Printed Near Field Communication System

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Abstract: This paper presents a printed near field communication system that can be integrated into everyday objects, like paper products or plastic parts. The interface is realised by high-volume production technologies, like printing and injection moulding, as they allow for the integration of “low-end” electronics at low costs and, thus, potentially enable a wide spreading of the technology. As a first functionality the identification of objects is realised.

1 Introduction

In the field of mobile and embedded interactive systems great ideas and inspiring demonstrators have emerged in recent years. However, the aspired wide distribution of such electronic systems into everyday objects requires new production technologies, which have to be extremely cheap with regard to production costs. One possibility to meet this demand is the direct integration of electronic components into devices during the production process.

Regarding automatic identification technologies, there are already different solutions available. On the one hand, bar code technology, which is really ubiquitous, allows identification of objects in a very simple way. The development of two-dimensional bar codes and new camera-based technologies [ALF06] have expanded the range of applications of bar codes. On the other hand, RFID technology provides outstanding possibilities for track & trace applications and data collection of physical objects’ current state. Nevertheless, the price of RFID tags still retard usage on item level scale.

Our approach is the direct integration of printed conductive structures both into paper products and plastic parts. The first step is the realisation of identification applications as this is a basic functionality of smart objects.

2 Technological Aspects

2.1 Printing Technologies

Since the discovery of the first conductive polymer materials in the 1970s extensive research has resulted in a great variety of conducting and semiconducting materials which are processable from a liquid state. In addition to conventional liquid processing technologies, like spin coating and spraying, especially printing technologies have attracted broad interest due to their large productivity compared to other structuring technologies [BRK99, SCM+06, PHL04].

The three major mass printing technologies are offset printing, gravure printing, and flexographic printing. All of these processes are characterised by the use of printing forms with a permanent image structure. They enable multiple reproduction of the image and feature high productivity compared to inkjet printing and other structuring technologies. These technologies can be distinguished by the principle of ink separation on the printing form. In offset printing it is due to differentiation of the surface energies changing between hydrophobic and hydrophilic state. The differentiation can also be caused by the topology of the surface of the printing form: in gravure printing image elements are located lower than non-image areas, in flexography image areas are located higher than non-image areas. For printing of electronic structures all three technologies are used, because each results in different layer characterisitics, like resolution of the structures, morphology and layer thickness [SHHF05, BFF+06, RKB+07].

2.2 Plastics Processing

The most important fabrication technology in plastics processing is injection moulding. There are different well-known technologies enabling the integration of inserts during the injection moulding process of plastic devices. Some of them, namely in-mould-film-decoration processes, seem to be suitable for the integration of printed electronic devices [WDK+07].

In-mould-labeling (IML) enables the decoration of plastic parts by back moulding a (preformed) decorative film. Printed foils are inserted into the injection mould by a handling device and bonded to the plastic part during the injection moulding process [JM01].

The in-mould-decoration process (IMD) also allows simultaneous decoration during the moulding process. A modified printed foil is fed through the mould and pressed into the cavity by the injection moulding material. Due to temperature and moulding pressure, the decorative layer is transfered from the carrier to the plastic parts [JM01].

3 Experimental

The aim of this work was the integration of printed electronic structures into plastics parts for identification purposes. Printed conductive structures serve as memory elements and enable the identification of objects. The layout of the memory structure consists of at least one basic electrode and several memory electrodes which are connected or not connected to the basic electrode according to the data to be stored. There are various possibilities for the specific design of the memory structures depending on geometric conditions.

3.1 Printing of Memory Structures

The memory structures were printed by means of flexographic printing at a printing speed of about $0.5\,\mathrm{m/s}$ on the laboratory printing press LaborMAN, a webfed press with a web width of $140\,\mathrm{mm}$ (figure 1a). Commercially available polycarbonate film Makrofol DE 1-4 ($100\,\mu\mathrm{m}$ thick) by Bayer MaterialScience was chosen as substrate. An inline corona pretreatment was carried out in order to increase the surface tension of the substrate and therefore improve the wetting of the "printing ink". The memory elements are printed with a commercially available, water-based dispersion of poly(3,4-ethylenedioxythiophene) doped with poly(styrenesulfonate) (PEDOT:PSS) by H.C. Starck (CLEVIOS P™, formerly Baytron P®). It is reformulated in order to make it printable with flexographic printing. After the actual printing process the printed structures are cured inline by heat.

3.2 In-mould-labeling

The in-mould-labeling experiments were carried out on a Krauss Maffei KM 90-340 B injection moulding machine. The printed film was cut manually into single labels. For first tests they were fixed with adhesive tape in the mould. Makrolon® (Bayer MaterialScience) was used to produce standardised test specimens. The following process parameters were used: melt temperature: $280\,^\circ\mathrm{C}$, mould temperature: $80\,^\circ\mathrm{C}$, injection speed: $60\,\mathrm{mm/s}$, internal mould pressure: $400\,\mathrm{bar}$, dwell pressure: $40\,\mathrm{bar}$ ($20\,\mathrm{s}$), and cooling time: $20\,\mathrm{s}$.

3.3 Capacitive Interface

The printed structures can be detected by capacitive near-field coupling, that means that they can be integrated into the product "under the surface". At the moment, the memory capacity is 16 up to 96 bit and depends primarily on the printed area. In the future, in addition to "read only" configurations also "write once, read many" memory devices are possible.

The equivalent circuit of the system consists of two capacitors connected in series. The input electrode of the reading device prototype (figure 1c) and the memory structure form the first capacitor; the memory structure and the output electrode of the reading device represent the second capacitor. An ac voltage is applied via the input electrode. The resulting signal is detected at the output electrode. This kind of reading device is very cheap compared to optical barcode readers. For the examinition of the printing and film insert moulding experiments, capacitance measurements are sufficent.

4 Results

4.1 Printing of Memory Structures

The printed layer thickness is about $0.5\,\mu\mathrm{m}$. On corona pretreated substrate the sheet resistance of the conductive layer is about $4.6\,\mathrm{k}\Omega$ in printing direction and $7.2\,\mathrm{k}\Omega$ crosswise. In comparison, on non-pretreated substrate the sheet resistance in printing direction is $5.0\,\mathrm{k}\Omega$ and $9.1\,\mathrm{k}\Omega$ crosswise. The conductivity depends on the roughness of the substrate, but in principle functional polymers can also be printed on paper, cardboard, various kinds of foils and all conventional print substrates.

4.2 In-Mould-Labeling

Figure 1b shows one injection moulded part of the in-mould-labeling process. Film insert moulding of printed electronic structures requires an adjusted process control to protect the printed electronic structures. High melt temperatures result in degradation of electrical conductivity. Distortion of geometric properties of the printed electronic structures could be caused by high injection speeds and high internal mould pressure. Carrying out the film insert moulding experiments at the specified process parameters resulted in functional samples.

4.3 Capacitive Interface

The reading technology is very reliable if a precise positioning (about $\pm 2\,\mathrm{mm}$) of the memory structures to the reading device can be assured. Figure 1c shows a reading device prototype. As this technology is not based on radio frequency communication but capacitive near-field coupling, the reading distance does not exceed 1 mm. Further development is focused on smaller memory structures and, thus, higher storage density.

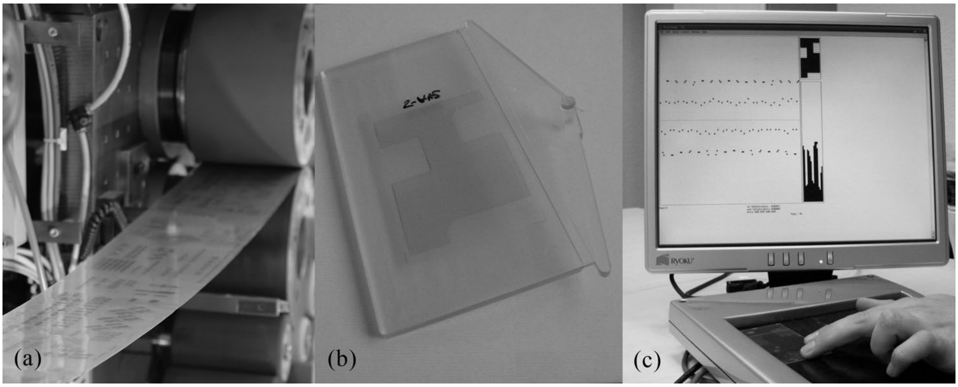

Figure 1: Printed near field communication system (a) printing of electronic structures on the laboratory printing press LaborMAN (b) moulded test sample (c) functional test at the reading device prototype

5 Applications, Outlook and Conclusion

The printed near field communication system combines well-known properties of everyday objects with electronic functionalities. The electronic structures, consisting of conductive polymers, are printed on standard substrates and integrated into various objects by means of high-volume production technologies.

There are various applications where low costs are more important than high memory capacities and high reading distances. Sometimes small reading distances are actually desired. Novel innovative products with additional electronic functionalities are able to bridge the gap between real world objects and electronic media. The field of applications besides the traditional electronics markets ranges from marketing, games, entertainment and packaging technology to specific industrial applications, e.g. anti-counterfeiting.

By printing conductive memory structures, experience in integrating printed electronics into various products can be gained. For future applications, additional functionalities could be integrated by this technology. Research on active devices, like printed OLEDs (organic light emitting diodes) and OFETs (organic field effect transistors) [ZHH+05], is in progress. In priniciple, the latter enables the printing of electronic circuits. Also printed sensors [CLS+06, AK01] could are possible in the future.

The realised identification application has some advantages compared to traditional barcode technology. The memory structure is protected against external influences, e.g. dust or scratches, and can not get copied. Additionally, the surface of the objects can be designed without special restrictions, because the electronic structures are placed under the surface of the device. Furthermore, the reading devices are much cheaper than optical barcode readers. Compared to RFID technology, the storage capacity of the tags and the reading distance are low, but the same is true for the costs for producing and integrating the tags. The printed electronic structures are robust, non-toxic and recyclable. The printed near field communication system provides a low-cost possibility for the identification of everyday objects and meets the demands of many emerging applications in the Internet of Things.

References

[AK01] N. A. J. M. Sommerdijk R. J. M. Nolte A. Kros, S. W. F. M. van Hoevell. Poly(3,4-ethylenedioxythiophene)-Based Glucose Biosensors. *Advanced Materials*, 13(20):1555–1557, 2001.

[ALF06] R. Adelmann, M. Langheinrich, and C. Floerkemeier. Toolkit for Bar Code Recognition and Resolving on Camera Phones - Jump Starting the Internet of Things. In A. Schmidt, M. Rohs, and M. Broy, editors, *Mobile and Embedded Interactive Systems (MEIS'06). Workshop Proceedings*, 2006.

[BFF+06] M. Bartzsch, U. Fuegmann, T. Fischer, U. Hahn, H. Kempa, K. Preissler, G. Schmidt, and A. C. Huebler. All-printed electronics and its applications: a status report. In *Digital Fabrication 2006. Final Program and Proceedings*, volume 2, pages 13–16, Denver, Colorado, September 2006.

[BRK99] Z. Bao, J. A. Rogers, and H. E. Katz. Printable organic and polymeric semiconducting materials and devices. *J. Mater. Chem.*, 9:1895–1904, 1999.

[CLS+06] J. B. Chang, V. Liu, V. Subramanian, K. Sivula, C. Luscombe, A. Murphy, J. Liu, and J. M. J. Frechet. Printable polythiophene gas sensor array for low-cost electronic noses. *Journal of Applied Physics*, 100(1):014506, 2006.

[JM01] F. Johannaber and W. Michaeli. *Handbuch Spritzgießen*. Hanser, München, Wien, 2001.

[PHL04] M. Pudas, J. Hagberg, and S. Leppaevuori. Gravure offset printing of polymer inks for conductors. *Progress in Organic Coatings*, 49:324–335, 2004.

[RKB+07] K. Reuter, H. Kempa, N. Brandt, M. Bartzsch, and A. C. Huebler. Influence of process parameters on the electrical properties of offset printed conductive polymer layers. *Progress in Organic Coatings*, 58:312–315, 2007.

[SCM+06] V. Subramanian, J. Chang, B. Mattis, S. Molesa, D. Redinger, A. de la Fuente Vornbrock, and S. K. Volkman. All-Printed Electronics: Materials, Devices, and Circuit Implications. In *Digital Fabrication 2006*, pages 21–24, 2006.

[SHHF05] G. Schmidt, U. Hahn, A. C. Huebler, and U. Fuegmann. Realization of electronic structures by means of flexographic printing. In *Proc. of the 1st international IARIGAI student conference on print and media technology (Printing Future Days)*, pages 100–103, Chemnitz, Germany, 14.-17. November 2005. Verlag für Wissenschaft und Forschung Berlin.

[WDK+07] K. Weigelt, M. Dinter, H. Kempa, U. Fuegmann, U. Hahn, M. Gehde, R. Baumann, and A. C. Huebler. Requirements for electronic devices due to new concepts for smart object fabrication. In T. Gessner, editor, *Smart Systems Integration 2007*, pages 641–643, Berlin, 2007. VDE Verlag.

[ZHH+05] D. Zielke, A. C. Huebler, U. Hahn, N. Brandt, M. Bartzsch, U. Fuegmann, T. Fischer, J. Veres, and S. Ogier. Polymer-based organic field-effect transistor using offset printed source-drain structures. *Applied Physics Letters*, 87:123508, 2005.