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PROJECT FINAL REPORT

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4.1 Final publishable summary report

4.1.1 Executive summary (not exceeding 1 page).

Printed electronics is set to revolutionize the electronics industry over the next decade and can offer Europe the opportunity to regain some of the lost manufacture to the Far East, in particular in the semiconductor and display industry.

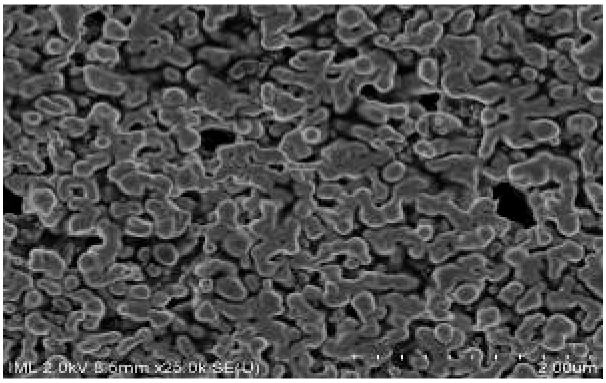


Figure 1 SEM image of Cu nano-particles [source IML 2016]

Figure 2 PLASMAS partners at the M32 internal workshop

PLASMAS (www.plasmaseu.eu) is an EU project (FP7-NMP-2013-SME-7) devoted mainly to support SMEs in Europe in the development of printed electronics focusing on the following objectives:

- Develop conductive nano-Cu materials for inks to be used in printed conductive interconnects;
- Develop semi-conductive nano-Si materials to form the basis of the printed semi-conductor logic;
- Develop inkjet-printable ink formulations for conductive nano-Cu and nano-Si structures;
- Develop inkjet-print processes for accurate, fast and low-cost printing of electronics

PLASMAS has developed Cu nano-particles in different ink formulations for inkjet and screen printing to be converted into conductive structure by either laser sintering or thermal curing in reactive atmosphere. Printing resolutions down to 30 µm have been achieved with resulting conductivity of a factor or ten of the bulk conductivity of copper. The following applications were addressed:

- Printed conductive structures such as circuit boards, electrical interconnects, R2R printed RFID antenna and grid electrodes with the aim replacing silver by cost effective copper inks.
- Printed reflective, low power electro-chromic (EC) display elements to demonstrate the cost effective manufacturing process and compatibility with printed logic.
- Fabrication of low cost, printed organic light emitting diods (OLED) displays and organic photovoltaics (OPVs) for visualizing cost effective solution based processing techniques which are scalable to large area and cost efficient production processes such as R2R.

The following demonstrators were fabricated: a smart card development a bistable electrochromic display for secure smart card applications, a printed magneto-resistive position sensor for automotive applications, a R2R inkjet printed RFID antenna based on Cu-nanoparticles aiming for a cost effective replacement of etched Aluminum antennas, as well as a Cu electrode based OPV and OLED device.

4.1.2 Summary description of project context and objectives (not exceeding 4 pages).

Over the past 15 years Europe has lost its market share of electronics manufacture to the Far East such that in 2011 only one EU company was in the top 30 Global PCB manufacturers. This has led to a declining market share in the electronic industry. Worryingly, Europe is also losing (mainly skilled) jobs for European citizens. These factors have posed a significant problem for the electronics manufacturing sector as a whole and indeed the economy of Europe. This loss of global market share is due in part to the fact that current manufacturing technologies are based on subtractive processing which involves numerous sequence steps which are expensive, wasteful (produce chemical waste) and have high power consumption. Utilising these traditional processes means that manufacture in Europe has become unfeasible due to high labour costs and stringent environmental legislation.

Printed electronics (PE) is set to revolutionise the electronics industry over the next decade and can offer Europe the opportunity to regain some of the lost manufacture. Printed electronics produces electronic systems using additive, printing / deposition technologies that significantly reduce the environmental impact, lower material costs and energy usage and reduce the sensitivity to labour costs through the use of highly automated processes. Printed electronics technology combines four Key Enabling Technologies (KETs): nano-technology, photonics, and advanced materials with smart production processes along the KETs value chain. The direct printing of conductive, resistive, capacitive and semiconducting structures offers a simpler, lower cost and more flexible process over traditional printed circuit board and semiconductor manufacturing techniques, in particular, for organic and large area electronic (OLAE) applications such as large area printed displays and smart integrated systems.

IdTechEx have forecast that the market for printed electronics will increase in revenues from **$29.3Bn in 2017 to $73.4 Bn in 2027.** The majority of these markets are OLEDs (organic but not printed) and conductive inks including metal nano particle inks (Fig. 3).

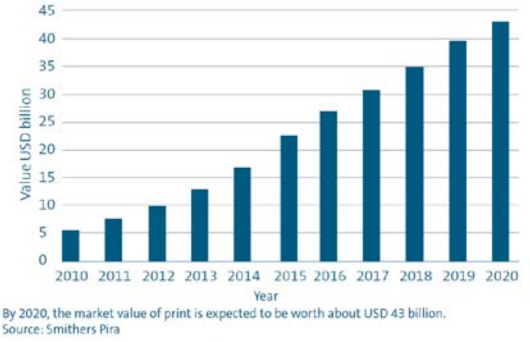


Figure 3 Expected market development of printed electronics according to the forecast of Smithers Pira

The PLASMAS project has addressed the two most fundamental components of electronics manufacture: semiconductor and conductive structures. Production of these semi-conductive and conductive structures using low cost, high throughput printing technologies enables rapid production of printed electronic components, on a wide variety of substrates. Therefore, PLASMAS enables new electronics applications, whilst overcoming the problems associated with traditional manufacturing stated above.

PLASMAS project has addressed the following challenges:

- Conductive nano-Cu materials that will form the basis of the printed conductive inter-connects;
- Semi-conductive nano-Si materials that will form the basis of the printed semi-conductor logic;
- Inkjet printing ink formulations for conductive nano-cu and nano-Si structures;
- Inkjet printing technologies for the accurate, fast and low-cost printing of conductive and semi- conductive structures.

In addition to these challenges, PLASMAS addressed applications in the organic and large area electronics (OLAE) market; OLAE applications in the photovoltaics (PV), signage, lighting, and display markets are rapidly growing. OLED display revenues alone are expected to reach $8bn by 2017 with 33% annual growth rate. Growing rapidly with these markets is the demand for transparent and highly conductive materials for electrodes, with n-type ITO currently the dictating transparent conductive oxide (TCO). TCOs are a fundamental component within OLED devices, but also, of course, in PV, displays and sensors etc. However, since indium is a scarce material, the need to replace indium is urgent, and PLASMAS presents ITO-free state-of-the-art OLEDs and OPVs based on printed embedded grid anodes.

Demonstrator 1 – Printed Cu-based conductive circuit boards, electrical interconnects, grid electrodes and printed silicon based logic. The PLASMAS project has demonstrated these materials on large scale integrated systems with multiple connections with the focus on clearly showing that printed Ag processes may be replaced by cost effective printed Cu processes and organic semiconductors can be replaced by printed Si processes for transistor based applications. This will form the basis for printed circuit board and logic exploitation.

Demonstrator 2 – Printed reflective, low power electro-chromic (EC) display elements to demonstrate the cost effective manufacturing processes and compatibility with printed logics. This will form the basis for the exploitation for RISE Acreo.

Demonstrator 3 – Fabrication of low cost, printed organic light emitting diode (OLED) displays using Cu grid electrodes as alternate transparent electrode. This will form the basis of the OLED display exploitation for CUT, Fraunhofer, JR etc.

Demonstrator 4 – Fabrication of R2R inkjet printed RFID antenna as cost effective alternative to etched aluminum antennas. This will form the basis for exploitation for 3DMM and IML.

Demonstrator 5 – Fabrication of low cost, printed organic solar cells (OPVs) with inkjet printed nano-Cu grid as transparent electrode for low cost energy harvesting to meet the needs for CO_2 reduction with environmentally friendly concepts. This will form the basis for the OPV exploitation for CUT, Fraunhofer, JR, etc.

- Concept 1 – This will consider the requirements of a specific end-user (Gemalto) for a bistable electro-chromic display for secure smart card applications.
- Concept 2 – This will consider the requirements of the SME end-user, PVI, a printed magneto-resistive position sensor for automotive applications.

The PLASMAS work flow and expertise is visualized in Fig. 4.

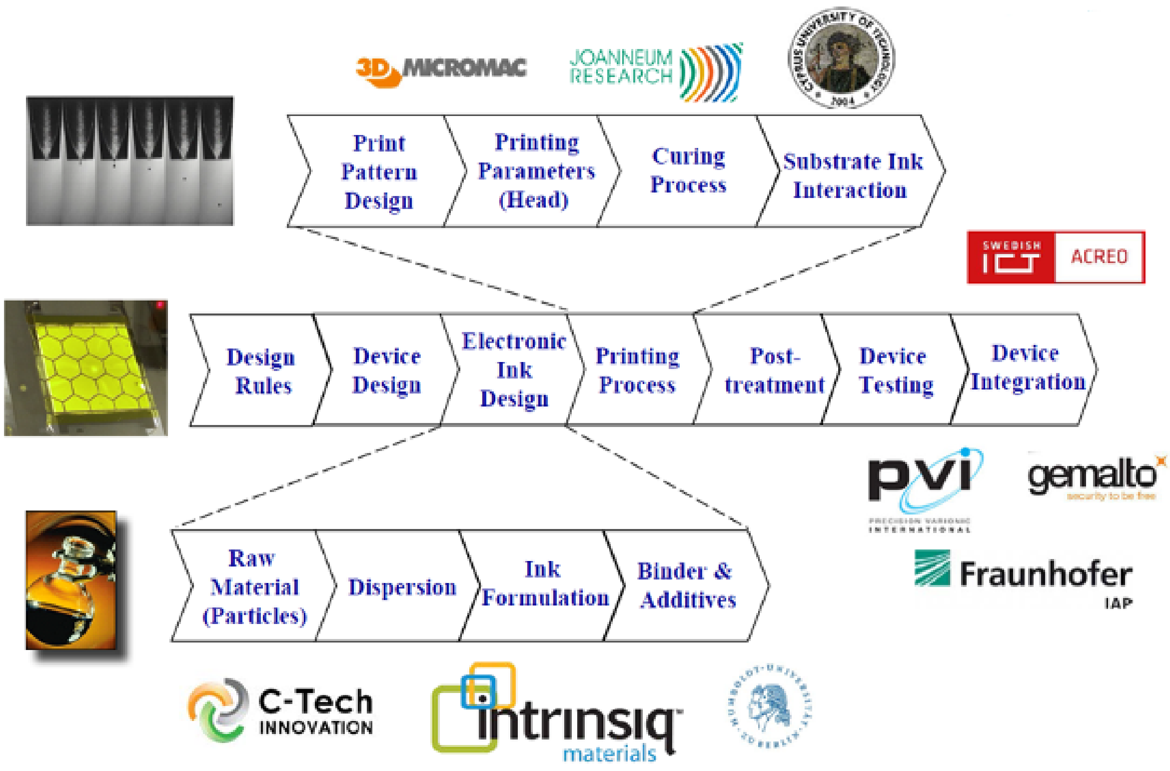


Figure 4 Work flow of PLASMAS project and expertise of PLASMAS partners

The results of the PLASMAS project specifically target three initial applications, all of them have significant market opportunities for the consortium partners:

1. Printed Cu for applications such as printed circuit boards, printed antennas, and printed electrical interconnects for various applications
2. Electro-chromic displays to replace current passive LCDs.
3. Printed Cu grid structures as alternate transparent electrode for applications in OLEDs and OPVs as cost effect replacement for e.g. ITO or printed Ag electrodes.

The PLASMAS consortium will look to specifically apply its technology to niche applications within these application areas. It will not compete directly with the large multi-national organisations that dominate the global market. Once the technology is established in the global market the platform technologies developed will be exploited within the wider OEM supply chain.

PLASMAS addresses a substantial and recognised market opportunity for the fast, low-cost manufacture of large integrated electronic systems based on rigid and flexible substrates with multiple interconnects. The technologies developed will replace the conventional, wasteful subtractive processes that are used to produce circuit boards and semiconductor devices with more economical processes based on printed electronics. Successful application and commercialization for the PLASMAS technology should: Involve 150x lower capital cost, generate only 0.005% of the currently produced hazardous chemical waste and use only 25% of the energy. This program will ensure EU based organizations, and specifically SMEs who have already developed IP for this market, are at the forefront of the printed electronics revolution. The project will strongly contribute to realize the inevitable technology shift and represents an opportunity to reclaim some of the electronics manufacturing and expertise that has been progressively lost to Far East Asia.

The PLASMAS consortium will consider the 3 Pillars Bridge Model to allow the innovative technologies we are developing to cross the 'Valley of Death'. According to the High Level Expert Group on Key Enabling Technologies there are 6 Key Emerging Technologies relating to NMP, namely: Nano-Technology; Micro and Nano – Electronics; Advanced Materials; Photonics; Industrial Bio-Tech And Advanced Manufacturing. The PLASMAS consortium has already developed technologies (1st stage) relating to 4 of these KETs that are ready for transition to the next development stage where we will take this basic knowledge and move the technology towards commercialization of marketable products (2nd stage). This will enable our consortium to accumulate the benefits from a range of KETs and develop integrated products using a holistic approach. Specifically within this 2nd stage we will create world-level prototypes of the final products and the processing technologies on pilot lines, fabricating sufficient quantities for further commercialization. These demonstrators will be validated against existing products and processes and the appropriate standards, allowing us to accelerate the learning curve within the consortium and keep control of the KETs we have developed. The PLASMAS technology will be initially developed for niche, non-mature markets (specifically large area network displays) to give us the maximum chance of commercial success without competing (and causing conflict) directly with the Large OEMs that dominate the global market. The consortium we have drawn together contains a large number of industrial organizations that can support the downstream production to ensure long-term sustainability and for the virtuous circle to be triggered. Transition to the 3rd stage (competitive manufacturing) will be considered as an on-going activity within the project.

The PLASMAS consortium involves 11 partners from five European countries involving two universities (CUT, UBER), three research institutes (Acreo, Fraunhofer and Joanneum Research) and six industrial partners (3D-Micromac, C-Tech, Gemalto, Intrisiq Materials, PRA (until M30) and PVI) of which five are SME. They have complementary skills on material and ink development, processing techniques, and device technology and system integration into end-user applications.

Fig. 5 PLASMAS consortium area distribution

For more information, you can visit the official PLASMAS website: http://www.plasmaseu.eu

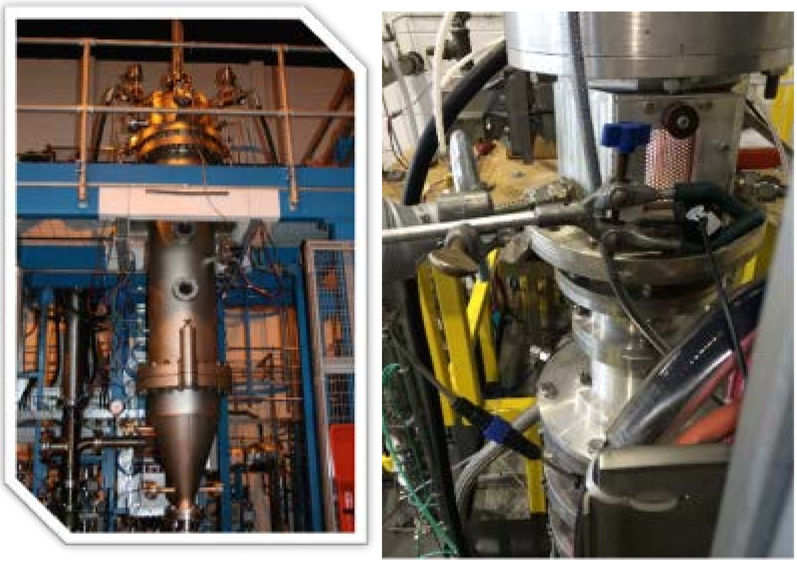
4.1.3 Description of the main S&T results/foregrounds (not exceeding 25 pages),

1. Development of nano-particle inks

The central task within PLASMAS was the development of nano-particle inks based on Cu, Si and NiSi. These nanoparticles were produced at Intrinsiq Materials by plasma methods.

Copper nanoparticles were synthesised in an argon atmosphere using a DC plasma twin torch system mounted on a PPR rig. This produced copper particles with a typical diameter of 50-100nm.

Silicon nanoparticles were produced on the smaller RPR rig, using a microwave plasma source developed by C-Tech. In some cases, the silicon particles were produced with low levels of boron dopant. For the silicon nanoparticles, extra measures needed to be taken to exclude air from the system to avoid surface oxidation. This involved transfer of the particles in a sealed container to a glovebox where the silicon ink was prepared.



(a) (b)

Figure 6: (a) The PPR plasma reactor for producing nano-copper and (b) the microwave plasma source for producing nano-silicon

The copper nanoparticles were used to formulate inks for printed electronic applications within the PLASMAS project. There were two classes of ink developed:

(i) Low viscosity inks for inkjet printing
(ii) High viscosity pastes for screen printing

For each application in the PLASMAS project different inks were developed to meet the particular requirements. At the end of the development, the final optimised inks for each application were as shown in Table 1; the properties of the optimized inks are summarized in Table 2:

Application	Optimised Copper Ink or Paste Type
Inkjet printing of grids on glass for OLED and OPV applications.	CI-005
R2R inkjet printing of RF antenna on polyester film	IM-2x
Screen printing of PCB's for automotive sensors	CP-007
Fine line screen printing for smart card and electrochromic displays	CP-PLS-010715-R1

Table 1: Optimised ink types for each application

Property description	CI-005	IM-2x	CP-007	CP-PLS-010715-R1
Materials	Nano copper	Nano copper	Nano and micron copper	Nano copper
Mean particle size	<100nm	<100nm	50nm-10µm	<100nm
Metal Loading	26%	35%	70%	60%
Viscosity	13 cP at 25°C	14 cP at 25°C	20-35 Pa.s at 50 rpm	20-35 Pa.s at 50 rpm
Surface Tension	30 mN/m	35 mN/m*	N/A	N/A
Deposition	DOD inkjet	DOD inkjet	Flatbed screen print	Flatbed screen print
Print thickness	Typically 0.5-1 micron	Typically 1 micron	Typically 10-20 microns	Typically 5 microns

Table 2: Properties of the optimised copper inks and pastes

The copper inks are not inherently conductive when printed, but must go through a sintering step to give conductive tracks. In the PLASMAS project the sintering was performed in two ways:

(i) Laser sintering – using continuous wave laser LAPS 60 or pulsed laser at 3DMM
(ii) Thermal sintering in a formic acid oven.

Laser sintering was used primarily for the CI-005 and IM-2x inks, while the thermal sintering was used for the CP-007 and CP-PLS-010715-R1 pastes.

The conductivities obtained after sintering depend on the sintering conditions and the thickness of the print, for example in tests at Intrinsiq Materials a sheet resistance of 14mΩ/□ was obtained with the CP-007 paste. The CP-PLS-010715-R1 paste was less conductive, at about 200-300mΩ/□ – in part because of the necessity to keep the temperature low to avoid distortion of the substrate. The two inkjet inks could achieve sheet resistances in the range of 300-500mΩ/□ - the sheet resistances for these being higher than for the screen pastes due to the thinner layers being deposited.

Silicon inks were produced in a variety of solvents, with the solvent being optimised to maximise stability. The inks were prepared in a glove box under argon, and shipped in a sealed container to avoid air ingress. However, it may be that even these precautions were inadequate as the sintered inks did not show electron mobility, possibly due to oxidation.

2. Inkjet printing of Cu inks

Cu-NP inks have been inkjet printed on various systems. Lab printers such as Dimatix DMP2850 and PixDro LP50 were used with Spectra SE-128 and Konica Minolta print-heads. Also, an industrial scale print-head (Starfire SG1014/SA, Fig. 7) has been implemented in a S2S (sheet-to-sheet) process as well as in a R3R (roll-to-roll) line (Fig. 7). Following a detailed waveform optimization for each print-head and printer various test designs on glass and different polymer substrates have been printed. The best resolution achieved on polyimide (Fig. 8) was ~30µm. For the device processing on inkjet printed nano-Cu grid a resolution of 100µm line has been targeted and achieved. Printing of 1D- and 2D-structures has been successfully implemented.

Figure 7 Industrial inkjet printer Starfire SG1024/SA and drop watcher installed in R2R machine (left) and Microflex R2R machine at 3DMM

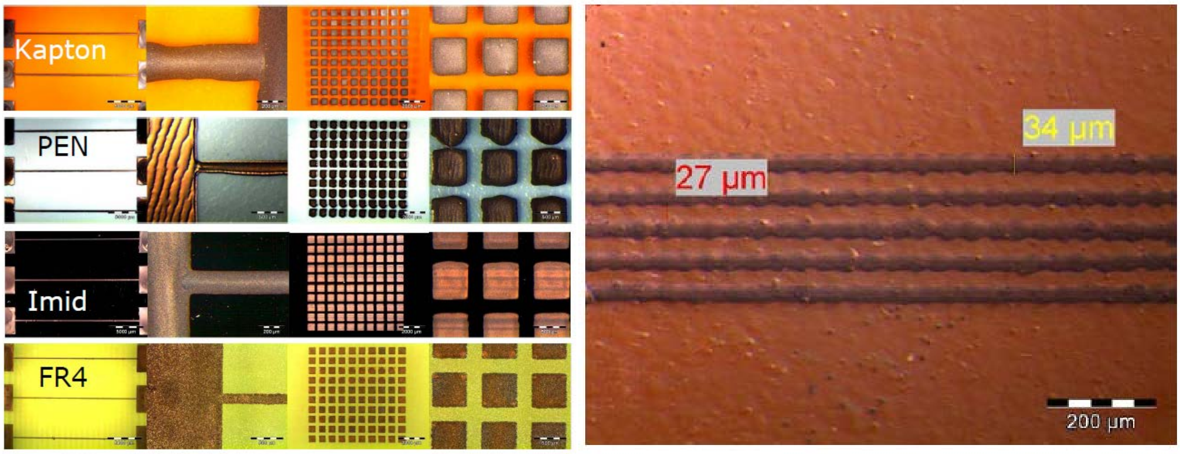
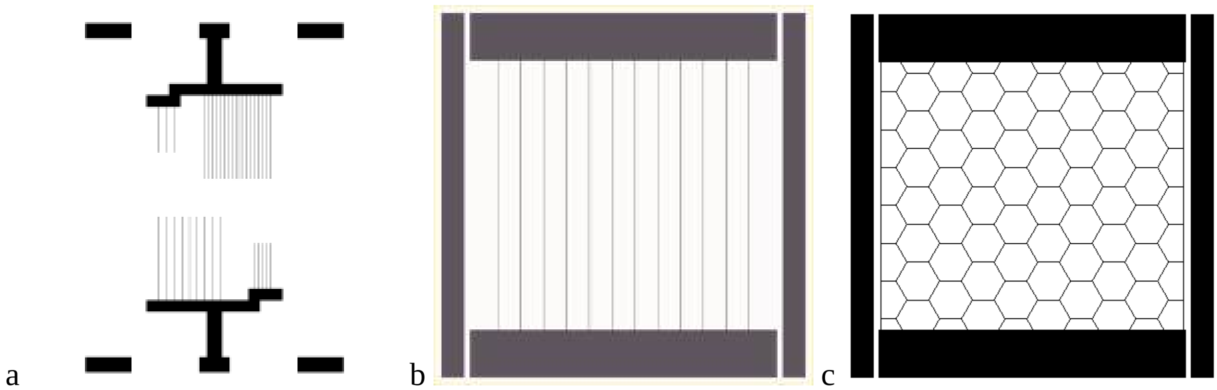
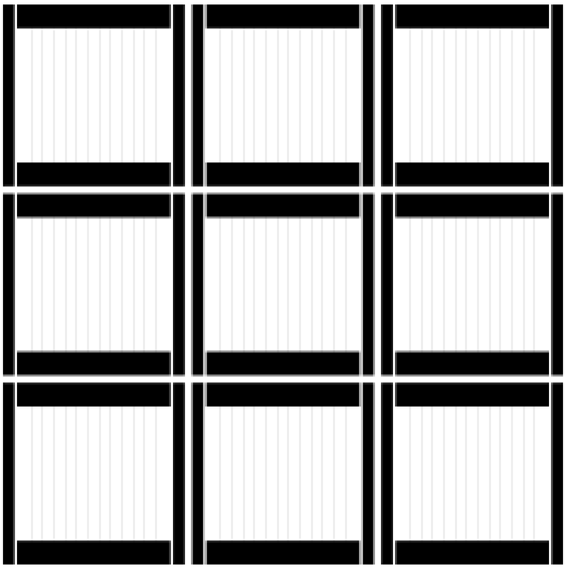


Figure 8 Inkjet printed and sintered Cu lines on different polymer substrates (left) and inkjet printed lines with highest resolution achieved on polyimide.

For the processing of OLED and OPV devices different layouts (Fig. 9) were created and printed on lab-scale sizes starting from 1 inch to 2 inch (Fig. 9 a-c) and up-scaled to 6 inch (Fig. 9 d-e). Printing and sintering conditions needed to be adapted for the different areas, i.e. lines were printed in a higher resolution than bus bars, also the sintering conditions needed to be adapted to avoid cracking at the connection between the lines and the busbars.

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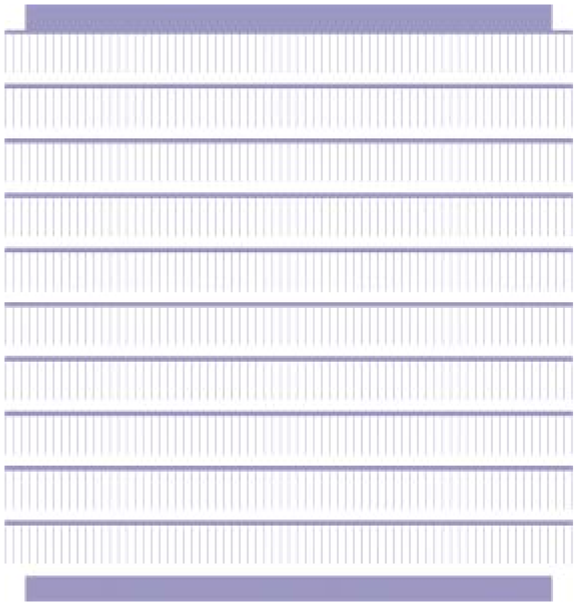
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Figure 9 Layouts for the Cu grid structure for the processing of OLEDs and OPVs

The optimized printed gridlines are homogenous and have typical widths below 100 µm, as can be seen in Figure 10. Heights exceeded 1 µm in particular in the crossing points of the honey comb structures. This typical height provides good conductivity of the grid but it impedes the processing of well working OLEDs on top of the grids. Therefore, an embedding process has been developed that allows good conductivity of the grids together with a flat electrode surface.

The printing parameters have been continuously optimized throughout the entire course of the project. One challenging task in this context constitutes the simultaneous printing of 1D-structures (grid lines) and 2D structures (areas, here busbars). Structures are generally printed with overlapping dots. As a direct consequence, more ink is printed per substrate area for 2D structures, when 1D grids and 2D busbars are printed in the same pattern and when the dpi-value is set to a constant value, e.g. 600 dpi (dots per inch), Therefore, we split for honeycomb grids the printing pattern into a 1D and a 2D part. By setting lower dpi values for the busbars compared to the dpi values of the 1D grids, we could compensate the different amount of printed ink per substrate area. The promising result of the optimized printing and sintering procedure can be seen in Figure 10. The edges of the busbar do not show defects and the good connection between grid lines and busbars revealed suitable conductivities for OLED processing.

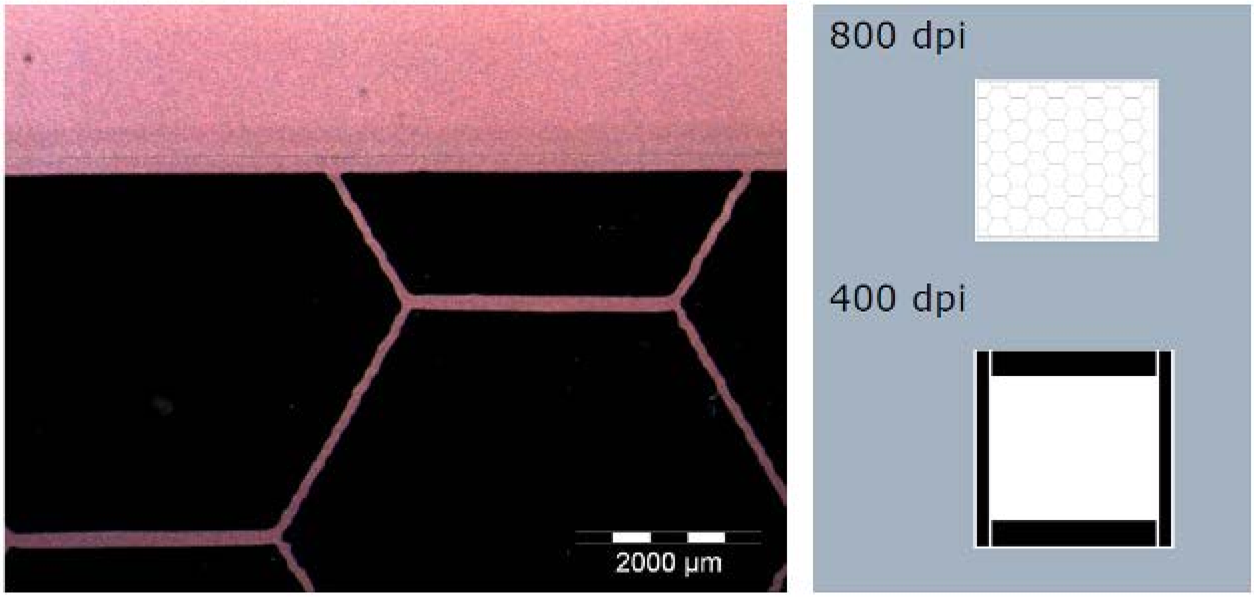


Figure 10 Optical image of an optimized honeycomb-busbar structure (left image) and the applied printing patterns with adjusted dpi-resolution (right image).

3. Screen printing of Cu inks

Screen printing was applied for printing highly viscos nano-Cu pastes as applied for interconnects (ICs) in the smart card design of Gemalto. The printed pattern is designed to be used for flip-chip bonding of bare-die ICs. From a printing point of view the largest challenge is to obtain the small linewidth/space needed for the flip-chip bonding. The pad pitch on the die is 100 µm and larger (varying at different positions on the die). First experiments were made to understand the impact of various printing parameters (bias in design, screen mesh choice, squeegee hardness, printer settings). Example results are shown in Fig. 11. Using stainless steel mesh it was possible to reach 50+50 µm line + space. This is shown in the right part of Figure 11. For these structures sintering was performed in reduced atmosphere as introduced above. Based on the optimization of the screen printed structure the integration into the smart card processing could be implemented.

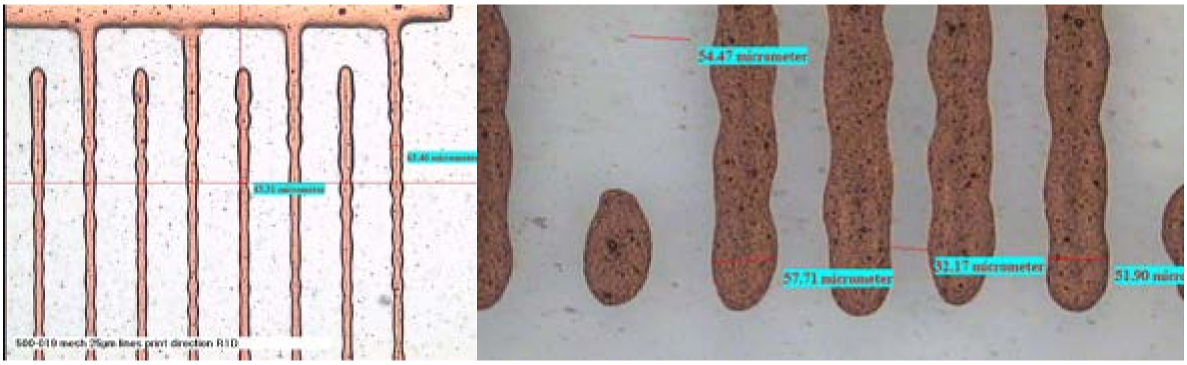


Figure 11 Test print of copper ink aiming at 50 µm line width (left) and 50 µm Cu-lines printed for flip-chip bonding (right)

4. Inkjet printing of Si inks

Silicon inks were successfully printed with Spectra S-class print-heads as well as single nozzle print-heads. The obtained resolution turned out to be sufficient for the desired application as a semiconductor in transistors.

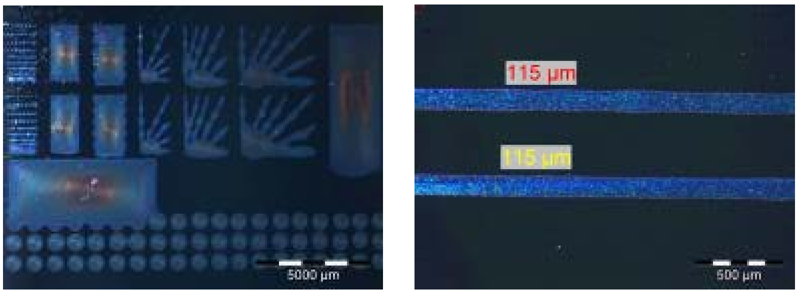


Figure 12 Inkjet printed silicion ink on SiOx.

The sintering of nano-Si was extensively studied using different substrates, laser sources and sinter parameters. The best results in terms of sintering were obtained from a 532 nm laser (Figure 13, middle). In order to guarantee an inert atmosphere during the deposition of the inks, they were spin coated in a glovebox onto the substrate of choice. Figure 13 (left) shows a photolithographically structured standard test layout for transistors, fully covered with nano-Si (transparent). As soon as the nano-Si gets laser sintered, it changes from transparent nature to greyish obaque. The gold electrodes underneath are not significantly harmed by this procedure.

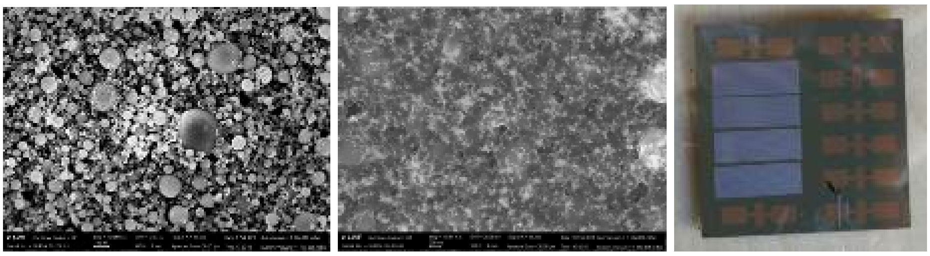


Figure 13 SEM image of an unsintered silicon layer (left) and a sintered silicon layer (middle). Foto of an standard transistor layout coated with nano-Si (right). As soon as the nano-Si gets laser sintered, it changes from transparent nature to greyish obaque.

Although a certain conductivity was found from the sintered structures, it was not possible to observe any semiconducting properties in standard transistor layouts. This is assigned to the high degree of oxidation of the silicion during synthesis of the nanoparticles and during sintering. Changes in formulation and processing in inert atmosphere did not lead to any semiconducting structure, therefore the work on the development of nano-Si was stopped at M31.

5. Inkjet printing of NiSi

Printed NiSi structures were successfully achieved by NTC using both Spectra (30 pL drop volume) and Konica Minolta (4 pL drop volume) printheads for the NSi-140314R1 ink provided by Intrinsiq Materials.

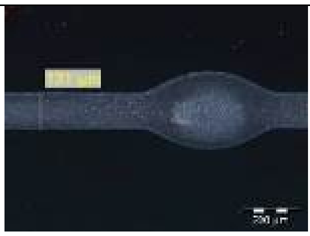
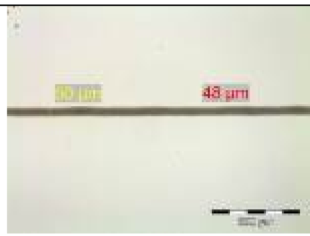
Spectra print-head on quartz glass		Konica Minolta print-head on lime glass	
			

Table 3: Best printing results for NiSi using Spectra and Konica Minolta print-heads

6. Processing of functional devices on inkjet printed nano-Cu grids

ITO-free OLEDs and OPVs on inkjet printed nano-Cu grids were developed and successfully processed from lab-scale to large area sizes for the first time.

Processing of OLEDs on embedded inkjet-printed nano-Cu grids

For OLEDs PEDOT:PSS covered embedded metal grids have been successfully developed and characterized by JR/NTC in close collaboration with IML, Fraunhofer and CUT, respectively with Ag-ink (model system) and Cu-ink (targeted system, Cu-ink provided by IML), as summarized in Figure 14.

For the Ag-ink based OLED (Fig. 14 a,b) as a model-system an increase in efficiency of 250 % compared to the ITO reference device has been observed at efficiencies of up to 9.4 cd/A and maximum brightness of 30.000 cd/m². This has been attributed to the positive outcoupling effect of the embedding matrix consisting of a commercial resist system of Ormocomp®/Ormoprime®. The targeted ITO-free inkjet printed nano-Cu grid based OLED (Fig. 14 c,d) exhibits a current density up to >1000 A/m² and luminance values up to >4000 cd/m². The calculated efficiencies vary from 3 to 5 cd/A. The onset is below 3 V (nominal value 2.2 V).

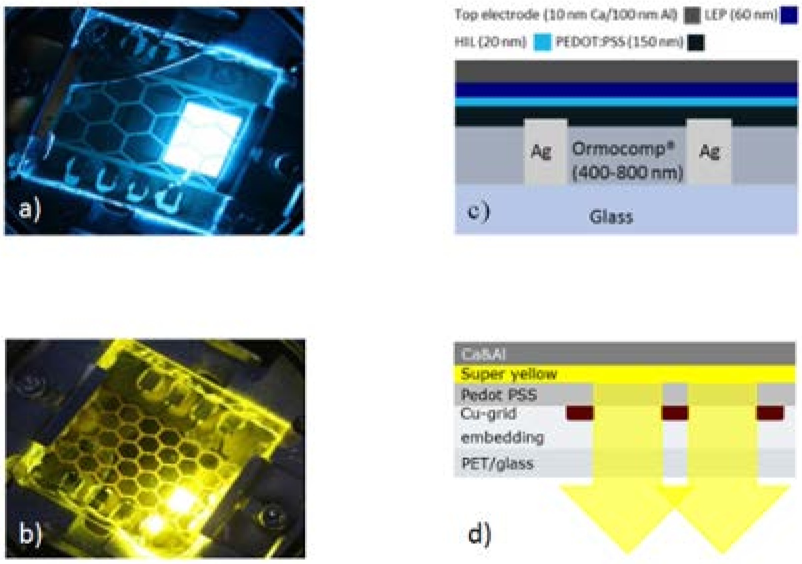


Figure 14 Working OLED of the (a) model system (Ag-grid) and the (b) targeted system (Cu-grid) with the corresponding OLED stacks (c) and (d)

For the up-scaling of the process in a next step substrate sizes of 2 inch were used with honeycomb and line grids. The embedded ITO-free Cu-grids were processed on glass and PET substrates at JR and then transferred to Fraunhofer for processing the active layers of the OLEDs. First the formulations were optimized with respect to the inkjet printing properties with respect to stability of the ink during the printing process and the wetting and drying properties on the embedded grids. The first layer consisted of PEDOT:PSS, where different formulations were investigated. Fig. 15a shows an OLED prepared with a neutral formulation of PEDOT:PSS (Clevios HIL E 100) and Fig. 15b with a highly conductive acidic formulation (Clevios PH1000). As clearly visible the higher conducting formulation shows a more homogeneous lighting whereas the first version using HIL E 100 induces the lighting mainly in the vicinity of the grid lines. Therefore, the higher conducting formulation has been chosen for further development.

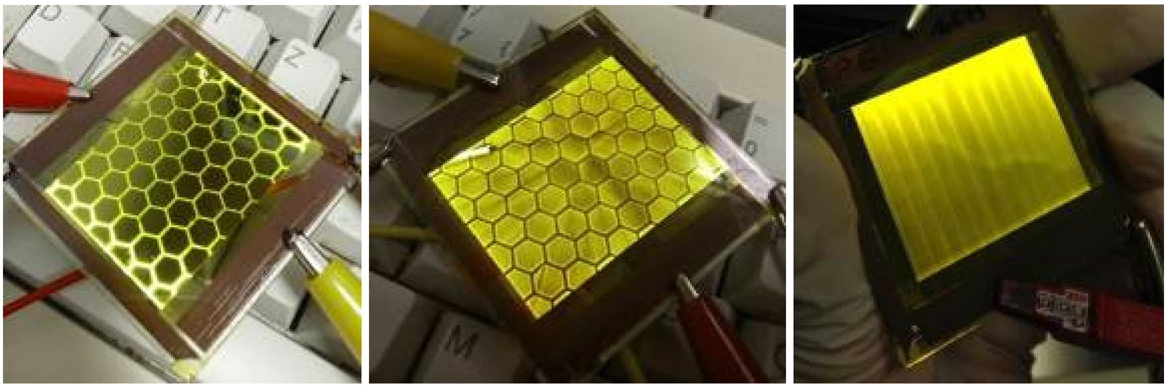


Figure 15 OLEDs on 2 inch substrates on embedded inkjet printed nano-Cu grids: a: using a neutral PEDOT:PSS formulation, b: using an acidic PEDOT:PSS formulation and c: optimized stack structure with additional hole injection layer.

During the optimization of the upscaling to large area OLEDs on 150 mm x 150 mm it turned out that the Clevios PH1000 formulation is not sufficient for the OLED processing to obtain homogeneous emission over the whole device area. Even though the emission looked homogeneous this stack configuration led to high onset voltages of typically more than 8 V, which often resulted in unstable devices introducing shorts e.g. at defects in the device or connection points between the busbar and the grid connection. Overcoating with increased layer thickness did not solve this issue remaining with the high onset voltage. From earlier studies on the device performance with different hole injection layers it has been tested to introduce a lower conducting PEDOT:PSS formulation, namely Clevios CH8000, for the adjustment of the work function to the emitting layer. With this step it was possible to process stable OLEDs exhibiting an onset voltage of below 3 V, where the risk of shorts due to defects was considerably decreased. The successful OLED processing is shown in Fig. 15c.

Processing of OPVs on embedded inkjet-printed nano-Cu grids

OPV device processing consisted of different steps. As a first step the printing, processing and sintering parameters for high quality and conductivity inkjet-printed (IJP) copper (Cu) grid were optimized. First devices were fabricated on small lab-scale size (9 mm²) with inkjet-printed copper grid combined with PEDOT: PSS as the bottom electrode and its optimization toward high efficient indium tin oxide (ITO)-free OPVs with IJP Cu grid. These processes were then transferred as reported above to 2 inch and to 6 inch substrate sizes for the fabrication of large area OPV modules.

The printing parameters were optimized and high resolution lines could be printed on glass with most common average height of ~450-500nm and ~80μm width. A limitation of ITO-free OPVs with inkjet-printed metal grids is the lines height and spikes which need to be overcoated by a thick PEDOT: PSS layer in order to avoid short circuits or high leakage current. In order to overcome the aforementioned limitation and also reduce the transmittance losses, ITO-free OPVs with embedded metal grid designs were developed. Furthermore, the specific embedded procedure followed in this study could provide design flexibility since the final embedded grid can be applied on any surface, both flexible and rigid. The embedding procedure followed the one reported for the OLEDs and is illustrated in Fig. 16.

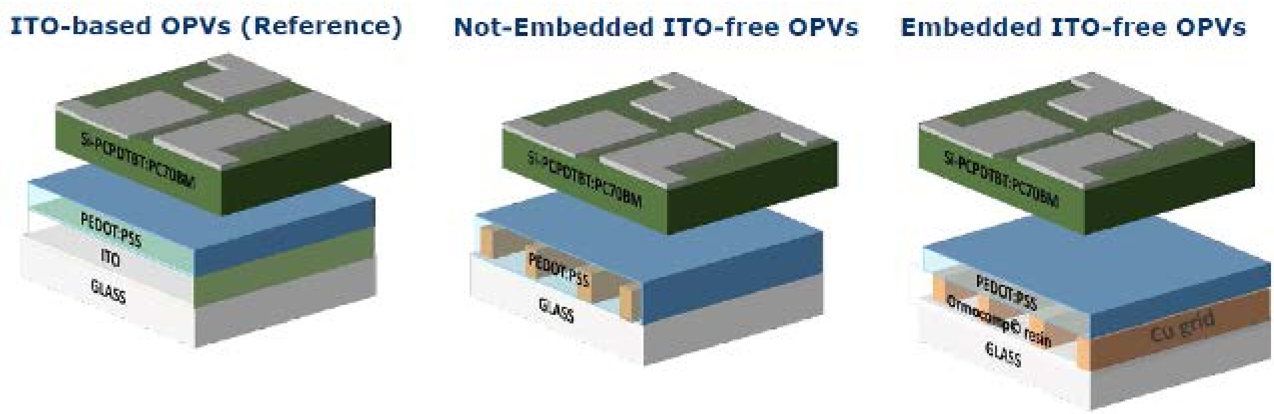


Fig. 16 Schematic view of the OPV architecture used for the development of organic photovoltaic devices on Cu-grids

In this study initially the OPV performance was investigated comparing three different PEDOT:PSS formulations with different conductivities. Clevios PH, Clevios FCE and Clevios P Jet NV2 with conductivity of 0.01 S/cm, 70 S/cm and 300 S/cm respectively, were used to investigate their effect and their compatibility on the overall device performance of the ITO-free OPVs with IJP Cu grid. For comparison reference OPVs with standard ITO/PEDOT:PSS bottom electrode were also fabricated. Best performance was obtained with the highest conduction PEDOT:PSS formulation. Therefore, for the up-scaling of the OPV to large area modules also a high conducting formulation was used, namely Clevios PH1000 with conductivity of 850 S/cm, which was re-formulated for the inkjet printability.

Different active materials were investigated for the fabrication of OPVs on ITO-free inkjet printed copper grids. Beside the model materials P3HT:PC_{60}BM described above low bandgap materials such as Si-PCPDTBT:PC_{70}BM (Fig. 17) and the commercially available material PVD4610:PC_{60}BM were investigated. From both systems higher efficiency solar cells can be expected than for the model system. Performance values of lab scale OPVs are given in Table 4 showing a considerably higher performance of the OPV for the low bandgap polymer as compared to P3HT:PCBM. Consistently for OPVs the performance on non-embedded Cu-grids was found to be higher than on embedded grids. The comparison of reference devices and those on ITO-free inkjet printed Cu grids still show their lower performance which is attributed to the need for further process optimization of the grid processing and the adaptation of the device processing on top of the grid structure.

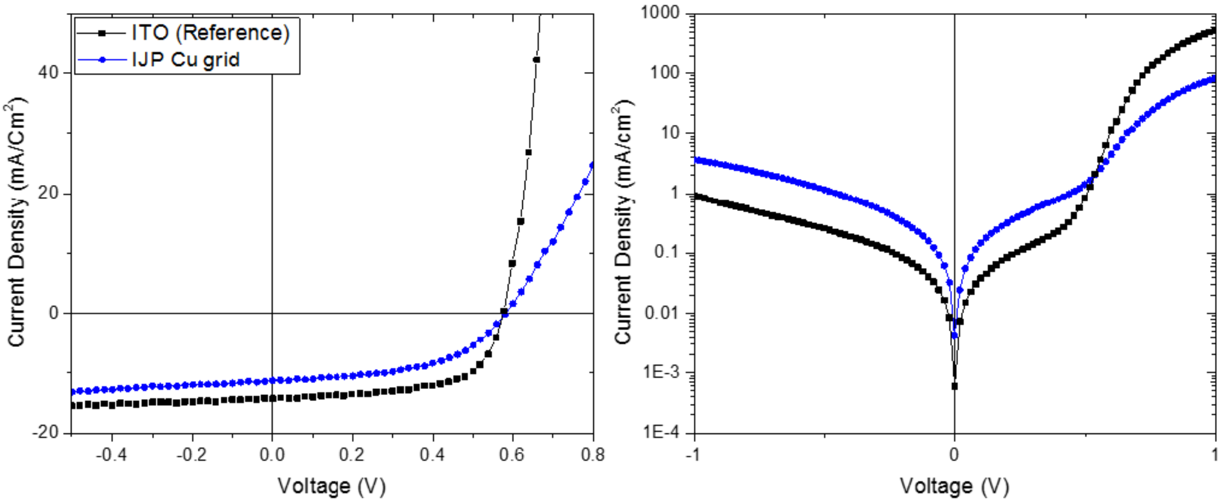


Figure 17 (a) Illuminated and (b) dark current density - voltage characteristics of OPVs with different bottom electrodes

OPVs	**V_{oc} (V)**	**J_{sc} (mA.cm-2)**	**FF (%)**	**PCE (%)**
ITO (Reference)	0.58	14.3	61.7	5.11
Not-embedded Cu grid	0.58	11.26	51.7	3.38
Embedded Cu grid	0.54	9.86	49.7	2.65

Table 4.1. Photovoltaic parameters of OPV with embedded IJP Cu grid as compared to a reference ITO-device

7. Processing of electrochromic displays

The display to be developed and manufactured was intended for Gemalto's smart card demonstrator. The display is designed to fit into an active inlay for a smart card. Besides the display, the smart card accommodates a flip-chip mounted bare die IC, a battery, a push button for activation of the display and printed conductors for connecting all parts. The design of the display (Fig. 18) fits with the size of commonly used printed text on smart cards. The display shall show four digits to provide a temporary security code for the user, as visualized on the right image of Figure 18.

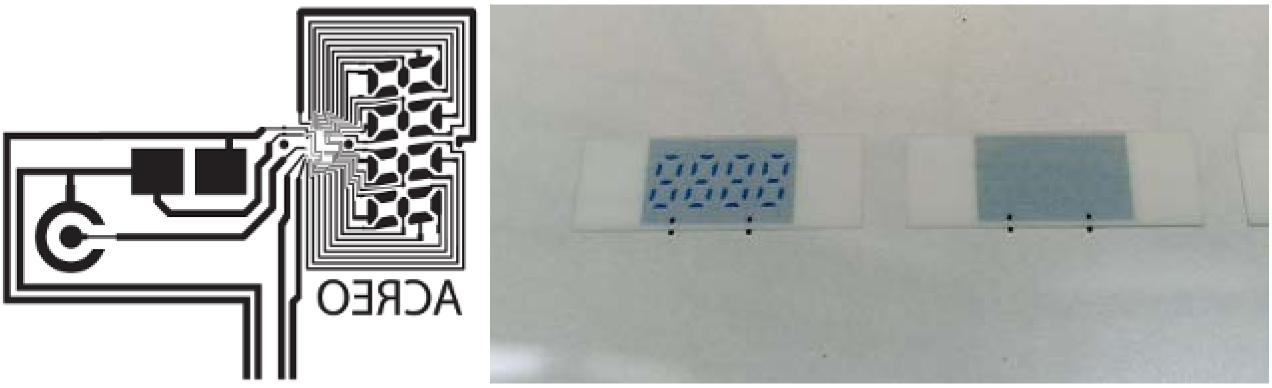


Figure 18 Smart card inlay with electrochromic display and printed electrochromic displays in coloured and uncoloured states

The individual inlays are produced on larger sheets (sheet size 300 x 500 mm) with 4 inlays in 4 rows. None of the display segments are connected to anything without the IC. All layers of this device were screen printed. To prepare for and assess manufacturing at a larger scale, the printing was done in automatic screen printing equipment.

The development work has contained a few iterations where the design of the smart card inlay has been continuously improved and errors have been corrected by changing designs or process parameters. These optimization processes allowed to print functional displays. The display switching properties were investigated by applying a voltage and measure the switch current as a function of time. The change in optical contrast was visually inspected by the eye, since the segments are too small for the existing contrast measurement equipment. Displays in the two different states are shown in Figure 18, right and Figure 19, where the left diagram shows the reduction (coloration) and the right diagram shows the oxidation (discoloration).

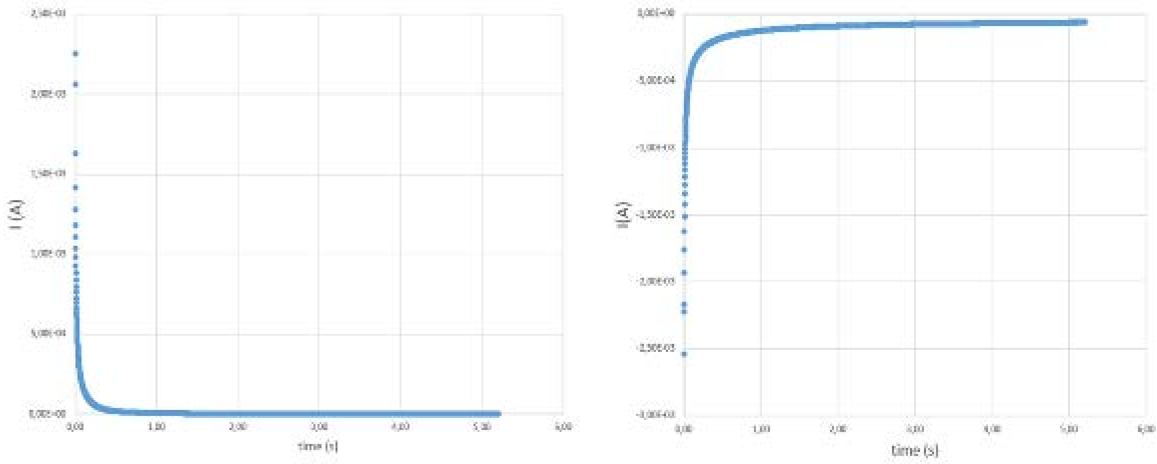


Figure 19 Display switching curves. Current vs. time.

Printed ECD smart pixel

The smart pixel means a printed display element controlled by a printed transistor, forming the fundamental building block for an active matrix addressed display. The display is the PEDOT:PSS based electrochromic display (ECD) developed by Acreo. The device was originally intended to use printed Si-TFTs, but the lack of success in that work called for a contingency action. It was decided to replace Si-TFTs with PEDOT:PSS-based electrochemical transistors.

Both ECDs and ECTs are based on the same materials and functionality. An electrochemical reduction or oxidation of PEDOT:PSS will simultaneously change both optical properties and the electronic conductivity. This allows the same material to be used as both display material and the conducting channel in a transistor.

Single smart-pixels were manufactured. The display elements fulfil the basic requirements needed for an extension to an active matrix display. A generic active matrix is shown in Figure 20.

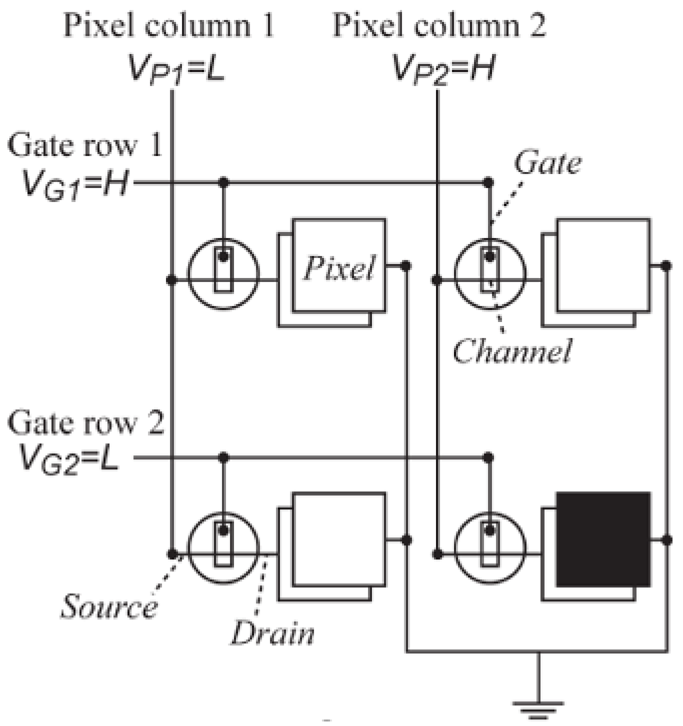


Figure 20 Active matrix display

The smart pixel is designed with the display area 6x6 mm. The transistors were then designed to be able to supply the current needed to switch such a display pixel in less than 1s. The channel size of the transistor is 200x200 µm. Sheets with separate transistors and displays were printed. A photograph of the front side and back side of two smart pixels is shown in Figure 21. The transistor operates below 2 V, in depletion mode and the current is modulated with approximately four orders of magnitude.

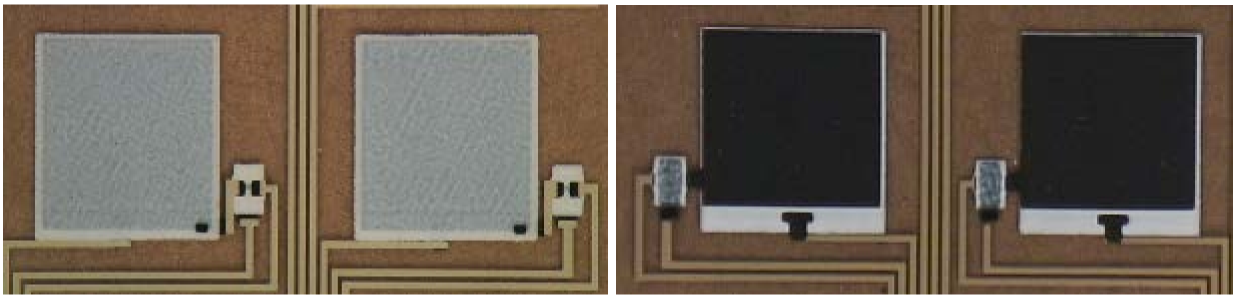


Figure 21 Front (left) and back (right) side of two printed smart pixels

A display matrix was designed to demonstrate the feasibility of ECT-addressing of ECD-pixels. The matrix is a 3x3 pixel design, which is the smallest meaningful matrix size, but still sensitive to insufficient switch properties of the transistors. Each transistor needed to be shut-off to prevent the switching of an ECD-pixel when not addressed and the transistor also needed to be stable under the time required to address and switch all pixels in a row. The printing was done on 125 µm thick PET substrates. The materials used are nano copper (Intrinsiq Materials), PEDOT:PSS (active material in ECD & ECT), Carbon conductor, UV-varnish (insulator) and electrolyte (Acreo proprietary material). The typical screen mesh for these prints is 120 threads/cm PET-mesh. The minimum feature size in this design is 200 µm. All prints were exposed to drying/curing with hot air and/or UV. The nano-copper layer was thermally sintered at IML in reducing atmosphere. Figure 22 shows the completed prints, front- and back-side, where the back-side is the print side and the front-side is the viewing side for the display.

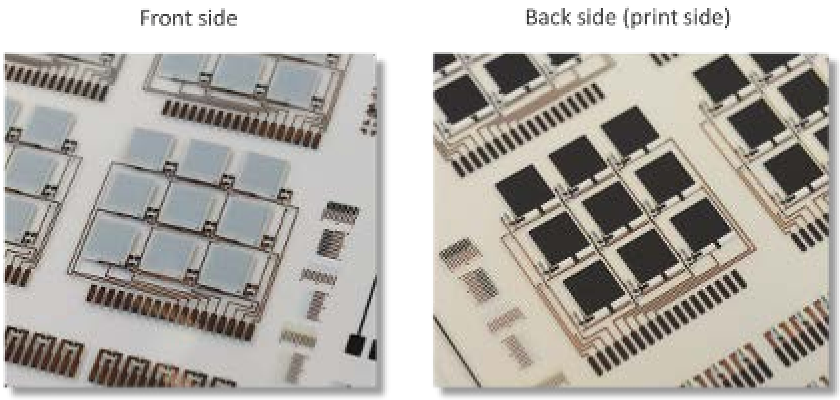


Figure 22 Front and back side of the completely printed display

8. Product environmental impact analysis

A product environmental impact analysis was included into the PLASMAS project in particular with respect to the use of nanoparticles. The toxicological properties of nanomaterials are still not fully explored, but the indications in the literature are that copper nanoparticles have a similar toxicity to copper salts, both in terms of human safety and in their effect on aquatic life, although the mechanisms may not be identical. There is an additional risk in handling the dry powder though due to the possibility of inhalation. There is very limited data on silicon nanoparticles. There are indications that they are less harmful, but precautions should still be taken due to the degree of uncertainty.

The risks and safety procedures for manufacturing powders and mixing of inks at IML were outlined, together with recommendations for handling of copper and silicon inks and pastes during the printing and sintering processes.

One of the PLASMAS project targets is to “Evaluate the environmental impact of the PLASMAS technology and prove there are no significant effects on the environment due to production”. In order to fulfil this requirement, this document presents a streamlined life cycle assessment (LCA) study for the technology developed within the project.

The four main stages required to conduct an LCA study have been reviewed and required actions defined. This includes specifying a goal for the study and its limits. A discussion on data source and quality has also been included. Impact categories have been defined and these can be used as measurable performance indicators for the project. Methods for impact assessment and steps for results interpretation have also been described.

The findings highlight that the implementation of PLASMAS technology in the target application would potentially bring an important reduction of the environmental impact, as well as a decrease on the human toxicity, by means of the mentioned energy and raw material (Cu) savings. Due to this, compliance with the target “Evaluate the environmental impact of the PLASMAS technology and prove there are no significant effects on the environment due to production" set in the WP4 can be corroborated.

However, equal footing comparison between the current state-of-art industrial processes and PLASMAS is not assured, as PLASMAS characteristics could differ at an industrial level. Together with this, the data gaps that may exist, as well as the assumptions that have been done for carrying out this study, contribute to the uncertainty when comparing the scenarios.

With this in mind, it cannot be definitely stated that PLASMAS constitutes a more environmentally respectful process than the conventional PCB etching processes. However, in the light of the results, it can be clearly asserted that the environmental impact will be, in the worst case, at the same order of magnitude, although, potentially, environmental improvement expectations displayed in this study would lead into a greener copper track formation system. In addition to that, the amount of energy and argon used within the novel process is expected to reduce, as argon recycling and throughput increase are projected. Therefore, it can be concluded that the sustainability and environmental credentials of PLASMAS application scenario are solid.

9. Fabrication of demonstrators

Within the PLASMAS project the fabrication of several demonstrators was performed all of which were based on the use of nano-Cu based inks for several applications in printed electronics.

OLED Prototype

For the processing of OLEDs on embedded inkjet-printed nano-Cu grids the printing and embedding process has been up-scaled for small to large area substrates as visualized in Figure 23. This included the nanoparticle Cu-ink printing as well as the processing of the active layers on top of the grid structure.

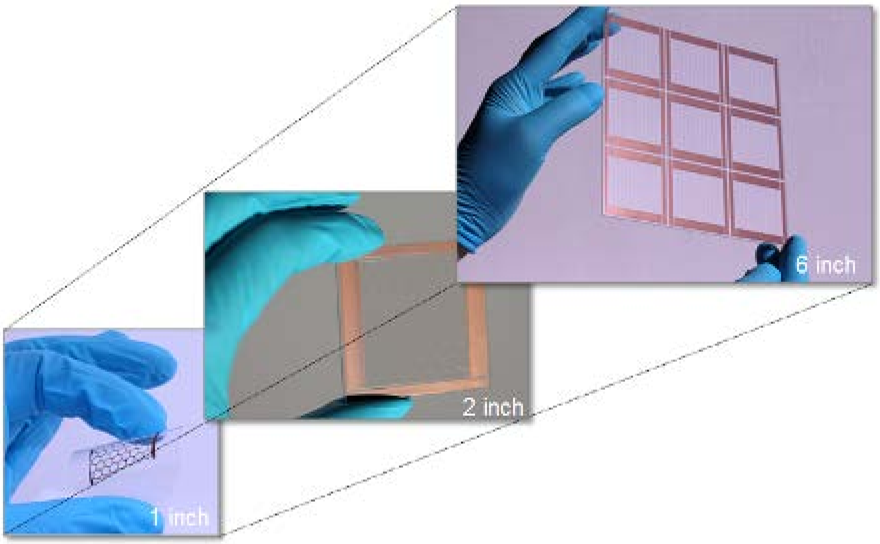


Figure 23 Upscaling of inkjet-printed Cu-grids from lab-scale (1x1 inch) over an intermediate step (2x2 inch) to large area grids (6x6 inch)

The active OLED layer stack consisted of two PEDOT:PSS formulations and the emitting material Superyellow, a commercial polyphenylenevinylene, which were all inkjet printed on the embedded Cu grids. The two different PEDOT:PSS formulations were needed for obtaining a homogeneous lighting of the OLED area. The first layer consisted of the high conductive formulation Clevios PH1000 which homogenizes the electrical conduction of the transparent ITO-free Cu grid structure. The second formulation, Clevios CH8000, adjusts the work function between the hole injection and emitting layer and optimizes the charge transfer between both. This leads to an optimized onset voltage of below 3 V as compared to ~8 V without the additional hole injection layer. Fig. 24 compares two devices prepared without (left) and with (middle) the additional hole injection layer demonstrating the homogenization of the lighting of the OLED. The upscaling process is shown on the right of Fig. 24, where nine 2 inch devices are fabricated on one 6 inch x 6 inch substrate, whereby one row comprising three devices are switched on simultaneously.

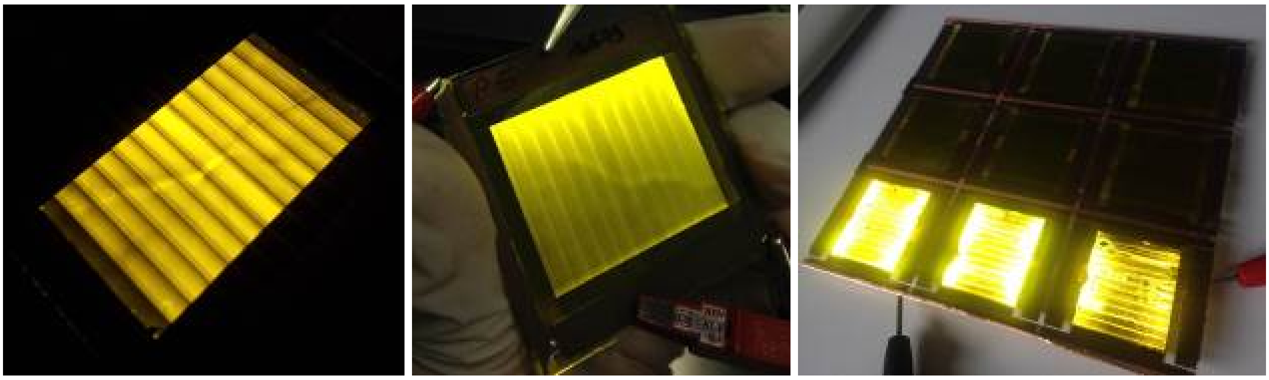


Figure 24 Small area OLED processed without (left) and with (middle) additional hole injection layer. The right hand image shows a device on a substrate size of 150 mm x 150 mm comprising nine OLED devices, here three of them are switched on together.

PCB demonstrator

This demonstrator uses innovative nano-copper pastes to print potentiometer tracks. This work has shown 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 different manufacturing stages are visualized in Fig. 25.

If these prototype potentiometer sensors are able to achieve the cost and technical performance PLASMAS predict, manufacturing potentiometers in EU at high volumes will potentially enable us to achieve cumulative sales of 40,000,000 units and €12.7m in cumulative sales revenue by 2022.

From the initial premise set out of using nano-copper ink as just a seed layer for further electroplating of copper followed by barrier layer (ENIG) we were able to eliminate the copper plating altogether by achieving excellent sintering and adhesion properties from the direct printing of the nano-copper ink. The elimination of this extra step resulted in a further cost saving of 5%.

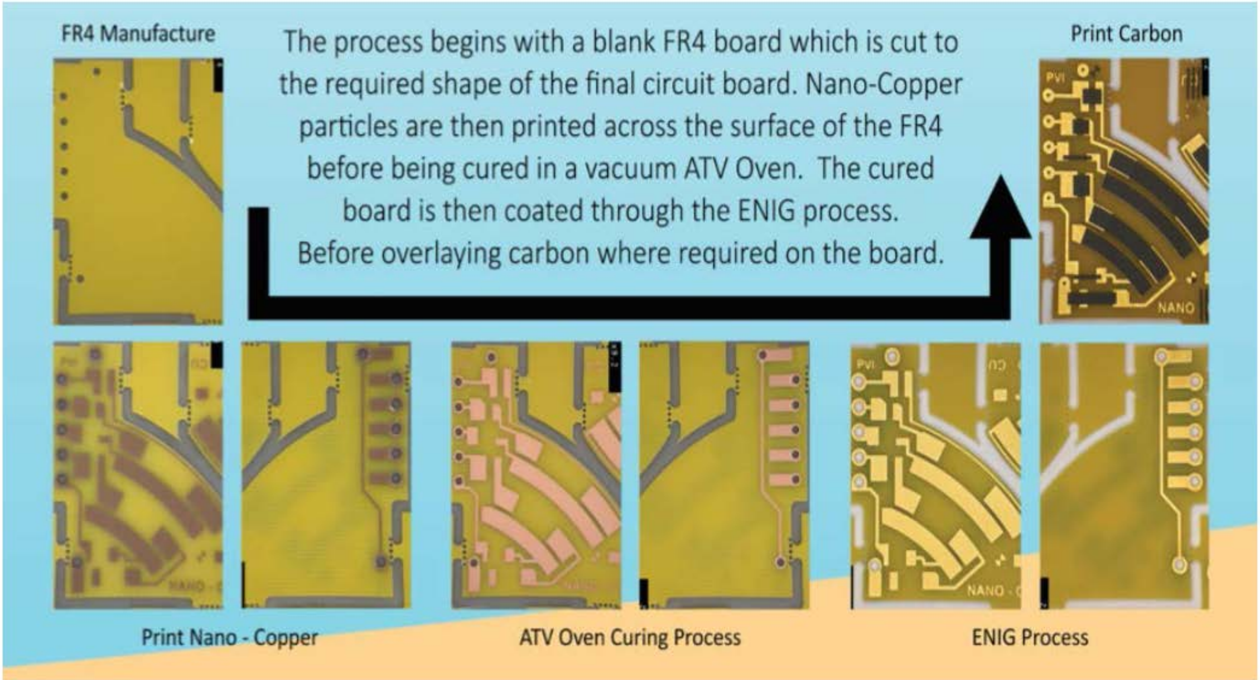


Figure 25: 100% additive manufactured automotive potentiometer. Top left: Blank FR4 drilled, routed and scored panel 165 mm x 195 mm. Bottom Left: screen printed and dry nano-Cu paste. Bottom middle: cured nano-Cu. Bottom right: PCB after ENIG barrier layer applied. Finally, top right: screen printed resistive carbon for automotive potentiometer for accelerator pedal.

Smart Card demonstrator

The design of the smart card demonstrator was agreed within the consortium as visualized in Fig. 26. Different processes were developed for the integration of functionalities. The Si-chip integration was enabled on a flexible circuit board utilizing Cu as circuitry and pad material. This step was necessary to connect Si dies on printed conductive tracks thanks to flip chip report on printed conductive tracks. In a first step only the conductive layers were printed by Acreo according to the pattern defined jointly between Acreo and Gemalto. Several gold bump configurations were tested and the configuration “accu-bump” was kept (Fig. 27 left). These were applied in a semi-automatic machine and finally the automated flip chip equipment Datacon was selected for the bonding. Processing parameters were optimized and the final processing was tested by mechanical and electrical tests on the connection by checking the voltage-current charecteristics on I/Os.

Figure 26 Smart card demonstrator within PLASMAS integrating an EC display and based on Cu circuits

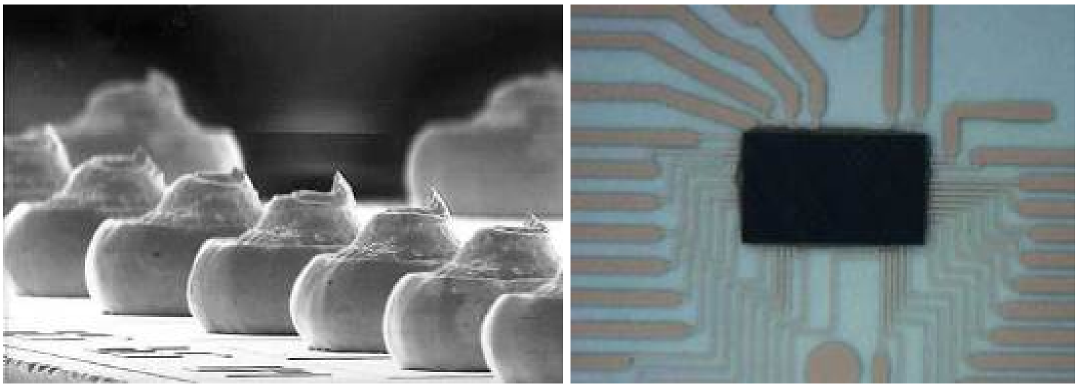


Figure 26 Accu bumps on chip (left) and flip-chip assembly on screen printed silver tracks

In case of connection of copper tracks, the “coined bump” shape gave better results as “Accu bumps” geometry damaged the copper tracks. Flip chip parameters, temperature, time, pressure were defined for a correct report of the chip thanks to an anisotropic conductive paste (ACP). All preliminary tests were performed on substrates having only the screen printed copper layer (fig. 26 left).

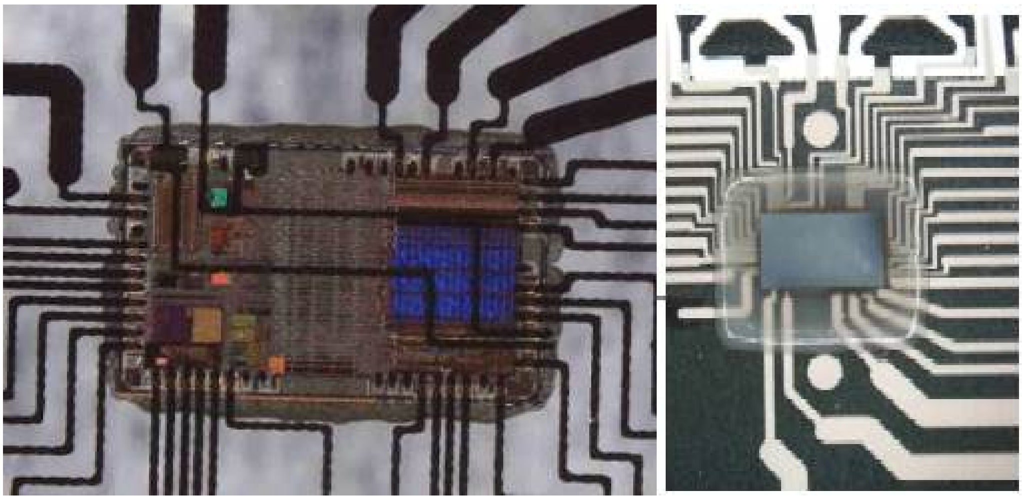


Figure 27 Flip-chip assembly on screen printed copper tracks (left) and chip encapsulation (right)

Chip encapsulation was provided by an UV curable resin (Fig. 27 right). As a result we reached a total thickness of 400 µm for the whole composition flexible substrate + chip + encapsulation.

Printed RFID antenna

Based on the development of the nanoparticles copper inks, the process development for R2R inkjet printing and the process development for laser sintering of the printed copper inks RFID antennas were printed and dried R2R and subsequently sintered by laser radiation.

The ink chosen for printing the demonstrator RFID antennas was the CI-IM-2X ink developed by Intrinsiq Materials. The ink was printed for RFID antennas using the microFLEX 2.0 (Figure 7) roll-to-roll processing machine developed by 3DMM. For printing the industrial inkjet print head Starfire SG1024/SA from Fujifilm Dimatix was integrated in the microFLEX 2.0. The antennas were printed using a drop size of 20 pl, a resolution of 400 dpi and a web speed of 1 m/min. Calculations showed that the printing process would be up-scalable to web speeds of > 60 m/min, which is much higher than the processing speed used for etching antennas out of aluminium foil. For sintering the printed antennas an Innolas Nanio laser with a wavelength of 532 nm and a pulse duration of 30 ns was used. Since for sintering only low intensities are needed for heating up the material, the laser beam was defocused by 15 mm to increase the spot size on the sample. The comparison of the bitmap and the actually printed and cured antenna is depicted in Figure 28.

About 20 m of web length were processed with RFID antennas, which correspond to about 400 RFID antennas but only 60 antennas were laser sintered (Fig. 29).

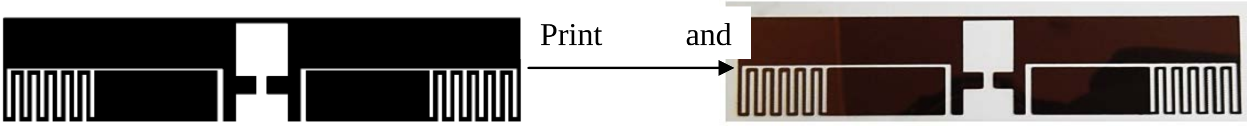


Figure 28 Bitmap file and printed and tested sample of UHF antenna

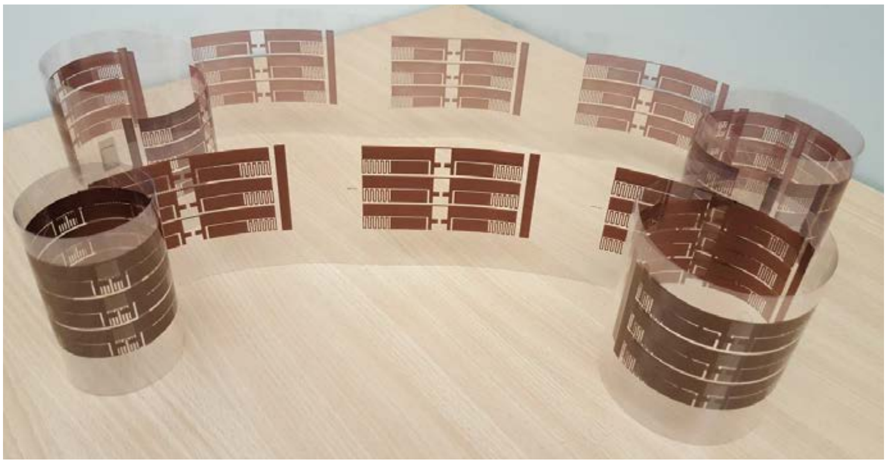


Figure 29 R2R printed RFID antennas (front). R2R printed RFID antennas laser sintered (back).

OPV demonstrator

Based on the development of the nano-Cu printing and its application as transparent electrode for organic electronic devices large area ITO-free organic photovoltaic prototypes were processed on non-embedded and embedded Cu-nanoparticle grid based electrodes. The copper based grid lines were ~ 400μm in width and ~ 1μm average height and were printed on 150x150 mm substrates (Fig.). The Cu-nanoparticles based functional layers were processed by inkjet printing. Laser sintering resulted in high conductive copper based electrodes with sheet resistances of 240-260 mΩ/sq for 1.2 μm film thickness (Conductivity: 30000-35000 S/cm).

The OPV demonstrators were processed on these ITO-free inkjet printed Cu-grids after the optimization of the deposition of the functional layers by inkjet printing. The resulting photovoltaic module PCE was considerably lower than the reference ITO-based OPVs processed with the same stack structure. Processing limitations negatively affect the device performance of large area Cu-based OPV modules. Despite the limited PCE achieved the project developed for the first time ITO-free OPVs comprising IJP Cu grid/PEDOT:PSS as the bottom electrode. The successful processing of the functional OPV demonstrators shows the potential of upscaling Cu grids for low cost ITO-free large area OPVs. The large area OPV demonstrator is shown in Fig. 30, a V_{OC} of 1.6 V and I_{SC} of 0.5 mA/cm² at a fill factor of 29% was achieved resulting in a module efficiency of 0.24%.

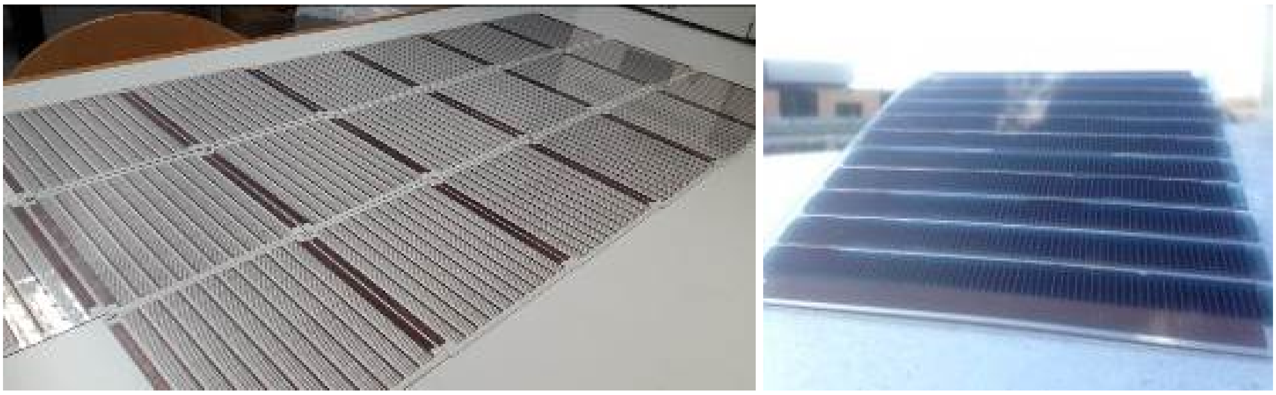


Figure 30 Inkjet printed Cu-grids for the fabrication of OPVs (left) and fully processed OPV demonstrator (right).

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4.1.4 Potential impact (not exceeding 10 pages).

1. Potential Impact

The PLASMAS results and innovation are expected to have a strong impact in the EU for the further development of the printed electronics market. This includes the development of Cu-based inks over a broad range of viscosities for various applications such as the development of fully printed organic electronic devices, alternate PCB manufacturing, high speed and high volume processing of RFID antenna. The main gain is the use of additive manufacturing which significantly reduces the environmental impact, lowers material and energy usage and reduces the sensitivity to labour costs due to highly automated processes. Specifically the PLASMAS results will impact the following areas:

- **Nano-Cu inks**: the availability of nano-Cu inks aver a broad viscosity regime allows the implementation of additive deposition processes into manufacturing for circuitry, grids as alternate transparent electrodes, RFID antenna, and other printed electronic devices.
- **Nano-Cu based grids** as transparent electrode for organic devices: there is a need for the replacement of transparent ITO electrodes in OE devices due to the fact that indium is a rare metal and expensive, vacuum based deposition techniques have a low material yield and high energy consumption and sputtered ITO layers are brittle when used for flexible applications. With Cu-based grids these limitations are overcome at a much lower material price compared to silver.
- **Cu inks as circuitry in ECD displays and for smart card integration:** Fully printed EC displays are accessible for smart card integration with screen printed Cu grids demonstrating cost-effective manufacturing processes.
- **OLEDs and OPVs on inkjet printed nano-Cu grids:** With the replacement of ITO by Cu-grids, large area OLEDs and OPVs become accessible as fully printed devices use cost efficient processing tools. With such OPV devices there is scope to reduce the CO_2 consumption for energy harvesting while gaining high design flexibility due to flexible production facilities.
- **Potentiometer sensors:** with nano-Cu-inks the additive manufacturing of such sensors is accessible, therby significantly reducing the production costs.
- **RFID antenna**: cost efficient processing of RFID antenna by inkjet printing makes flexible designs at low cost and high throughput accessible at lower prices than for etched Al antennas.
- **Machinery**: through the PLASMAS project microwave and R2R production tools for the processing of Cu-based inks and their deposition is available to a large market.

The contribution of PLASMAS to wider societal aspects includes the following:

- Improvement of employment prospects: printing nano-particle inks enables processing technologies which are competitive for the European market so that some of the loss of the electronic industry in Europe will be compensated. Thus the outcome of PLASMAS will contribute to the increase of employment aspects of European industries contributing to the increase of Europe's economic growth.
- Increase of the number of scientists and researchers: The scientific and technological subjects of PLASMAS will open the way for the increased participation of a higher amount of students to work with cutting-edge technologies.
- Increase of the mobilization of scientists and researchers within the European cooperation since several researchers worked in PLASMAS have increased their technical - managerial skills, expertise and competences by interacting and disseminating the project results.
- Improvement of the industrial production processes by the introduction of additive manufacturing technologies rather than subtractive, thereby saving material and energy. This also will benefit the environment and will reduce the carbon footprint of the relevant industrial sectors, in combination to the achievement of better health, safety and quality of working conditions of EU workers and citizens.
- The wide market implementation of OE devices (OPVs, OLEDs, sensors, etc.) as well as of integrated OE devices in several consumer products will Pave the way for future availability of low cost OLED devices and low-cost solar-powered portable devices (laptops, tablets, mobile phones, sensing units, displays).

2. Main dissemination activities

One of the main disseminations tools is the PLASMAS website which has been created at the start of the project, kept up-to-date over the whole lifetime of the project and will remain online after the project. There is a public area informing about the project and important events where the project is presented. The private arae with password secured access is thought for the exchange of project documents such as the deliverables, meeting minutes and presentations.

Another dissemination instrument are publications, two have been published before the project end, another six are planned or already in preparation. Furthermore a project flyer and a project video was created and made public through the project website. A newsletter was published summarizing the lead-user workshop held to present the PLASMAS demonstrators. Also partners regularly publish company newsletters to present project results such as RISE Acreo, 3D-Micromac and Fraunhofer.

One of the most important dissemination events of the project was the organization of a lead-user workshop during the LOPE-C trade fair 2017 in Munich, where all PLASMAS demonstrators were presented to the public.

In addition, all PLASMAS partners regularly participated in scientific conferences and commercial fairs presenting the project with talks, posters or on a booth at trade shows.

3. Exploitation of results

Nano-copper inks and pastes - IML

IML's plans for commercialisation of the developed technology initially involves approaching their existing client base for printed electronics solutions. This will be followed by actively seeking potential clients via the planned dissemination activities during the first year of exploitation.

They will apply their understanding of markets and technologies within the field of printed electronics in order to target new business opportunities related to the Plasmas platform technology. This integrated exploitation approach will be accompanied by the following activities:

- Transfer of research results into actual products and services
- Market analysis and client meetings to identify the best use of the results of the Plasmas work and for creating new business opportunities
- Engaging the end user network of the consortium partners to achieve a high degree of exploitation
- Demonstrate how the results of Plasmas can create a competitive advantage for the participating partners and European businesses, in the electronics and printed electronics domain

During 2016/2017, initial meetings with Intrinsiq Materials primary client base have been held and various opportunities explored which will potentially utilise the Plasmas technology and supply chain. Additional meetings with potential clients at major printed electronics trade shows have also been held and are currently being followed up and developed under NDA and JDA/collaboration

Two of the formulations developed in the program are already being offered for sale, and have attracted considerable interest, and could be potential solutions in up to six commercial developments that are either in place or about to start.

In addition to the nano-copper ink and pastes that are already considered as saleable products, further formulations were made during the course of the program that are at a lower level of readiness. These will be further refined and developed after the end of the program and are expected to add to the portfolio of printable copper products.

Modular processing equipment – 3D Micromac

Modular R2R printing and laser processing machine for RFID antennas and printed electronics.

Thanks to PLASMAS a process development for inkjet printing of conductive structures and subsequently laser sintering of the printed structures was carried out. 3DMM was able to establish a S2S inkjet test station for fast and cost effective printing process development.

3DMM would like to carry on the development for printing and sintering and would like to cooperate with Intrinsiq for further development of the ink. Further improvement of the used substrate, ink, printing process and sintering process is planned.

Potential synergy - 3DMM will recommend to its customers in printed electronics the inks from Intrinsiq, and Intrinsiq can recommend the 3DMM processing equipment to their customers.

Potentiometer sensors – PVI

This project investigated the use of innovative nano-copper pastes to print potentiometer tracks. This work has shown that it is feasible to manufacture PVI's potentiometer sensors in the UK using printed electronics to achieve a sale price 20-25% lower than is currently achievable using sub-contractors in the Far East.

However, this can only be achieved commercially if the printed potentiometer sensors are able to:

- Meet the demanding automotive reliability standards, and
- Be easily integrated into vehicle wiring harness during mass manufacture
- This project develops nano-metal pastes, printing and curing technology strategies to achieve a pre-production manufacturing route and prototypes samples comparable to standard potentiometer sensor sold on the market.
- If these prototype potentiometer sensors are able to achieve the cost and technical performance we predict, manufacturing potentiometers in EU at high volumes will potentially enable PVI to achieve cumulative sales of 40,000,000 units and €11.32m in cumulative sales revenue by 2022.

One drawback is that current state of the art suppliers are artificially increasing the price of the raw (non-copper cladded) PCBs which is reducing the expected cost reduction down below 10%.

Thus, currently PVI is seeking for opportunities and further collaboration and funding to develop a generic substrate tailored for printed electronics nano-material formulation to overcome this.

Electrochromic Displays – Acreo

RISE Acreo's electrochromic display technology is very close to being commercialized. The integration with copper conductors will potentially give a lower cost production and will allow more applications.

RISE Acreo, as a non-profit research institute, is continuously involved in industry projects where the products demand low cost. A current ongoing project where large area printed conductors ar ebeeing developed for an industrial customer, would benefit very much from a printable conductor with potentially lower cost than today's silver ink. The large commercial potential and associated project agreements prevents RISE Acreo from disclosing more details about the customer or application.

The work on active matrix addressed displays will be continued. RISE Acreo's customers have requested this type of device for a number of years. Not until now They have been able to make a fully printed active matrix display. Further development into larger displays (more pixels) is expected to lead to products in the future. Typical applications where this is requested are active and intelligent packaging and Internet-of-Things applications where e.g. a sensor response need to be displayed. The results from PLAMSAS will be fed into industry-funded development projects. European customers will benefit from the project results.

Copper grids for OLED and OPV devices (IAP/Joanneum/CUT/HUB)

Cu grids are an interesting alternative as transparent electrode in organic electronic devices.

Further work needs to be carried out on the following aspects:

- Control of height of the printed lines with the aim of reducing the height to decrease surface roughness to be able to directly process on the grid
- Understand the interaction with the active materials, control the work function between Cu and the functional layers
- Investigate the function of a passivation layer on Cu to prevent oxidation of the surface layers

Work should be continued since the need for alternative transparent electrodes is seen. Further funding will be provided by the EC as well as national funding agencies. Further work between the partners building on the PLASMAS project is planned.

There is an exploitable technology developed by Joanneum Research during this project involving the grid transfer process. This process is being considered for patenting and a patent application may be written. Highly promising advances in technology constitute the keysteps in producing ITO-free Cu-grid based electrodes for OLEDs. Within the PLASMAS project we were able to meet a major requirement of OLED grids, namely a very flat electrode surface while maintaining the indispensably low resistance provided by inkjet-printed Cu-grids of suitable cross section. This embedding process of Ag-grids on rigid substrates (investigated at NTC based on the research of a CUT co-worker) and the development of a flexible resin allowing an embedding process of Cu-grids on flexible substrates (JOANNEUM RESEARCH) constitute highly promising alternatives to ITO-based OLEDs. The flexible embedding process is based on UV curing and allows roll-to-roll-fabrication techniques. Further investigation and development of embedded Cu-grid based electrodes is highly recommended as it can lead to the commercialization of a cost-competitive future key-technology for OLEDs.

Microwave plasma sources – C-Tech

There have been no saleable products developed by C-Tech in the Plasmas project. However, the technology advance has opened up opportunities in new sectors for C-Tech and provided a scale up route for promising applications

The development of the large scaled up plasma system at 10x larger has improved the possible commercial offerings by opening up the development of processes to new market that are looking for larger production volumes. Previously the scale up potential of the microwave plasma was limited to parallel production in a number of units with a 6 kW maximum power output. The new system developed in PLASMAS enables direct scale up of any plasma process to a single 60 kW system which has a maximum throughput of gas which can be up to 400x greater than the existing systems installed at IML during the project.

Additionally, the development of the gas handling system and particulate formation control philosophies have allowed the yield in Si particles to be increased from below 5% to above 98%. This increase dramatically affects the commercial potential of producing particulates from a fluid precursor. If the post processing had been successful the cost reduction in production at commercial quantities would have dropped by over 90% compared to the state of the art at the start of the Plasmas project.

The key development step in taking this to market is finding the mass application of the particulate technology. It is clear that the production of the inks through the IML processes is a realistic and commercially viable route to the production of nano-particle inks. It is therefore the continuing task to find and develop marketable products that fit a need in commercial or academic research.

The project partnership with IML and others has been very productive and the search for new applications for the technology developed in PLASMAS will continue.

Additionally, some of the progress made is already being applied in two further research projects ALISE and LIBRE. Both of these H2020 projects are focussed on the development pf novel materials and the unique properties of the plasma and the techniques developed in PLASMAS are being utilised to control the formation and properties of the materials in these projects.

Gemalto

For Gemalto ECD and silver print technology industrialisation and qualification is needed to go to saleable product. At the moment, the copper print version of the smart card is considered to be not mature enough for sale. With an improved Cu material and process the implementation of Cu printing would be reconsidered due to its expected price advantage.

4.1.5 Project website

The main tool for the dissemination of the project results is the PLASMAS website (http://www.plasmaseu.eu). The website has been constructed and uploaded on-line since the beginning of the project (month 3). This website will remain on-line after the end of the project.

The main target of the website is to promote the mission and goals of the project and to inform the society on the activities and achievements of the project. The following Figure shows the main page appeared during the loading of the website. It is composed by the main logo (top part) indicating the project title, the flag of the European Union and a brief introduction of the project. Links are given to upcoming events, where PLASMAS partners are present.

Fig. 31 Entry page of the PLASMAS website

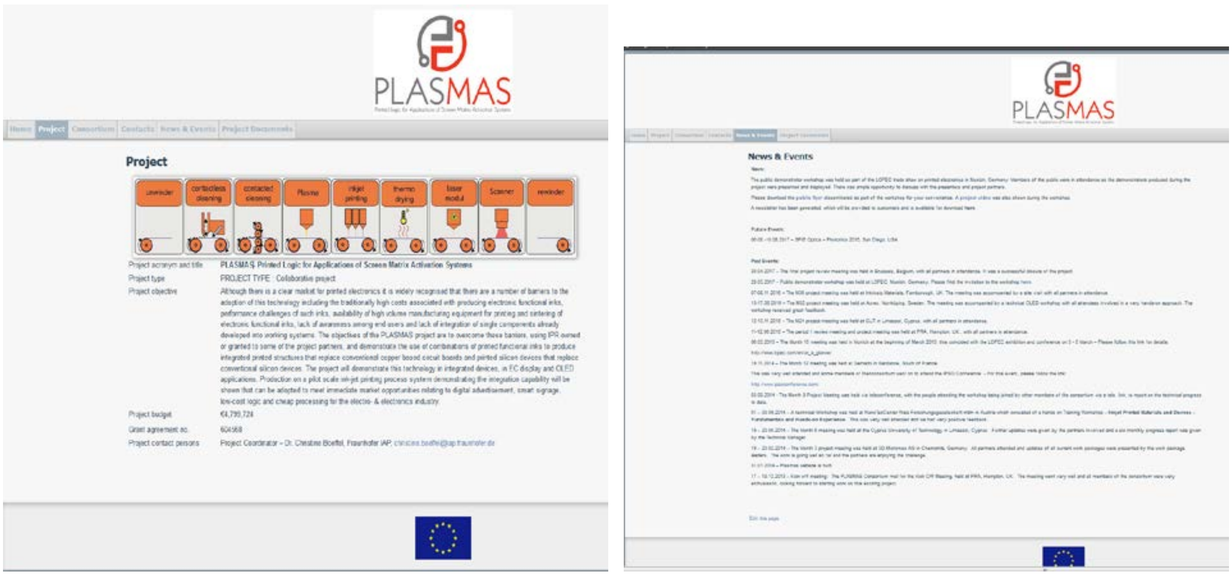

Fig. 32 Project description (left) and list of news and events (right) in the public domain of the PLASMAS website

Fig. 33 Secure area of the PLASMAS website providing information to the Consortium members

The secure area of the website includes information on the

- Project documents (e.g. updated DoW)
- Templates/reports/presentations
- Consortium Meeting Presentations & Minutes
- Dissemination Kit (flyer, public presentation)
- Deliverables
- Reports

Fig. 34 PLASMAS project logo

Project partners:

Partner 1	**Coordinator, Research Institute**
Name	**Fraunhofer Institute for Applied Polymer Research**
Address	Hansastraße 27c, 80686 München, Germany Tel: +49-331-568 1915
WEB	www.iap.fraunhofer.de
Contact person	Dr. Christine Boeffel, +49-331-5681915 christine.boeffel@iap.fraunhofer.de Walter Krause, +49 (0)89 12 05 27 13, walter.krause@fraunhofer.de
Partner 2	**Research Institute**
Name	**NanoTecCenter Weiz Forschungsgesellschaft GmbH**
Address	Franz-Pichler-Strasse 32, 8160 Weiz, Austria Tel: + 43 316 876 8003
WEB	http://www.ntc-weiz.at/
Contact person	Dr. Paul Hartmann, Scientific Managing Director, +43 316 876 3001, paul.hartmann@joanneum.at Dr. Gerburg Schider, +43 316 876 8024, gerburg.schider@joanneum.at
Partner 3	**SME**
Name	**Intrinsiq Materials Ltd**
Address	Y25 Building, Cody Technology Park, Ively Road, Farnborough, GU14 0LX, United Kingdom, +44 (0) 7776 457 255
WEB	www.intrinsiqmaterials.com
Contact person	Dr. Richard Ward, +44 (0)1252 399787, richardward@intqm.com Dr. Ian Clark, ianclark@intqm.com

Partner 4	**Research Institute**
Name	**Acreo Swedish ICT AB**
Address	Box 1070, SE-164 25 Kista, SwedenTel: +46 (0)10 522 00 30
WEB	https://www.acreo.se/
Contact person	Peter Dyreklev, Senior Scientist Printed Electronics, +46 761 15 88 65, peter.dyreklev@acreo.se David Westerberg, Development Engineer, +46 705 328 591, david.westerberg@acreo.se
Partner 5	**SME**
Name	**PRA**
Address	14 Castle Mews, High Street, Hampton, TW12 2NP, UK.Tel: +44 (0)208 487 0800
WEB	http://www.pra-world.com/
Contact person	Stephen Ryley, coordinator/project manager, +44 1664 501501, s.ryley@pra-world.com
Partner	**SME**
Name	**C-Tech Innovation Limited**
Address	Capenhurst Technology Park, Chester, CH1 6EH, United Kingdom +44(0)0151 347 2900
WEB	http://www.ctechinnovation.com
Contact person	Robert Bell, Project Manager, Tel: 01513472989, rob.bell@ctechinnovation.com Stuart Dalrymple, +44 151 347 2900, stuart.dalrymple@ctechinnovation.com
Partner 7	**SME**
Name	**3D-Micromac AG**
Address	Technologie-Campus 8, 09126, Chemnitz, Germany Tel: +49 371 400 43 67
WEB	http://3d-micromac.com/
Contact person	Maurice Clair, Development Engineer, +49 371 400 43 67, clair@3d-micromac.com Frank Peuckert, +49 371 400 43 912, peuckert@3d-micromac.com
Partner 8	**University**
Name	**Cyprus University of Technology**
Address	Archbishop Kyprianos, 31 Limassol Savings Cooperative Bank

	Building 3rd Floor, Limassol, 3036, Cyprus Tel: +357 25 00 2500
WEB	http://www.cut.ac.cy/
Contact person	Prof. Stelios A. Choulis, Director of the MEP research unit, +357 25 00 2605, stelios.choulis@cut.ac.cy Efthymios Georgiou, efthymios.georgiou@cut.ac.cy
Partner 9	**End-User**
Name	**Gemalto SA**
Address	6 Rue de la Verrerie, Meudon – 92190, France Tel: +33 4 42 36 50 00
WEB	www.gemalto.com
Contact person	Alain Le Loc'h, Project Manager, +33 4 42 36 52 94, alain.le-loch@gemalto.com
Partner 10	**End-User**
Name	**Precision Varionic International Ltd**
Address	Sensor House, Langley Road, Hillmead, Swindon, SN5 5WB, United Kingdom. Tel: +44 (0) 1793 879879
WEB	www.pvi.co.uk
Contact person	Dr Pufinji Obene, Operations Director, +44 (0) 7791649944, pufinjiobene@pvi.co.uk
Partner 11	**University**
Name	**Humboldt-Universität zu Berlin**
Address	Unter den Linden 6, 10099 Berlin, Germany. Tel: +49 (0) 30 2093 0
WEB	http://www.hu-berlin.de
Contact person	Prof. Emil J. W. List-Kratochvil, Head of Hybrid Devices Group, +49 (0) 30 2093 7697, emil.list-kratochvil@hu-berlin.de Dr. Felix Hermerschmidt, Postdoctoral Researcher, +49 (0) 30 2093 7565, felix.hermerschmidt@hu-berlin.de

Figure 35 PLASMAS project presentation during SID displays week 2016 in San Francisco at the booth of Fraunhofer

Figure 36 Presentation of the PLASMAS project during LOPE-C 2017 at the Munich Trade Center by IML (top row), ACREO (middle left) and Fraunhofer (middle right and bottom)

Figure 37 Presentation of the PLASMAS project by IML during Printed Electronics Europe 2017 in Berlin

Figure 38 Laboratory work during the PLASMAS workshop on OLED and ECD processing at Acreo, Sweden before the M32 meeting.

4.2 Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).

The plan should consist of:

- Section A

  This section should describe the dissemination measures, including any scientific publications relating to foreground. **Its content will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

  This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential **will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Economic transformation in Hungary and Poland'*		*European Economy*	*No 43, March 1990*	*Office for Official Publications of the European Communities*	*Luxembourg*	*1990*	*pp. 151 - 167*		yes/no
2										
3										

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Conference*		*European Conference on Nanotechnologies*	*26 February 2010*				
2								
3								

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical* *2. Industrial inspection*	*2008* *2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner)* *Beneficiary Y, Beneficiary Z, Poss. licensing to equipment manuf. ABC*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

4.1 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	604568-3
Title of Project:	Printed Logic for Applications of Screen Matrix Activation Systems
Name and Title of Coordinator:	Dr. Christine Boeffel

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***NO***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	

• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		
Work package leaders		
Experienced researchers (i.e. PhD holders)		
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
x No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
x	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify
x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

x Yes- please specify
○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

x Yes- please specify
○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[10]: 1.3
○ Associated discipline[10]: 2.2
○ Associated discipline[10]: 2.3

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
x No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ x	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- x Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- x Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- x Local / regional levels
- x National level
- x European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**2**
To how many of these is open access[11] provided?	
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[12]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

x	Increase in employment, or	x	In small & medium-sized enterprises
❑	Safeguard employment, or	x	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	x

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes x No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes x No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

x	Press Release	x	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
x	DVD /Film /Multimedia	x	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	x	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

PhD students, International Conferences, Exhibitions

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.	
2.	
N	
Total	