PLASMAS presents demonstrators at LOPEC, Munich

In the final stages of the PLASMAS project, the consortium presented six demonstrators to a public audience as part of a demonstrator workshop held at the LOPEC trade show in Munich, Germany. The demonstrators showed the feasibility of using copper nanoparticle inks in a variety of printed electronics applications.

The PLASMAS consortium has tackled the task of implementing printed copper conductive structures in a number of demonstrators presented to the public. The demonstrators showcased the use of copper nanoparticle inks and pastes, which are manufactured by Intrinsiq Materials Ltd, implementing inkjet and screen printing techniques. The table below shows the presentations covering the demonstrators.

Demonstrator	Presentation partner
Electrochromic displays	Rise Acreo AB
OLED on nano-Cu grid	Fraunhofer IAP
Smart card demonstrator	Gemalto SA
PCB demonstrator	Precision Varionic International
R2R inkjet-printed RFID antennas	3D Micromac
Cu-grid based PV device	Cyprus University of Technology

Three of the demonstrators are based on inkjet-printable Cu inks (OLED, OPV, RFID antenna) while three others are based on screen-printable Cu paste (EC display, smart card, PCB).

Processing of the inks was performed by inkjet and screen printing. Line widths down to 30 µm at heights between 200 nm and 1 µm were achieved by inkjet printing and processed as grid structures to replace ITO as transparent electrode. Processing of OLEDs and OPVs on such grid structures could be performed by overcoating the grid or after embedding it in an inert resin.

By screen printing structures with line width down to 50 µm at heights of several microns, chip connection on flexible substrates for smart card applications is enabled. The integration of an EC display into the smart card allows the introduction of new features for such applications.

For PCB and RFID applications the cost factor is very crucial for the commercialization of any product. Therefore material and processing costs need to be competitive with alternate processing techniques. Inkjet printing and laser curing on R2R facilities offer a competitive technology for the processing of RFID labels on various substrates such as PET or paper.

In the following section we describe the results achieved and introduced the demonstrators in more detail.

Inkjet-printed Cu grids used in ITO-free OPVs and OLEDs

Inkjet printing (IJP) with drop on demand technology has the ability to be integrated in a roll to roll production line reducing the fabrication cost and providing technological opportunities and design flexibility. Inkjet printing is widely used in the fabrication of metal grid designs as a substitution of the rigid and expensive indium tin oxide (ITO). The PLASMAS project developed for the first time ITO-free OPVs and OLEDs comprising IJP Cu grid/PEDOT:PSS as the bottom electrode.

OPV results:

- Lab-scale Cu-based grid OPVs have been developed. ITO-free non-embedded Cu-based OPVs have 3.4% PCE and embedded Cu-based OPVs 2.7%, whereas reference ITO device show PCE of 5.1%.
- Laser sintering can be successfully applied on Cu structures providing sheet resistances of 240-260 mΩ/sq for 1.2 µm film thickness (conductivity 30000-35000 S/cm).
- Functional inkjet-printed Cu grids were developed also on large area (150 × 150 mm) substrates with ~ 400 µm width and ~ 1 µm average height.
- Cu printing grids on large area (150 × 150 mm) substrates shows the potential of upscaling Cu grids for ITO-free large area OPVs.

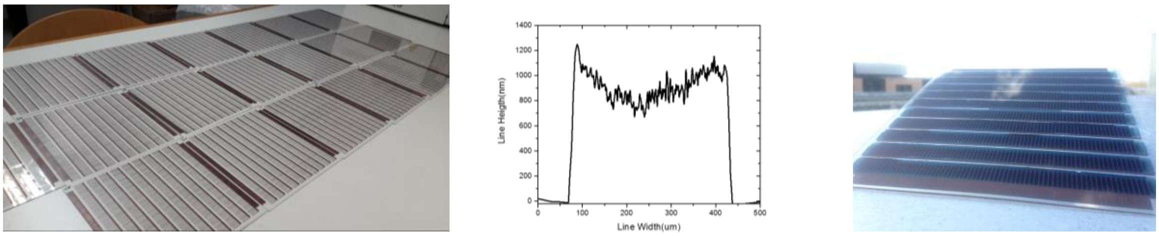

Figure 1: Photograph of large area electrodes after inkjet-printing of Cu grids (left), profile of inkjet-printed Cu grid line (centre), photograph of final large area Cu-grid based OPV (right).

OLED results:

- Yellow polymer light emitting diode with inkjet-printed planarized embedded Cu-PEDOT:PSS electrode on lab scale substrates achieved.
- Upon upscaling inhomogeneities visible, resulting from thickness variations of PH1000 layer; nevertheless, functional large area OLED achieved.
- Gaps along Cu lines after embedding lead to higher PEDOT:PSS layer thickness through capillary effect.

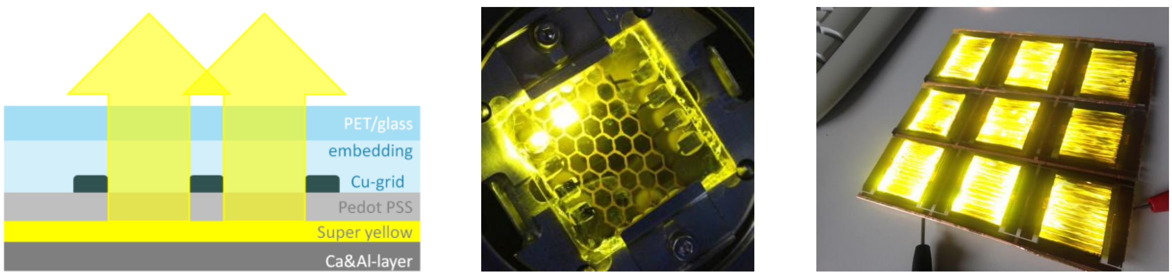

Figure 2: Schematic of OLED architecture (left), photograph of functional small area yellow OLED (centre), photograph of functional large area yellow OLED (right).

R2R inkjet-printed RFID antennas

For the production of RFID antennas on a roll-to-roll based process, the manufacturing flow was optimized in order to realize the up-scaling process. The first prototypes were printed on laboratory scale, whereby the ink was evaluated considering printability and ink-to-substrate interactions. Secondly, the process was upscaled to S2S test facilities, whereby the compatibility with industrial printheads were analysed. In a final step, the entire process was upscaled to R2R by implementing the industrial printhead and all previous findings.

Results:

- RFID Antennas inkjet-printed R2R with Starfire SG1024/SA and CI-IM2x copper ink
- Upscalable to >50 m/min production speed
- Printed antennas successfully sintered by laser radiation
- Sheet resistance less than 1 Ω/sq
- Flexible machine concept available
- Low cost of ownership

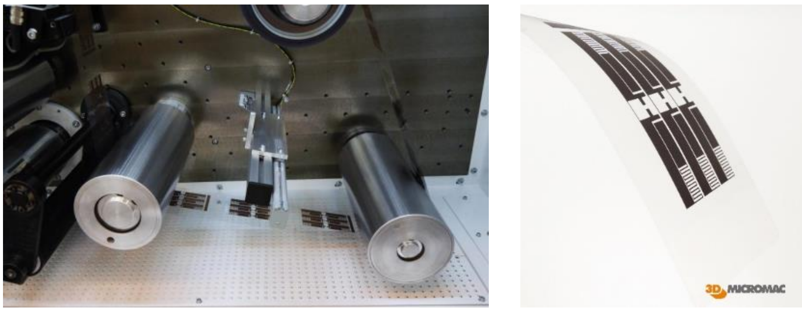

Figure 3: Photograph of flexible substrate being manoeuvred through R2R machine (left), final inkjet-printed RFID antenna (right).

Electrochromic display integrated in smart card

The electrochromic display is based on screen printing. Specifically, a sheet fed flatbed screen printing process is used, which has the possibility to be upscaled to R2R manufacture. The sheet sizes are up to 500 × 500 mm on PET substrates of 50-300 µm thickness. The minimum feature size is 200 µm, and even 50 µm in optimum conditions. Drying/curing of printed features are achieved using hot air and UV. The target is a bi-stable electrochromic display card for secured application with 4 digits.

Results:

- Screen printing of circuits with nano-copper inks
- Hybrid circuits combining printed electrochromic displays and Si-chips
- Screen printed copper for flip-chip assembly in smart card
- Process and materials compatibility - organic materials and copper ink
- Industrial screen printing - possible to upscale production

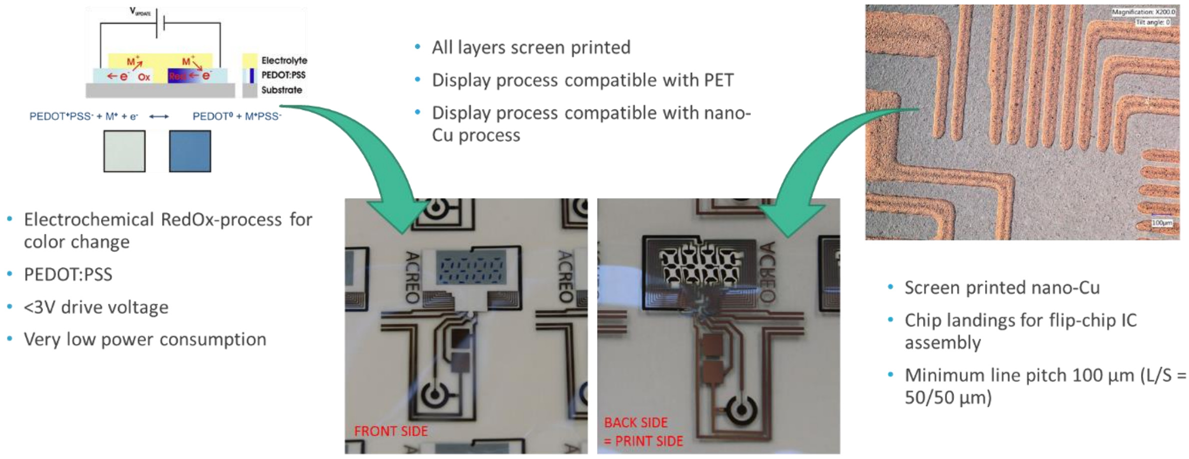

Figure 4: Process flow of electrochromic display manufacture. The conductive tracks are screen-printed from Cu paste and the electrochromic display utilises the electrochemical redox process of PEDOT:PSS, resulting in a colour change at low drive voltages.

Automotive sensor PCB

The use of the innovative nano-Cu pastes to print potentiometer tracks is based on the highly successful proof of concept by Precision Varionic International and Intrinsiq Materials. The work showed that it is feasible to manufacture potentiometer sensors in the EU using printed electronics to achieve a sales price 20-25 % lower than is currently achievable using sub-contractors in the Far East.

The interplay of the manufacturing of the ink as well as the printing and curing technology strategies to achieve a pre-production manufacturing route and prototype samples comparable to standard potentiometer sensors sold on the market.

If these prototype potentiometer sensors are able to achieve the cost and technical performance predicted, manufacturing potentiometers in the EU at high volumes will enable cumulative sales of 40,000,000 units and £11.32 m in cumulative sales revenue by 2022.

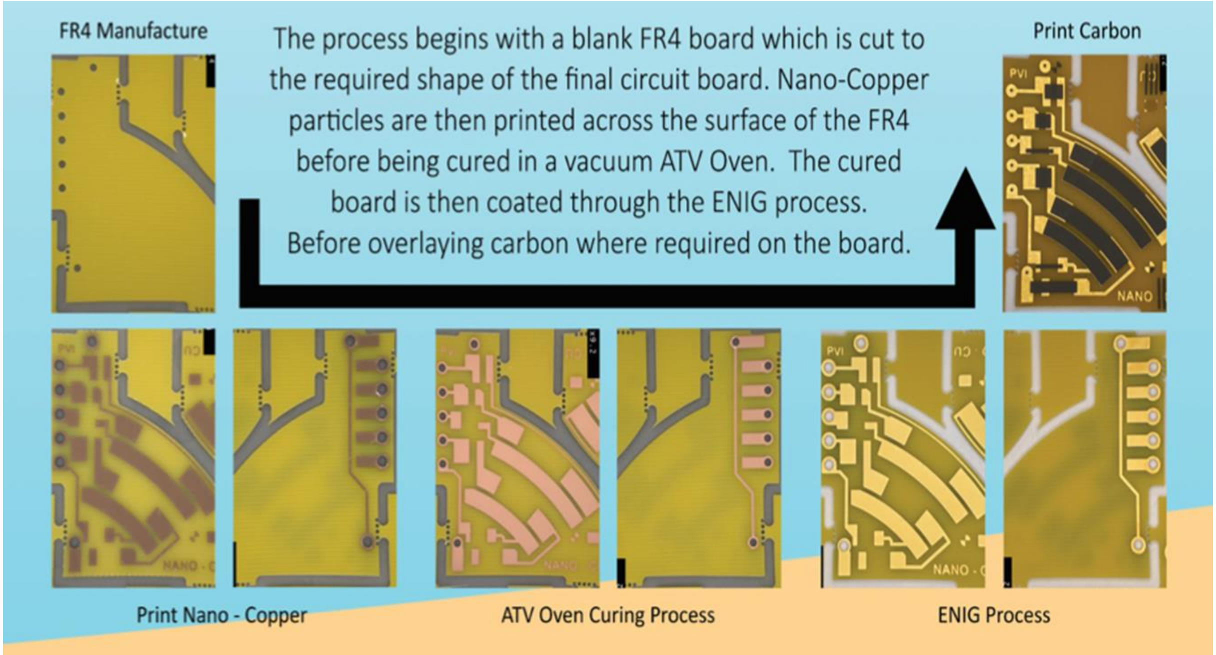

Figure 5: Process flow of PCB manufacturing steps.

Demonstrator summary

The PLASMAS project has produced conductive structures using low cost, high throughput printing technologies, enabling rapid production of printed electronic components, on a wide variety of substrates, enabling the above demonstrators. The PLASMAS consortium focused on technological research combining multiple KETs (Key Enabling Technologies): nanotechnology, photonics and advanced materials with smart production processes. The project addressed demonstration activities focusing on preparing for product development and advanced additive manufacturing.