Inkjet Printed Active Element on Paper Based on Conductive and Thermochromic Materials

Liisa Hakola, Kim Eiroma, Jali Heilmann, Kaisa Lehtinen, Tapio Mäkelä, Marja Vilkman; VTT – Technical Research Centre of Finland; Espoo, Finland

Abstract

Inkjet printing is a suitable technology for fabricating rapidly and inexpensively electronic structures that contain layers made of different inks. It is easy to integrate several printheads together for printing multiple inks and these printheads don't require much space when compared to, for example, conventional printing units. Inkjet printing also has a very low material consumption which makes it possible to jet typically very expensive conductive inks. Therefore inkjet printing enables printing of inexpensive active electronic elements even on such low-cost products as packages or other paper-based products.

VTT has developed and fabricated a game demonstrator that consists of six ink layers all inkjet printed. The layers were made from conductive, dielectric, thermochromic and regular inks printed on a paper substrate. The concept of the game was that a question and three alternatives for the correct answer were presented. When pressing any of the alternative answers, electrical contact between two ink layers triggered a colour-change reaction exposing whether the chosen answer was correct or incorrect. The reaction occurred in a couple of seconds.

Although a working demonstrator was realized challenges still remain for the fabrication of an inexpensive, preferably inkjet printed, power source.

Introduction

In inkjet-printed electronics, typical inkjettable materials include metallic nanoparticle, metal precursor, conductive polymer and UV-curable dielectric inks. Plastic films, such as polyester (PET) or polyimide (PI) have conventionally been the flexible substrate materials of choice. This is primarily due to the outstanding uniformity of their surface properties and their non-porous nature. Some film materials, for example polyimide (PI), can withstand the high temperatures that are required in sintering of metallic nanoparticle inks. In order to meet the low-tolerance demands of printed electronics, the chemistries of both substrate and jettable material need to be engineered to be compatible with one another. Only this will ensure accurate deposition of printed ink drops.

Using flexible fiber-based substrates introduces a new set of challenges for printed electronics. Papers, even coated grades, are far more heterogeneous than polymer films with regard to their surface properties. The porous structure of the surface can absorb the functional component, such as nano-scale metal particles, within itself. Hygroscopic fiber-based materials also suffer from poor dimensional stability when heated, and can withstand temperatures of only up to 100 °C.

However, when the aforementioned challenges in using fiber-based materials as substrates for printed electronics have been overcome, their many advantages can be exploited. These include for example low cost and low environmental impact. Paper and cartonboard are therefore also the preferred packaging material, and thus, the prospect of printing electronic elements in-line directly onto packaging is attractive.

The objective of the study presented in this paper was to develop an all inkjet printed electronics demonstrator on paper. A concept about a simple game card was invented. The basic principle of this game card is presented in figure 1.

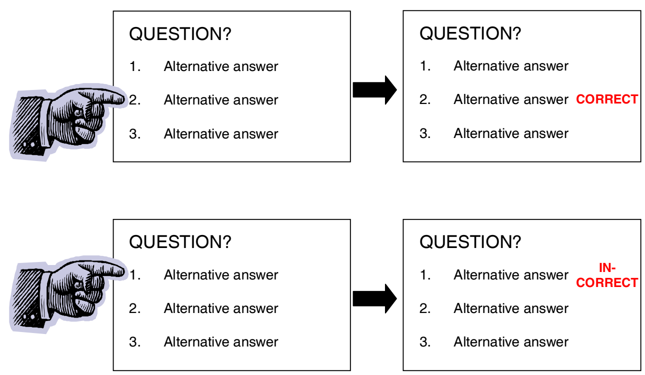

Figure 1. Basic principle of the game card demonstrator presented in this paper.

In the game card there is a question with three alternative answers. When a player presses with his finger the answer he thinks is correct, next to the answer appears a text that shows if the chosen answer is correct or incorrect. This phenomenon is based on conductive and thermochromic materials.

Materials and Methods

A total of four different ink types were needed for making the demonstrator. The inks were 1) conductive ink (Inkjet Silver Conductor AG-IJ-100-S1 nano-particle ink from Cabot), 2) dielectric ink (TGH1015 CL from Allied Photo Chemicals), 3) thermochromic ink (from Akzo Nobel Inks) and 4) CMYK inks (inks for Epson Stylus Photo 890 printer from Epson). All inks were designed for inkjet printing except the thermochromic ink that was designed for flexography printing. The thermochromic ink was mixed with water and a surfactant (Triton X-100) to make it inkjet printable. The thermochromic ink is blue below 37 ^{o}C and transparent above 37 ^{o}C.

Two paper substrates were needed. One photographic paper and one LWC paper (65 g/m^2).

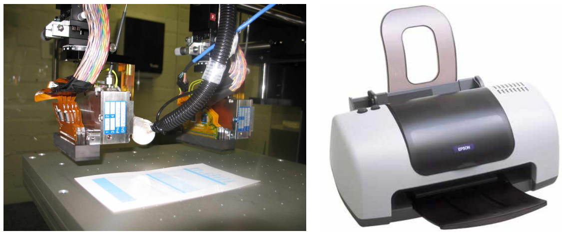

Figure 2. *Industrial printheads (on left) and table-top printer (on right) that were used in this study.*

Inkjet printers at VTT were used for printing. Conductive and dielectric inks were printed with industrial, piezo-electric printheads from FUJIFILM Dimatix. XY precision table with a positional repeatability of 1 µm from iTi was used for moving the substrate during printing. Printheads with 80 pl drop size were used. Thermochromic and CMYK inks were printed with a table-top inkjet printer from Epson (Epson Stylus Photo 890).

Results

The final demonstrator was a size of 5 cm × 8 cm and it consisted of two paper substrates laminated together. The first paper substrate contained two ink layers on top side and the second substrate two ink layers on bottom side and two ink layers on top side. Top side of the first substrate and bottom side of the second substrate were facing each other after lamination. All the layers needed were inkjet printed.

First, two conductive layers were inkjet printed with the conductive ink on the photographic paper. The sample was cured in 100 ^{o}C for one hour. This sample served as the first substrate as presented in Figure 3.

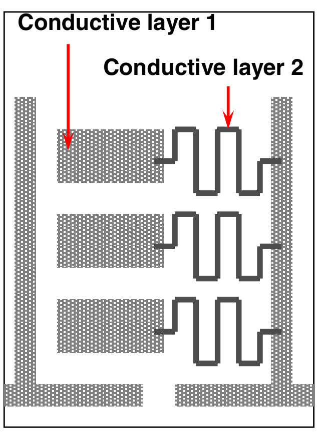

Figure 3. The first substrate needed for making the demonstrator.

Second, one conductive and one dielectric layer were inkjet printed on the bottom side of the LWC paper as presented in Figure 4. Conductive layer was cured in 100 ^{o}C for one hour and dielectric layer UV cured in 120 W/cm^2 for 10 s. The idea was to make the dielectric layer higher than the conductive layer. This sample served as a part of the second substrate.

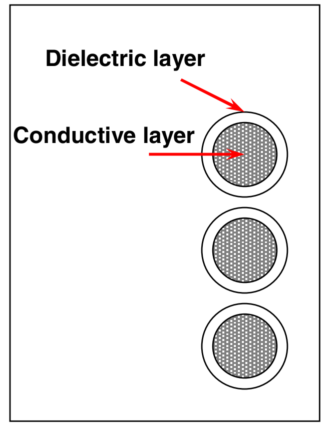

Figure 4. The second substrate with layers on the bottom side for making the demonstrator. This should be understood as a mirror image.

Third, layers on the top side of the second substrate were inkjet printed. One CMYK layer including game card design was printed and one thermochromic layer was printed on top of the rightmost part of the CMYK layer to hide the text that shows the correctness of the alternative answers. Figure 5 presents the final second substrate.

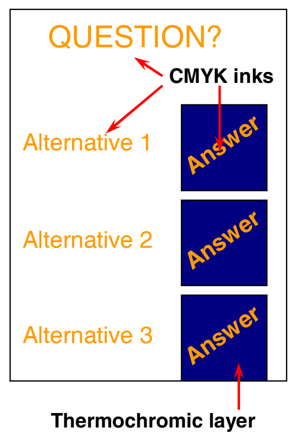

Figure 5. The second substrate with layers on top side for making the demonstrator.

First and second substrates were laminated together as presented if Figure 6. The user presses the far left part of the CMYK layer. This causes an electric contact between conductive layers on first and second substrate. This contact allows the thermochromic layer to heat above 37 ^{o}C causing the thermochromic layer to become transparent. This allows the text below the thermochromic layer to be seen i.e. the user can see if he has chosen a correct answer. This is based on the phenomenon where a through current heats up the conductor below the thermochromic layer thus causing a change in the temperature of the thermochromic layer.

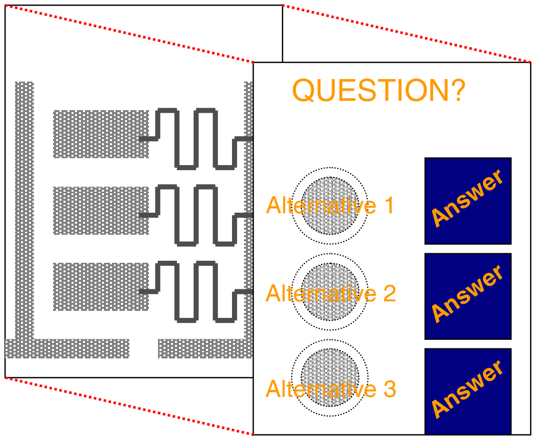

Figure 6. The first and second substrate laminated together.

Figures 7-9 show photographs on how the game card works. The game card is connected to a power source that should have a voltage of approximately 1-3 V. First, the user chooses a wrong alternative answer ("1927") and the thermochromic square next to this answer becomes transparent revealing a letter "V" that means the answer is incorrect (Figure 8). Then the user chooses the right answer ("1917") and the square next to this answer reveals a symbol "%" that means the answer is correct (Figure 9).

Figure 7. The final game card with a question and three alternative answers.

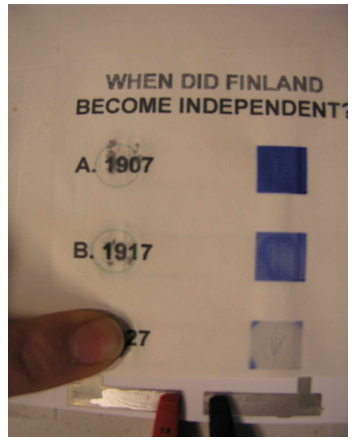

Figure 8. From the game card an incorrect answer is chosen and the square reveals this.

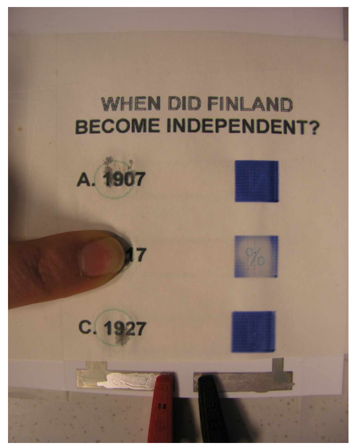

Figure 9. From the game card a correct answer is chosen and the square reveals this.

This shows that the concept works. Although all parts of the demonstrator were inkjet printed there still is a need for an external power source to make the game card work. The final goal would be to also inkjet print the power source needed.

Conclusions

This paper has presented a concept for an all inkjet printed active element. It has been proven that this type of concept works when printed on paper substrates, providing the quality potential of the paper is matched to the complexity of the elements to be printed. This concept can be used as entertainment elements on printed products such as magazines or packages. It could also serve as an intelligent tampering detector on packages. Tampering would result in breakage of the element which would then cause the element to lose its functionality.

References

[1] L. Hakola, Improving quality of inkjet printed metal nanoparticle conductors, Proc. IS&T NIP22, Denver, USA, p. 99-102 (2006).

[2] K. Eiroma, L. Hakola, The effect of curing conditions on the performance of inkjet printed nanoparticle conductors, Proc. NTNE2006, Helsinki, Finland, Poster (2006).

[3] J. Heilmann, The Application of Inkjet for the Printing of PDLC Display Cells, Proc. IS&T NIP 21, Baltimore, USA (2005).

Acknowledgements

The authors would like to thank Research Assistant Seppo Kuosmanen for performing most of the inkjet printing trials and VTT for funding the research.

Author Biography

Liisa Hakola graduated as Master of Science from Helsinki University of Technology in 2002 and her Master's Thesis was about the effect of ink composition on print quality in inkjet printing. She has studied Graphic Arts and paper technology. Since her graduation Liisa has worked at VTT as a research scientist. Her research work focuses on industrial inkjet printing, new coding methods as well as using inkjet printing as a manufacturing technology. She has published several international scientific papers as well as given conference presentations in the field of functional printing.