SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series A
Faculty of Chemical Technology
**17** (2011)

# MASS PRINTING TECHNOLOGIES FOR TECHNICAL APPLICATIONS

Andreas WILLERT [a1], Jens HAMMERSCHMIDT[b]
and Reinhard R. BAUMANN[a,b]
[a]Fraunhofer Institute for Electronic Nanosystems ENAS, DE–09126 Chemnitz
[b]Chemnitz University of Technology, DE–09126 Chemnitz

Received September 30, 2011

*The increasing use of printing technologies for the manufacturing of sensors, electronic circuits, conductors, other functional layers, etc. is a trend in current manufacturing environments. Hence, printing technologies have been utilized as a tool to deposit certain amounts of functional material on various substrates to gain a new quality in regard to cost effectiveness and production volume. Most of the already presented approaches are lab-based – only a few are already in the market. In this paper, we elucidate how inkjet technology and machine development of large area manufacturing technology employed for the printing of functional layers with the aim of technical applications are utilised. We describe the workflow for the manufacturing of fully printed microsieves providing the functionality porosity to be integrated in applications of filtration. Another example given is the manufacturing of batteries based on printing techniques in a pilot production line, with a push button printed complementary and SMD-LEDs mounted during assembly.*

[1] To whom correspondence should be addressed.

## Introduction

Printing technologies have been established during the last years as particular dedicated material deposition systems [1]. For a long time these techniques have been used only for material deposition of colourful and black inks onto various types of substrates. Even today, not all questions concerning printing quality issues, especially in respect to colour faithfulness, have been answered. Nevertheless, printing technologies have been adapted to several technical production processes. Just to cite a few: screen printing of silver antennas [2], inkjet printing of RGB colours for LCD and Plasma displays [3], screen printing of silver conductors of solar cells [4], screen printing of heating elements incorporated in cars [5], printing of organic circuitry [6], or gravure printing of touch screens [7].

In this contribution, we describe the workflow of employing printing technologies for functional material deposition. In contrast to graphic arts industry workflows the main issue is the printing process itself. Mostly there are high demands in regard to functional ink, functional layer thickness, surface energy of the substrate, register, and drying issues. To illustrate the proceeding and the outcome, we will present two examples of functional devices: a printed microsieve and a thin film battery demonstrator.

## Workflow

In graphic arts industry, the workflow divided into pre-media, prepress, press and postpress processes is well established [8]. This workflow is dedicated to the application of printing inks and varnish. Taking functional inks into account, basically all processes can be adapted to the different demands. Some considerations have already been published [9,10]. Therefore, the print process itself is being presented in this paper as subchapters in the respective paragraphs.

## Printed Microsieves

Microsieves are a particular kind of membranes exhibiting an enhanced flow rate and accurate size selectivity in filtration applications compared to conventional *track etched membranes* and *tortuous path membranes* [11]. Meanwhile microsieves manufactured by lithographic processes [12] have been evolved to a commercially available product for the employment in micro filtration, emulsification, or sensing systems [13]. However, the established manufacture requires sophisticated and cost intensive micromachining equipment, and is exclusively based on silicon materials. For these reasons, alternatives [14-17] have been investigated, among them our promising approach (of the Chemnitz University of Technology) to employ inkjet printing [1] as a low cost and digital manufacturing method to achieve large areas of polymeric microsieves. An example of such a fully inkjet printed microsieve is given in Fig. 1.

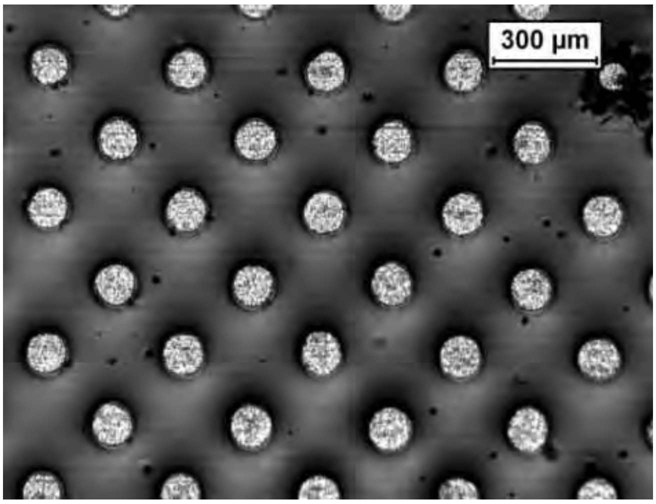


Fig. 1 Example of a fully inkjet printed microsieve

## Manufacturing

The manufacture is based on previous works [18] and follows the process published recently [19]. Employing the Fujifilm Dimatix Materials Inkjet Printer 2831 (DMP 2831) with 10 pL printheads, firstly an array of sessile drops composed of 30 wt% water and 70 wt% ethylene glycol is deposited on aluminum foil (hydrophobized with 1,1,1,3,3,3-hexamethyldisilazane). Secondly, a UV curable ink (Crystal UFX7683, Sunjet) is printed into the interspaces of the sessile drops. These act as molds and prevent the UV curable ink from covering the places occupied by the sessile drops. Thirdly, the UV curable ink is cured by using the BlueWave-50 (Dymax Light Curing Systems), and subsequently the sessile drops evaporate. In a last step, the aluminum foil is etched away in a solution of 17 wt % hydrochloric acid. The resulting microsieve then floats on the aqueous phase.

In the process, the diameter of the pores can be adjusted by changing the volume of the pore forming sessile drops. This is achieved by the variation of the number of printed droplets merging to one sessile drop on the aluminum foil. Employing this approach average pore diameters between 38 and 114 µm were realized [19].

The workflow described is currently improved to achieve both, an up-scaling to larger areas of about 10 cm² and an inline manufacture (Fig. 2). Instead of using a laboratory inkjet system like the DMP 2831, two industrial Fujifilm Dimatix Galaxy printheads with 256 nozzles each in sequential order are employed (30 pL for sessile drops, 50 pL for the UV curable ink). The substrate is moved on an X-Y table.

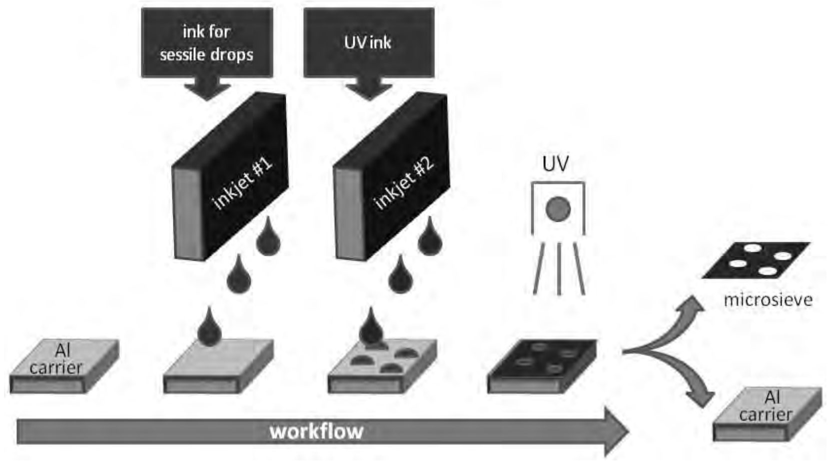


Fig. 2 Workflow of microsieve manufacturing in one machinery setup

Whereas the manufacture on laboratory scale required the change of printheads to print two inks, now both are deposited consecutively in one printing process. Furthermore, the step of UV curing is directly integrated in the machine. Due to the fact that this process is not in production scale, the aluminum carrier is dissolved in acid to obtain free floating microsieves.

## Thin Film Battery Demonstrator

The basic idea to employ screen printed batteries in applications is to gain benefits from high flexibility in regard to thickness, geometrical shape, voltage, capacity and weight. To design a battery dedicated to a defined application rather than taking off-the-shelf solutions, takes into account the specific demands of the defined application. The benefits can be clearly listed: matching energy content, seamless integration, high production efficiency — just to name a few. As outcome the environmental balance is much better than employing metal encapsulated battery cells.

The basic battery concept has been developed in close cooperation between the Chemnitz University of Technology, Fraunhofer ENAS and printechnologics GmbH. The basic decision has been to focus on primary batteries promising low cost applications without the need of any recharge environment.

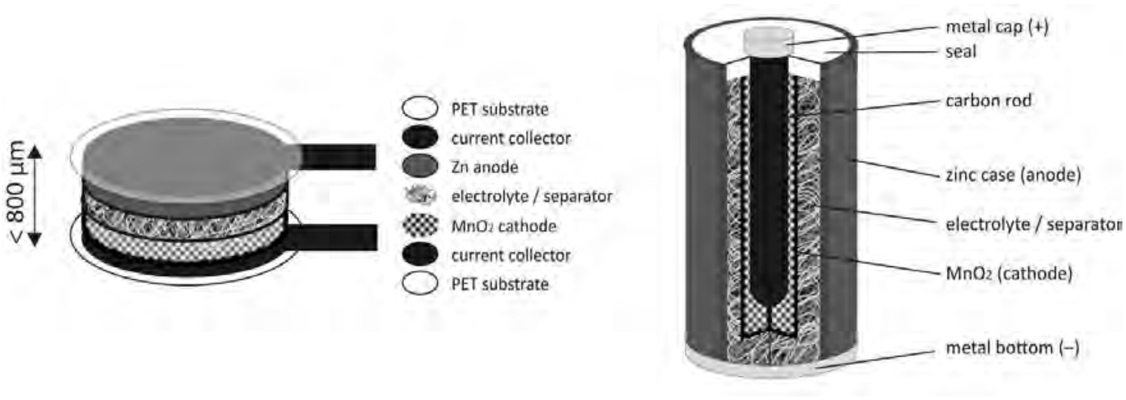


Fig. 3 Printed film battery (left) and cylindrical form factor (right)

## Battery Systems

When comparing primary battery systems, one result is that many of them are environmental hazardous. For example, quicksilver, lithium or several acids used as electrolyte are harmful to living beings. The printed batteries presented here are based on the environmental friendly Carbon-Zinc system employing zinc (Zn) as anode (zinc powder, diacetonalcohol (DAA) as solvent and conductor carbon), manganese oxide ($MnO_2$) as cathode ($MnO_2$ powder, diacetonalcohol (DAA) as solvent and conductor carbon) and gelled zinc chloride ($ZnCl_2$) as electrolyte.

Widely known standard form factors of batteries are cylindrical like shown in Fig. 3 on the right. Encapsulation is done using metal shells while the main volume is used for the chemicals to deliver electrical power to consumers.

The main idea of a printed primary battery (Fig. 3 left) is to design a battery dedicated to a specific application. Amazing features among others are low thickness and ductility. Basically all chemical substances from the cylindrical battery setup are the same. The main difference is that single layer thicknesses are in the range of 100 µm or below. The occupied battery areas can be modified easily by changing the layout geometry. In contrast to most of established battery systems, also serial connections can be manufactured during the buildup of the battery.

## Manufacturing

The lab-manufacturing of primary batteries is accomplished by using semiautomatic sheet-to-sheet screen printing processes using an EKRA E1 – XL screen printer and a 3D-Micromac MicroDryer and prospectively a dedicated machinery for sealing the cells. In contrast to other printing technologies, screen printing enables the application of relatively high layer thicknesses and makes the imprinting of almost every material using adapted special inks possible. Thus, the screen printing of metal grain based electrode materials seems to be reasonable.

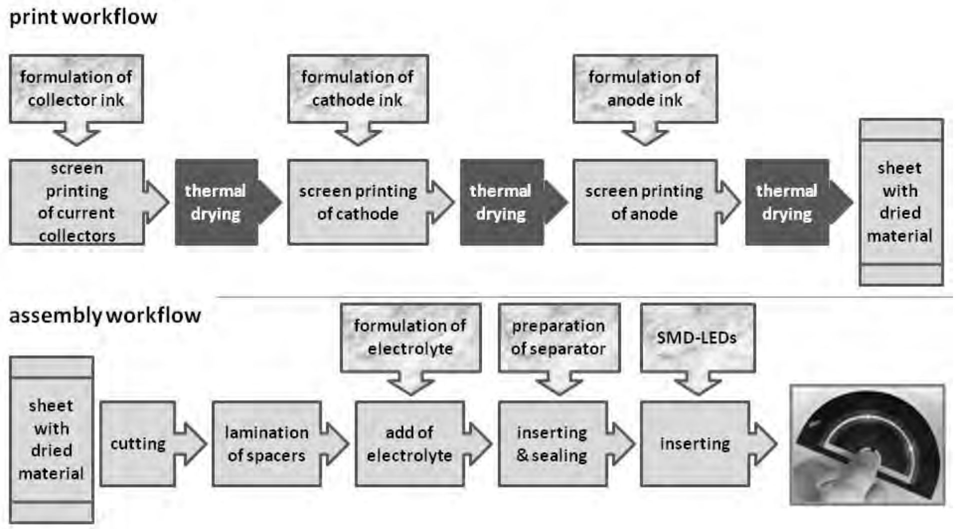


Fig. 4 The workflow of the manufacturing of printed battery demonstrators: the print process itself (upper part) and the assembly workflow (lower part)

## Applications

The printed battery and its application raised some interest in the New York Times Magazine "The 9th Annual Year in Ideas" and the RTCC report of the UN in 2010.

Fig. 5 Printed battery demonstrator including two printed batteries, printed interconnects, printed push button and assembled SMD-LEDs

In the following research, the printed battery demonstrator (Fig. 5) has been developed. In the manufacturing process the current collectors as well as the electrodes are printed. Within the assembly process SMD LEDs, separator layers and electrolyte are added and the whole device is sealed.

## Conclusion

In this contribution, we have presented the developed workflow concepts for two technical applications: microsieves and printed batteries. These concepts enable the manufacturing and pilot production of microsieves and batteries solely based on mass printing technologies.

In future, we expect further emerging applications by employing printing technologies for dedicated material deposition. Therefore the excitement remains to see highly sophisticated printing technologies being employed not only for colourful ink deposition, but for functional material deposition in various fields.


## Acknowledgements

*The work of microsieves was supported by Werner A. Goedel. Experiments of microsieves and the image preparation were done by Eva-Maria Eck. The financial support for the investigations of microsieves in the project MikroHips is granted by the BMBF (FKZ 03FO2142).*


## References


[1] Singh M., Haverinen H.M., Dhagat P., Jabbour G.E.: Adv. Mater. **22**, 673 (2010).

[2] Shin D.-Y., Lee Y., Kim C.H.: Thin Solid Films **517**, 6112 (2009).

[3] Kim Y.D., Kim J.P., Kwon O.S., Cho I.H.: Dyes Pigment. **81**, 45 (2009).

[4] Erath D., Filipović A., Retzlaff M., Goetz A.K., Clement F., Biro D., Preu R.: Sol. Energy Mater. Sol Cells **94**, 57 (2010).

[5] Schierer R., Erismis H., Nemec D.: DE 10 2009 034 306 A1, July 21, 2009.

[6] van der Brand J., Kusters R., Barink M., Dietzel A.: Microelectron. Eng. **87**, 1861 (2010).

[7] Lee J.Y., Oh Y., Park H.J., Kim S.H., Park S.S., Kim W.C.: U.S. Patent US 2011/0080368 A1, May 13, 2010.

[8] Kipphan H.: *Handbook of Print Media: Technologies and Production Methods*, Springer-Verlag, Berlin, Heidelberg, New York, 2001.

[9] Baumann R.R., Willert A., Blaudeck T.: Adv. Print. Media Technol. **37**, 327

(2010).
[10] Willert A.,Blaudeck T., Baumann R.R.: *Printing Technologies for Functional Layer and Device Manufacturing*, IX$^{th}$ Seminar in Graphics Arts, University of Pardubice, Pardubice, 2009.
[11] van Rijn C.J.M., Elwenspoek M.C.: *Proc. Micro Electro Mechanical Systems*, MEMS '95, 1995, pp. 83-87.
[12] Kuiper S., van Rijn C.J.M, Nijdam W., Elwenspoek M.C.: Membr. Sci. **50**, 1 (1998).
[13] Aquamarijn Micro Filtration BV. [Online]. Available: http://www.aquamarijn.nl (04.06.2011).
[14] Bikel M., Çulfaz P.Z., Bolhuis-Versteeg L.A.M., Garduño Pérez J., Lammertink R.G.H., Wessling M.: J. Membr. Sci. **347**, 93 (2010).
[15] Prenen A.M., van der Werf J.C.A., Bastiaansen C.W.M., Broer D.J.: Adv. Mater. **17**, 1751 (2009).
[16] Yan F., Goedel W.A.: Chem. Mater.**16**, 622 (2004).
[17] Greiser C., Ebert S., Goedel W.A.: Langmuir **24**, 617 (2008).
[18] Jahn S.F., Engisch L., Baumann R.R., Ebert S., Goedel W.A.: Langmuir **25**, 606 (2009).
[19] Hammerschmidt J., Eck E.-M., Sowade E., Jahn S.F., Ebert S., Morschhauser A., Goedel W.A., Baumann R.R.: *Complete Digital Fabrication of Polymeric Microsieves*, Proceedings of Non-Impact Printing / Digital Fabrication 2010, Austin, TX, USA, 2010.