Central Challenges When up Scaling the Manufacturing of Thin-Film Battery Applications

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Abstract

In recent years the field of large-area, organic and printed electronics has demonstrated various applications of functional devices. For most of the applications, a reliable supply with electric energy tailored with respect to functional devices and applications is a mandatory, making thin-film battery a challenging area of research. Among a variety of manufacturing concepts printing technologies and their established workflow provide interesting opportunities to fully integrate the battery in a product by customizing its size and shape regarding the device to be driven by that battery. Hence, these printed electronics applications will contribute a new momentum in the packaging market.

Out of the well-known battery concepts for thin-film batteries, the well understood zinc manganese dioxide battery system is very promising due to its simplicity and its environmental sustainability. Therefore it has been chosen to study appropriate fabrication opportunities based on printing technologies. In this paper, we report on the development of a process workflow and, the setup of a pilot manufacturing line, taking into account the requirements to adapt the energy content, the size and the shape to the powered product. The overall manufacturing procedure is divided into single process steps, following the traditional printing workflow which is used in the printing and media industries consisting of Prepress, Press and Post Press.

The paper maps the advantages of an automated production process and covers the introduction of process documentation, aspects of quality control, cost minimization and the efficiency improvement. A basic concept for an adapted digital workflow comprising the definition of relevant metadata and job ticket content, which is required for further industrial fabrication of thin film batteries, will be presented.

Introduction

For graphic communication the most important challenge is to draw the addressee's attention, particularly in the field of packaging, advertising and greeting cards. The quality of information perception attests the success for a printed product. Since the matter of mobile power is ubiquitous, starting from transportation aspects up to light weight portables, the main focus is often set upon power supply and its storage. But instead of using standardized power sources, contacting them conventionally to a device, a new approach is to apply just the appropriate amount of energy, which is necessary due to the consumer load. Based upon a greeting card example this paper describes the customization of a flexible printed battery and an illuminating device towards an assimilated system that highlights the given theme. Therefore the aim was not to attach a giveaway battery sample to a card; furthermore the ambition was to create a fully integrated device that represents the potential of printing technologies.

***Figure 1**. Greeting card sample*

To meet this expectation several approaches have been developed previously to manufacture electronic devices via printing [1].

Printing of electrical energy sources as part of the manufacturing process offers numerous advantages. So is printing itself considered to be a technology with extraordinary throughput, reproducibility and the applicability for highly efficient mass production. Therefore the use of this technique opens a high flexibility.

This is not only related to the applied substrates, which can be paper, plastic foil or textiles as well. But also shape, size and layout of printed structures are variable likewise and may be exchanged very quickly. Hence the promising connection of printing and manufacturing of electrical energy sources identifies many opportunities to optimize production technology, reduce production costs and avoid special waste. The highest potential is most likely the development of new applications, e.g. smart cards and tags, lab-on-chip systems or even 3D smart objects that are powered with printed energy sources [2]. The focus of this paper is to distinguish between standard batteries compared to printed smart systems in which an energy source has already been embedded.

Manufacturing

Printed batteries are available in the market for a few years e.g. Enfucell, Power Paper, blue spark. They are sold as a single device that has to be connected to external electrical circuitry by the customer. In contrast to this traditional business model we demonstrate a fully integrated product consisting of a shape-adapted battery, a push-button, wiring and commercial SMD LEDs. The devices are sequentially manufactured on the same substrate and finished by lamination; giving an autonomic flexible, 1 mm thin product that can easily be integrated in an otherwise produced greeting card.

To achieve such a printed smart system the central idea was to join the adaptable power source with the card theme by using the LED-array, representing the headlights of the E-Mobile on top. In order to seamlessly fit within the final product an electrical circuitry was conceived for the LED alignment and the eco-friendly battery. Due to the use of printing technologies it was possible to customize its size and shape just to the requirements in terms of voltage and capacity.

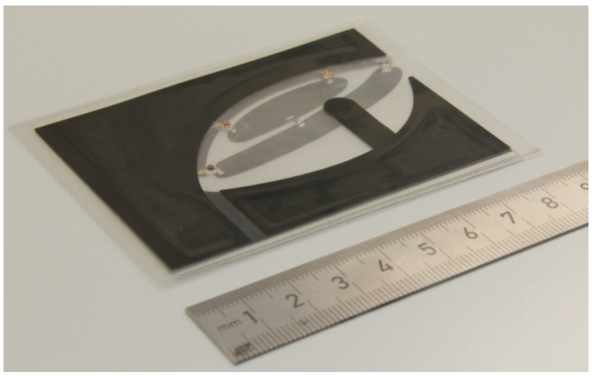

Figure 2*.Custom designed battery*

In this way the battery is merging into the circuitry, which can be seen in figure 2. The manufacturing of the custom design was accomplished by using semi-automatic, sheet-to-sheet screen-printing and blading processes. Among others this technology enables coating application of highest layer thicknesses and makes the imprint of almost every material with special inks possible [3]. Thus, the application of screen-printing for processing electrode materials appears to be reasonable. The different battery components were applied layer by layer as shown in the third figure.

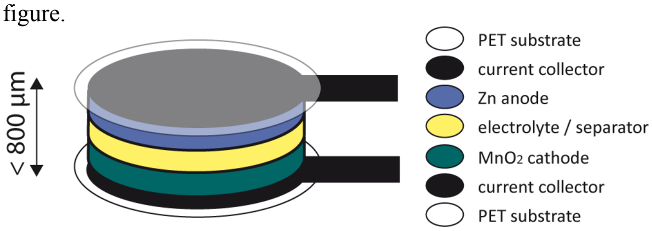

Figure 3*.Assembling scheme of printed batteries*

As a first step current collectors were printed onto PET foil of 100 µm thickness utilizing the table top screen printer Ekra E1-XL. After drying the first coat by the help of a continuous-flow dryer 3D Micromac microDRY, positive and negative electrode materials need to be layered. For the appliance within the staple articles like greeting cards an environmentally friendly chemical system was analyzed. The use of zinc and manganese dioxide prevents the final smart system from being classified as special waste. The chemicals, formulated with high amounts of solid matter, were printed by the same technology and dried afterwards comparably.

Subsequently all remaining parts for the LED array were added to the so-called half-cells. Consisting of two yellow and green SMD LEDs, respectively, and one resistor all pieces were positioned in the circuitry, applied to electrical contact and glued to the substrate. Afterwards the electrolyte, which is based on zinc chloride, was added to both electrodes (positive and negative) using the doctor blade process. The batteries were sealed afterwards by using a proprietary assembling technique and high performance adhesive tape.

Figure 4*. Integration of the smart system to a card demonstrator; including a zinc-manganese battery, a push-button and assembled components*

The printed and fully integrated devices are very thin and lightweight, including a battery with nominal voltage of 4.5 V and weighing in total less than 5 g. Since the inlays are printed onto a plastic foil substrate, the advantage of being flexible leads to diverse scopes. Due to its design, the manufacturing of series connections of printed batteries is possible as well. Thus, integer multiples of the nominal voltage of 1.5 V are realizable and batteries up to 6 V were already produced. The nominal capacity of the manufactured zinc manganese batteries is 2 mAh/cm².

Process development

After approval of function and device integration the next step was to develop a process sequence to raise the quantity number from lab scale up to a volume of 500 demonstrators. Therefore quite some changes had to be taken in account beginning with redesigning the printing screens, split and change the order of intermediate steps like laser treatment up to parallelization of semi-finished parts in printing and assembling.

The constructive steps differ very strong regarding to its up scaling opportunities. To give an impression, the table at the next page shows their allocation among each other, indicating that printing actually takes less than 15% of total time consumption.

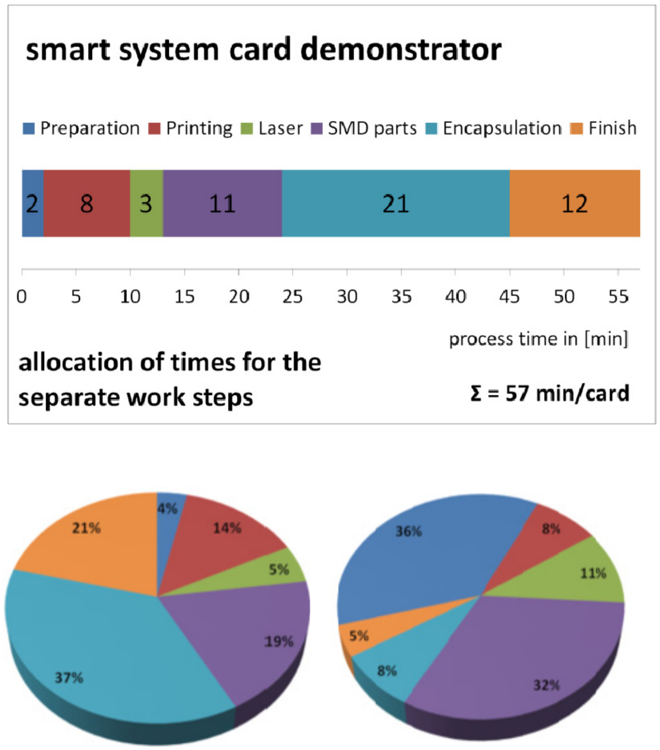

***Figure 5**. Comparison of major steps in smart card demonstrator manufacturing regarding its time consumption*

With process development and parallelization it was possible to reduce the cycle time down to one fifth of the default value. By integrating in-process inspections to every intermediate manufacturing step the total amount of waste dropped significantly. Furthermore also the battery performance could be stabilized due to a more reproducible assembling process. In this way the durability of the smart system lasts for approximately 1500 flash ups over a two seconds period. The result can be seen in the last figure on the bottom.

***Figure 6**. Printed smart system as a luminescent greeting card*

Conclusion

With the help of the investigations on printed primary batteries a basis for the development of smart integrated systems towards a roll-to-roll production has been established. Manufacturing techniques comprising the direct integration of products have been demonstrated with this greeting card. Furthermore, the transformation of all device components into printable elements is one of the next steps in the further development. A connection of printed batteries with consumers, e.g. sensors or RFID applications should be aspired as well or approached in an embedded way.

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Author Biography

Michael Espig studied industrial Engineering and Business Administration at Chemnitz University of Technology. In 2007 he received his diploma degree for a thesis covering the development of a liquid toner model. After working 3 years as Head of Logistics and Materials Management at SGL Rotec GmbH & Co. KG he returned to CUT as research assistant at the department of Digital Printing and Imaging Technology. His work is now focusing on printing thin-film batteries.