PRINTING SMART PACKAGING

In the first of a two-part series, Prof. Wim Deferme introduces the PAPERONICS project and explores low-cost multisensory paper and packaging applications

Printed electronics (PE) have developed into a megatrend in packaging, food, pharmaceutical, automotive and construction industries (see Figure 1). Their applications are multiplying as consumer interaction, instant feedback, traceability or anti-counterfeit features are seamlessly integrated in new product lines.

However, PE's production is still expensive and often based on stand-alone solutions or specific application scenarios. That is why 40 research centres and companies joined in the PAPERONICS project to investigate the future of efficient, affordable and sustainable printing of electronic components directly on paper and plastics. Here, we present the project's results.

WHAT IS PAPERONICS?

PAPERONICS was launched within the European CORNET (Collective Research Networking) framework and brought together organisations active in the field of paper, labels, cardboard, ink and printing technology, RFID (radio frequency identification) tags, scavenger and encapsulation technology, software applications, design, as well as end users of packaging. The meetings took place between 2019 and early 2021.

As the project's initiators we propose a gradual shift of smart packaging functionality from external label elements to electronics fully printed on the package piece. This transition, presented in **Figure 2**, relies on state-of-the art components and printing technologies.

Today's standard RFID smart packaging flow has little in common with the actual packaging industry. Only a small part of the process is performed in the packaging lines as the tags are generally supplied as labels on rolls by traditional RFID manufacturers. The future scenario would entail a complete flow performed by the packaging companies. The long-term vision is to enable the manufacturing and integration of all functional electronic components (e.g. RFIDs, sensors, signage) directly on paper or plastic packaging surface within the printing or conversion lines.

CHOSEN SUBSTRATE: PAPER

Therefore, PAPERONICS' aim was to facilitate involvement of the traditional packaging industry with the supply chain of new smart applications. **Figure 3** shows a schematic supply chain for smart packaging with an exemplary RFID tagged package. We believe

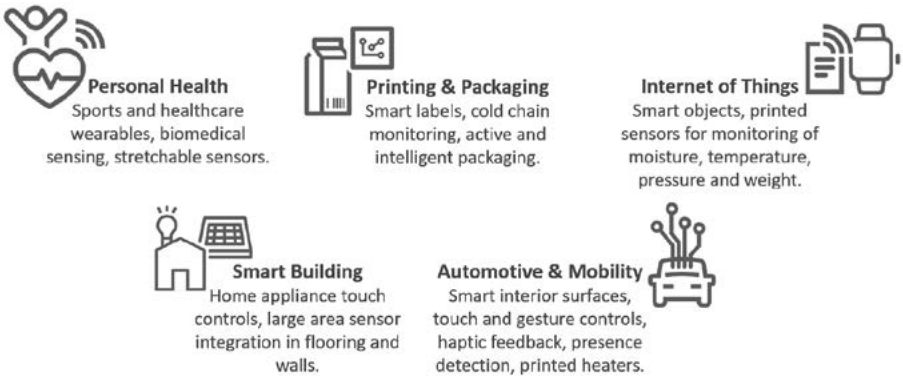

Figure 1: Application fields of printed electronics (modified from Quad Industries)[1]

that some steps can already be performed by the packaging manufacturer in collaboration and close feedback loop with their partners from the value chain.

PAPERONICS chose paper as the printing substrate because of its advantages such as recyclability, thermal stability and stiffness. On the other hand, paper's surface roughness and porosity can highly influence a printing ink's conductivity. That said, paper has the potential to deliver low-cost, innovative applications which can serve multiple purposes within intelligent packaging[2].

INKS AND PRINTING TECHNIQUES

Our first challenge was the selection of paper substrates from the 76 samples provided by the project's industrial partners. All substrates were screened for surface roughness and air permeability as these properties determine the final conductivity of the printed functional ink. Subsequently, two nanosilver inks were screened-printed on all substrates. The third nanosilver ink was applied by roll-to-roll screen printing and finally, the fourth nanosilver ink was tested with aerosol jet printing. Based on the measured paper

"We propose a gradual shift of smart packaging functionality from external label elements to electronics fully printed on the package piece"

	TODAY All Labels	PAPERONICS Labels + Printed	FUTURE All Printed
Labelled	RFID chip + antenna	RFID chip, signage, energy storage	-
Printed	-	antenna, interconnect, sensors	antenna, interconnect, sensors, RFID, signage, energy storage

Figure 2: Vision and roadmap for smart packaging applications

	Chip manufacturing	Antenna manufacturing	Tag assembly (chip + antenna)	Label conversion	Package integration
Today	Company 1	Company 2	Company 3	Company 4	Packaging company
Paperonics	Company 1	Packaging company			
Future	Packaging company				

Figure 3: Proposed evolution of the smart packaging flow using RFID tagged package as an example

properties, its thermal stability (after curing of the ink) and sheet resistance of the ink, as well as some visual and mechanical aspects, 13 substrates were selected for further research including morphological studies (at Fraunhofer IVV) and recyclability (Papiertechnische Stiftung-PTS) (**Figure 4**).

Various printing technologies available at the facilities of IMO-IMOMEC at Hasselt University, AML at KU Leuven, PM at Chemnitz University of Technology, LabelTech, Chiyoda and VIGC were applied, including screen printing, aerosol jet printing, offset, rotogravure and flexo printing to investigate which inks and techniques were compatible with the fibre-based substrates. The final selection was used in the development of three demonstrators.

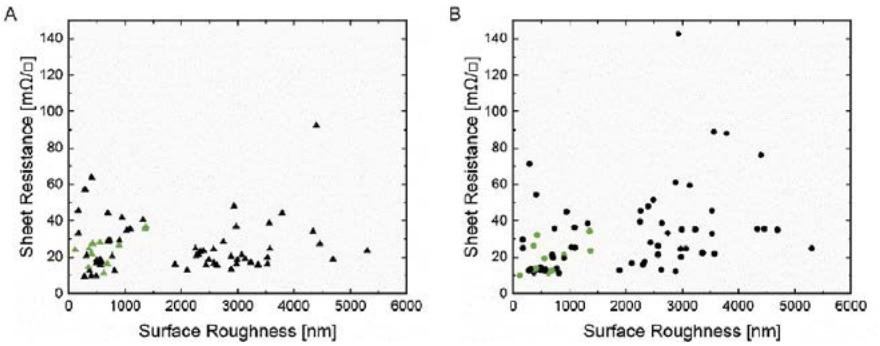

Figure 4: Sheet Resistance as function of average Surface Roughness of 5 'Orgacon SI-P2000' (▲, A) and 'Loctite ECI 1011' square prints (●, B). Green symbols indicate the 13 paper samples that were selected for further investigation

DEVELOPING PROTOTYPES

The first demonstrator was a customer relationship packaging in which a printed antenna (by IMO-IMOMEC) was combined with a thin-film IGZO microchip (imec) into an RFID label (operating at 13.56MHz) – all to be integrated in durable and reusable cardboard boxes. For this demonstration FETRA provided paper, Agfa and Henkel supplied ink, Roartis provided the conductive adhesive and Quad Industries connected antenna and microchip to the smart label. This label was then integrated within intelligent packaging.

A survey yielded ideas about track and trace applications, product authentication and consumer interaction. Finally, a foldable cardboard box with an RFID label to be used for third-party e-logistic companies was prepared as the final demonstrator. Software tools were developed in close collaboration with I4CRM to allow the package status to be followed up at any time in the logistics cycle. The cardboard and the tailoring of the prototypes were delivered by Ropak. The quality of carton and the stability of different boxes was evaluated in the labs of MPR&D IMO-IMOMEC to investigate whether the final box can withstand several distribution cycles.

PAPERONICS' results will be presented and discussed during a dedicated session at the Industrial Print Integration conference on 23–24 November 2021 at Dorint Kongresshotel Düsseldorf/Neuss, Germany. To register for the conference please visit www.ipi-conference.com ■

The second part of this article will be published in Specialist Printing Worldwide issue 1, 2022.

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1 *QuadIndustries. "The building stones for smart products: printed electronics." (accessed May, 2021)*

2 *K. L. Yam, P. T. Takhistov, and J. Miltz, "Intelligent Packaging: Concepts and Applications," Journal of Food Science, vol. 70, no. 1, pp. R1-R10, 2005.*

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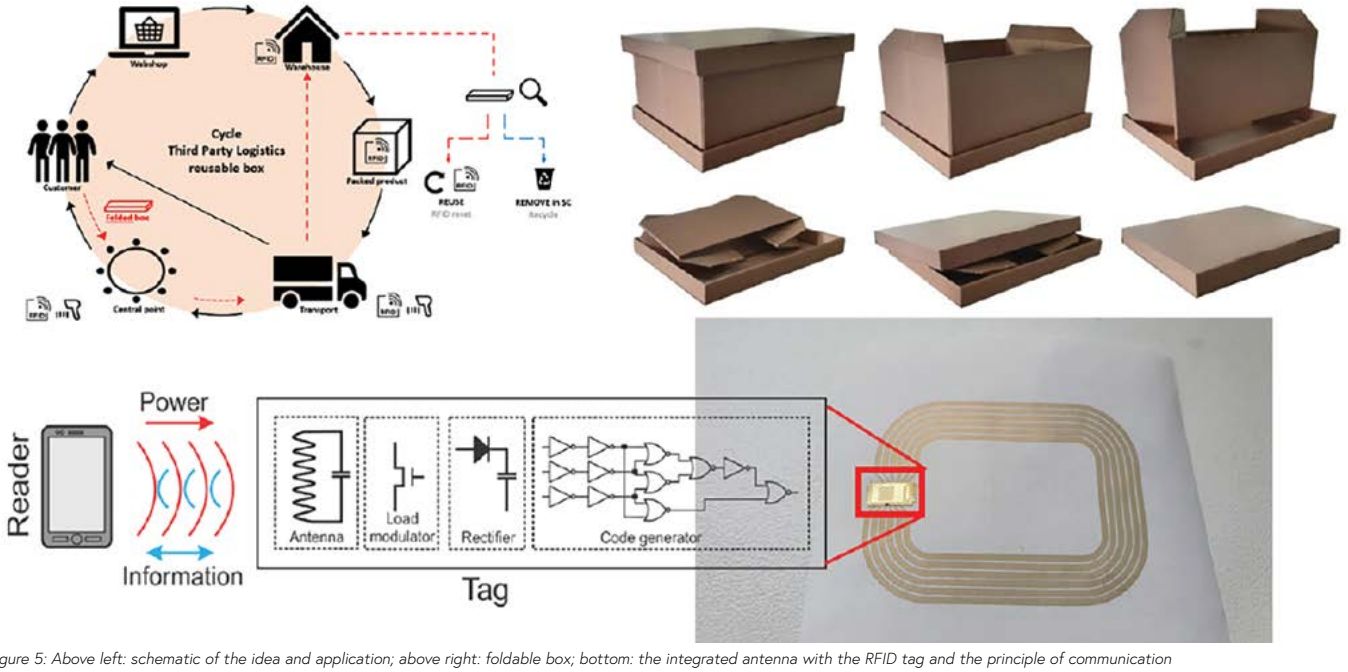

Figure 5: Above left: schematic of the idea and application; above right: foldable box; bottom: the integrated antenna with the RFID tag and the principle of communication