver free, indium free fully flexible top illuminated EL device. This opens up the possibility for using even less expensive substrates and for the use of the TCA within other lighting technologies.

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The effects of substrate correction on printing conformity

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Abstract

Printing has become more and more of a manufacturing process. As a manufacturing process, the goal is to meet specifications. When printing on nonconforming papers, printing conformity is jeopardized. The use of the substrate-corrected colorimetric aims (SCCA), as specified in ISO 13655, represents a solution. But benefits of SCCA are not fully understood and the solution not widely adopted in the printing industry. A research question arises: "What is the effect of substrate correction on dataset conformity for a large number of offset, digital printing, and proofing jobs?" To answer the question, this research uses a database of 60 jobs to study the effect of substrate correction on printing conformity where the white points of the dataset and the color of the printing paper vary. The results show that substrate-corrected color aims (SCCA) enable more job conformance and reduce failed jobs for both conforming and non-conforming papers.

Keywords: printing standards, substrate correction, printing conformity

1. Introduction

When printing is managed as a graphic arts process, acceptability is not explicit until the customer subjectively signs off at the press site. When printing is managed as a manufacturing process, acceptability is specified objectively based on standards.

As the printing industry migrates toward the manufacturing model, a number of conditions must be fulfilled in order to enable an efficient, productive, and profitable printing operations. These conditions include:

(1) applicable printing standards that communicate requirements objectively;
(2) measurement devices that indicate product characteristics (CIELAB) and process behaviors (TVI, gray balance), and
(3) process automation and control efforts that demonstrate printing conformity. If one or more of the above conditions is not fulfilled, the benefits of automated manufacturing processes will suffer.

2. Problem statement

Printing specifications include aims and tolerances of material, process, and product characteristics. Customers prefer printing on "clean and bright" papers. These papers, containing optical brightening agent (OBA), do not conform to printing specifications. They also affect printed colors. Thus, there is a dilemma between meeting the print buyer's paper preference and conforming to printing specifications.

3. Literature review

When measurement backing causes color measurement difference of reflection print (McDowell, Chung and Kong, 2005), ISO 13655 (International Organization for Standardization, 2009a) specifies the tristimulus linear correction method to reconcile the difference. Later, the tristimulus linear correction method was extended to correct paper color difference between target and sample (Mc-Dowell, 2011).

Standardization and quality assurance of fluorescence measurement is a subject of interest in science, business, and industry (Zwinkels, 2008). The calculation of the substrate-corrected colorimetric aim (SCCA) is carried out by

(a) converting CIELAB of the target dataset to CIEXYZ (D50, 2 degree),
(b) converting the white point of the sample from CIELAB to CIEXYZ,
(c) computing the substrate-corrected CIEXYZ using the tristimulus linear correction, and
(d) converting the substrate-corrected CIEXYZ back to CIELAB.

Previous studies (Chung, 2013; Chung and Tian, 2011) show that printed solids and gray balance conformity are affected by the color of the substrate. The use of the tristimulus linear correction to modify printing aims (SCCA) improves the overall color conformity. In contrast to tristimulus value approaches, brightened substrate correction can be carried out using a spectral-based complex subtractive mixing model (Dattner, Bohn and Urban, 2011; Dattner and Bohn, 2012).

ISO/FDIS 15339-1 (International Organization for Standardization, 2014a) and ANSI/CGATS.21 (American National Standards Institute, 2013) specify the use of the tristimulus linear correction to correct substrate-induced colorimetric difference. ANSI/CGATS TR016 (American National Standards Institute, 2012) is the first tolerance specifications for dataset conformity assessment. CGATS TR016 is based on ΔE00 as the metric with a multi-level tolerance scheme. In this research, we will focus on the effect of SCCA in assessing deviation conformity of a job.

Using substrate-corrected colorimetric aims (SCCA) to meet printing specifications represents a solution. But SCCA is not widely understood and adopted in the printing industry. The research question of interest is: "What is the effect of substrate correction on dataset conformity for a large number of offset and digital printing jobs?"

4. Methodology

This research begins by collecting 60 jobs, identified by ID numbers only, from a wide range of sources not to be named. These jobs contain CIELAB measurement values of the ISO 12642-2 target and their target datasets.

The next step is to analyze the deviation conformity by job according to CGATS TR016 (American National Standards Institute, 2012) with SCCA and without SCCA.

Deviation conformity by parameter (dataset, CMYK solids, CMYK midtone tints, and CMY triplets) is also computed between measurements and the substrate-corrected aims and their conformity level determined according to CGATS TR016 (American National Standards Institute, 2012).

The last step is to analyze the effect of SCCA on deviation conformity of the database.

5. Results

5.1 Introduction

This section analyzes conformity levels achieved by all jobs between two colorimetric aims (published and substrate-corrected). We then analyze how paper colors vary and their influence on conformity assessment.

5.2 Conformity outcome of the database by job

Figure 1 illustrates the conformity outcome of the database by job according to the CGATS TR016 (American National Standards Institute, 2012) scheme.

A general observation is that the use of SCCA raises the overall conformity level of the jobs in this database and reduces the number of failed jobs.

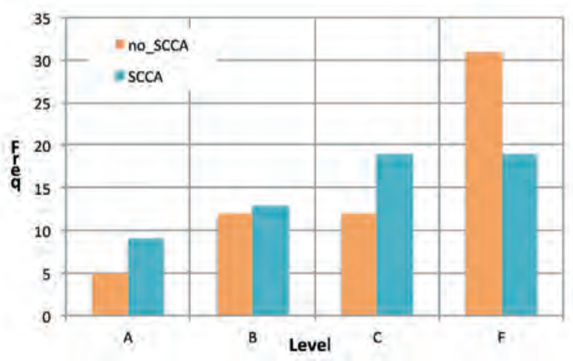

Figure 1: Conformity assessment outcome of all jobs

5.3 Conformity outcome of the database by parameter

By analyzing each of the 10 normative requirements we can get a better understanding of the interaction between the SCCA process and the individual requirements.

Looking first at the requirement to match the IT8.7/4 data set (Figure 2, left) and the requirement to match the CMY triplet (Figure 2, right), we can see that SCCA has a positive effect on both parameters.

Figure 3 illustrates the conformity assessment outcome of CMYK solids. SCCA benefits CMY solids except the black solid. This result is expected because the color of the substrate impacts the color of the printed solids (the XYZ values) in the areas where the ink does not absorb light. Only the black ink absorbs all regions of light.

SCCA benefits the midtone conformance (Figure 4) more than it does in the solid conformance because there is more unprinted paper visible in the midtone area.

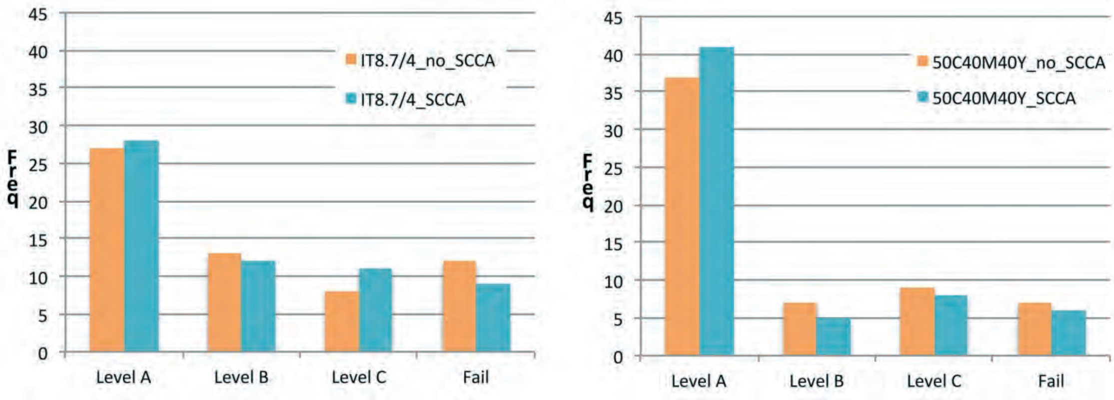

Figure 2:
Conformity assessment outcome by dataset (left) and CMY triplet (right)

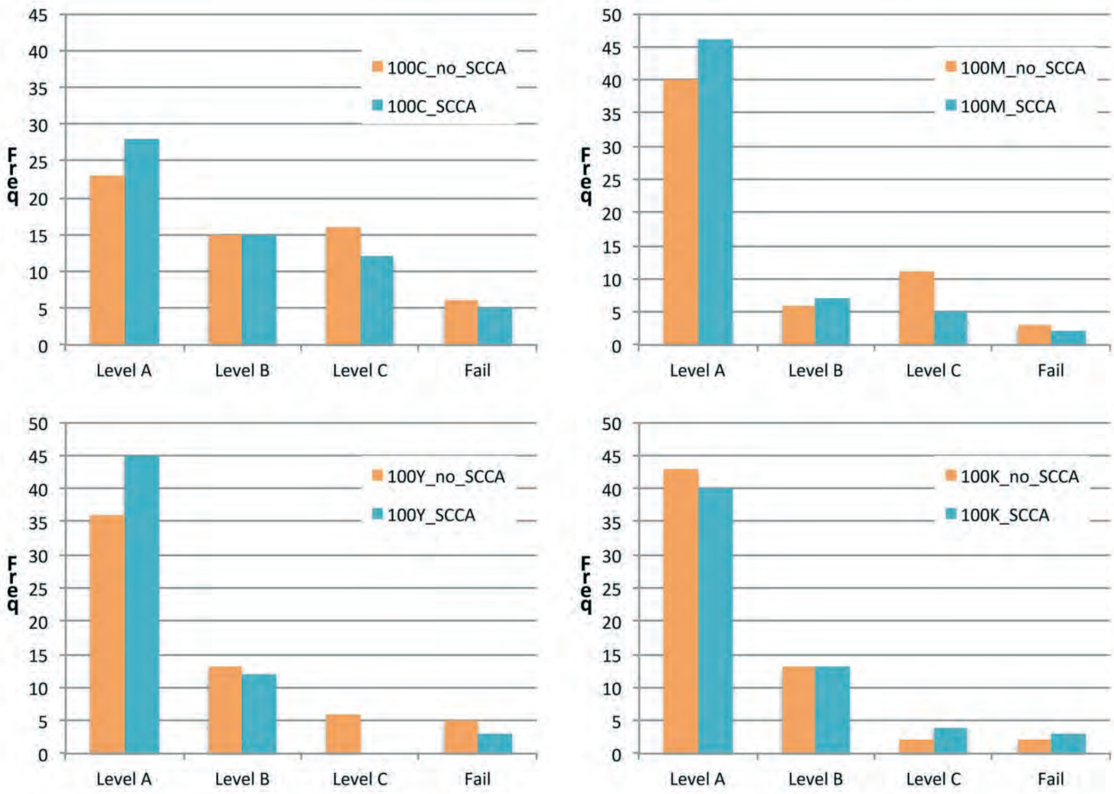

Figure 3:
Conformity assessment outcome by CMYK solids

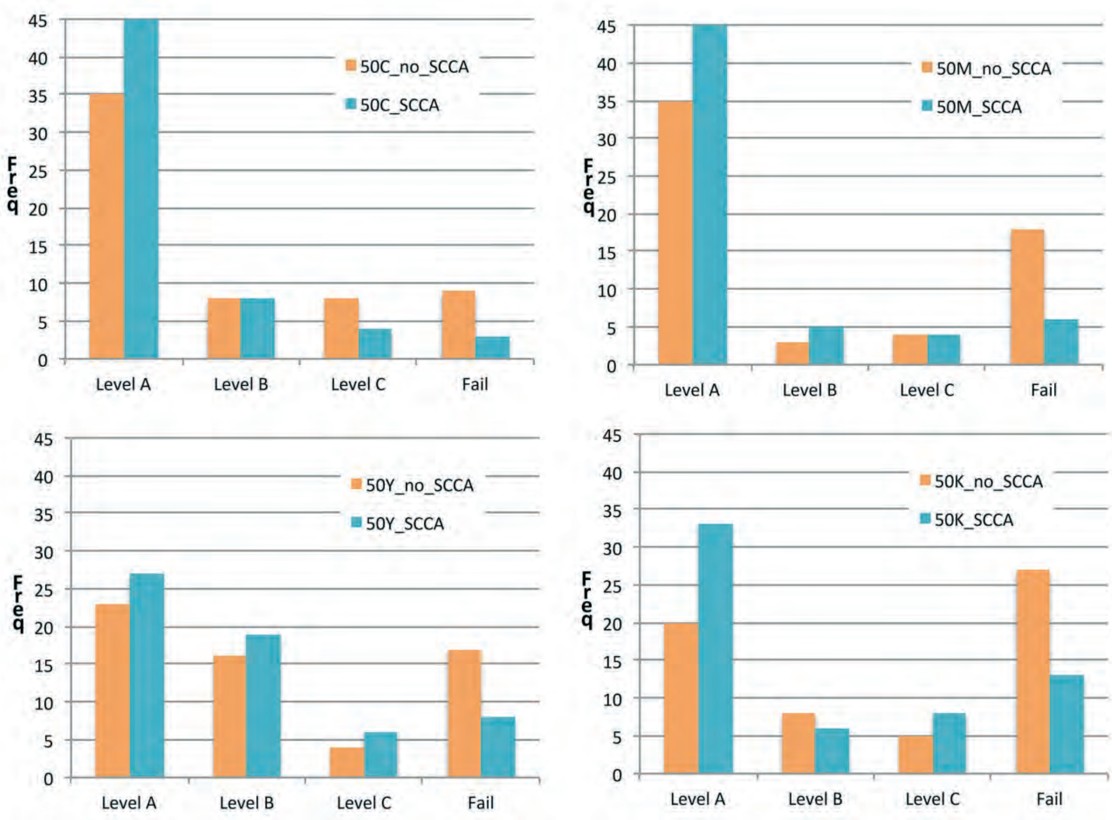

Figure 4: Conformity assessment outcome by CMYK midtone

5.4 Analysis of paper color

In the database, GRACoL 2006 and Fogra 39 are used as the dataset aims. The white points in these two datasets are the same (95L*, 0a*, -2b*).

Figure 5 shows a*b* plots of all 60 paper colors. The target aim (0a*, -2b*) is shown as a red dot. The tolerances (+/- 2Δa*, +/- 2Δb*) according to ISO 12647-2, are shown as dotted lines.

Figure 6 illustrates the L* distribution of all 60 papers with the aim (95L*), as a red dashed line, and tolerances (+/- 3 ΔL*), as black dotted lines. There are more papers with darker shades than there are papers with lighter shades than the target.

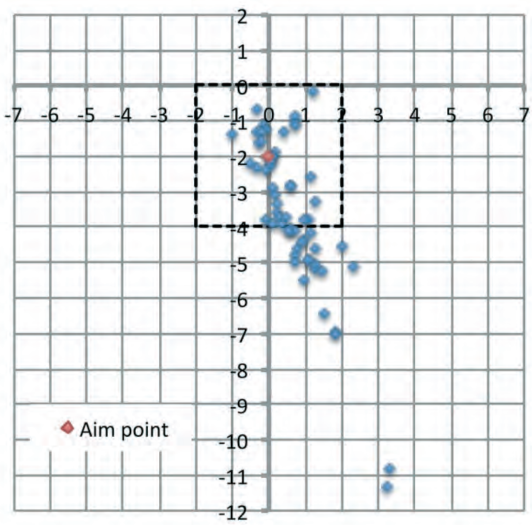

*Figure 5: Distribution of paper colors in terms of a*b* plots*

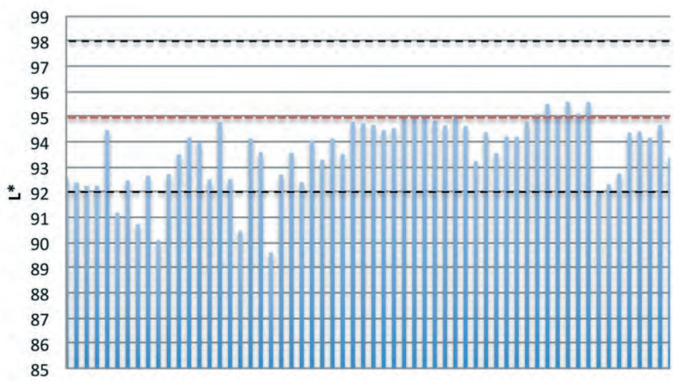

Figure 6: Histogram of paper L values*

By analyzing the paper color conformity according to the ISO 12647-2, there are 33 jobs conformed and 27 jobs not conformed.

Paper color is the fifth color that influences printed color using CMYK process inks. This raises an interesting question, "What are the effects of substrate correction on printing conformity between non-conforming papers and conforming papers?"

5.5 Conformity outcome of the database with conforming paper

Figure 7 illustrates the conformity assessment outcome of the 33 jobs using conforming papers according to TR016. We can see that SCCA increases Level A conformance more while it decreases job failure. Based on this finding, we can conclude that substrate correction benefits job conformity when conforming substrates are used.

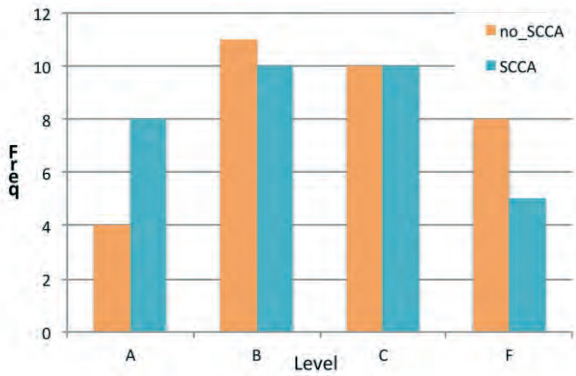

Figure 7: Conformity assessment outcome of conforming papers (n=33)

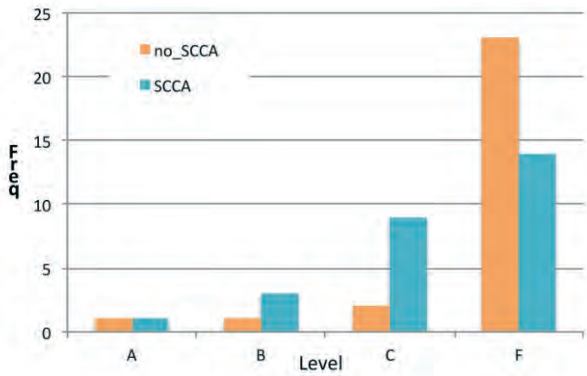

Figure 8: Conformity assessment outcome of non-conforming papers (n=27)

5.6 Conformity outcome of the database with non-conforming paper

Figure 8 illustrates the conformity outcome of 27 jobs using non-conforming papers as per ISO 12647-2. There are a few Level A conforming jobs. SCCA increases more Level B and Level C conformance while it decreases failure jobs.

We can also conclude that substrate correction benefits job conformity when non-conforming substrates are used.

6. Discussion

6.1 Effects of press calibration and substrate correction

Printing conformity to dataset is affected by at least two factors. A primary factor that causes non-conformity in process color printing is printing calibration (International Organization for Standardization, 2009b). A secondary factor is the color difference between the white point of the dataset and the printing paper. In this research, we studied the effect of press calibration and substrate correction in terms of (1) job using conforming paper when the press is calibrated, (2) job using non-conforming paper when the press is calibrated, and (3) job using conforming paper when the press is not calibrated.

6.2 Case 1 - Job using conforming paper when the press is calibrated

Case 1 (ID #4) is a print with a conforming substrate that, although conforming, does not exactly match the white point of the data set. Figure 9 contains six graphs. Together, they describe how substrate correction works in the tristimulus (X, Y, Z expressed as percentage) color space.

Specifically, the three graphs at the top row show the amount of linear correction according to the white point difference between the dataset and the printing paper. A conforming paper shows small amounts of ΔX, ΔY, and ΔZ (expressed as percentage) in the top row of Figure 9.

The three graphs at the bottom row of Figure 9 show the deviation between the measurement and the two dataset aims. The color plots are color differences without SCCA and the gray plots are with SCCA. When the deviation is small, the plots are clustered around the horizontal axis, indicating good press calibration.

Case 1 shows good press calibration. It also shows that SCCA further improves the conformity in the highlight region of the color space.

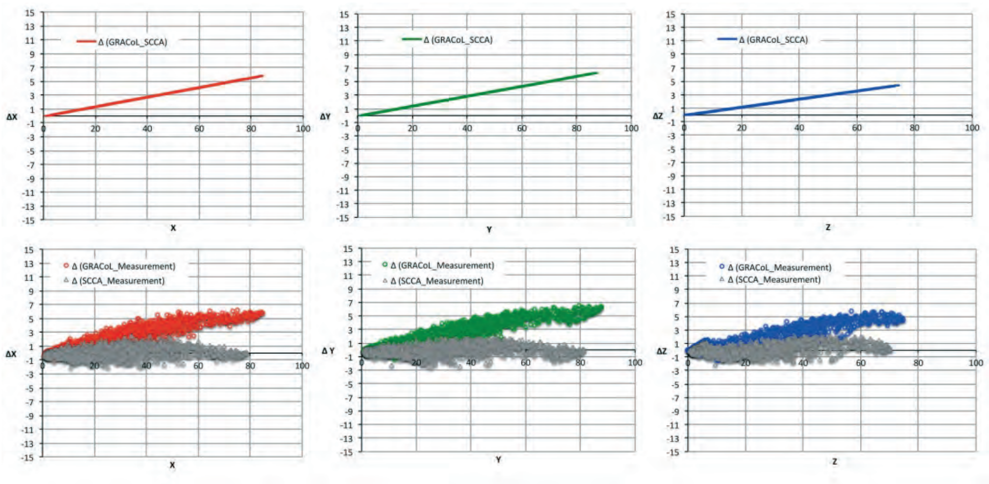

Figure 9: Effect of the tristimulus linear correction - Case 1

6.3 Case 2 - Job using non-conforming paper when the press is calibrated

Case 2 (ID #21) is a print with a non-conforming substrate. In this instance, the non-conforming substrate is CCNB or Clay-coated News Back with a low L* value (90L*). Figure 10 (top row) indicates that larger amounts of cor-rection are called for due to lightness difference between CCNB (90L*) and the dataset white point (95L*).

Figure 10 (bottom row) indicates that the job failed if the substrate corrected color aims are not used. SCCA removes the paper color difference, improves the conformity in the highlight to midtone region of the color space, and changes the conformity assessment outcome.

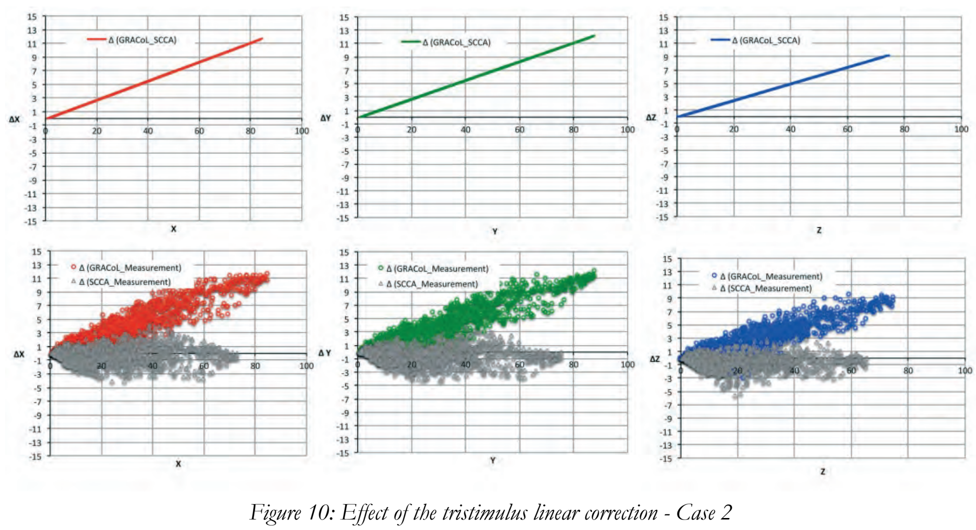

Figure 10: Effect of the tristimulus linear correction - Case 2

6.4 Case 3 - Job using conforming paper when the press is not calibrated

Case 3 (ID #26) is a print using conforming paper, as indicated by small amounts of corrections in Figure 11 (top row). Figure 11 (bottom row) shows large color difference due to poor color calibration. In other words, SCCA can remove the paper-induced color difference, but cannot change the conformity assessment outcome when the printing system is not calibrated.

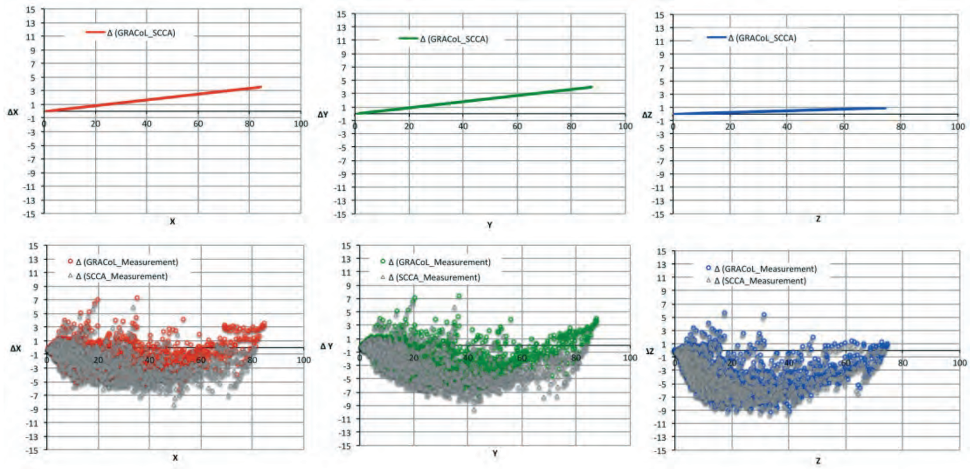

Figure 11: Effect of the tristimulus linear correction - Case 3

6.5 Relationship between paper color difference and printing conformity

From an operational point of view, substrate correction is beneficial to printing conformity regardless of whether paper conforms to standards or not. We may also want to know, "What is the upper limit of the substrate difference that a job can conform to dataset with SCCA?" Figure 12 illustrates how job conformity relates to paper color difference.

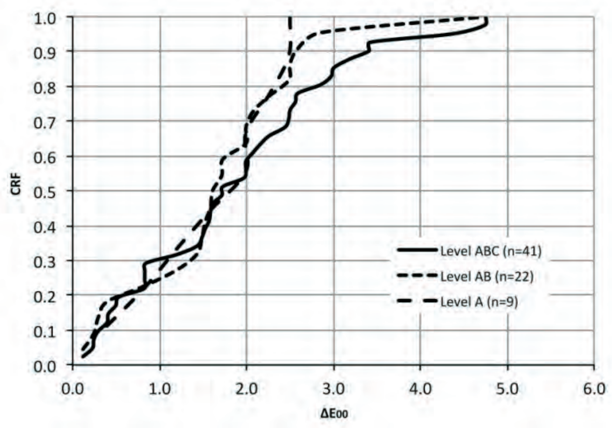

Figure 12: Job conformity as a function of paper color difference

There are 9 jobs in the database that meet Level A conformity and the substrate color difference among these jobs is less than 2.5 ΔE00. There are 22 jobs in the database that meet Level A and Level B conformity and the substrate color difference among these jobs is less than 5 ΔE00.

There are 41 jobs in the database that meet Level A, Level B, and Level C conformity and the substrate color difference among these jobs is also less than 5 ΔE00. Thus, we can conclude that substrate correction is beneficial to printing conformity when substrate difference is below 5 ΔE00.

7. Conclusion

This research tackles a dilemma between meeting the print buyer's paper preferences and meeting printing specifications. It used a database of 60 jobs to study the effects of substrate correction on printing conformity where the white point of the dataset and the color of the printing paper vary. The overall results show that substrate-corrected color aims (SCCA) enables better job conformance and reduces the number of failed jobs for both conforming and non-conforming papers. The effects of SCCA may be summarized as follows:

(1) When a job uses conforming paper and the press is calibrated, it will meet the conformity requirements and the effect of SCCA is noticeable, but negligible;
(2) When a job uses non-conforming paper and the press is calibrated, SCCA can remove the paper color difference and change the conformity assessment outcome of the job; and
(3) When a job uses conforming paper and the press is not calibrated, it will fail the conformity requirements regardless of whether the substrate is color corrected or not.

The results show that when the press is calibrated, which should be the case in a print manufacturing process, the SCCA method removes the paper color difference and improves the outcome of conformity assessment.

More and more non-conforming papers with OBA proliferate in the printing markets. Paper color introduces a bias in the process control and jeopardizes conformity assessment. It is imperative that printing standards specify the substrate correction method to enable printers to print to the substrate-corrected color aims.

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Dynamics of ink absorption of packaging paper

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Abstract

Liquid absorption dynamics of packaging papers has been studied with an Emtec PDA device, using water-based flexographic ink and water as testing liquids. While the liquid is penetrating into the paper structure, the measured ultrasonic transmittance values change with the absorption time and form two time regimes. The transmittance increases with time in the first regime and decreases in the second. All of the papers are internally sized and other paper making parameters, e.g., refining and calendering have strong impacts on the absorption behaviour of the papers - for instance, on the maximum transmittance and the transition time from regime 1 to regime 2 - while different fibre blends exhibit only marginal effects. Comparative studies with cloth made of synthesised fibres suggest that it is modifications of wood fibres by the liquids that are responsible for the two-regime structure. Responding to liquid absorption, wood fibres expand in length and width, regain their lumens and change in surface energy, etc. These are probably the origins of the decreasing transmittance in the second time regime.

Keywords: liquid absorption, ink-paper interaction, inkjet, package printing

1. Introduction

Absorption of ink, ink vehicle, and colorants by a paper substrate is important for the final print quality, such as print gloss, print density, print mottle, print through, etc. The major paper properties that influence the ink absorption include topological characteristics, surface energy, porosities, and pore-size distributions (Alam et al., 2007; Kettle, Lamminmäki and Gane, 2010). The major ink properties for the ink absorption are ink viscosity and surface tension. When it comes to ink-paper interaction, contact angle is the most important parameter. Nevertheless, many properties, for instance surface energy, contact angle, etc., are subject to modifications by the ink, resulting in strong time-dependence of the measured value. Hence, to understand the dynamics of ink absorption into the paper's pore structure is both difficult and tricky.

There are a number of traditional measurement methods often used for studying liquid-paper interaction and liquid absorption. The contact angle between ink droplet and substrate surface indicates the trend of ink spreading or wetting on the surface. The Bristow Wheel and the Cobb Tester (TAPPI, 1998; Bristow, 1967) report the volumes of liquid absorption by the paper substrate. These techniques provide information about the total absorption volume for a time period and/or a large area, which may not be relevant to printing. Moreover, they only provide accumulated result over the testing period; hence no insight into the dynamic process of the liquid-paper interaction is given.

In the last decade or so, quite a few measurement devices have been developed, dedicated to liquid absorption dynamics and based on different measurement principles. The Micro Drop Absorption Tester (Micro DAT) (Ström, Borg and Svanholm, 2008), the Automatic Cobb tester[1] and the Automatic Scanning Liquid Absorptometer[2] are instruments that measure the absorption rate of the paper.

The Emtec PDA (penetration dynamics analyser) records transmittance of ultrasonic signals along time in response to the liquid absorption process. The Clara device (Lamminmäki et al., 2010; 2011) measures capacitance changes along time while a conductive liquid is penetrating into the paper substrate. Yet none of the existing measurement techniques is either capable or robust enough to reveal the liquid absorption dynamics, e.g., the depth of liquid penetration along time. For example, a physical model (Yang, Liu and Gu, 2013) is needed to convert the ultrasonic transmittance to depth of liquid penetration.

Physical models play an important role in understanding and interpreting experimental observations and bring insights into the sophisticated ink-paper interaction process.

The Bosanquet model is an extension of the Lucas-Washburn model, used in modelling capillary-force driven absorption processes (Schoelkopf et al., 2000; Ridgway and Gane, 2002). This model has further been extended to modelling printing processes wherein a print nip is engaged (Yang, 2013).

Liquid absorption by paper is a complex dynamic process. One of the reasons is that paper is a living material that responds to changes in environmental conditions, e.g., hydro-expansion of wood fibres leads to structural changes of a paper sheet. It is hence inappropriate to treat paper as a material of rigid porous structure. In other words, experimental observations obtained over a long time period (seconds, tens of seconds, or longer) with a large volume of liquid (ink) cannot quantitatively reflect what happens in a printing process where absorption of a small ink volume under a very short absorption time (thousandths or tenths of a second) is involved.

This work is part of our efforts to understand the complex dynamics of liquid-paper interaction and to establish the relationships between papermaking parameters and liquid absorption behaviour of packaging papers.

2. Materials and methods

2.1 Materials

Four carefully selected packaging papers are included in this study. They were made of different blends of softwood and hardwood fibres, filler contents, refining and calendering grades. These differences led to different structures and properties of the paper sheets, listed in Table 1.

Table 1: The material compositions and the properties of the samples

Paper/ Properties	Material composition	Calendering	Degree of Refining	Filler content (%)	Gloss (top side/bottom side) (%)	Roughness (top side) (μm)	Cobb60 ($g\,m^{-2}$)
1	> 80% softwood	No	Low	0	14.16/5.0	3.43	18.31
2	> 80% softwood	High pressure	High	0	14.56/6.22	3.05	5.51
3	60% softwood	Standard	Standard	6	14.14/5.36	3.25	4.88
4	30% softwood	Standard	Standard	6	14.98/6.12	2.56	3.34

Papers 1 and 2 possess the same raw materials, more than 80% of softwood fibres and no fillers, but different refining and calendering degrees. Papers 3 and 4 have different fibre blends, but otherwise identical pulping and paper-making parameters.

As a consequence, these papers exhibit different properties, e.g., in surface roughness, gloss and absorbency (Cobb60). Comparing paper 2 with paper 1 suggests that higher refining and calendering degrees improve gloss and reduce liquid absorption because of reduced porosity of paper 2; while for papers 3 and 4, the one with a lower portion of soft wood fibres tends toward improved pa-per gloss and reduced absorbency.

2.2 The measurements of ultrasonic transmission

The Emtec HVL[3] instrument consists of an ultrasound generator and a receiver, between which there is a vertically movable sample holder and a liquid container beneath the sample holder. The paper sample is mounted to the measuring head by an adhesive tape. When the sample is in contact with the liquid (water in the present study), liquid absorption begins, due to the capillary pressure. The measuring head sends a beam of ultrasonic waves of 1 MHz. The intensity of the ultrasonic signal attenuates due to scattering and absorption mainly by voids inside the paper (testing sample). When the liquid fills the voids, the transmittance varies as illustrated in Figure 1. The transmittance of the ultrasonic waves that propagate through the paper is recorded by the measuring cell sitting beneath the liquid container. The transmittance is sampled throughout the whole measurement process, from 0.05 s after the release of the sample's holder and at the minimum possible time interval of 0.003 s. For comparative purposes, a piece of cloth made of synthesized fibres (polyester) was also measured. In contrast to wood fibres, the synthesized fibres had no lumen and little hydro expansion or contraction.

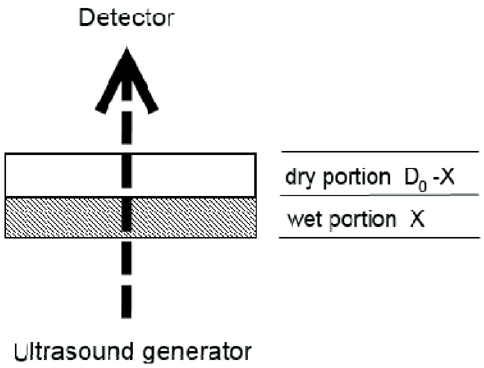

Figure 1:
The measurement priciple of the Emtec PDA tester. The thickness of the dry sample is D_0, at time t, the depth of ink penetration is X

Water and a flexographic ink of viscosity 15 s were used as the testing liquids for all of the experiments. The ink was prepared from flexographic ink (product code: ICF292) produced by Ink Color (Suzhou)[4] and deionized water.

2.3 The physical model

The detected transmittance of ultrasonic signal varied as the liquid penetrated into the paper sheet due to modified attenuation of the sample. We have recently developed a model that bridges the transmittance values with the depth of liquid penetration (Yang, Liu and Gu, 2013), shown in Equation 1,

$$X(t) = \frac{\log(T(t))}{\log(T_{wet})} D_0 \quad t \in (0, \text{tmax}) \qquad [1]$$

where X is the depth of liquid penetration, T(t) the transmittance at time t and T_{wet} the transmittance when the sample becomes thoroughly wetted. The quantity D_0 denotes the thickness of the paper sheet in its dry state.

The dynamic characteristics of liquid penetration experimentally obtained from Equation 1 can further be parameterized into physically meaningful parameters. According to the Bosanquet model (Bosanquet, 1923, Schoelkopf et al., 2000; Ridgway and Gane, 2002; Yang, 2013), the depth of liquid absorption as a function of time t can be expressed as in Equation 2.

$$X(t) = \left(\frac{2b}{a^2}\exp(-at) + \frac{2b}{a}t - \frac{2b}{a^2}\right)^{\frac{1}{2}} (\text{t<tmax}) \qquad [2]$$

The quantities a and b are constants defined in Equation 3, and may be regarded as the collective properties of the paper and the liquid, namely

$$a = \frac{8\eta}{R^2\rho}, \qquad b = \frac{P_e}{\rho} + \frac{2\gamma\cos\theta}{R\rho} \qquad [3]$$

where R is the radius of a capillary, ρ the mass density of the liquid column, η the viscosity of the liquid, γ the surface tension of the liquid and θ the liquid-paper contact angle and finally P_e the external pressure exerted on the liquid.

According to Equations 2 and 3, the liquid absorption can ultimately be characterized by two parameters, a and b.

3. Results

Figure 2 depicts the normalized transmittance values of the papers upon absorption of water, wherein the initial transmittance values of the dry papers are set to 100 %. As can be seen, all of the papers exhibit similar responding features toward liquid absorption. Their transmittance values increase rapidly with the time of water absorption at first but fall slowly back after reaching their maxima. It is also clear that the percentages of the maximum increases are proportional to the time needed to reach the maxima. Relatively speaking, paper 2, that probably has low porosity and fine pores due to high refining and calendering grades, exhibits the largest improvement in transmittance. On the contrary, paper 1, that has the lowest refining degree and is not calendered, demonstrates the smallest improvement. Considering the fact that papers 1 and 2 have the similar (raw) material compositions, their differences in refining and calendering result in significant differences in papers structure and absorption behaviour. Paper 3 and 4 behave very much the same, indicating that water absorption is not at all sensitive to their differences in the proportion of soft wood pulp.

The transmittance curves in Figure 2 can be divided into two time regimes: firstly, an increase along time then a decrease after reaching the maxima. When propagating in the paper, an ultrasonic beam attenuates due to scattering and absorption. When the paper sheet is dry, it has a multitude of voids, or pores, which scatter and absorb the ultrasonic beam. Upon liquid absorption, the voids and pores are rapidly filled by the liquid. Then the attenuation decreases and consequently the trans-mittance increases. This is probably the major reasons for the building up of the first time regime. The regime shift may be attributed to the fact that the water absorption also modifies the paper structure and the surface chemistry (Yang, 2013), as further explained in the next section.

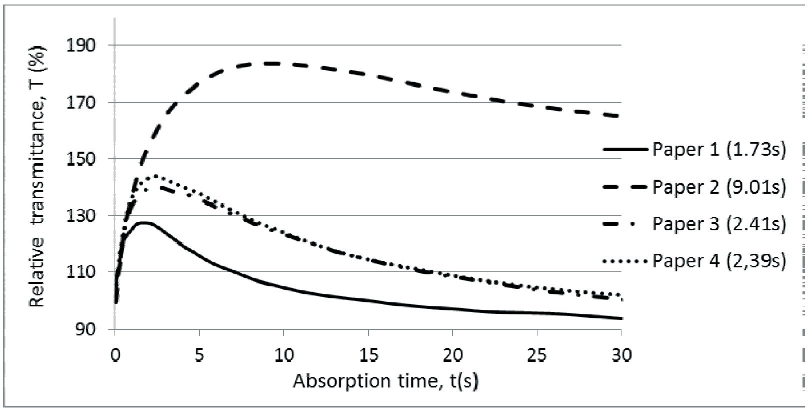

Figure 2: The measured transmittance values of four packaging paper samples with water as the testing liquid. The initial transmittance is set to 100 % for each of the paper samples. The time t_{max}, when the transmittance reaches its maximum is shown in parentheses in the legends

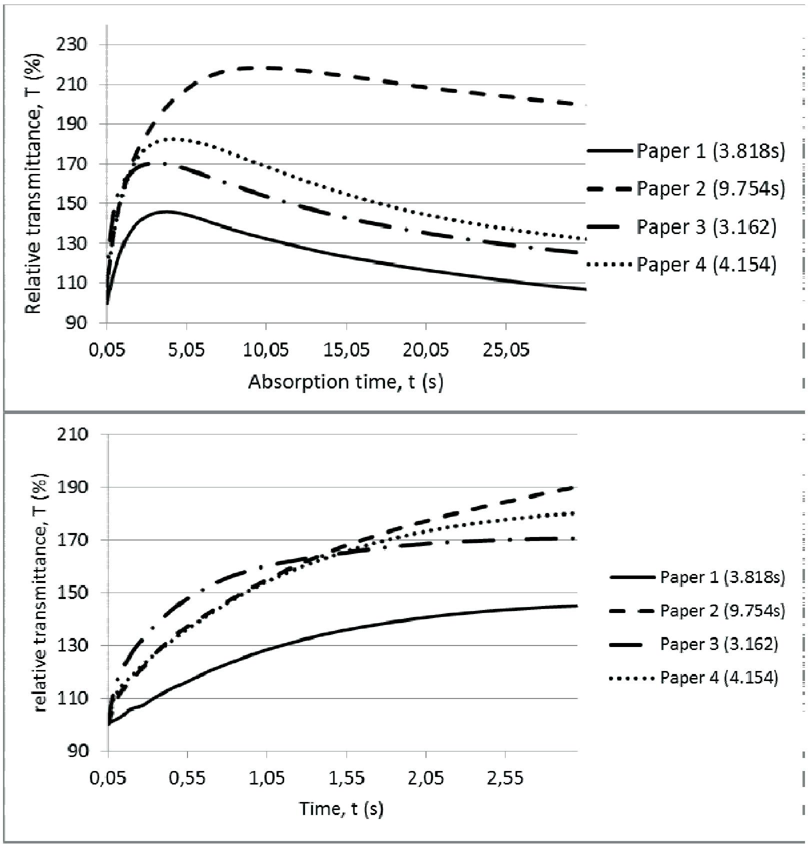

Figure 3: The measured transmittance values of four packaging paper samples with flexographic ink (15 mPas) as the testing liquid. The initial transmittance is set to 100 % for each of the paper samples. The time, t_{max}, when the transmittance reaches its maximum is shown in the parentheses in the legends. The bottom panel shows the short term absorption, $t < 3s$

Figure 3 shows the results of ink absorption with a flexographic ink of viscosity 15 mPas. Compared to the water absorption, the maximum transmittance values become higher and the time to reach the maxima are longer for all of the papers. This can easily be attributed to the higher ink viscosity. Besides, the absorption behaviours of papers 3 and 4 differ somewhat from each other.

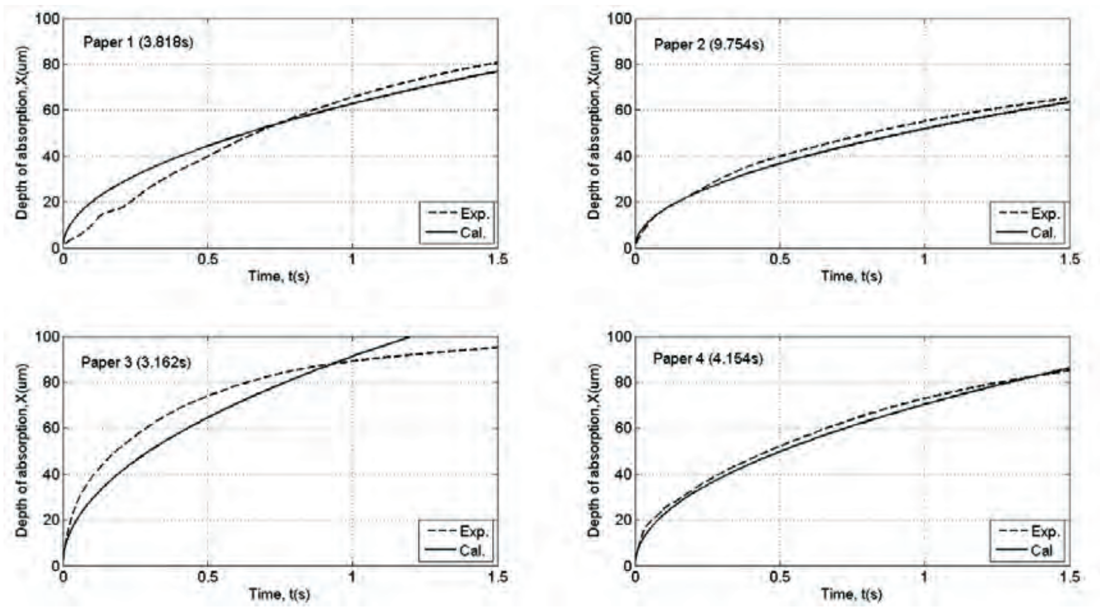

Figure 4: The depths of ink absorption into different packaging papers. The values calculated from the measured transmittances are denoted by dashed lines and those calculated from the Bosanquet model by solid lines

Figure 4 depicts the time dependence of ink penetration depth in a short time period. In the figure, the dashed lines represent the depths calculated from the measured transmittance values, employing Equation 1, and the solid lines represent the values calculated using the theoretical model (Equation 2). Despite that papers 1 and 2 use the same fibre blends, their differences in refining and calendering result in significant differences in ink absorption depth. Having a tighter porous structure, paper 2 is more difficult for the ink to penetrate into or requiring a longer time. Paper 3 has the shortest regime transition time, and the ink has penetrated through almost the entire paper thickness. In addition, the differences between papers 3 and 4 indicate that the rate of ink absorption increases with increasing content of soft wood fibre.

4. Discussion

As shown in Figures 2 and 3, the transmittance development along time can be divided into two regimes, separated by a maximum transmittance for each of the papers. In the first regime, the transmittance increases upon liquid absorption, which is in line with our expectations. When propagating in the paper, an ultrasonic beam attenuates due to absorption by air and papermaking materials and also due to scattering by the empty voids or pores. When the paper sheet is dry there are many voids or pores which attenuate the ultrasonic beam. Upon liquid absorption, the voids and pores are rapidly filled by the liquid. The attenuation decreases and consequently the transmittance increases. However, the behaviour observed in the second regime is largely unexpected because, intuitively, one would have expected that the transmittance would stay at the level of maximum transmittance as the paper sheet becomes saturated by the liquid.

It is therefore surprising that the transmittance decreases with time and can even reach a lower level than the initial transmittance of the dry sheet. Considering the fact that the total amount of physical materials involved, paper and liquid (water or ink), is practically unchanged throughout the measurement period, their atenuation of the ultrasonic beam is also constant. Therefore, it is reasonable to attribute the decreasing transmittance or, equivalently, increasing attenuation to structure changes in the paper sheets.

Liquid penetration of paper is much more than just filling the pores in the paper. It has been observed that the sizing effect on regions that are affected by intrafiber flow is significantly decreased after some time (Senden et al., 2007). This observation suggests that paper is an "active" material that responds to liquid penetration through e.g., changes in pore structure and in the surface energy of the paper sheets. The modification of paper structure/properties by liquid penetration is a progressive process wherein time becomes an important parameter. Unfortunately this fact has often been overlooked or forgotten.

In an earlier report (Yang, Liu and Gu, 2013), we proposed three possible mechanisms to account for the formation of the second regime, i.e., the decreasing transmittance with increasing absorption time. Firstly, hydro expansion of the paper network expands the void space inside the paper sheet with a speed that may exceed the liquid filling speed. The net effect is then an increased void space and stronger absorption of the ultrasonic waves. Secondly, the fibre-wall swelling renews the volume of their lumens which were collapsed in their dry state, and the regained lumens are not easily accessible to the water. Thirdly, the water modifies the surface chemistry of the wood fibres that span pore surfaces, leading to decreasing contact angle of the liquid with the wall of the capillary. In other words, this results in a higher surface energy of the capillary wall or can even turn the capillary wall from hydrophobic to hydrophilic. Accompanying this transition, moving along the capillary (pore) surfaces rather than filling pore spaces becomes more favourable. Depending on the degree of sizing, the time of the transition differs.

To examine and verify the hypotheses mentioned above concerning the mechanisms of the two-regime structure and also to exclude other possible mechanisms, such as generation or accumulation of air bottles in the liquid bath or inside the paper structure, measurements with a piece of cloth of synthesized fibres (polyester) was made. The testing time was set to two minutes which is much longer than any of the transition times of the heavily sized papers. Compared to wood fibres, polyester fibres have no lumens.

They neither swell nor expand upon liquid penetration. Figure 5 depicts the test results wherein the maximum transmittance was set to 100 %. As can be seen, the initial transmittance was zero and it increases quickly with time. After reaching its maximum, the transmittance remains more or less constant during the remaining time and no decreasing transmittance along time is observed. This indicates that pore filling by water (or ink) is indeed the cause of increased transmittance in paper. This also means that the two time-regime structure observed for the papers are associated with the fibers in the papers. This supports our arguments that modifications in the structures and properties of the papers by water or ink, during the process of liquid absorption, are responsible for the formation of the two time-regime structure.

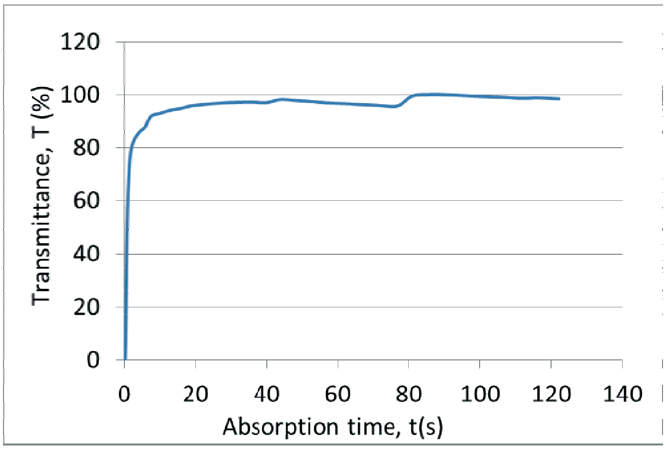

Figure 5:
The measured transmittance values of a piece of cloth made of synthesized fibers (polyester). The maximum transmittance was set to 100 %

5. Conclusions

Upon liquid absorption, the transmittance values of the papers changed with absorbing time and formed two time regimes. Papermaking parameters, e.g., degree of refining and calendering have strong impacts on the absorption behaviour of the papers in addition to sizing, for instance, on the maximum transmittance and on the transition time from regime 1 to regime 2. Differences in fibre blend, on the other hand, exhibit only marginal effects. With the help of the physics models, we were able to convert the measured transmittance values to depths of liquid penetration into the paper sheets. Comparative studies with cloth made of synthesised fibers did not show a two-regime structure. This suggests that it is wood fibres, responding to liquid absorption, that are responsible for the two-regime structure. These insights into absorption dynamics are important for understanding ink-paper interaction and print quality in both inkjet and flexographic printing.

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Notes

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[2] http://www.krkkumagai.co.jp/english/e_products/20/e_2071_2072_1.pdf
[3] www.emtec-papertest.de
[4] www.inkcolorsz.com/en/

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Novel services for publishing sector through co-creation with users

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Abstract

The traditional goods dominant logic is very much provider-centric. In the case of publishers, journalists produce content for a product such as a newspaper. The product is delivered to consumers, who experience a newspaper service by reading the product. The service dominant logic shifts the focus from provider-centric to customer-centric. Hence, companies need to focus on gathering and sustaining audiences, and on developing their services not just for their readers but together with them. In this study, we present three case studies in which the publishers wish to understand their readers' expectations and needs regarding new news services and to develop the services together with the readers. Two of the case studies show how to involve the users from the very beginning of the development process all the way to the prototyping. The Owela co-development platform was utilized in all cases.

The study shows the importance of co-creation with users when developing new services. The loyalty and commitment to the publisher's brand increases when the readers feel that their opinions are valued. The process increases the publisher's understanding of readers' expectations and needs and thus emphasizes the users' voice in the new service under development. Although the cases focus on publishers' digital news services, the same approach may be utilized in the development of physical products as well.

Keywords: co-creation, digital services, newspaper publisher

1. Introduction

Several simultaneous forces shape the magazine and newspaper markets at the moment. This has resulted in major changes in the core business logic. The most important changes take place due to media convergence and new ways of advertising. By media convergence we refer to the traditional media industry integrating with the telecommunications industry and with information technology (Küng, Picard and Towse, 2008). The convergence is shaping consumers' media usage habits and opens up the markets for the new competitors, causing media and audience fragmentation (Napoli, 2003). New ways of advertising are especially seen in the increasing volume of online media content, causing traditional media companies to experience a gradually deteriorating source of income. Due to these changes and to the rapid development and popularity of mobile devices, consumers have an ever increasing supply of news content which they can consume when and wherever they want. This is one of the main reasons for a major pressure towards publishing houses to create new services for their customers, and consequently increase their competitiveness. (Viljakainen, Toivonen and Aikala, 2013; Viljakainen and Toivonen, 2014).

Traditionally, media products (both goods and services) are produced at the professional end of the communication chain, and then distributed to media audiences who consume the media products, very much based on Goods Dominant Logic. The value of the media product or service is determined by the media firm, and then calculated in terms of market value, i.e., on how many products are sold or on the amount of advertising revenue. The on-going shift towards service business and Service Dominant Logic means that a media firm cannot create value by itself, but value is co-created with the beneficiary (Vargo and Lusch, 2004; 2008).

The competencies (knowledge and skills) of media professionals and the customers become the main source of value, not the media products (Viljakainen, 2013). In effect, the role of customers in the success of media firms becomes essential, because customers are coproducers of services and co-creators of value.

Customers are not isolated and segmented entities, but rather, they operate as part of their own networks and communities in creating value.

According to a study by Viljakainen, Toivonen and Aikala (2013) on two Nordic magazine publishing markets (Finland and Norway) there is an evolutionary change towards service business, which to a large extent is pertinent for the entire traditional media business. As a consequence of audience fragmentation, media firms need a better understanding of how value is co-created in each customer segment, since the value propositions for each customer segment is different. According to Viljakainen (2013), the technological change that transforms media consumption habits and causes fragmentation of audiences is at the same time changing the logic of how media firms perceive their audiences. Hence, the rationale of capturing value in media business is shifting from treating people as audiences for media content to gathering and sustaining communities where like-minded people are empowered to become active.

When firms enter Service Dominant Logic, the focus shifts from provider-centric toward customer-centric value co-creation. One concrete action a publisher may take is customer involvement in the development of new services.

In this paper we take a look at newspaper publishers' actions towards developing new services in three case studies. The case studies present how publishers may develop their services by involving the readers at different phases of the development process.

This study shows examples of how co-development can be utilized to enhance the user experience, get new ideas and serve the readers better by close collaboration. Even though the case studies are examples of digital services, a similar approach can be used in the case of physical.

2. Co-creation with customers

Companies are increasingly interested in collaborative innovation with customers and users (Greer and Lei, 2011). Different methods of user participation in new product development have been developed for decades in several fields, focusing either on rich face-to-face interaction or on large-scale surveys. More recently (Friedrich, 2013), the use of social media tools in user-centric design processes has been discussed. Viewed from the perspective of people, social media has become a part of everyday life. People use social media for communication among friends and family, for organizing events, for sharing opinions and for collecting the power of individuals to act together. People feel more empowered whether it comes to media, consuming, innovation or civic participation (e.g., Shirky, 2011). Users do not accept the role of passive consumers but look for opportunities to contribute towards a better world and better products (Aalto, 2011). There are several reasons for involving users in innovation and design processes. In information systems design, user involvement is expected to lead to more accurate user requirements, features that meet users' needs, a greater acceptance of the system, and enhanced ease of use (Kujala, 2003; Mao et al., 2005). In the marketing and service research literature, customers are seen to add value to the product or service when they are involved in the co-creation, even in the early phases of the innovation process (Piller and Ihl, 2009; Prahalad and Ramaswamy, 2004). The greater role of consumers in the innovation process is expected to increase product quality and the likelihood of its success, since consumers' own ideas are more likely to be valued by them (Hoyer et al., 2010). At the same time, it is also possible to learn what the most important issues to the customers are when using the service.

Depending on the focus group involved, different issues may arise as the defining factors that in the end have a major impact on whether the service is used or not and whether the customers are willing to pay for the service.

Digital media services may change people's daily routines and media habits, and influence their experiences even when they are not using the service. In a study by Grenman et al. (2014), a facsimile version of digital newspaper was delivered to people living in rural areas and the readers were invited to take part in a study of how a digital news service is adapted by people who are used to receiving a printed newspaper. Before the experiment, the participants received their paper version of the newspaper in the late afternoon. During the experiment, the digital version of the same newspaper was available already in the morning. This caused big changes in the participants' daily life; they woke up earlier or changed their morning routines in order to be able to read the newspaper at the breakfast table. Their media habits changed and they consumed less other media. One of the most important positive experiences created by the mere existence of the service was a feeling of being more equal to people living in cities as the news content was available to them in the morning.

3. Methods

For involving the users in the development of digital news services, three case studies with three different newspapers were carried out by utilizing the Owela co-development platform. Owela is an open living lab designed for user centric studies by VTT (Friedrich, 2013). It consists of blog-based discussion tools, user diaries, chats, questionnaires and polls that can be combined for different innovation and design purposes. Owela may be utilized to involve the users in all different phases of an innovation process, i.e., it is possible, e.g., to plan and develop products and services for the future, study the attitude and opinions of the users and estimate the acceptability of different ideas and prototypes (Figure 1). Online web tools enable interaction between users, developers and researchers during the entire innovation and research process.

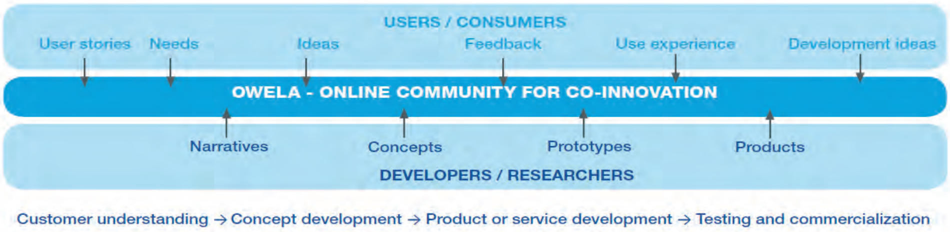

Figure 1: Use of Owela at the different phases of an innovation process

In this study, we utilized Owela for:

- evaluating publishers' ideas and concepts presented as sketches of the new services,
- evaluating prototypes that were generated based on the feedback we received from participants and
- evaluating concepts.

Owela provided us with better tools for collaborating with users than traditional online questionnaires or social media sites. Being an online tool, Owela can be used regardless of time or location. Anyone can join the open conversations and users can build on other participants' contributions, making it more interactive and interesting than a traditional questionnaire study. Compared to research efforts on Facebook, for instance, Owela offers structure and the ability to modify the platform and control the data without having to rely on an outside provider with whom we have no collaboration agreement. Through Owela, we are also able to collect and access demographical details on the participants, as they are registered users of the service.

Publishers were not interviewed during this study, but they participated in creating the Owela project spaces. They also took part in the Owela discussions and were thus able to get direct feedback from users. The analysis results were presented to company representatives and discussed in detail, and the publishers were able to give researchers feedback on the interpretation of the results.

The prototypes were a collection of html-pages, which we call non-functional presentations of the new service. Using non-functional presentations instead of functional prototypes makes it possible to gather knowledge of the user experience evoked by the service without making large investments. The case studies included in the project and referred to in Figure 2 were:

1. *Kaleva* - local newspaper in Northern Finland, especially in Oulu area
2. *Turun Sanomat* (TS) - local newspaper in the South-Western Finland, especially in Turku area
3. *Hufvudstadsbladet* (HBL) - the largest newspaper for the Swedish speaking population in Finland

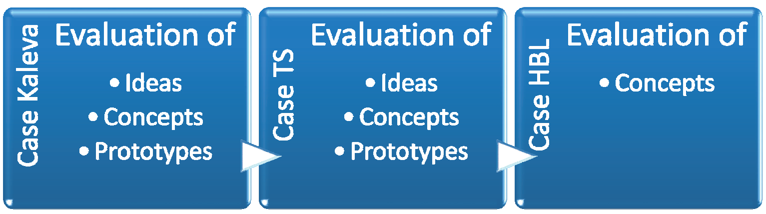

Figure 2: Progress of the study

4. Case studies

4.1 Case: *Kaleva*

Kaleva wanted to develop new features for their online newspaper and preferably make their users more committed to choosing their services instead of other online news sites. Their main focus in the Owela discussions was on extra services that they could offer to their registered users. The users were also asked questions about their media usage habits. *Kaleva* implemented three rounds of testing in Owela; one round during the first phase in 2012 and two rounds during the second phase in 2013. Detailed information on the participants in the different Owela rounds is presented in Table 1. Users were regionally targeted.

Table 1:
Information about participants in different Owela rounds in the case Kaleva

Month_year	Number of participants	Women (%)	Men (%)	Age distribution	Average age
8_2012	35	29	71	24-46	33
5_2013	53	47	53	17-85	52
8_2013	112	21	79	17-85	50

In the first phase, the publisher presented the participants with two ideas: (1) a prototype of a collaborative story, where readers could participate in writing an article for the newspaper, and (2) a participatory event creation case, where users could contribute through, e.g., their own photographs and reviews about the event online afterwards.

During the second phase in 2013, the focus of the study shifted away from co-creating the newspaper towards extra services that could be offered to users of *Kaleva's* online news site. A majority of the people who participated in the Owela study were registered and active users of the Kaleva.fi online service. They were asked questions pertaining to their use of the service and their wishes for the future. As the participants were familiar with *Kaleva* and the services that its website offers, they were motivated to develop the service. Although it was already possible to register your own username for the *Kaleva* website, having your own account did not seem to offer enough benefits to justify doing so. *Kaleva* staff proposed some improvements to the service, but even more new and improved features were suggested by the users.

The user feedback made it easier for *Kaleva* to focus on features that were generally liked and accepted, to get new ideas and to prioritize their development efforts. Features of the upcoming service were developed further based on the feedback received during the first round of the project. A couple of months later, the new service was tested with screen prototypes that had some interactivity. The prototype was evaluated and feedback was gathered again through Owela.

4.2 Case: *Turun Sanomat*

The aim of the *Turun Sanomat* case was to create a new type of news service in the form of a tablet newspaper. The service was to provide additional value to the readers of the newspaper, including daily news, a wider set of additional content, and journalistic entertainment. The new service would be an additional news service for all the readers, both subscribers and potential new customers.

Readers of *Turun Sanomat* were involved in the development of the new service from the very beginning. They were invited to co-develop the novel news service on the Owela platform.

Detailed information about participants in the different Owela rounds is presented in Table 2. Users were regionally targeted.

Table 2:
Information about participants in different Owela rounds in the case Turun Sanomat

Month_year	Number of participants	Women (%)	Men (%)	Age distribution	Average age
11_2012	29	48	52	20-63	34
6_2013	18	61	39	26-71	50
12_2013	109	46	54	30-78	51

In the first phase in late 2012, the publisher presented their view of the new service as a non-functional presentation to a panel of readers. Through the presentation, participants easily got the idea and were able to join the discussion with their own proposals.

The publisher received valuable and to some extent surprising feedback; some features that the publisher loved were not interesting to the readers. On the other hand, readers ideated some completely new features for the service. In spring 2013, the study focused on users' media habits. The participants also discussed the kinds of news content they would like to read on a tablet device, and voted for the most interesting topics. The publisher developed the idea further and created a prototype of the service (see Figure 3). The prototype was evaluated by the users in the third round in Owela in December 2013.

Users evaluated the first impression, layout, structure and content of the service. They also were asked to navigate to different pages on the site and give their opinion of the site. Also, advertising in the new service was discussed. Participants were also asked to suggest a name for the news service.

Figure 3: Prototype of a new service for Turun Sanomat

4.3 Case: *Hufvudstadsbladet*

KSF Media, the publisher of the Swedish-language newspaper *Hufvudstadsbladet* (HBL), wanted to receive feedback on a new digital service concept from readers that have critical attitudes towards digital services. The aim was to lower the threshold to start using a digital service and to commit the users to HBL's new digital service. The service was a digital evening edition of the HBL newspaper, HBL Kväll (see Figure 4). KSF Media aimed at offering their readers novel news content in the afternoon, at the same time familiarizing them with digital news. The content of the evening edition included additional information on printed HBL news articles, news from the website, some unique content written especially for HBL Kväll and some news that were to be printed in the following day's newspaper.

In this case, HBL really wanted to target critical readers who were not so familiar with digital devices and who were not willing to read digital news.

Altogether 55 readers (53 % women, 47 % men) were involved in the Owela discussions. The age of the participants varied between 30 and 76. The average age was 60 years, which was higher compared to other case studies.

Participants were invited to Owela to discuss their media habits, the idea of an evening edition of the newspaper, their first impressions, and the content and layout of the service. Participants gave feedback on navigation properties, interactive content and the proper time of publication. They also voted for their favourite first page design out of four options and explained the reasoning behind their choice.

Figure 4: Prototype of a new evening edition of HBL news, HBL Kväll

5. Results

5.1 General

In the case studies of *Kaleva* and *Turun Sanomat*, two concepts of novel news services were evaluated and further developed from idea to prototype. In both cases, the participants were involved in the service development from the beginning of the process. In the beginning, participants were quite skeptic about the ideas presented to them. Their initial thought was that the service would not give them any added value. During the project, the prototypes of the new digital news services of *Kaleva* and *Turun Sanomat* were generated based on the feedback received through several evaluation phases. At the end, the participants were familiar with the features of the service and found them valuable. They also were delighted to find features whose characteristics they had influenced themselves. With *Hufvudstadsbladet*, the new digital service was already developed and comments on the service were collected.

5.2 Case: *Kaleva*

The users were active mobile media users and interested in local news. Well-liked features were, for instance, the possibility to follow certain news topics as well as the comments associated with news items. Users expected that the possibility to follow content of their liking would increase the time they spent on the Kaleva.fi website. Following a certain journalist and saving old news articles were thought to be interesting additional features. The most desirable features included news notifications and digests, discussions and personal pages, picture galleries and separate sections for advertising.

Users were interested in commenting and sharing news. They desire to act on their own terms; publishers should give them as much freedom as possible. Sometimes, especially with pictures, users want to keep the rights to the picture and want their real name to be shown with the picture. Sometimes, mainly with texts, users want to use pseudonyms.

The study indicates that the written comments/texts reflect the users' personalities more than the pictures they have taken, and thus there is hesitation involved with texts. Some users were enthusiastic about the possibility to promote themselves while others did not want visibility or that their activity would be measured. They also feared that it would only generate unnecessary comments.

Even though the users at first were unable to see clear benefits from registering to the service, in the end, a clear majority of the users felt that the proposed features would bring additional value to registered users. Users would improve the proposed concept by featuring the main news article more prominently on the first page. Accessibility features for colour blind or visually impaired readers were also thought to be important.

5.3 Case: *Turun Sanomat*

Readers of *Turun Sanomat* share very similar media usage habits; they read the printed version of the *Turun Sanomat* newspaper in the morning, and magazines and afternoon papers during the day. They watch television in the evening and read free news content on the internet. Local news content is highly appreciated, it is seen as a huge competitive advantage for *Turun Sanomat.* Readers did not wish to include video and audio content in a tablet news service. Although they felt that video content would well suit sport news and documentary content, statements from politicians could be available only as audio content.

The participants much liked the prototype of the new service even though there was not much functionality in it. They gave mainly positive comments; the service was something new and different from other news channels. The prototype of the service was seen to be clear, interesting and easy to use. There was plenty of content and pictures on the site. Somebody thought there was too much and it made the site seem disorganized. Readers were worried they would miss an interesting piece of news.

Participants felt that the content was versatile and that there was no more need to visit several different news sites. As a result, *Turun Sanomat* obtained information from their readers and potential new customers on how to develop their new service further. They also received positive feedback that let them know they had done the right things when developing the new service.

5.4 Case: *Hufvudstadsbladet*

Most of the participants read the printed version of the HBL newspaper in the morning. About half of the readers read the news just once, the other half read the news several times during the day. It was not very common among the participants to read news articles on a mobile phone or a tablet. Digital devices were used when traveling abroad or at the summer cottage where the newspaper is delivered later in the afternoon.

The readers' reactions towards the new service concept was very critical, most of the readers (83%) felt that they did not have a clear need for a news update in the evening. The main reasons were that they followed the news on television and that they did not have time to read the news in the evening due to, for example, hobbies and events.

However, readers were very pleased with the layout and content of the news service. The layout was found to be fresh, clear and colourful. The content of HBL Kväll was found to be versatile and interesting for all the members of the family. The participants felt that the target audience for the service was young readers and people living in the Helsinki region. It was pointed out that the content in the evening edition has to be up-dated - it has to be something new and unique. Some readers would also appreciate more detailed analyses of daily news in the evening edition. Some readers found it important to have links to social media while others did not use any social media. Most importantly, the social media links did not disturb any readers.

The test persons thought that they would read HBL Kväll using a mobile phone. As a result, HBL obtained information from their readers on how to develop their new service further and ideas on how to market the service also to critical users.

6. Discussion

The media usage habits are changing and the ways readers consume media are different today than a few years ago. People's daily routines change as well. To meet the readers' needs for new services, publishers need to listen to the readers and understand their needs and expectations. Understanding daily routines is essential in order to find the time slots when different kinds of reader groups are willing to consume media. New services have better possibilities to break through when they meet the user needs well. User-centric methods help companies and researchers to understand the needs and to interact with the users at every stage of the service development process. Utilizing an online social media tool such as Owela for presenting different versions of possible new services makes the development agile by providing a platform that is independent of time and place of participation. At the same time, it is also cost-effective as non-functional prototypes may be used.

There was some hesitation from the publisher side about asking their panels of readers to join the evaluation in Owela. This kind of hesitation is, in our experience, quite common. The researchers' task is to alleviate these worries, for example, by facilitating the evaluations in a way that makes it seem that the "stupid ideas" come from the researchers rather than from the publishers. After all, it is necessary to engage the right users, as the publisher's own readers and real potential new focus groups are the most important evaluators. In order to succeed against all the new digital services being offered, publishers need to get their readers to commit themselves to using their services. If users feel that their voices are being heard and that they are allowed to participate in developing the service, they are more likely to continue using the service. This is well in line with the findings in a study by Hoyer et al. (2010).

While the cases were quite different, they shared certain characteristics. What it all essentially boils down to is providing additional value to customers in order to enhance their experience and make them more committed to using service. Whenever users feel like their voices are being heard and they are provided with attractive new features, products and services, their relationship with the service provider is strengthened further. Although the initial response towards new services might be cautious, after the features and the whole service are defined more carefully and communicated to the users in the right way, they will most likely see the additional value. In the *Hufvudstadsbladet* case, the users largely rejected the ideas, partly because they did not fit in with their ideas of a newspaper and its role in their everyday life. The result was quite obvious because of the chosen user group, i.e., people with very critical attitudes towards digital services. The publisher, however, obtained very valuable information on their views and, for example, their feedback on the first page designs made it easier for the publisher to choose a layout among the candidates. In the end, the planned features and services would, according to our research, succeed in attracting more users and making them into more loyal customers. In the *Kaleva* case, users are more likely to register their own user name and stay logged in while they visit the site, and in the *Turun Sanomat* and *Hufvudstadsbladet* cases, more likely to consume the new service.

7. Conclusion

The media market today is a fiercely competitive field with domestic and foreign as well as paying and free of charge news sources vying for the attention of readers. Readers, on the other hand, have only a limited amount of time to spend with their news media of choice, so suc-cess can depend largely on how media houses can manage to attract users and keep them committed and loyal.

Our study shows the importance of involving the users from the early stages of the development process when aiming to create new services. In cases where the users participated in the development process from the very beginning, when the new service was still in the idea phase, the service prototypes were seen to be valuable and the readers found the time they had spent with the development process worthwhile. They could see that the publisher had listened to their wishes in the proposed new service. Although valuable information was received from the readers also in the case studies carried out during later phases of the development process, it was much more challenging to take into account the ideas provided by the readers. By listening to the users and by using participatory design methods when developing and promoting new services, publishers are able to increase customer loyalty and thereby their possibilities to succeed. The key issues in the described case stories revolve around additional value and commitment to the brand and service.

Additional value usually comes from something that the service provider creates or offers - something, such as a new feature, that makes the service more appealing to its users. Commitment is more closely dependent on the users' contributions, and it can be achieved through involving the users, listening to them, making them feel like this is "our thing", a joint effort, and that their opinions are valued. While additional value can in some cases be created independently by service providers, linking it to user feedback can make it easier to turn the additional value into commitment, thus making it all the more valuable.

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An oral presentation based on this paper was given at the 41st International Research Conference of IARIGAI in Swansea, Wales, UK, September 7-10, 2014

Topicalities

Edited by Mladen Lovreček

Contents

News & more

200 years of mechanical newspaper printing

Some 360 years after Gutenberg invented the hand press, a new steam-powered double-cylinder printing press from Friedrich Koenig and Andreas Bauer was used for the first time on the night of November 28, 1814 to print *The Times* in London. This year mechanical newspaper printing celebrates its 200th birthday.

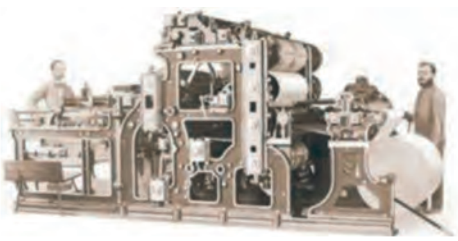
Possessed by the idea of using steam power to replace the back-breaking labor involved in printing with the hand press, trained printer and ingenious inventor Koenig implemented a rotating cylinder into the printing process. This is what it is known today as rotary printing.

The double-cylinder press for *The Times* in 1814 was an important landmark in the 500 years history of printing. Its hourly output of 1 100 printed sheets compared to 240 by Gutenberg's hand press Printing and distributing thus became much faster, more up-to-date and cost-effective.

With their cylinder press Koenig and Bauer did not simply replace muscle power with machine power; they created the technical requirements for the distribution of printed media to less prosperous social classes and made an important contribution to establishing an informed society. The London premiere 200 years ago initially only concerned newspaper printing, however books, magazines, catalogues and much more were printed mechanically shortly afterwards. The 'Times press' printed paper sheets on just one side, but Koenig applied to patent a perfecting press almost at the same time.

Nearly three years later in, 1817, the two pioneers founded the world's first printing press factory Schnellpressenfabrik Koenig & Bauer near Würzburg. In 1876 Koenig & Bauer delivered the first web rotary press to *Magdeburgische Zeitung* in 1876. The conical former developed in the USA soon after, paved the way for the folded newspapers and further improvements to performance. In 1888 Koenig & Bauer shipped the first four-colour web press to St. Petersburg. The very first special presses for printing luxury colour products followed at the beginning of the 1890s. Additionally, the company's interest in banknote printing awakened.

This ground-breaking invention by Friedrich Koenig to guide paper, and later also many other substrates as individual sheets or as a web from a roll, over a rotating cylinder and to print directly or indirectly (over a blanket cylinder in offset) using a mechanically inked printing form is still used in analogue printing today.



Editorial system for academic purposes

At Dortmund technical university, journalism students focus on the link between theory and practice, what the distinctive characteristics of quality journalism are, and how topics be produced for multiple channels and presented interactively.

For some years, the Institute of Journalism has been using DC-X digital asset management system; now the University has decided to upgrade to the "complete solution" using the Content-X editorial system jointly developed by ppi Media and Digital Collections. The new "all-rounder" system combines the DAM functions of DC-X with those of InDesign, processing media-neutral content for use in different media channels.

The system allows for an automated workflow to the highest level: it can create media-neutral content quickly and flexibly and deliver it automatically to all media channels. The user-friendly GUI and simple operation enables producing of images, individual texts or entire articles for print, online and mobile using different design templates. It is the first time it has been used for training at university.

Imaging engine

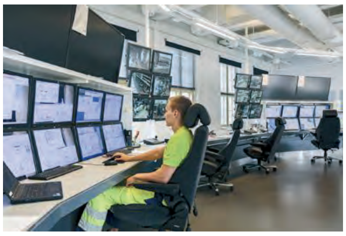
Imaging Engine 14 has been released, by Esko, followed by Imaging Engine powered by the Adobe PDF Print Engine.

This new version of Imaging Engine is more powerful, faster and offers a more user friendly experience than FlexRip and NexusRip. It is powered by the Adobe PDFPrint Engine. This new version is secure and reliable to the highest degree. It is faster than previous versions and gives consistent high output. With multi-core processing ability, it enables better workflow automation.

Turning trees into fuel

One of the leading world paper manufacturers UPM-Kymene decided to enter an alternative product strategy.

In the ongoing transformation of Finnish forest industry and conforming with the company's Biofore strategy, a biorefinery will be opened in Lappeenranta - the world's first wood-based operation that will produce diesel fuel. Construction stated in 2012, while start-up phase begun this autumn.



Once put in full operation, the refinery is expected to produce 120 million liters of BioVerno fuel a year using a hydrotreatment process developed by UPM. BioVerno diesel is from crude tall oil, a residue of pulp production, with a large portion of raw material coming from UPM's own pulp mills in Finland. This fuel reduces greenhouse gas emissions by as much as 80 per cent compared to traditional diesel, and works with all diesel engines just as well as any regular diesel.

New printing ink plant in India

Meeting the needs of the rapidly growing market, printing ink manufacturer Toyo Ink opened its second plant in Dahei, India. It has three divisions on 21 100 sqm: the varnish division, the ink production and storage divisions.

The plant is intended for offset inks, with the annual capacity of 10 000 tons which is three times larger than the first Noida plant, which is also producing gravure inks for food packaging.

TOYOINK
Visible Science for Life

It is estimated that the total consumption of the offset, packaging, screen printing, special inks and coatings in India is said to be 20 000 tons per month. The demands of the Indian market are continuously growing in quantities, as well as in product range and quality.

New markets for press manufacturer

After facing serious problems, which led to closure of some operations, one of the leading press manufacturers KBA is looking at the future with more optimism. Reorganization is paying off, however it requires continuing reduction in the payroll, with the number of employees that will fall far below 4 500 by 2016.

Despite the poor capacity utilization, the web and special press division has turned a lost last year Although sheetfed presses are strong, orders for newspaper and commercial webs were far below company's low expectations and the greatest source of optimism surrounds its newer developments.

New Italian subsidiary KBA-Flexotecnica - which produces presses for flexible packaging - generated satisfactory sales in Germany and the USA, and the inkjet web presses are being shipped out, not to newspaper and commercial printers but for industrial applications. The first super-wide RotaJET - with a web width of more than 1.60 meters - was delivered recently.

But while generally exports are high, Asia Pacific sales are decreasing as a result of China's economic slowdown. The expansion of activities in growth markets, such as digital and special packaging printing, is aimed at contributing to better and stronger market position.

High volume digital press

With the increasing demand for high-volume and top quality digital printing, Konica-Minolta introduced two versions of their bizhub PRESS series - C1085/C1100. They are meeting the best global standards for high quality output, offering faster and more efficient performance.

The press is capable of small lot orders and variable data printing jobs with tight deadline, with effective speeds of 100/85 ppm on 55 to 350 gsm papers.

It maintains the stable high image quality demanded for high-volume printing, using, Simitri HD E toner, S.E.A.D. IV image processing technology, and the output feedback system. With JDF support, APPE, Pantone, industry-standard Fiery and Creo controller, both models represent state-of-the-art models for the printing industry.

KONICA MINOLTA

Multifunctional options help ensure added value. They also enhance the efficiency during post-processing, with booklet making, auto ring binding, perfect binding, hole punching, GBC punching, as well as six types of folding and stapling.

Two color digital duplicator

Latest advance in digital duplicating is a fully automatic cut-sheet digital duplicator, producing two-color documents in a single pass at rates of up to 150 pages per minute. With the ME9450 duplicator, speed, color, versatility and reliability are built in. Duplicator features advanced workflow capabilities to reduce pre-press and make-ready times by up to 50 % over more traditional two-color processes.

It combines 150 ppm high-speed two-color printing with true 600 dpi image quality, producing sharp, clear images of even fine lines and small characters. Swappable color cylinders provide over 70 available colors to choose from, and the duplicator accommodates a wide range of paper types, giving a range of options for the output from a variety of formats: hard copy, electronic file, USB storage, or files already stored in the unit. Changing out consumables is fast and easy.

RISO

Easy 2-Color process allows for various methods of color separation, depending on the actual job requirement.

In addition to saving time and effort re-inserting paper for two-color output, the ENERGY STAR™ -compliant digital duplicator has no heating elements, and uses one-sixth the power of a toner-based system, saving you money as well.

The high speed grip for newspaper output

Probably the fastest single-gripper conveyor with a speed of up to 100 000 copies per hour and 1:1 pick-up will supply five lines with total output of 2.3 million copies of a daily newspaper, each with two compensating stackers and a film wrapper with cross strapping. The system interfaces with upstream and downstream components and with the new mailroom process management system.

The new high speed universal gripper conveyor NewsGrip, produced by Müller Martini, uses a slim aluminum profile for flexible and compact guides with tight bends, and says these can easily assembled, exchanged or adjusted to changes in the chain run.

At the World Pubishing Expo in Amsterdam Müller Martini also introduced a ProLiner D inserting system with a double production mode.

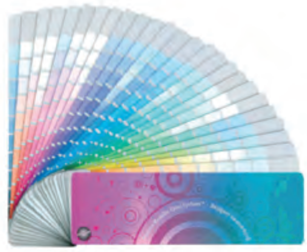
The option enables a newspaper with few inserts to run faster, while retaining single production for products with a lot of supplements. Existing ProLiners can be retrofitted. Additional components are needed according to configuration, with an intermediate opening module added and the conveyor adjusted.

Metallic color system

Metallic colors and decorative effects give added value to branded printed products. Color Logic developed a suite that can be efficiently applied to a wide array of printing methods and materials. It comprises Process Metallic Color Swatchbook and Decorative Effect Software.

COLOR LOGIC

The Process Metallic Color Swatchbooks are color communication system for reflective substrates, metallic inks and coatings. The system provides solution for 250 metallic colors for decorative effect substrates, inks and coatings. Printers and convertors are granted a license to manufacture their own process metallic color charts, versus trying to match a generic purchased swatch book of metallic colors, which was printed under unknown conditions and more often, with substrates and inks that are not applicable to the printing process of the printer.



The Color-Logic Design Suite enables graphic designers to create a virtually unlimited array of metallic colors and decorative effects using color palettes and plug-ins for Photoshop®, Illustrator®, InDesign®, and Quark Xpress®.

The most affordable system for printing metallic colors and decorative effects, Color-Logic requires only five colors to create 250 metallic colors and decorative effects in a single pass of a 5 color press (or multiple passes on a press with 4 colors or less).

The Process Metallic Color System is compatible with offset, inkjet, flexography, screen printing processes and digital presses. It is compatible with current and future decorative substrates, inks, and coatings.

Printers and converters can execute Color-Logic files on their current presses. The system is ideal for packaging, pouches, direct mail, POP, signage, post cards, literature, booklets, labels, shrink sleeves, calendars etc.

Ecological cold foil application

The Eco-Eagle Cold Foil system is a value-added finishing technique for cold foil applications. The add-on system can retrofit to new or existing 28-inch up to 80-inch sheet-fed offset presses from most major press manufacturers. It offers users the flexibility to apply a single 40-inch width of foil or multiple widths of foil, in any combination, as narrow as 2 inches. This ability greatly reduces foil cost and consumption. In addition, the cold foil system operates on about the same amount of electricity as a 1 500 watt hair dryer, reducing energy demands in production environments. This year, Eagle Systems has added the ability to use a 16 000k foil roll which allows for less change over during a job run.

The Eco-Eagle system provides the benefits of high-quality performance and reliability, as well as efficient machineability and cost effectiveness. Spot or overall foil coverage is printed inline and then overprinted at standard press speeds. The process uses standard printing plates and features setup times of less than 10 minutes. Eco-Eagle is completely automated thereby eliminating the human interface and operator/machine intervention.

3D camera press control

Full-colour print quality control and regulation system is new enabled by the newly developed IDS-3D camera system. All functions are now executed with combined intelligence on full-color print lines, without the need for any printed bars, strips or markings.

Dual-sensor IDS-3D camera has built-in process algorithms to ensure simultaneous closed-loop corrections, such as: optimisation of the CMYK colour register, ink keys, including water balance optimization, immediate recognition and signalling of incorrectly positioned print plates and irregularities and/or printing errors in relation to the virtual TIFF image and/or approved print.

Light production printer

As the first for a device in this category, the Xerox Color C60/C70 is suitable in any print environment, including quick print shops, in-plant operations, agencies, small businesses and manufacturers. The device offers turn-key features and media-weight versatility. Users can easily enhance and expand their application offerings to include rugged polyester labels, menus, signs and vinyl window clings.

It prints on linen for unique applications like event planning, appliques and luxurious embellishments. Xerox's Emulsion Aggregation (EA) toner, with its unique ultra low-melt technology, navigates the traditionally difficult peaks and valleys in linen and different other specialty substrates like polyester.

With the output of up to 70 color pages, it additionally offers efficient pre-programmed workflow solutions for job accounting, job security, monitoring and tracking and has variable-data capabilities for personalized applications.

The printer gives sharp, consistent and accurate image quality with the 2 400 x 2 400 dpi resolution and enhanced front-to-back registration accuracy. This precise image quality is combined with flexible inline finishing options, such as stapling, hole-punching, folding and face trimming. Output is up to 70 color pages per minute.

Cloud-based color standardization

A unique cloud-based color management solution is ensuring ink savings, quality control, and color standardization across devices, platforms, and locations. Users pay per click (for each color profile), obtaining profiles that generate highly accurate, repeatable color with superior grey balance, and eliminating the need to make significant investments in hardware or software.

With a holistic approach to color and considering every variable, CMA developed ColorCloud to offer efficient, economical, online profiling. Advanced understanding of substrates, and how they interact with different solvents, result in superb reproduction quality with less investments.

ColorCloud's color algorithms reproduce highly accurate, repeatable color via many methods, including calculation of the color relationship between the four printing inks to accomplish an outstanding grey balance and an overall reduction in the amount of toner or ink used, yielding considerable toner or ink savings for customers. ColorCloud delivers color-accurate results and consistency day after day. Customers only need a web browser and a measurement device (a combination of spectrophotometer and colorimeter for measuring print and displaying accurate color readings.

Bookshelf

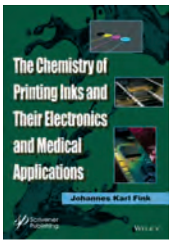
The Chemistry of Printing Inks and Their Electronics and Medical Applications

In the last few years, research and interest in printing inks has literally exploded in the journal and patent literature. This well-documented book focuses on the chemistry of inkjet printing inks, as well to special applications of these materials. It is intended for researchers and engineers in chemistry, polymer science, materials science, electronics engineering, biotechnology, medical and electronic device manufacturers, as well as the ink/dye industry.

The volume comprehensively covers the rapidly developing field of printing inks and their many important applications in the electronics and medical industries. After an introductory section on the general aspects of the field, the types and uses of inkjet printing inks are summarized followed by an overview on the testing methods. Special compounds used as additives, dyes, and pigments in inkjet printing inks are documented.

The applications to the medical field - drug delivery systems, tissue engineering, bioprinting, 3-D printing - as well as their fabrication methods, are detailed. The applications in the electronics industry are also documented such as flexible electronics, integrated circuits, liquid crystal displays, RFID, solar cells, along with descriptions of their special inks.

A chapter on 3-D printing discusses the basic principles, rapid prototyping, as well as their uses and applications. The Chemistry of Printing Inks and Their Electronics and Medical Applications incorporates many structures of the organic compounds used for inkjet printing inks as some of the polymer and organic chemists using the book may not be familiar with them. The book contains four useful indices: an index of tradenames, an index of acronyms, an index of chemicals, as well as a comprehensive general index.



The Chemistry of Printing Inks and Their Electronics and Medical Applications
Author: Johannes Karl Fink
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88 illustrations

White Magic: The Age of Paper

Paper is older than the printing press, and even in its unprinted state it was - and still is - the great network medium behind the emergence of modern civilization. In the shape of bills, banknotes and accounting books it was indispensible to the economy. As forms and files it was essential to bureaucracy. As letters it became the setting for the invention of the modern soul, and as newsprint it became a stage for politics.

In this brilliant new book author describes how paper made its way from China through the Arab world to Europe, where it permeated everyday life in a variety of formats from the thirteenth century onwards, and how the paper technology revolution of the nineteenth century paved the way for the creation of the modern daily

3D Printing

Author: Christopher Barnatt

Publisher:
CreateSpace Independent
Publishing Platform
2nd edition November 2014
ISBN-10: 1502879794
ISBN-13: 978-1502879790
Paperback, 306 pages

The second edition is a major update of the highly popular 3D Printing: The Next Industrial Revolution. The book provides an extensive overview of all 3D printing technologies, together with a detailed analysis of the 3D printing industry, and broader predictions for future digital manufacturing. Already it is possible to 3D print in hundreds of different plastic, metal and ceramic materials.

While traditionally 3D printing has been used for rapid prototyping, by 2020 most things that are 3D printed will be industrial tooling or final products. Already more than half a million 3D printable files are listed on object sharing websites, with desktop 3D printers that can fabricate them priced from $500.

The book features over one hundred interviews, examples and illustrations, and is a valuable resource for all those who want to remain up-to-date with the Next Idustrial Revolution.

Environmental Performance and Sustainable Labeling

Authors: Danielle Jerschefske and Michael Fairley

Publisher:
Tarsus Publishing
2nd edition August 2014
ISBN-10: 1910507016
ISBN-13: 978-1910507018
Paperback: 164 pages

This book provides label converters and suppliers with information about the environment, sustainability, climate change and waste debate as it affects the label industry, and reviews the legislation, guidelines, directives, protocols and industry initiatives that have been introduced over the past decade.

It sets out guidance on how the environmental management system can be established, implement ISO 14000 in the areas of materials selection and usage, production performance, carbon emissions, waste management, life cycle assessment, transport and distribution, and concludes with considerations on end-user. The book will help meeting the challenges on sustainable labeling.

press. His key witnesses are the works of Rabelais and Grimmelshausen, Balzac and Herman Melville, James Joyce and Paul Valéry. Müller writes not only about books, however: he also writes about pamphlets, playing cards, papercutting and legal pads. We probably think we understand the "Gutenberg era", but it can be understood much better when we explore the world that underpinned it: the paper age. Today, with the proliferation of digital devices, paper may seem to be a residue of the past, but Müller shows that the humble technology of paper is in many ways the most fundamental medium of the modern world.

Author tells an alternative history of paper. He argues, convincingly, that paper has been, and continues to be, integral to our civilization and the modern world. Through a carefully structured sequence of illuminating vignettes, he brings together fascinating facts from across the globe and the centuries to reveal the long-running and fundamental impact of paper on human life, work and culture.

White Magic: The Age of Paper
Author: Lothar Müller
Publisher: Polity, November 2014
ISBN: 978-0-7456-7253-3
Hardcover, 352 pages
Format 237 x 160 mm

The History of Labels: The evolution of the label industry in Europe

The evolution of labels and the story of the early label industry pioneers in Europe can be traced back over several hundred years. However, it was most certainly the period of the Industrial Revolution during the late 1700s and early 1800s that really began to shape the use and production of labels in a way that we would recognize them today.

Charting the label's development from first being produced in single colors on wooden hand presses, this book explores all aspects of the industry's history through from the invention of the first presses and paper-making machines to the advent of self-adhesive converting in Europe.

Its rich history and how centuries of innovation has had a profound impact on the modern day branding and use of products including food and medicines is set out-out in 'The History of Labels'. Topics within this volume include Evolution of papermaking and label papers in Europe, The printing press and the early label press pioneers, From woodcuts and engravings to digitized origination, imaging and platemaking, Getting labels into shape - cutters, punches and dies, Inks, coatings and varnishes - their early history and evolution, Evolution of metallic look images, The evolution of barcoding and others. This new book is an useful title for all those who have an interest in how the world of labels and label production has grown from its early origins.

The History of Labels:
The evolution of the label industry in Europe
Authors: Michael Fairley and Tony White
Publisher: Tarsus Exhibitions & Publishing
1st edition July 3, 2014
ISBN-13: 978-0954751883
Paperback, 230 pages

Harold Innis's History of Communications:

Paper and Printing - Antiquity to Early Modernity

This book is based on Harold Innis's unpublished manuscript exploring the history of communications. Three of Canada's foremost communications historians, Buxton, Cheney and Heyer have pulled together some exciting material. They compiled and edited three core chapters from the legendary Innis manuscript, making it thus - for the first time - widely accessible to the public.

Ranging widely across time and space, Innis presents a kaleidoscopic portrait of the various surfaces, writing systems, and practices that have shaped human communication. Framed by the authors' excellent introduction, this book offers a fascinating new perspective on the linkages between material and cultural history that Innis was making in his later work.

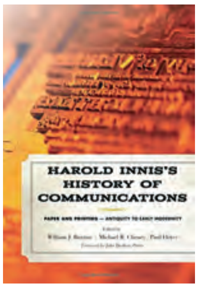
Here, Innis examines the development of paper and printing from antiquity in Asia through to 16th century Europe. He demonstrates how the paper/printing nexus intersected with a broad range of other phenomena, including administrative structures, geopolitics, militarism, public opinion, aesthetics, cultural diffusion, religion, education, reception, production processes, technology, labor relations, and commerce, as well as the lives of visionary figures.

Editors knit the chapters into a cohesive narrative and help readers navigate Innis's observations by summarizing the heavily detailed factual material that peppered the unpublished manuscript. They provide further context for Innis's arguments by adding annotations, references, and pertinent citations to his other writings. Their rigorous editing of previously unpublished chapters from Innis's history of communications brings to the public extraordinary examples of his brilliant research and his groundbreaking conceptualization of communication.

The end result is both a testament to Innis's status as a canonical figure in the study of communication and a surprisingly relevant contribution to how we might think about the current sea change in all aspects of social, cultural, political, and economic life stemming from the global shift to digital communication.

Here at last, Harold Innis's History of Communication is a masterful rendering of many of the unpublished writings by the man who inspired Marshall McLuhan and taught us to look at the material and organizational infrastructure of communication media as foundational to manners of thought and the natures of civilizations. Innis's theories remain highly relevant in the contemporary society.

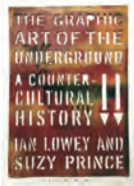
It is mandatory reading, essential as we address the dominance of digital communication in the twenty-first century.



Harold Innis's History of Communications:
Paper and Printing - Antiquity to Early Modernity
Editors: William J.Buxton, Michael R. Cheney, Paul Heyer, John Durham Peters
Publisher: Rowman & Littlefield Publishers
December 2014
ISBN-10: 1442243384
ISBN-13: 978-1442243385
Hardcover, 200 pages

The Graphic Art of the Underground: A Countercultural History

Authors: Ian Lowey and Suzy Prince



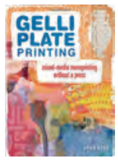
Publisher: Bloomsbury Visual Arts,
November 2014
ISBN-10: 0857858181
ISBN-13: 978-0857858184
Hardcover, 272 pages

The Graphic Art of the Underground: A Countercultural History takes the reader on a dazzling journey through the visual art and design of alternative and youth cultures from the 1950s to the present day. The book showcases the visual art and design from a series of iconoclastic, postwar youth movements.

It is the story of the alternative cultures that have blossomed over the past 60 years or more can be told through their oppositional, provocative art, which is why the book is so compelling, teasing out links between different movements through interviews with some the key figures.

Gelli Plate Printing

Author: Joan Bess



Publisher: North Light Books
September 2014
ISBN-10: 1440335486
ISBN-13: 978-1440335488
Paperback, 144 pages

In this premier guide, artist Joan Bess, inventor of the concept for the Gelli plate, unleashes the fun through more than 50 step-by-step techniques. With them, intriguing patterns can be created using tools like sponges, textured rollers and homemade combs. Learn how to incorporate stencils and rubber stamps. Experiment with metallic paint, dimensional paint and gel medium. Become a texture-hunter, creating a wide world of effects using embossed papers, natural objects, rubber bands, lace, corrugated cardboard, metal tape, die cut letters. Anything goes, even with beginners.

For experienced printmakers, the inspirations in these pages will push you to experiment, adapt, combine and layer.

Bookshelf

Academic dissertations

Doctoral thesis - Summary

Author:
Nicolas Fulleringer

Speciality field:
Fluid Mechanics, Energy, Processes

Supervisor:
Jean-Francis Bloch

Defended:
11 December 2014 at INP Pagora/LPG2 Grenoble, France

Contact:
lgp2@pagora.grenoble-inp.fr

Contribution to the study of friction phenomena. Application to paper materials

The optimization of numerous technological processes requires a deep understanding of the paper friction phenomena. This thesis aims to better understand these phenomena in order to improve the envelopes separation in franking machines.

First, standardized methods for measuring the paper-on-paper friction force having proved limited in terms of repeatability and experimental conditions, two measurement methods - low and high speed - were developed. Similarly, the friction measurement has been adapted to the different contacts encountered in franking machines.

Secondly, these methods have been used to study the mechanisms of friction with the paper material including the dependency of the paper-on-paper friction to length of the displacement, the influence of both temperature and humidity on the paper-on-paper friction, and the main frictional properties of the envelope-on-envelope, rollers-on-paper, and pads-on-paper contacts, respectively.

Thirdly, a comprehensive model of the envelopes separation in a franking machine was created. This process aims at displacing, with no damage, only the bottommost envelope of a stack of envelopes. This model allows to identify, characterize and propose an optimization of the main process parameters.

Doctoral thesis - Summary

Author:
Raphaël Bardet

Speciality field:
Materials, Mechanical, Civil Engineering, Electrochemistry

Supervisors:
Julien Bras and Naceur Belgacem

Defended:
11 December 2014 at INP Pagora/LPG2 Grenoble, France

Contact:
lgp2@pagora.grenoble-inp.fr

Nanocelluloses as potential materials for specialty papers

The original feature of this work is to investigate the contribution of two families of nanocellulose for their application within specialty papers. Two families of nanocellulose are existing, i.e. Cellulose Nanocrystals (CNC) and Cellulose Nanofibers (CNF). It results in different properties in suspension and solid states. CNF with their ability to form entangled network are used as dispersive network for particles.

In contrast, the self-assembly properties of CNC are used to obtain iridescent films. First, the films based on nanocellulose were considered as model layers. Then, results were implemented at the industrial scale within the papermaking process.

It is proposed to use CNF based coating for saving opacifying pigments in lightweight paper, and manufacturing iridescent pigment to impart anti-counterfeiting properties. These sustainable and cost-effective approaches were then validated at pilot scale.

The Journal of Print and Media Technology Research will publish summaries of high quality academic thesis within the scope of the journal. Short summaries should be submitted to <journal@iarigai.org> by the thesis supervisor. Information on type and field of the thesis, author, supervisor, date and university of defense or presentation, as well as on how the full thesis can be obtained must be provided.

Events

Graphics of the Americas 2015

Miami, Florida, USA
February 26 to 28 2015

Graphics of the Americas Expo (GOA) is the most respected event in the world of blended communications as nowhere else can one find such an eclectic spread of designing kits, designing software, colors, printing material, learning tools, international journals on designing and more. This will offer a true picture of the changing dynamics of the graphic arts industry. A platform for face to face discussions and business opportunities with industry peers and leaders, this event is one that can help visitors to establish identity on the global graphic arts scenario.

Expert sessions on printing, publishing, photoshop and such other tools as well as those on marketing and brand positioning further makes GOA an event that must not be missed.

The seminars at GOA will feature the most interesting, inspirational, thought-provoking and forward-thinking icons in the industry. These seminars will also provide participants with in-depth educational content, case studies, and actionable insight.

FESPA Brasil

Sao Paolo, Brasil
18 to 21 March 2015

Brazilian and international print markets will witness a dedicated exhibition for the wide format and textile printing sectors. Organized as a regional event by FESPA Brazil, this trade show will bring to print solution providers andvisitors a comprehensive display of wide format print technologies.

The exhibition will be held from 18 to 21 March 2015, and will be co-located with ExpoPrint Digital, which covers the commercial digital printing market. It aims to deliver leading industry manufacturers who will be demonstrating the latest product launches and solutions for wide format digital printing, textile printing, garment decoration, screen printing, signage and digital signage.

Business owners operating in these sectors have four days to discover the range of print applications and opportunities, talk to suppliers and make business decisions to boost the development of their company. While also taking time to attend seminars that will address key topics such as exploring print applications, sustainability, finishing and print business management.

Expo Print Digital

Sao Paolo, Brasil
March 18 to 21 2015

Digital Printing is not the future: it is here and now. There is no question about whether digital printing will dominate the graphic arts market, and whether there is any time left for traditional printers.

The question today is much more focused on the industry segment that printing companies are covering. If the specialty is commercial printing with long runs, like generic promotional brochures, offset printing system is unbeatable. If, on the other hand, the company works with small runs, a careful analysis shuld be considered about the adoption of a digital printing system. In addition to speeding up the process, production can still be diversified with direct mail printing with variable data, production of books and magazines on demand, transpromotional printing, among other services.

The Brazilian market is one of the world's most promising markets and the Brazilian graphic arts industry is recognized by its entrepreneurship and dynamism that reveals a successful future. Therefore, ExpoPrint Digital was created as a successful and logical step, since it was born from a partnership with Digital Image & Print which has had three editions held. It will feature the presence of major suppliers from the graphic arts segment.

Afeigraf, Association of Manufacturers and Agents for Equipments and Supplies for the Brazilian Graphic Industry, and APS Feiras & Eventos are together in this big event focused on the graphic arts market: ExpoPrint Digital Latin America. The event will be organized alongside with the FESPA Brasil, that will cover another exciting segment of printing industry.

Codex V book fair

Richmond, California, USA
February 8 to 11 2015

Digital is dead, at least for one week in February 2015. Over 200 of the world's most distinguished book artists and artisans, private presses, and fine art publishers will be exhibiting their work at the upcoming biennial CODEX International Book Fair, February 8 through 11 in Richmond, California. There is definitely no better place to find, see and collect the world's greatest contemporary artist books, fine press books, and fine art editions.

The Book Fair offers four days of access to 200 of the world's leading fine presses and book artists. Now in it's 10th year, this extraordinary event has been acknowledged as the leading International Fine Press and Artist book fair. Exhibitors are coming from Germany, UK, Italy, France, South America, The Netherlands, Mexico, Israel, China, Austria, Poland, Australia, Russia, and Japan. The event also attracts special collections librarians, curators, and private collectors from all over the world.

Color management conference

New Delhi, India
12 February 2015

NPES will partner with co-organizers the International Color Consortium (ICC) to introduce the NPES-ICC Color Management Conference 2015. Themed, "Manufacturing Success with Color Management", this one-day event is set to explore the ubiquitous issues of color management.

Renowned overseas experts are invited to share the latest trends of ICC color management and the applications in different areas. Participants will hear and participate in discussions on color management, from capture to production. The conference will provide a unique opportunity to interact with peers exchange ideas and discuss strategies. The conference, designed for end users, is expected to attract 300 participants from the digital, offset, packaging, and newspaper industry.

International book fair

Leipzig, Germany
12 to 15 March 2015

March in Leipzig is characterized by reading. The Leipzig book fair and its reading festival "Leipzig reads" are the spring events of the book and media sector. Authors, readers and publishing companies meet to collect information, to engage in exchange and discover what is new. Especially this mixture makes the book fair an exciting and varied experience for young and old.

Held every March, it is a massive draw for publishers, writers, readers and journalists. An ideal communication platform, the Leipzig Book Fair provides extensive information about new publications as well as current and future trends in the German-speaking and European markets.

TAGA Annual technical conference

22 to to 25 March 2015
Albuquerque, New Mexico, USA

Print professionals, scientists, and researchers will be among the industry's brightest minds gathered at the 67th Annual Conference of the Technical Association of the Graphic Arts (TAGA). Attendees of the conference will come together from around the world to discuss industry innovations and present papers on research and development activities.

The TAGA conference features technical and scientific papers on research straight from the laboratory, studies from the pressroom, and developments in software and engineering systems. This conference focuses not only on graphic arts systems, software, and computer technology developments, but also on the more traditional areas of press, ink, and paper engineering applications.

More than 30 technical papers on emerging technologies and industry changes will be featured, as well as leading keynote speakers such as:

- Ink on Substrate - New printing processes and applications that can expand the positioning of today's printer (Chris Travis, KBA)
- Using data and a print-centric strategy to manage omni-channel marketing (Michael Van Haren, Quad/Graphics)
- Printed electronics: Opportunity, challenge, or hype? (Dr. Bruce Kahn, Clemson University)
- Scientific and technology innovations for a secure country (Patrick Younk, Los Alamos National Laboratory)

The technical papers will highlight the latest developments in printing technologies, packaging equipment, consumables, workflow, color management, forensic marking, the impact of OBAs, and printed electronics, to name but a few of the topics.

Graphics Canada

Toronto, Canada
16 to 18 April 2015

Canada's largest and longest running showcase for the graphic arts and printing industry. Attracting the full spectrum from the design community, smaller quicker printers, medium-sized facilities to the country's largest operations.

Graphics Canada was launched more than 50 years ago. With 200 exhibitors representing over 300 companies and held in three large exhibit halls at the Toronto International Centre, the event provides an unique opportunity to inspire, influence, entice and persuade the largest gathering of graphic arts and print buyers in Canada.

Graphics Canada 2015 also features educational conferences, sponsored pavilions and other co-located events, including:

- SGIA Specialty Graphics Theatre
- G7 IdeaAlliance Canada Summit
- Printing Sales Training
- Graphics Canada Seminars Theatre
- Cross Media Conference
- Innovations Theatre
- Printing Software Conference

Publish Asia 2015

Bangkok, Thailand
28 to 30 April 2015

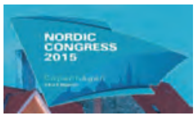
As one of the important regional events of WAN-IFRA, Publish Asia is the leading newspaper industry event in Asia. It has gathered more than 400 media executives from various countries in many countries across Asia Pacific. For its 15th edition, Publish Asia will be held in Bangkok from 28 to 30 April 2015. Journalists worldwide are facing growing pressure to do more with less and maintain high editorial standards while reaching larger audiences on multiple platforms.

The Newsroom Summit will tackle problems facing editors, managing editors, chief reporters, and all those who are involved in managing newsrooms in a multiple-media environment. The CEO Conference for senior executives will be supplemented by three different simultaneous events - Newsroom Summit Asia, Advertising Summit Asia and Printing Seminar. It is intended to help CEOs, managing directors and senior management executives benchmark their transformation strategies and to give them inspiring insights from media leaders. It will showcase innovative business models and concrete ideas for preserving the effectiveness and sustainability of news publishers' print operations.

The Printing and Production Seminar will feature recent innovations and best practices in newspaper production that can have a decisive impact on a news media group's bottom line. This event is targeted to the technical and production directors, plant managers and IT heads.

Nordic Print Congress

Copenhagen, Denmark
24 and 25 March 2015



The NordicPrint Congress is intended to promote innovation in the print industry and to create a dynamic networking environment.

Partciants will have the opportunity to hear from top industry experts, meet actors across various printing sectors and learn how to develop their businesses, with special emphasis on the dynamic Nordic market.

Supported by FESPA's Profit for Purpose program of reinvestment, the Nordic Print Congress is organized by four national associations, members of FESPA, and will be hosted by Grafisk Arbejdsgiverforening in Copenhagen.

International Conference on Communication, Media, Technology and Design

Dubai, UAE
17 to 19 May 2015

International Conference of Communication, Media, Technology and Design aims to gather academicians who are interested in communication, media studies and design from all over the world. The ultimate aim is to promote different ideas to offer a place for participants to present and discuss their innovative recent and ongoing research and theoretical work and/or their appli cations or development.

The scope of the conference includes a wide array of topics related communication and media technology and design.

The themes of the conference aiming for the exchange of information on research, development, and applications of communication technologies, social media, visual communication and design, integrated marketing communication, communication education, communication barriers, health communication, media management and economics, political communication and communication and media studies in general.

Call for papers

The Journal of Print and Media Technology Research is a peer-reviewed periodical, published quarterly by iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries.

Authors are invited to prepare and submit complete, previously unpublished and original works, which are not under review in any other journals and/or conferences.

The journal will consider for publication papers on fundamental and applied aspects of at least, but not limited to, the following topics:

- Printing technology and related processes

  Conventional and special printing; Packaging, Fuel cells and other printed functionality; Printing on biomaterials; Textile and fabric printing; Printed decorations; Materials science; Process control

- Premedia technology and processes

  Color reproduction and color management; Image and reproduction quality; Image carriers (physical and virtual); Workflow and management

- Emerging media and future trends

  Media industry developments; Developing media communications value systems; Online and mobile media development; Cross-media publishing

- Social impacts

  Environmental issues and sustainability; Consumer perception and media use; Social trends and their impact on media

Submissions for the journal are accepted at any time. If meeting the general criteria and ethic standards of scientific publishing, they will be rapidly forwarded to peer-review by experts of high scientific competence, carefully evaluated, selected and edited. Once accepted and edited, the papers will be printed and published as soon as possible.

There is no entry or publishing fee for authors. Authors of accepted contributions will be asked to sign a copyright transfer agreement.

Authors are asked to strictly follow the guidelines for preparation of a paper (see the abbreviated version on inside back cover of the journal). Complete guidelines can be downloaded from:

http://www.iarigai.org/publications/

Papers not complying with the guidelines will be returned to authors for revision.

Submissions and queries should be directed to:

journal@iarigai.org or office@iarigai.org

Guidelines for authors

Authors are encouraged to submit complete, original and previously unpublished scientific or technical research works, which are not under review in any other journals and/or conferences. Significantly expanded and updated versions of conference presentations may also be considered for publication. In addition, the journal will publish reviews as well as opinions and reflections in a special section.

Submissions for the journal are accepted at any time. Papers will be considered for publishing if meeting the general criteria and ethic standards of the scientific publication. When preparing a manuscript for JPMRT, please strictly comply with the journal guidelines, as well as with the ethic aspects. The Editorial Board retains the right to reject without comment or explanation manuscripts that are not prepared in accordance with these guidelines and/or if the appropriate level required for scientific publishing cannot be attained.

A - General

The text should be cohesive, logically organized, and thus easy to follow by someone with common knowledge in the field . Do not include information that is not relevant to your research question(s) stated in the introduction.

Only contributions submitted in English will be considered for publication. If English is not your native language, please arrange for the text to be reviewed by a technical editor with skills in English and scientific communication. Maintain a consistent style with regard to spelling (either UK or US English, but never both), punctuation, nomenclature, symbols etc. Make sure that you are using proper English scientific terms.

Do not copy substantial parts of your previous publications and do not submit the same manuscript to more than one journal at a time. Clearly distinguish your original results and ideas from those of other authors and from your earlier publications - provide citations whenever relevant. For more details on ethics in scientific publication, please consult:

http:// www.elsevier.com/ethicguidelines.

If it is necessary to use an illustration, diagram, table, etc. from an earlier publication, it is the author's responsibility to ensure that permission to reproduce such an illustration, diagram etc. is obtained from the copyright holder. If a figure is copied, adapted or redrawn, the original source must be acknowledged.

Submitting the contribution to JPMTR, the author(s) confirm that it has not been published previously, that it is not under consideration for publication elsewhere and - once accepted and published - it will not be published under the same title and in the same form, in English or in any other language. The published paper may, however, be republished as part of an academic thesis to be defended by the author. The publisher retains the right to publish the printed paper online in the electronic form and to distribute and market the Journal (including the respective paper) without any limitations.

B - Structure of the manuscript

Title: Should be concise and unambiguous, and must reflect the contents of the article. Information given in the title does not need to be repeated in the abstract (as they are always published jointly).

List of authors: i.e. all persons who contributed substantially to study planning, experimental work, data collection or interpretation of results and wrote or critically revised the manuscript and approved its final version. Enter full names (first and last), followed by the present address, as well as the e-mail addresses.

Separately enter complete details of the corresponding author - full mailing address, telephone and fax numbers, and e-mail. Editors will communicate only with the corresponding author.

The title of the paper and the list of authors should be entered on a separate cover page (numbered as 0). Neither the title nor the names of authors can be mentioned on the first or any other following page.

Abstract: Should not exceed 500 words. Briefly explain why you conducted the research (background), what question(s) you answer (objectives), how you performed the research (methods), what you found (results: major data attained, relationships), and your interpretation and main consequences of your findings (discussion, conclusions). The abstract must reflect the content of the article, including all the keywords, as for most readers it will be the major source of information about your research. Make sure that all the information given in the abstract also appears in the main body of the article.

Keywords: Include three to seven relevant scientific terms that are not mentioned in the title. Keep the keywords specific. Avoid more general and/or descriptive terms, unless your research has strong interdisciplinary significance.

Abstract and keywords should be entered on a separate page, numbered as page 1. Do not continue with the main body of the text, regardless of the possible empty space left on this page.

Introduction and background: Explain why it was necessary to carry out the research and the specific research question(s) you will answer. Start from more general issues and gradually focus on your research question(s). Describe relevant earlier research in the area and how your work is related to this.

Methods: Describe in detail how the research was carried out (e. g. study area, data collection, criteria, origin of analyzed material, sample size, number of measurements, equipment, data analysis, statistical methods and software used). All factors that could have affected the results need to be considered. Make sure that you comply with the ethical standards, with respect to the environmental protection, other authors and their published works, etc.

Results: Present the new results of your research (previously published data should not be included). All tables and figures must be mentioned in the main body of the article, in the order in which they appear. Do not fabricate or distort any data, and do not exclude any important data; similarly, do not manipulate images to make a false impression on readers.

Discussion: Answer your research questions (stated at the end of the introduction) and compare your new results with the published data, as objectively as possible. Discuss their limitations and highlight your main findings. At the end of Discussion or in a separate section, emphasize your major conclusions, specifically pointing out scientific contribution and the practical significance of your study.

Conclusions: The main conclusions emerging from the study should be briefly presented or listed, with the reference to the aims of the research and/or questions mentioned in the Introduction and elaborated in the Discussion.

Introduction, Methods, Results, Discussion and Conclusions - as the scientific content of the paper - represent the main body of the text. Start numbering of these sections with page 2 and continue without interruption until the end of Conclusions. Number the sections titles consecutively as 1, 2, 3 ..., while subsections should be hierarchically numbered as 2.1, 2.3, 3.4 etc. Use Arabic numerals only.

Note: *Some papers might require different structure of the scientific content. In such cases, however, it is necessary to clearly name and mark the appropriate sections.*

Acknowledgments: Place any acknowledgments at the end of your manuscript, after conclusions and before the list of literature references.

References: The list of sources referred to in the text should be collected in alphabetical order on a separate page at the end of the paper. Make sure that you have provided sources for all important information extracted from other publications. References should be given only to documents which any reader can reasonably be expected to be able to find in the open literature or on the web. The number of cited works should not be excessive - do not give many similar examples. Responsibility for the accuracy of bibliographic citations lies entirely with the authors.

Please use only the Harvard Referencing System. For more information consult, e. g., the referencing guide at:

http:// libweb.anglia.ac.uk/referencing/harvard.htm.

List of symbols and/or abbreviations: If non-common symbols or abbreviations are used in the text, you can add a list with explanations. In the running text, each abbreviation should be explained the first time it occurs.

Appendix: If an additional material is required for better understanding of the text, it can be presented in the form of one or more appendices. They should be identified as A, B, ... etc., instead of Arabic numerals.

Above sections are supplementary, though integral parts of the Scientific content of the paper. Each of them should be entered on a separate page. Continue page numbering after Conclusions.

C - Technical requirements for text processing

For technical requirement related to your submission, i.e. page layout, formatting of the text, as well of graphic objects (images, charts, tables etc.) please see detailed instructions at http:// www.iarigai.org/publications/journal.

D - Submission of the paper and further procedure

Before sending your paper, check once again that it corresponds to the requirements explicated above, with special regard to the ethic issues, structure of the paper as well as formatting. Once completed, send your paper as an attachment to: **journal@iarigai.org**. You will be acknowledged on the receipt within 48 hours, along with the code under which your submission will be processed. The editors will check the manuscript and inform you whether it has to be updated regarding the structure and formatting. The corrected manuscript is expected within 15 days. At the same time the first (or the corresponding) author will be asked to sign and send the Copyright Transfer Agreement.

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