Summary for the final report
Low cost multisensory paper & packaging applications – (PAPERONICS)

In the CORNET project PAPERONICS, three German (Technische Universität Chemnitz, Papiertechnische Stiftung Heidenau, Fraunhofer IVV Freising) and Flemish partners (University of Hasselt, KU Leuven, IMEC Leuven) worked on research into printed elements on paper to realise various electronic functionalities in packaging, such as consumer interaction and feedback via mobile phones, traceability, security in online commerce and monitoring of storage and transport conditions (Figure 1).

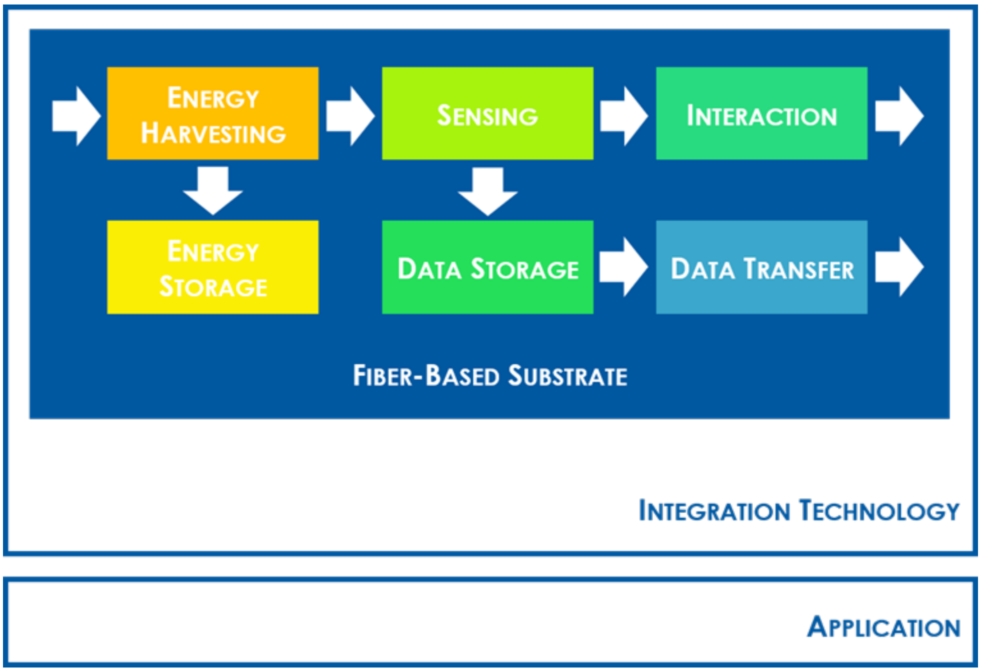

Figure 1: Exemplary functionalities in smart packaging (Source: PAPERONICS)

Today, the value chain of the necessary components for these innovative solutions is widely distributed, so the potential of smart fibre-based packaging is often not exploited. SMEs face numerous challenges in realising this. For cost-effective and flexible production, it is advantageous to integrate as many manufacturing steps as possible at the packaging company. Printing processes play an important role in this. The project investigated the potential offered by different printing technologies in combination with suitable inks on common substrates and the hurdles that need to be overcome. It is obvious that the properties of the substrate have a great influence on the printing result (Figure 2).

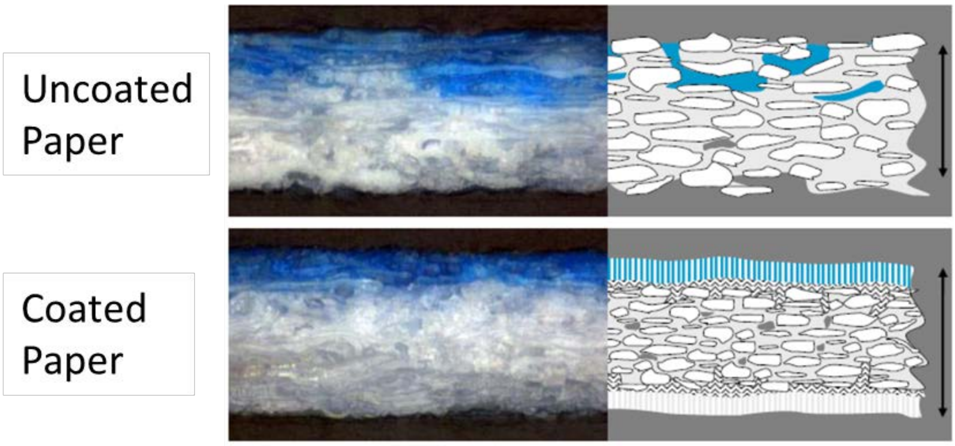

Figure 2: Penetration behaviour of ink in different substrates (Source: PTS)

Therefore, a smooth plastic film that is available in reproducible quality is usually preferred for printed flexible electronic components. Paper, on the other hand, is available on the market in countless different variants. A large selection (76) of different papers was therefore characterised and evaluated in the project. As expected, there were major differences in topography (Figure 3), roughness, porosity and absorptivity.

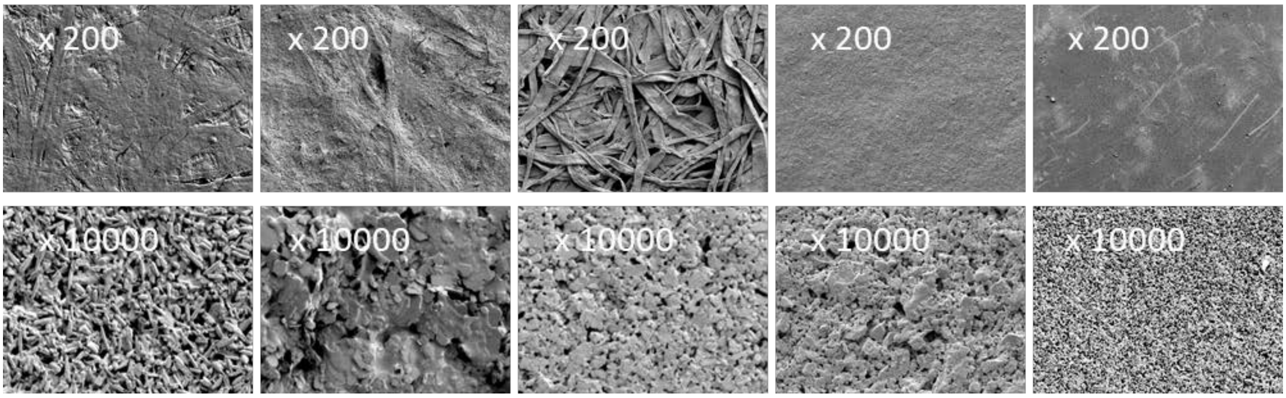

Figure 3: Electron micrographs of different papers at 200x or 10000x magnification (Source: Fraunhofer IVV)

Numerous substrates could be printed well with suitable silver inks in various processes. In principle, a smooth, less porous surface is more suitable for obtaining fine conductive structures such as RFID antennas with low resistance. However, the result also depends strongly on the printing process and the properties (viscosity, solids content, particle sizes, type of solvent) of the ink used. In addition, the drying process must also be taken into account. Using a roll-to-roll screen printing process, it was possible to print conductive tracks with high conductivities and good accuracy even on an uncoated glassine paper (Figure 4).

Figure 4: Roll-to-roll screen printing process using the example of printed RFID antennas (Source: TU Chemnitz)

In cases where low-viscosity inks are necessary, as in Aerosol Jet® Printing, the surfaces must be smoother and have to have lower absorption capacity. If the substrate does not meet this requirement, it can be modified by planarising coatings with suitable lacquer formulations. Organic layers applied with a wet coating process have shown to reduce the microscopic roughness by an order of magnitude and improve the printability (Figure 5).

In addition, such a planarised substrate can be equipped with good barrier properties comparable to those of typical food composite films by vapour deposition of inorganic materials, preferably in combination with further organic layers (Figure 6 left). The project also investigated the interaction of inorganic barrier layers and absorber materials in film composites that can be used as lighttransmissive encapsulation of components sensitive to oxygen and water vapour (Figure 6 right).

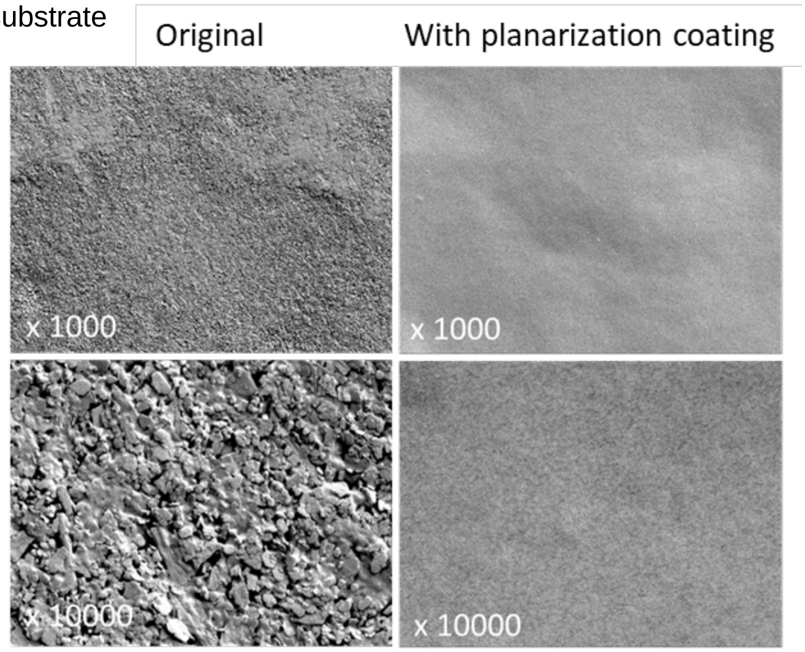

Figure 5: Significant reduction in roughness and porosity due to wet-chemically applied planarization layer (Source: Fraunhofer IVV)

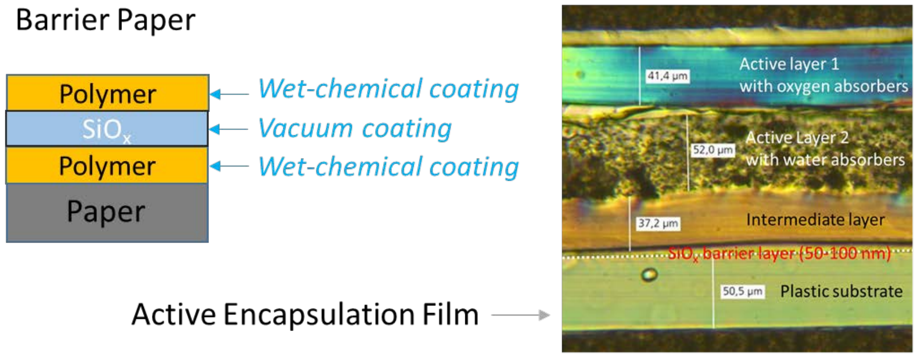

Figure 6: Encapsulation solutions developed in the project (Source: Fraunhofer IVV)

It was shown that by integrating oxygen scavengers, a significant delay of the oxygen breakthrough can be achieved and thus an insufficient barrier of the packaging material is well compensated. For water vapour, however, the situation is less positive: Although the integrated absorbers showed high effectiveness, their capacity was exhausted much earlier than was the case for the oxygen absorbers. This is due to the fact that the permeability of the barrier films for water vapour is significantly higher than for oxygen and thus considerably more water than oxygen reaches the absorber layers in the same time. To protect against water vapour, a higher barrier effect is therefore necessary for particularly sensitive components such as organic solar cells or OLEDs than is provided by low-cost food films coated with evaporated silicon oxide, for example. However, the humidity absorbing particles also reduce light transmission and cause significant light scattering. Therefore, there are clear limits to this solution. However, the absorbers can catch trapped gases in the production process during the encapsulation of the sensitive components and thus enable cost-effective processing in air. Furthermore, the produced encapsulation films and coated substrates were examined for their printability. Printable encapsulations represent an enormous advantage over traditional designs, as they can reduce the use of light-absorbing substrates. In the tests carried out, transparent electrodes or current collectors typical for solar cells or OLEDs were produced using flexographic printing, which showed no disadvantage compared to traditional designs.

Another important aspect that was investigated in the project is the recyclability of the substrates (with and without printed patterns). To assess these materials, they were disintegrated for 10 min with a standard disintegrator in the laboratory. To determine the defibration behaviour, the non-fibrous residue was determined using a Brecht-Holl fractionator (0.7 mm hole) (PTS-RH 021:2012). The total stock was then sorted (0.15 mm slot, Haindl fractionator) and laboratory sheets were prepared from the accepted stock for testing for adhesive and optical interfering substances. There were already clear differences in the initial substrates. Among the coated papers there were both good and only conditionally recyclable ones. Printing with silver tracks did lead to a deterioration in the optical quality of the recyclate. However, taking into account that when applied to a finished packaging material, the optical inhomogeneities resulting from the silver tracks are diluted, the influence is tolerable (Figure 7).

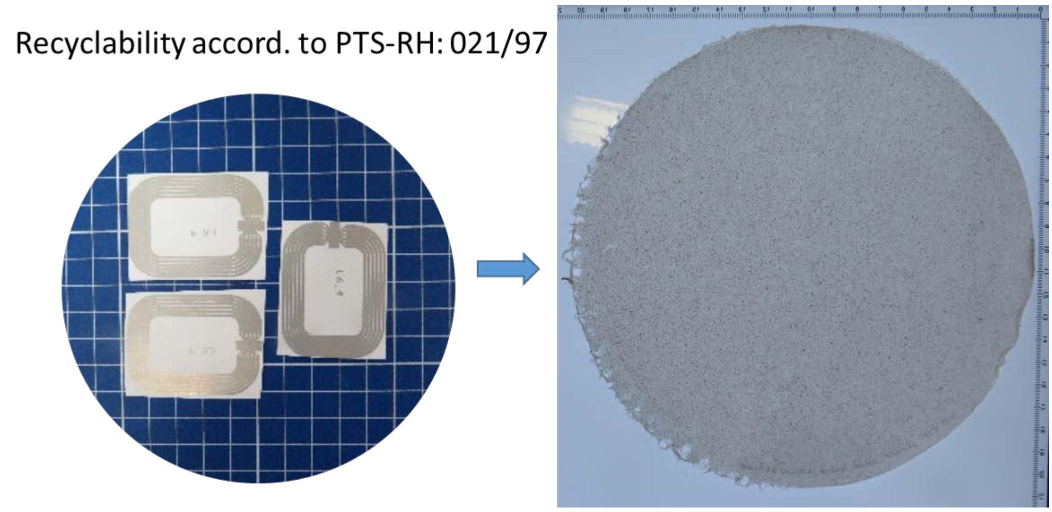

Figure 7: Accept sheet (right) of defibrated and sorted paper samples printed with Ag RFID antennas (left). (Source: PTS)

The functional elements applied to the fibre-based substrates must also be robust enough for the intended application. To this end, various investigations were carried out into the behaviour of the prints under stress or ageing processes. The print samples of the project partners were subjected to bending, torsion and abrasion stresses as well as accelerated heat and light ageing. Furthermore, the water resistance was tested. After the stress or ageing loads, the samples no or only minor impairments with regard to functionality.
Three demonstrators were developed and produced in the project (Figure 8), having different functionalities (1 customer relationship, 2 anti-counterfeiting, 3 temperature monitoring). It was shown that printed electronics on paper can be a promising and sustainable alternative to comparable products on plastic films.

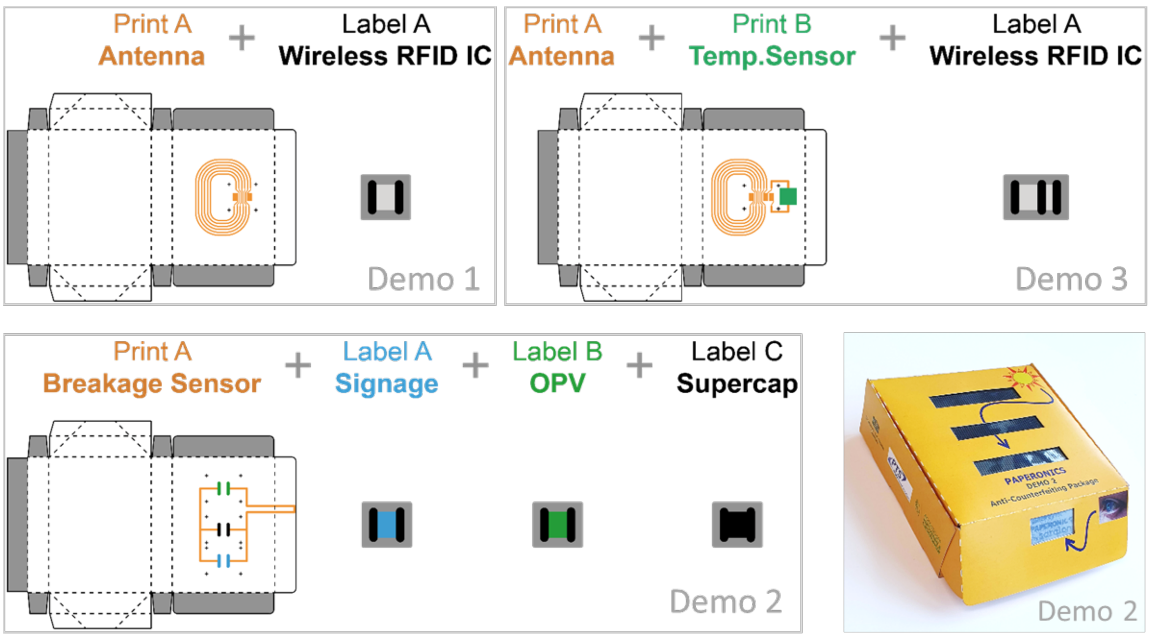

Figure 8: Demonstrators produced in the project (Source: PAPERONICS/TU Chemnitz)

For this purpose, the NFC antennas, as required in two demonstrators were first produced using sheetfed screen printing. This process was then adapted to the rotary screen printing used in the industrial environment. These printed antennas can be used by a microchip for interaction with the customer as well as in logistics (Demo 1, customer relationship). By connecting the antenna and a microchip with a newly developed irreversible temperature-sensitive resistor, a remotely readable temperature sensor was developed for monitoring cold chains, for example (Demo 3, temperature monitoring).
For the demonstrator to implement the counterfeit protection (Demo 2), other elements of printed electronics were combined to create a new functionality. For this purpose, an electrochromic display, a solar cell and an opening sensor were combined on a roll-to-roll screen-printed circuit board. The device monitors the opening of a package: If the package is opened to counterfeit or replace the product in the package, this is indicated by the display. In order to reduce the limited functionality due to dependence on solar radiation, a printed supercapacitor was developed that bridges short-term weak solar radiation. The electrical parameters of the supercapacitor were adapted to the other components of the demonstrator. The demonstrator was then completely integrated into a package (Figure 8).

The integration of smart functions into fibre-based packaging in the near future seems realistic. PAPERONICS was able to show SMEs from the packaging industry design and production paths for this. Manufacturers of input materials, e.g. paper substrates or inks, can also benefit from the project results in the further development of their products for use in printed electronics.

IVLV members can download the complete final project report from our homepage. All you need is to register in the section "My IVLV". Non-members can request the final report from the IVLV office at office@ivlv.org.

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