Applied Printed Electronics for Added Value Packages

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Abstract

Printing electronics is an emerging technology and future fields of application are automotive, healthcare, intelligent textiles, illumination, displays and packaging.

This paper focuses on printed electronics in packaging, a continuously growing market as predicted by research institutes and the OE-A (printed and organic association).

How printed electronics can enhance the function of a package? The answer must be differentiate according to the product value as well as the package design and function. Key issues here are on the one hand the benefits of the printed electronics, for example to attract customers, and on the other hand, the additional costs. Premium packaging can tolerate higher additional costs as convenient ones and are the target for implanting printed electronics.

These days, the packages with integrated printed electronics are rare to find on the shelves. The added value to available packages will be discussed in detail as well as the technologies behind. The technologies segments are:

- Signals (optical, mechanical and digital)
- Sensors and switches (detection and interaction)
- Support (power supply, data processing)

The different technologies are compared according to their state-of-the-art, performance, integration options, potential and costs. Very value technologies for packaging are optical ones, as electrochromic, electroluminescent and OLED displays.

The OE-A as the leading organization published in 2015 their sixth edition of “Organic and Printed Electronics” written by their members being more than 200 companies, research institutes and universities active worldwide in the field of printed electronics. According to this report, the printed electronics in packaging is an emerging market.

Combining this report with the potential of the different technologies shows possible product opportunities in the short to long-term future.

Introduction

Printed electronics in packaging is an emerging market as predicted by research institutes and the OE-A (printed and organic association). At the moment, there are only a few test packages with printed electronics on the market. In order to evaluate the potential of printed electronics, the different package functions are analyzed according to their potential to be enhanced by electronics. An example demonstrates how electrics can improve many package functions as long as high costs are acceptable. High costs of additional electronics must result in strongly enhanced functions to attract customers. Another option is to enhance only the selected function of lighting and signage at lower costs by hybrid smart objects. They consist of printed as well as silicon elements. Comparing the attractiveness and costs of the different displays gives examples for existing and future smart objects.

Electronics to enhance Package Functions

Package Function

The three segments of a package function are protection, rationalization and communication. Figure 1 to Figure 3 show the packaging segments.

The package functions are checked up on how electronics can enhance the performance of packages. In the segment of protection electronic already helps to protect against theft and forgery. For example, RFID elements protect clothes shops against theft. As another example, adding a temperature sensor to an RFID tag allows the documentation of temperature conditions during transport, storage and trade. Here the electronics enhances the sub segment circulation of the segment rationalization. A display or a speaker can inform the buyer for example about ingredients or origin of the good, as well as how to use or dispose it. In adding light, switches or motion sensors help to increase the advertising function by attractive designs or interaction features animating the potential user to touch the package. To summarize, the three function segments of a package, as protection, rationalization and communication are strengthened by silicon-based electronics.

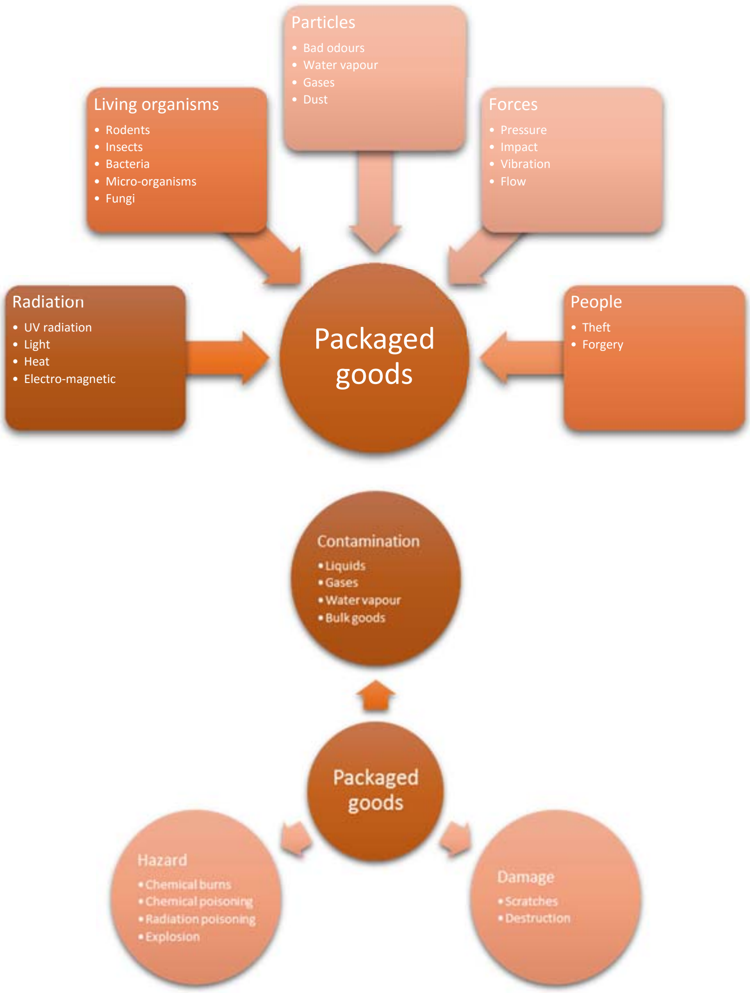

Figure 1: Packaging function protection (top: protecting the packed goods against environmental impact; bottom: protecting the environmental against the packed goods)

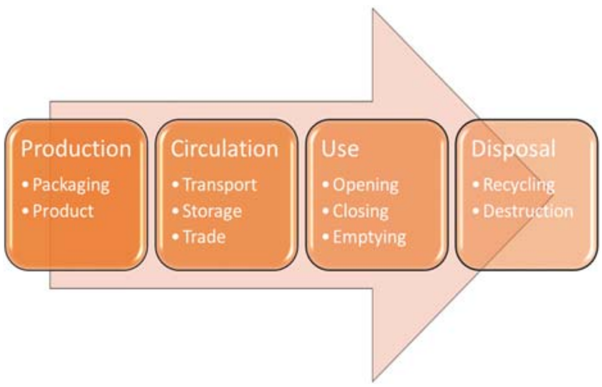

Figure 2: Packaging function rationalisation

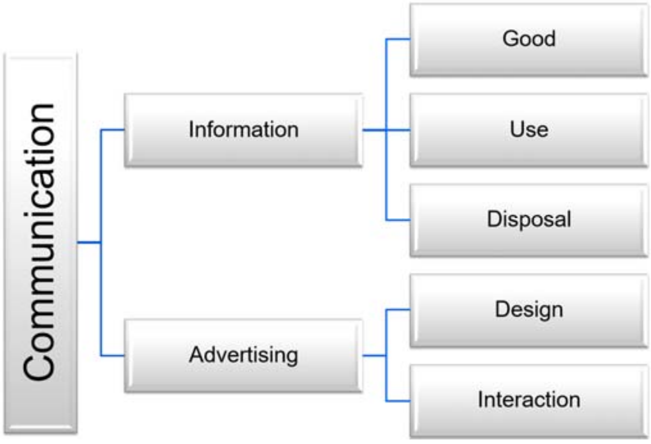

Figure 3: Packaging function communication

Potential of Printed Electronics

In the late 1940 the discovery of semi-conductive properties of organic materials flags the beginning of organic and printed electronics[1]. Solving the semi-condutive organic materials opens the door for printing electronics. The devolpment of solvable conductors, semi-conductors and isolators was the premise for printing these materials on flexible materials, as PET or PEN films. Combining different structured layers can produce the basic elements of the semi-conductive industry, as

- conductive lines,
- isolators,
- resistors,
- capacitors and
- transistors[2].

During the last decade, worldwide research activities created new printable electronic materials allowing – at least on lab scale – the printing of

- batteries, accumulators,
- organic photovoltaic cells (OPV),
- organic light emitting diodes (OLEDs),
- electro-luminescence displays (EL),
- electro-chromic displays (EC) and,
- sensors for the measurement of temperature, pressure, glucose, ...,
- memories,
- small controllers and
- ... .

The advantage of the printing technology consists in the high productivity of the printing process itself, running with web speeds upto 900 m/min at web with of several meters. Large areas of more than one hundred thousand square meter per hour of flexible materials can accuratly be coated with thin and structured material layers, as newspapers or magazines. The resolution is is far beyond the one of the human eyes of some tens of micrometers. Printed electronics demands a higher resolution and accuracy. This is achieved by reducing web speed and width. Optimizing the printing processes and printing high quality materiales in clean enviroments, the resultion goes down to two micrometers. But the semi-conductive industry uses resolutions in the range of tens of nanometers. Even it requests dimensions five nanometers for further increasing the switching speed of transistors[3]. There are about three orders of magnitude between mimimum resolution of printed and semi-conductive electronics. Therefore electronic devices with high switching speeds or large number of basic electronic components are out of range for printed electronics.

The roadmap of the OE-A (printed and organic association) segments in six categories, as to be seen in Figure 4. There are shown products that have already reached the market or are expected to do so in short term. The figure also indicates more advanced products entering the market in some years[4].

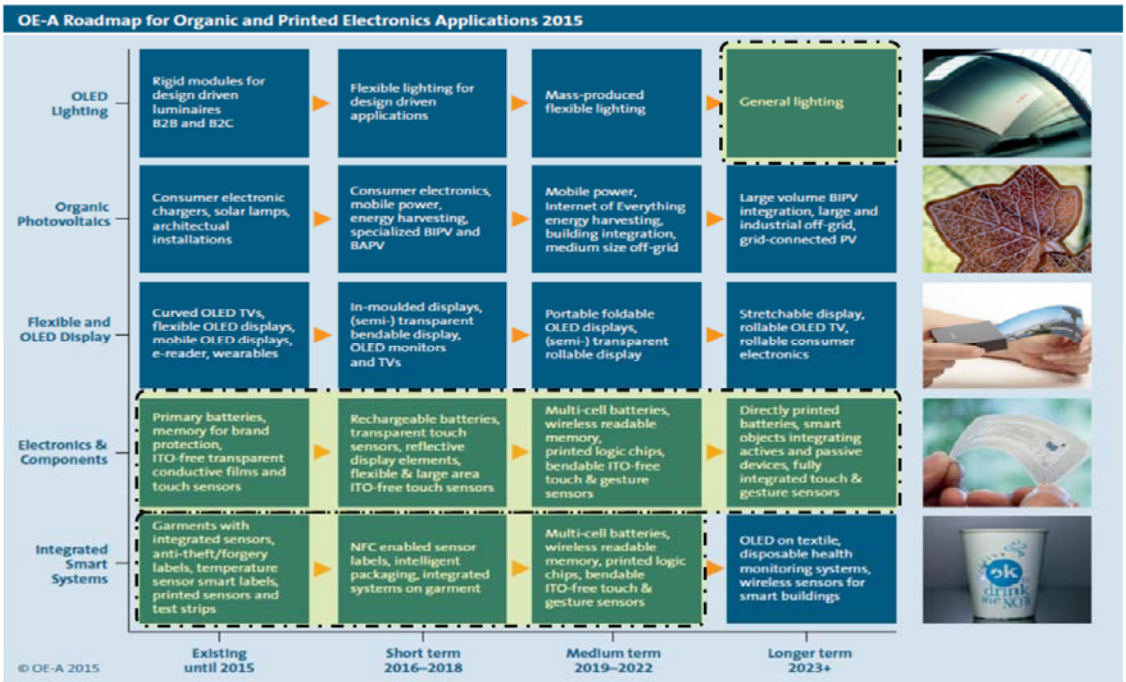

Figure 4: OE-A Roadmap[4] for organic and printed electronics, with forecast for the market entry in large volumes (general availability) for different applications. Relevant areas for packaging are marked.

Functions of Packages Enhanced by Electronics

In the beginning the functions enhanced by electronics were extracted from all function of a package. The segments of electrical elements upgrading packages are analyzed and reveal potential printable features.

Figure 5 lists the extrated functions versus the electrical elements and rates the attractivness of the package enhanced by the respective electronics. The most attractive ones are displays and speakers in combination with wireless connetions. As discussed above, printed electronics is already at least on pilot scale in the segment lighting & signage. In mid term future research and development efforts will succeed to print mechanical signal device on production scale.

The electrical components for upgrading a package divides in the following segments:

- Signals
  - Optical
  - Mechanical
  - Digital
- Sensors & switches
  - Detection
  - Interaction
- Support
  - Power supply
  - Signal & data processing

Figure 5: Packaging functions versus electrical functions

		Optical signals		*Mechanical signals*		*Digital signals*		*Sensors & Switches*	
		Display & e-readers	Lighting & signage	Speakers	Vibrations	Wireless	Wire based	Detection	Interaction
People	Theft	3	3	6	1	9	6	6	
	Forgery	9	3	3	1	9	9		
Circulation	Transport					9	1	9	
	Storage					9	3	9	
	Trade	6	1			9	3	6	
Information	Good	9	3	6		9	9		
	Use	9	3	6		9	9		
	Disposal	9	3	6		9	9		
Advertising	Design	9	9						
	Interaction	9	6	9	3	9	6	9	9

The semi-conductive industry supplies components for all these segments. Things are different in printed electronics. **Lighting & signage** is a strong field of printed electronics. There electro-luminescence, electro-chromic and thermo-chromic displays compete with OLED and LEDs. Mechanical signals, as speakers or vibrators, are available in lab scale but more research and time is requested for upscaling to production. The printed electronics can support digital signal processing by connecting silicon-based components mechanically and electrically. In addition antenna and resitors are common products, for example in the automobile industry.

The segement of **sensors & switches** contain a lot of printed products in at least pilot scale, as for the measurement of temperature, pressure, glucose and others. In addition there are current free press sensors for some years on the market. The industry already prints touch and light sensors with a working current and additional data processing. Magnetic and gesture sensors are still on lab scale.

The backbone of displays and sensors are **support** units for power supply and signal & data processing. Products with printed batteries and solar cells have entered the market recently, but not accumulators. Printed antenna in combination with RFID/NFC processors helping to harvest energy. In the field of basic electrical components there are capacitors and resistors industrial printed, but there performance is far beyond the one of silicon based ones. Very small memories are printed on a pilot plant.

Smart Objects for Upgrading a Package

Example – Milk Package with Display and Sensors

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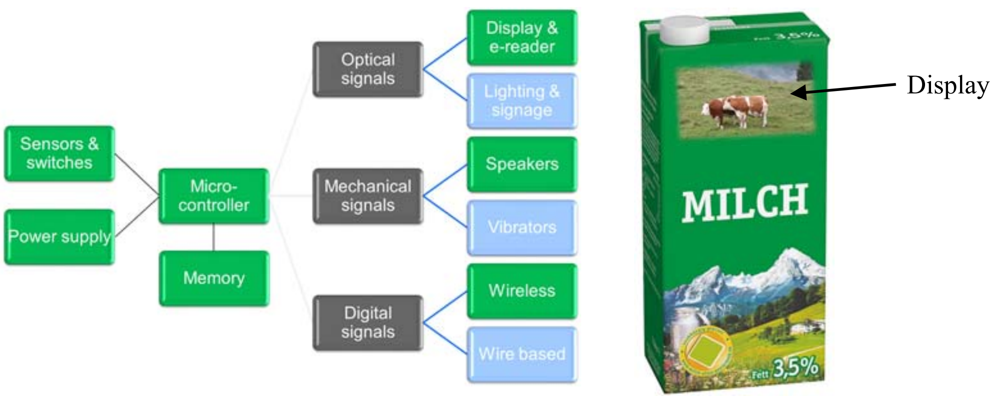

Figure 6: Setup of a smart object: Milk package with integrated display, speaker, processor and power supply

Here, smart objects are alone standing electrical components integrated in a package. According to the previous chapter, a smart object enhances package functions by signals, sensors and switches. Batteries or accumulators power microcontrollers to processing the information of sensors and switches into optical, mechanical and digital signals. The smart object is integrated into the package, see in Figure 6.

For example, the milk package has a display – here showing cows on alpine pasture – and a speaker for advertising and giving information about origin, content quality and actual prize. The enhanced package attracts more buyers and help them to use, e.g. providing recipes. In addition, integrated sensors measure quality parameters of the milk and sends this information to the microcontroller. It goes either to its display or wireless to a host server for further data handling.

This milk package is feasible and its packaging functions described above are enhanced. The cost added by the electronics exceeds the benefit of the electronics by orders of magnitudes. Maybe high value products are an adequate target market. Another option consists in reducing the cost of the smart object by decreasing its functions and replacing expensive components by printed electronics. The most expensive component is the ridged display. Replacing this optical signal by lighting and signage opens the door for printed electronics.

Smart Objects with Printed Electronics

The analysis shown in Figure 5 indicates high values of the communication functions advertising and interaction versus light and signage. Therefore, the different electrical components to support this are listed and compared in Figure 7 and Figure 8.

TFT displays are used in smartphones and are very brilliant, but due to their high costs only reasonable for very high valuable goods. **Area OLEDs** have only one colour and a high brightness making them attractive for high value illumination applications. **Electroluminescent displays** are a cheaper and very flexible alternative. However, they show less brightness and higher power consumption than OLED area displays.

LEDs are low cost light emitters. Combining serval of these point spots to one lighter replaces more and more light bulbs in all application fields. Printed batteries powers a few LEDs for hours showing a medium homogenous illumination.

The other printed optical displays, as **electro-chromic** and **thermo-chromic** ones, are easy and very cost-effective to print, but they are not light emitting and need a light source limiting their field of applications. The first one is more attractive, because it can partly change the transparency of films. In addition, its power consumption is very low for activating the display. In contrast, the thermo-chromic displays request heating elements for a constant colour change consuming a lot of electrical power.

Figure 7: Features of optical signals

	Function	Attractiveness	Minimum Power Supply	Costs for a Small Display incl. support
Electro-chromic	Color change: transparent to blue	Medium Opacity change	Printed battery 1.5V	Very low
Thermo-chromic	Color change: Variable colors	Low Color change	Block battery 9 V	Very low
Electro-luminescent	Illuminated areas	Medium Low brightness	Two Mignon AAA plus DC/AC inverter	Medium (Inverter)
OLED (area)	Illuminated areas	Very high High brightness	Block battery 9 V	High (Display)
SMD LEDs	Illuminated spots	High	Printed battery 3 V	Low
TFT displays	Moving pictures	Very high Variable information	Block battery 9 V	Very high (Controller)

Applying the cost and attractiveness filter on the different types of displaces reduces the technologies for enhancing the communication function of a package by lighting and signage to the following list:

- Electro-chromic signals: Very low cost and medium attractiveness
- Electro-luminescent signals: Medium costs and medium attractiveness
- SMD LEDs: Low costs and high attractiveness

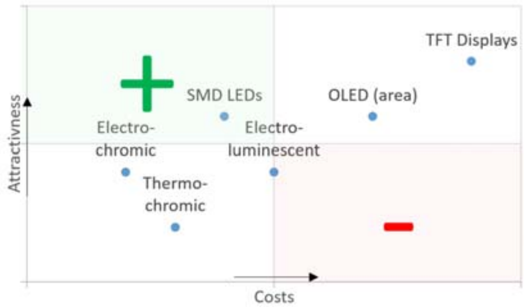

Figure 8: Rating of optical signals for packaging applications

Adding some simple microcontrollers allows to control several of these displays and to increase the communication function strongly.

Electro-chromic Object

A small voltage of about minimum 1.5 V for a few seconds turns the display from transparent to blue. There Li ions migrating to a PeDot layer change its color, see Figure 9. The mimimum components of an electro-chromic display are

- a switch to turn it on,
- the electro-chromic area itself, two or four screen printed layers,
- an energy supply and
- an electrical connection between the different parts.

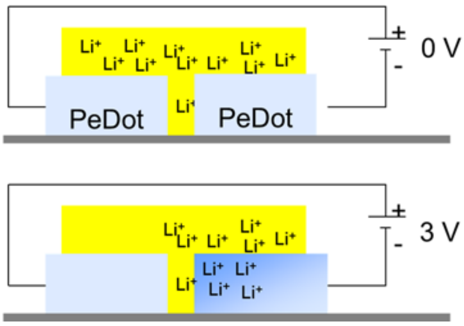

Figure 9: Function of an electro-chromic display (Top off and bottom on)

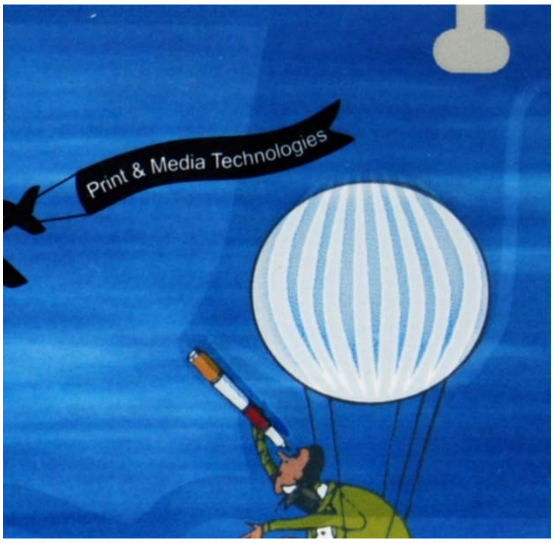

Figure 10: The Hague (left side – off; right hand – on)

The low energy consumption of the display allows the use of even printed battery having a capicity far below coin cells. An other option is the use of an USB cable or NFC. Good examples are “The Hague” or the “Baverian Display” developed by students of the Munich University of Applied Sciences[6].

Electro-luminescent Object

A minimum of four screen printed layers are requested for an electro-luminescent display. Both outer layers build a capacitor with an isolation and electroluminescent layer between. Connecting the capcitor layer to a high frequency AC power supply, accelerates electrons inside of the electro-luminescent layer and result in emitting light. To power an electro-luminescent requires a high voltage and high frequency, for example 110 V and 400 Hz. Normally inverters are used to transform a three to nine volts DC current to the high frequent AC current. The mimimum components of the display are

- a switch to turn it on,
- the electro-luminescent area itself, four to five screen printed layers,
- an DC/AC inverter,
- an energy supply and
- an electrical connection between the different parts.

For shorter runtimes and small illuminated areas of upto 10 cm² AA or AAA batteries are suffient, but for longer runtimes or larger areas a permanent power supply is requested.

One famous package having electro-luminescent is the Bombay Sapphire from the Karl Knauer KG. Lifting the package activates the silicon based electronics and the printed light animation starts, see Figure 11. The cost structure of this demonstrator advise to use it for packaging of high priced goods.

Figure 11: Electro-luminescent display in the Bombay Sapphire from Karl Knauer (Picture© Karl Knauer KG)

SMD LED Object

Depending on the color, SMD LEDs run at 1.8 to 3.5 V. Due to the low currents starting at 2 mA, their energy consumption is very low. Component sizes starts in the tenth of millimeters range. The mimimum components are

- a switch to turn it on,
- one LED,
- an energy supply and
- an electrical connection between the different parts.

Similar to electro-chromic displays, printed batteries have enough capacity to power serveral LEDs for some hours, whereby the brightness is decreasing by time. Using a coin cells opens more options, as adding a microcontroller, touch or other sensors.

A newly developed battery switch uses a coin cell in combination with two magnets as switch, see Figure 12[6]. As long as the package is closed, the disconnect magnet holds the coin cell close to the lid. Only one pol of the coin cell is connected with one pol of the electrical circuit by conductive lines on a flexible substrate. By opening the package, the disconnect magnet moves away and cannot hold the coin cell. Now the weaker connect magnet pulls the coin cell to the second conductive line of the second pol of the electrical current. Hence opening the lid, starts the electical current and the LEDs are on.

Due to combining battery holder, electrical switch, electrical wiring and closure to one element, the battery switch is very cost-effective and can be one key issue to integrate printed electronics in packaging.

Figure 12: Battery switch showing coin cell, two magnets and printed silver lines [6].(Left: Box closed – switch off; right: Box open – switch on)

Figure 13: Package with battery switch[6].(Left: Box closed – switch off; right: Box open – switch on)

Conclusion

Taking the best of both worlds – printed and silicon electronics – gives opportunities for smart objects based on hybrid electronics. For example silicon microcontrollers can drive printed sensors and displays right now. In the mid term future there are also printed mechnical signals, as speakers and virbrators.

Printed electronics can improve the functions of a package and save production costs. Key issue is the break-even between additonal costs and benefit. As analyzed for the stage of development of printed electronics now, lighting & signage increase the communication function, especially in the field of design and interaction. In the next years pilot production of mechnical signals will start and open the door to enhance more packaging functions.

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