Printed hybrid systems

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ABSTRACT

This paper presents research activities carried out at VTT Technical Research Centre of Finland in the field of hybrid integration of optics, electronics and mechanics. Main focus area in our research is the manufacturing of electronic modules and product structures with printed electronics, film-over-molding and polymer sheet lamination technologies and the goal is in the next generation of smart systems utilizing monolithic polymer packages. The combination of manufacturing technologies such as roll-to-roll -printing, injection molding and traditional component assembly is called Printed Hybrid Systems (PHS).

Several demonstrator structures have been made, which show the potential of polymer packaging technology. One demonstrator example is a laminated structure with embedded LED chips. Element thickness is only 0.3mm and the flexible stack of foils can be bent in two directions after assembly process and was shaped curved using heat and pressure. The combination of printed flexible circuit boards and injection molding has also been demonstrated with several functional modules. The demonstrators illustrate the potential of origami electronics, which can be cut and folded to 3D shapes. It shows that several manufacturing process steps can be eliminated by Printed Hybrid Systems technology. The main benefits of this combination are small size, ruggedness and conformality. The devices are ideally suited for medical applications as the sensitive electronic components are well protected inside the plastic and the structures can be cleaned easily due to the fact that they have no joints or seams that can accumulate dirt or bacteria.

Keywords: Printed electronics, over-molding, embedding, hot lamination, multilayer polymer substrate, smart system integration

1. INTRODUCTION

VTT Technical Research Centre of Finland develops smart system integration based on the combination of roll-to-roll printed and assembled functionalities, flexible substrates and plastic integration. VTT's target is to develop innovative products with integrated optical, electrical and mechanical functionalities. Research is carried to develop novel device fabrication technologies as well as integration technologies in order to quarantine seamless system integration and functionality.

Figure 1 shows an example of a future product concept. The Smart Spoon contains sensors for temperature and weight measurements. Sensors, user interface components, such as, the OLED display and organic photovoltaic cell for energy harvesting, can be manufactured by the use of printing on a flexible foil. The display-photovoltaic foil, with additional silicon-based electronic chips and components, is integrated into the handle using plastic injection molding. The result is a product that can be used like any conventional spoon but has additional functions, such as, measuring the temperature of drink or the weight of a portion of sugar.

The integration technology allows for the design of shapes of electronic products more freely, as it becomes possible to print circuits on flexible foils instead of conventional rigid circuit boards. Therefore, industrial product designers will gain more design freedom as the manufacturing technology is being developed towards more flexible, design-friendly and inexpensive form of electronics. In addition, comparatively low-cost circuits and components can be produced in very high volumes using flexible plastic substrates and continuously running roll-to-roll (R2R) printing technology. By combining the expertise of this new electronics manufacturing technology with the efficient 3D shaping technology of

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injection molding, there is great potential to build a new high-throughput manufacturing platform that can deliver complex integrated optical, electrical and mechanical functions.

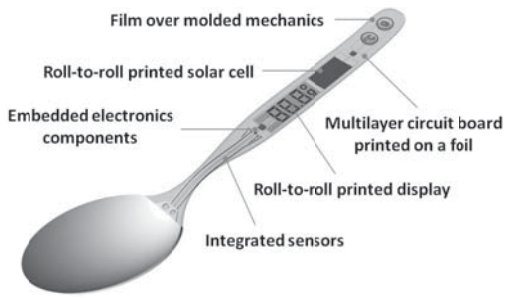

Figure 1. Smart Spoon concept.

VTT is conducting active research in the field of photonics, printed electronics and hybrid manufacturing of smart systems. Large investments have been made to a pilot printing facility that is used to develop novel product concepts by the use of R2R printing processes. The smart systems research focuses in combining manufacturing technologies, such as, roll-to-roll -printing, injection molding and traditional component assembly to enable seamless integration of the new technology into traditional products at a comparatively low cost.

This paper presents research activities carried out at VTT in the field of hybrid integration of optics, electronics and mechanics. The integration concept - Printed Hybrid Systems (PHS) - is described in Section 2 and device fabrication technologies and integration technologies are depicted in Section 3. Several demonstrator structures, which show the potential of the integration technology, are described in Section 4. Discussion is given in Section 5 and summary and conclusions in Section 6.

2. PRINTED HYBRID SYSTEMS MANUFACTURING CONSEPT

The overview of the Printed Hybrid Systems concept is shown in Figure 2. VTT's experience is in integrating chips and flexible components on roll-to-roll printed backplanes and other flexible substrates as well as creating 3D plastic structures based on assembled foil over-molding. We have designed and manufactured several proof-of-technology demonstrators with integrated back lighting (LEDs and OLEDs), indicator lights, capacitive touch control switches, optics, control electronics, power sources and storage as well as sensors.

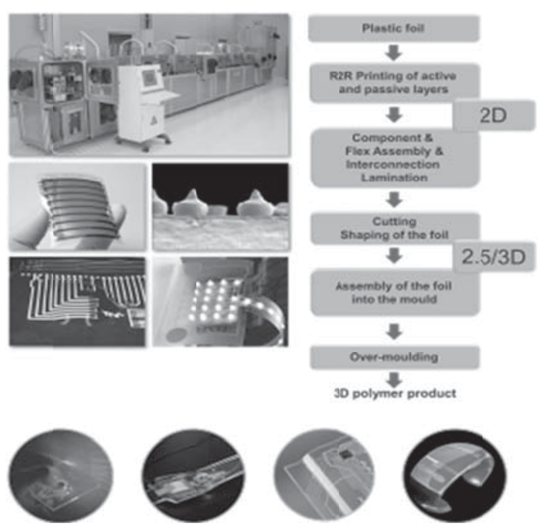

Figure 2. Printed Hybrid Systems concept is based on seamless combination of roll-to-roll printing, component assembly, lamination, foil forming and foil-over-molding processes.

Printed Hybrid System concept idea is to assemble bare chips (devices) or SMT components on a substrate or circuit board and use this sub-assembly as an insert in injection molding process. Process flow for in-mold integration of electronics when using plastic foil material subassemblies is shown in Figure 3. Mechanical and optical structures are formed by the use of injection molding and bare chips are sealed in the injection molding process in such a way that mechanical and optical interconnections as well as device encapsulation are provided for the module or system. We have studied possibilities to add functionality of the plastic products and at the same time to reduce packaging and material costs by utilizing in-mold integration technology into electronic and optoelectronic module manufacturing. By using flexible plastic foils and cost-effective printing methods together with efficient 3D shaping of the foils and injection over-molding technology, there is a great potential for building a new high-throughput manufacturing technology platform that can provide products in various applications fields with complex optical, electrical and mechanical functions at very low cost.

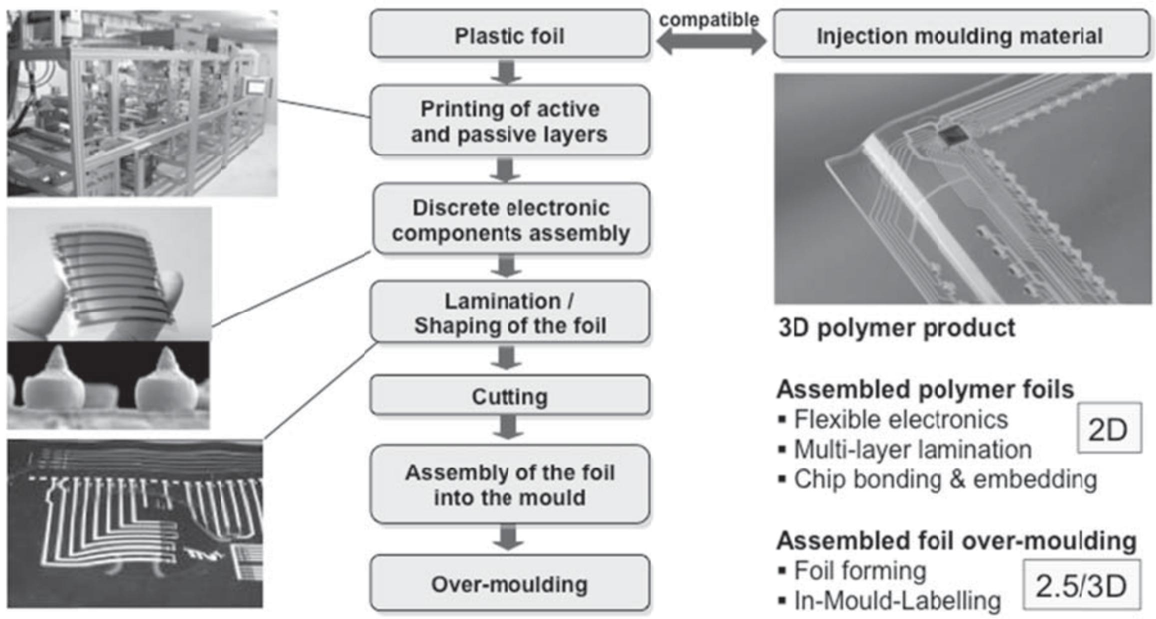

Figure 3. Printed Hybrid System concept utilizing plastic over-molding process.

Injection molding is one of the main technologies used in the PHS concept. Injection molding is a cyclic process, in which complex 3D geometries are formed from the raw material with a single process step. This simplicity makes it possible to produce large quantities of complex parts fast and cost efficiently. The great benefit of molding in general comes from the fact that the shapes will need to be tooled only once into the mold and then the geometry can be copied. Low yield has been a big hurdle, which has effectively prevented the use on high-pressure injection molding in electronic component packaging. Hot-melt molding and casting are commonly used in protecting electronic devices as the pressures related to the process are not that high and there is a good probability of obtaining reasonable yield. With printed electronics many of the components can be manufactured as flat structures, which are much less prone to be damaged by flow of melted plastics to the mold cavity. The demand for high yield is also not that strict as the printed sub-assemblies cost less and the threshold for feasible production is lower. Furthermore, the added value of embedded structures can be used in justifying the higher complexity of the production method.

The main benefits of injection molding in comparison to the standard electronics over-molding techniques are faster cycle times and higher precision parts. Repeatability in the injection molding process is very good and the mold itself can be used for accurate positioning of components to molded features. When an electronic assembly is over-molded the optical and mechanical features necessary for the module functions can be created simultaneously with the protective packaging. Insert molding is a common technology for manufacturing things like connectors and cables. In this type of molding wires or pieces of sheet metal are placed on the other half of the mold and plastics are injected into the cavity. Vertical injection molding machines equipped with rotary tables or linear slides are commonly used for this purpose. In these machines the insert pieces can be assembled to the lower half of the mold and then moved under the top half and injection unit.

The main objective of system integration development is to enable multifunctional plastic foils with high compactness, a high degree of autonomy, overall integration of several functionalities and reduced installation costs. System performance, reliability and cost optimum will be sought for the specified application requirements. This will be done by hybrid integration of the best-suited combination of functionality building blocks, such as, lighting elements, photovoltaics, batteries, sensors, RF and CPUs as well as high-throughput and high-yield manufacturing processes, such as, lamination, printing, bonding and encapsulation. VTT is developing methods to attach standard electronic components such as Si-based processor chips or power sources and storage to flexible printed circuit boards. The integrated manufacturing vision is combined with roll-to-roll-compatible, stop-and-go post-processing and component assembly on flexible foil and injection molding.

The competitiveness of VTT's Printed Hybrid Systems integration technology is based on the combination of asset as follows: Integration of electrical, optical, and mechanical functionalities; Utilizing 3D system miniaturisation – "air out", volume and weight reduction and less mechanical parts (*e.g.*, elimination of buttons and holes); Allowing for greater freedom for product design – new innovative products: New shapes and sizes - more appealing; Allowing for high throughput manufacturing processes and simpler manufacturing value chain for products.

3. PRINTED DEVICES AND INTEGRATION METHODS

3.1 R2R printed devices

Printing facilities for printing of electronics and photonics functionalities is one of the key assets in the PHS concept. Main in-house facilities include pilot production machines for rotary screen, flexography and gravure printing, see Figure 4. When using continuously running roll-to-roll (R2R) printing technology, extremely low-cost electronics can be produced in high volumes. In addition to simple passive circuits, such as, conductors, resistors and dielectrics, active optoelectronic components, such as, organic light emitting diodes (OLEDs) and organic solar cells (OSCs) have been printed. VTT's approach is to apply R2R printing methods in order to manufacture flexible devices on flexible substrates. The R2R processes with high throughput capability will decrease considerably the fabrication costs.

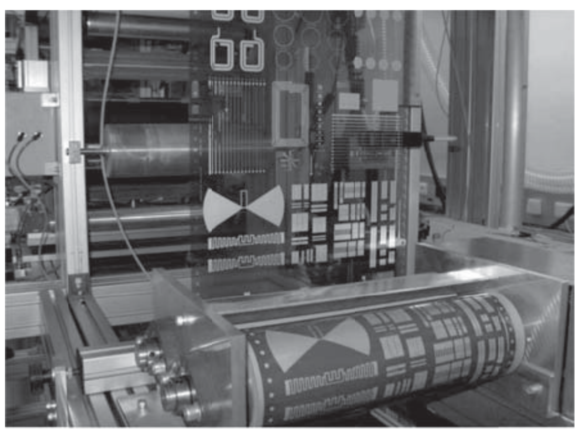

Figure 4. Roll to roll (R2R) printing machine producing printed electronics circuits.

The R2R machines have several successive printing units that make it possible to manufacture multilayer circuits by printing conductive and non-conductive layers on top of each other. Both sides of the substrate can also be printed and several sheets laminated together. Vias are created in the sheet-to-sheet process by punching holes to the plastic foils and filling them with the same conductive paste that is used in printing. [1]

When combining printed resistors on a flexible substrate, we get a flexible strain gauge sensor, see Figure 5. Strain gauges are used in industrial monitoring systems to measure forces and tensions in mechanical structures. The gauges have been developed for decades and offer very high performance with high precision and excellent immunity to interference such as temperature variation. Roll-to-roll printed strain gauge sensors cannot yet provide the same performance as conventional strain gauges but their advantage is that they enable monitoring of very large surfaces. If printed sensors are arranged in arrays, distortion profile measurements, for example, can be used effectively. It is also possible to integrate a network of sensors directly by printing them on one foil rather than wiring discrete sensors to measurement electronics. In consumer products, low-cost strain gauges can be used to monitor pressure applied to a gamepad or to measure weight from the bending of a cup handle.

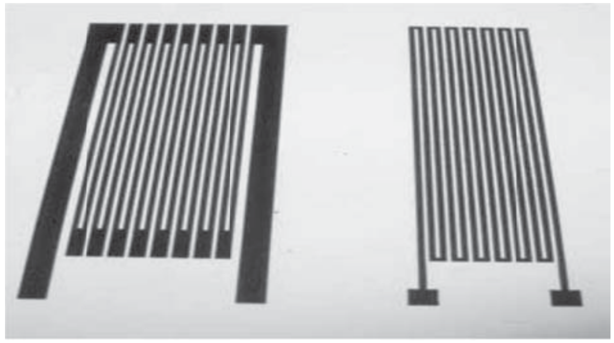

Figure 5. Printed strain gauge sensor.

Organic light emitting diodes (OLEDs) are divided according to the active materials used in the OLED stack into two classes, small molecule and polymer based OLEDs. Due to their currently still enhanced performance in the means of stability and luminous efficiency, the commercially available products are mostly based on small molecule materials. In order to ensure an adequate lifetime of the products, glass as a substrate and vacuum based evaporation techniques are used in the current manufacturing processes. Even though a rigid glass substrate functions as an excellent barrier protecting the organic materials from degradation, it prevents the utilization of the flexibility of the organic materials. Significant amount of investments and research efforts are directed aiming to obtain flexibility of displays and OLED light sources.

The potential for lowered fabrication costs has been the motivation for the utilization of polymer based OLED materials ever since their discovery. The schematic description of the layers used in a polymer-based printed OLED device is shown in Figure 6a, and printed OLED devices on a flexible foil are shown in Figure 6b. The OLED consists of thin organic films deposited between two electrodes. The processing flow can be described as follows. Initially, on the base substrate barrier layers reducing the oxygen and moisture absorption into the organic OLED films are deposited. The barrier substrate is then coated with a transparent anode. The barrier substrate coated with transparent anode is cleaned, its charges removed, and its surface energy adjusted by means of washing, deionization, and plasma or corona treatment. The pre-treatment of the substrate is essential since the thickness of the following layers is in the order of sub-micrometers, and therefore, any impurities, such as, dust particles become critical. On the pre-treated barrier-anode substrate, the hole injection layer as well as the emissive layer and cathode are then deposited by printing. Each of the layers is dried directly after the printing in order to minimize the dissolution and interfacial mixing of the underlying layer during deposition of the following active layer. Finally, the OLED elements on the substrate are encapsulated by laminating a foil containing barrier layers and an adhesive layer on to the substrate. Since the light emissive area of OLED is formed on the location where anode and cathode are overlapping each other, patterning of the electrodes is needed [2].

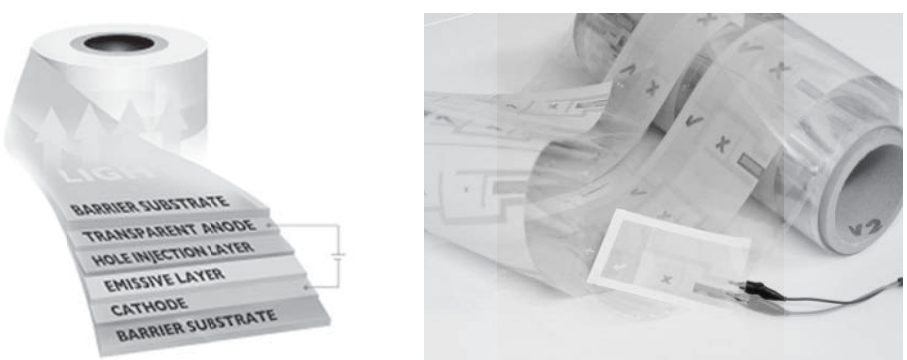

Figure 6. OLEDs devices printed on a flexible foil.

Photovoltaic cells based on conjugated polymers have high potential for a low-cost photovoltaic technology. In recent years, active research of polymer-based solar cells has improved the energy conversion efficiency and stability to an attractive level for commercialisation. One of the main advantages in polymer-based solar cells is the possibility to process solar cells in high volumes on flexible, light-weight substrates by exploiting R2R compatible processing methods including printing and coating methods. For a photovoltaic converter made by a single solar cell of a given size, enough energy might be delivered to empower low power applications, but the voltage level remains limited by its open-circuit voltage. Therefore, it is essential to use series connected solar cells in order to increase the voltage to an adequate level or parallel connected solar cells if higher current is needed.

VTT has demonstrated organic solar cell modules consisting of several series connected cells (active area arranging from 9.65 to 15.45 cm^2) prepared with R2R compatible gravure printing method, see Figure 7, the printed organic solar cells with a printed hole injection layer and an active layer. When optimizing the printing process, we analyzed the electrical performance and efficiency of gravure-printed solar cells with the active layer prepared with several different total concentrations and ratios of P3HT:PCBM commercial materials. A power conversion efficiency of 2.8% under AM1.5G solar illumination was obtained for a single element. We showed that by using the above-mentioned methods to optimise printability, the surface roughness values approached those obtained with the spin-coated sample. The high power conversion efficiency of 2.8% obtained with fully gravure-printed organic solar cells confirms gravure printing's potential as a manufacturing method for organic electronics. [3]

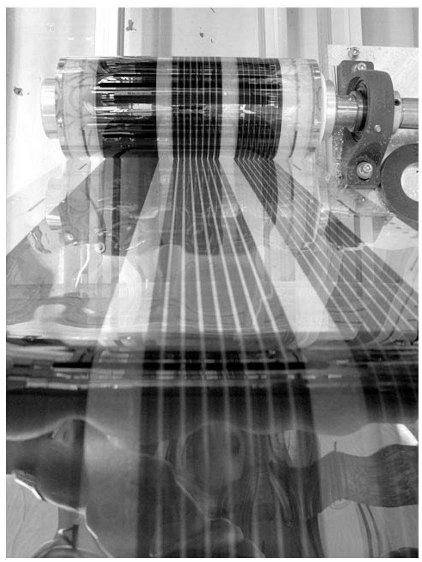

Figure 7. Organic Solar Cells printed on a flexible foil.

VTT has demonstrated the use of continuous roll-to-roll hot embossing in high-throughput manufacturing of disposable thermoplastic foil-based chips. The microfluidic chips served as a platform in a sensitive CE assay to detect an antibiotic resistance indicator *mec*A gene in S. *epidermidis*. Microfluidic CE chips were imprinted into a continuous PMMA web with an embossing speed of 0.5 m/min, resulting in an output of approximately 300 microfluidic chips per hour. Due to careful optimization of the R2R manufacturing process and a high degree of automation, the chip quality was highly repeatable and less operator dependent than in piece-by-piece manufacturing techniques for microfluidics. The developed solvent bonding protocol proved suitable for sustaining the separation gel loading pressure, and for the resulting optical chip quality. Another advantage of the R2R embossing setup was the large available stamp surface area on the cylindrical embossing tool. With a size of roughly 180mm x 40 mm, multiple stamp copies could be used in the same embossing run, which was a true asset for fast testing of different microfluidic chip designs. We conclude that R2R hot embossing is a suitable and reliable technology for fast, continuous and low-cost production of microfluidic devices. [4]

3.2 UV nanoimprinted devices

Polymers are applicable materials for photonic device fabrication due to their good optical properties and versatile processability at low temperatures, and therefore, provide possibility for low-cost fabrication. Recently, nanoimprinting or nanoimprint lithography (NIL) has obtained a plenty of research interest. In NIL, a mold is pressed against a substrate coated with a moldable material. After deformation of the material, the mold is separated and a replica of the mold is formed. Compared with conventional lithographic methods, imprinting is simple to carry out, requires less-complicated equipment and can provide high-resolution with high throughput. Nanoimprint lithography has shown potential to become such a method that low-cost and high-throughput fabrication of nanostructures is possible. UV-nanoimprinting can be used to fabricate polymer-based single-mode and multimode waveguides. The structures can be fabricated on flexible substrates, also.

Figure 8b shows a ridge waveguide fabricated by the use of UV nanoimprinting. The waveguide core is fabricated on a glass substrate by imprinting using a commercial UV cured Ormocore material. The width of the single-mode waveguide structure is 2µm and height 0.8µm. The mold, which was used to imprint the waveguide structure, is shown in Figure 8a, and it was fabricated by the use of a commercial positive resist material Ormocomp. [5]

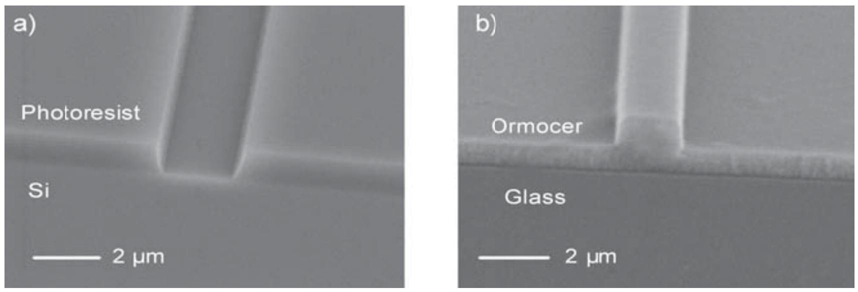

Figure 8. a) Imprinting mould consisting of patterned positive tone resist on a silicon wafer and (b) cross section image from a replicated ridge waveguide based on UV-curable hybrid polymer on a glass substrate.

Imprinting can be used to fabricate cavities and microfluidic structures. Figure 9 shows an optical waveguide structure combined with a microfluidic structure. This enables fabrication of novel sensor structures, for example, combining microfluidic channels and MEMS pumps with optical detection waveguide structures.

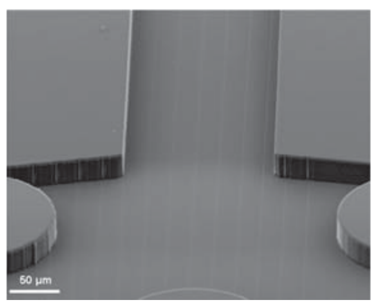

Figure 9. Waveguide structure combined with a microfluidic structure.

Currently, the UV imprinting process is carried out in sheet level. Therefore, the sheet-level fabricated components or sub-assemblies are handled using pick-and-place machines similarly as discrete chips, components or subassemblies.

4. DEMONSTRATORS

VTT has designed and manufactured several integration concept demonstrations in a number of research projects over the past couple of years.

4.1 Over-molded mobile phone add-on lens

Mobile phone add-on less shown in Figure 10 represents an example of an optical module fabricated by the use of over-molding. In the demonstrator, two green LED chips were wire-bonded on a standard FR4 circuit board along with two white SMD LEDs. The circuit board with the devices was inserted into a mold cavity and over-molded with clear PMMA plastic. When the LEDs were embedded inside the plastic element, one air interface was removed from the optical path enabling better light coupling efficiency and thus, better illumination. The components were assembled to the circuit board before the molding, and therefore, no additional assembly steps were needed in the module packaging. Bare LED chips were able to withstand the high pressures and temperatures during injection molding process. When carefully designing the mold and optimizing the molding process parameters, manufacturing yield can be feasible for integrated module production. The central part of the lens structure was molded to a double-aspheric shape, which is used as a macro lens. The module is used as an add-on lens for a conventional mobile phone camera. The add-on lens converts the mobile phone to mobile microscope. [6][7] The integrated module fulfills both optical imaging and illumination functions needed in microscopy with a single compact design.

Figure 10. Over-molded illumination and imaging lens.

4.2 Over-molded origami electronics LED lighting

Figure 11 shows a demonstrator structure that was used in testing the feasibility of so-called “origami electronics”: electronics circuit that can be cut and bend into 3D shapes. The part is an “ice-scraper” that is used to scrape ice off the car windshield during the wintertime. The piece equipped with embedded lighting LEDs allows for the use of it for temporary illumination purposes. This is extremely simple device including a battery, a mechanical on-off switch and embedded LEDs in the plastic structure. Cutting and folding a printed circuit foil into the injection mold obtained these functionalities. This origami-like procedure was enabled by the fact that the substrate carrying the electronics components and optoelectronics chips is fully flexible. The demonstrator showed that fairly complex electro-mechanical structures could be manufactured with one process step by utilizing the flexibility of the foil. In addition, it shows that several manufacturing process steps can be eliminated by printed hybrid systems technology.

Figure 11. “Ice-scraper” demonstrator.

4.3 Laminated LED subassembly

The basic structure of a laminated demonstrator is shown in Figure 12. In the manufacturing process the polycarbonate sheets with an individual thickness of 100 µm were printed with conductive patterns produced by screen-printing using silver-based thick film pastes. The final integrated multilayer structure including the embedded LED chips was fabricated by laminating the flexible substrates together in a hot lamination process. The final demonstrator size was 50 x 75 mm^2 consisting of six 25 x 25 mm^2 modules. Each module consisting 5 x 5 LED devices resulting a total number of 150 LED devices with 5 mm pitch. A phosphorous foil was placed on top of the blue emitters in order to generate white light. The demonstrator brought 11600 cd/m^2 (I_{LED}=2 mA) average brightness, 22 lm/W luminous efficiency, 5550 K color temperature, CIE values (0.331, 0.411), CRI $\geq$ 70 and 6.3% total power conversion efficiency. [8]

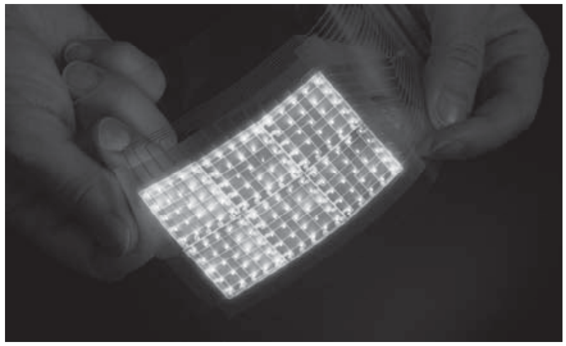

Figure 12. Assembled backplane with 6 x 25 laminated LED chips.

A more advanced demonstrator, a flexible display consisting of 5 x 7 LED chips and capacitive ON/OFF control switches was demonstrated. Display structure consists of three sheet layers with embedded LED devices. The processing of the multilayer structure was started by stabilizing polycarbonate sheets with temperature treatment. Via holes (Ø=100…275 µm) and cavities (Ø=400 µm) for the LEDs were punched. Vias were filled in with Asahi LS-106D-1 Ag paste using stencil printing. Then the conductors for layers L1b and L3b were screen-printed. The used paste was Asahi SW1400 Ag. The sheets were dried at 80 °C for 20 min after printing. The pads for LED chips were printed next. Then the LED chips were assembled with manual die bonder one-by-one into the cavity. The type of LED devices was Cree C470RT290 and the emission color was blue. The bottom area of the chip was 300 µm x 300 µm and the thickness 115 µm.

Integrated capacitive ON/OFF switches were embedded into the multilayer structure by screen printing the detailed sensor structures on the surfaces of the intermediate layers. In the manufacturing process the sheets were placed in the alignment jig and hot laminated together in vacuum. The laminator used in the experiments was Lauffer Pressen RLKV 25/1. The peak temperature in the lamination process was 165 °C and the total lamination took about 1 h. The assembled structure can be bent in two directions and was shaped curved using heat and pressure. The manufactured and operating flexible display demonstrator is shown in Figure 13.

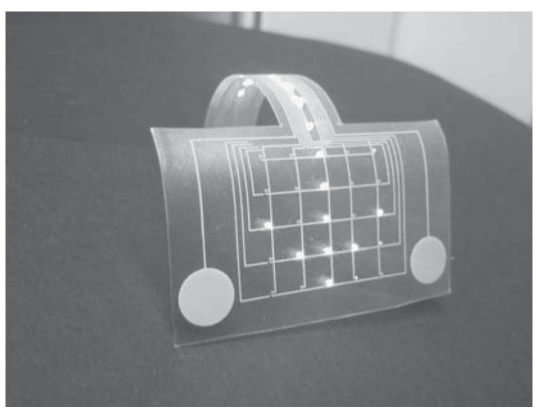

Figure 13. Display demonstrator with capacitive control switches.

Demonstrated technology enables implementation of eye-catchers, info panels, interactive digital price tags and user interfaces to be used in advertising, informing and man-machine interfacing. Implemented multi-layer structure is possible to integrate into 3D product structures in injection molding process.

4.4 Parking status indicator and automotive rear lamp

The architecture of the autonomous traffic light and automotive light was designed in an EU FP7 project PRIAM. Two demonstrator backplane lay-outs were designed based on architecture designs and first Roll-to-Roll printings of the backplanes were carried out. In addition, CAD 3D models of full systems were generated taking in account all the components specifications, the materials usage, the automatic Sheet-to-Sheet, Sheet-to-Roll and Roll-to-Roll assembling processes and the European standards for each sector of applications. First set of assembled demonstrators were made out to validate selected specifications in terms of materials, processes and components. The preliminary working demonstrators were successfully demonstrated and tested. In Figure 14, a flex-to-flex bonding polycarbonate substrate containing secondary batteries and polyimide straps for electronic device bonding is shown Figure 14.

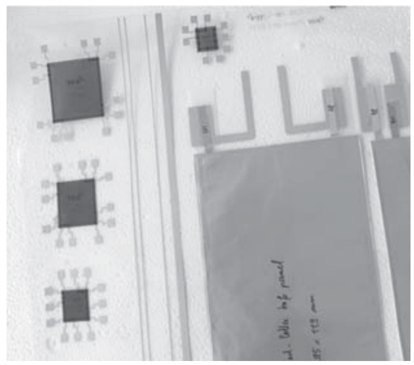

Figure 14. Flex-to-flex bonding test substrate containing secondary batteries and polyimide straps.

4.5 Over-moleded OLED subassembly

Tests were carried out in order to study the feasibility of the concept of embedding flexible printed OLEDs into plastic structures with the IML process. The OLED foil material with the greatest potential was found to be polycarbonate terephthalate (PET) and over-molding material polycarbonate (PC). OLED samples in the over-molding tests had the following structure: ITO-PET, organic layers, Ca/Ag cathode and barrier-protecting foil laminated with UV-cured epoxy. Over-molding experiments were carried out with a conventional hydraulic injection molding machine Engel ES200/50 HL equipped with an ISO 294-3 plate cavity mold. The experiments showed that the OLED components survive the injection molding temperatures and pressures and the elements are able to emit light after embedding. One manufactured over-molded OLED demonstrator is shown in Figure 15. [9]

Figure 15. Over-molded OLED demonstrator.

4.6 Over-molded optical touch panel

Figure 14 shows a more complicated functional module-level demonstrator, an integrated optical touch panel. The touch panel is based on a plastic structure that operates as a light guide. A series of infrared (IR) LEDs are positioned on one side of the structure and a series of detector components on the other side. The light travelling in the light guide between these two electronic components is attenuated, when the screen surface is touched with a finger. When several light sources and detectors are used as an array, the signal attenuation can be localized, leading to touch panel operation.

Key benefits of in-molded touchscreen technology [10] are perfect transmissivity, due to the fact that no new layers are introduced between the actual screen and the viewer, and 3D formability, which allows for the addition of touch functionality around device covers with the same assembly. The latter is also an implication of novel integration methods and paradigms: touch functionality can be an integral part of the device cover. The control electronics may also be molded in, and the electronics may still be assembled onto planar film in a standard pick-and-place process (the 3D formation is done at the mold insert phase). Due to the fact that electronics are molded in, the touch panel is highly environment proof and durable. This technology is most suitable for small to midsize terminals, such as, mobile phones, industrial and medical terminals and, naturally, any hand-held (or automobile) devices. The touch panel demonstrator also shows that the technology does allow novel applications with high environmental and durability demands.

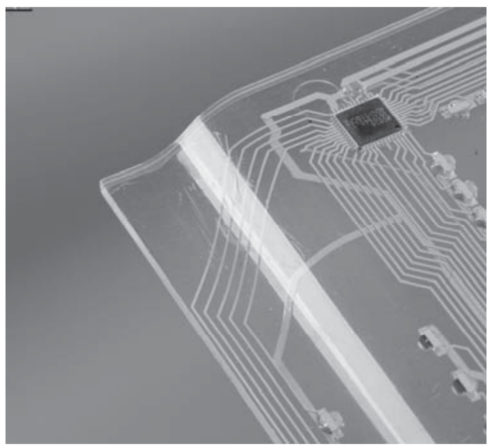

Figure 16. Over-molded touch panel.

5. DISCUSSION

Potential short and medium term applications and market opportunities for Printed Hybrid Systems based on the use of plastic integration are enhanced user experience based on integration of simple touch control switches, signal lights and decorations in conformal 3D structures. The applications are

- Automotive interiors
- Aviation interiors
- Medical and healthcare products
- Consumer products
- Point-of-sale products

Long-term vision of VTT's plastic integration technology is to enable cost-effective realization of more complex products with multifunctional integration of user-interfaces (touch control, reflective and emissive display and indication), lighting, power sources and storage, micro fluidistics, sensors, diagnostics and data processing, memory and wireless communication.

Figure 17 shows the production concept for manufacturing of future printed hybrid systems modules by film-over-molding technology. The manufacturing line starts from R2R printed electronic foil. In the pre-assembly stage, electronic devices and components are assembled on the planar foil with standard pick-and-place machines and attached by gluing or reflow soldering process. At this stage, sheet-level fabricated components or sub-assemblies are assembled on the R2R printed foil, also. The sub-assembly is then rolled with the carrier sheet to the injection molding machine in which parts of the foil are cut and shaped with the mold. When the plastic is injected into the cavity the components are embedded in the polymer structure, which also forms the 3D shape of the final module or system. If needed, further components can be assembled on top of the molded piece before the module is released from the carrier foil by cutting.

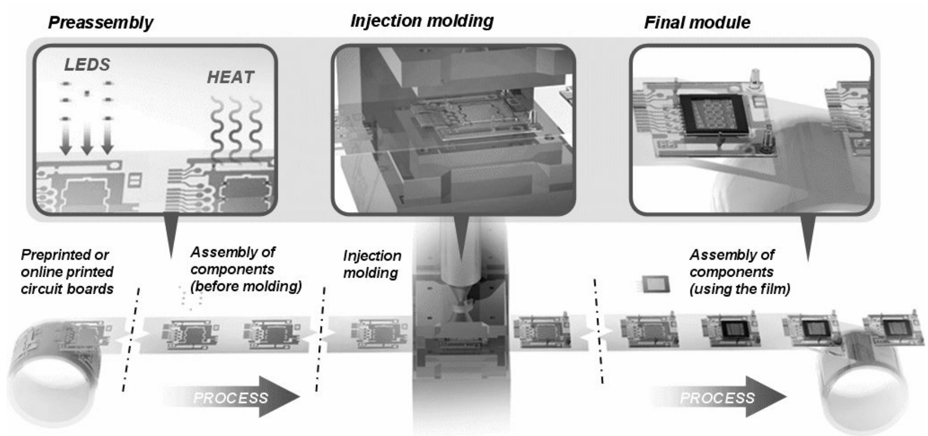

Figure 17. Stop and go roll-to-sheet production for Printed Hybrid Systems.

Many companies have shown a large amount of interest to the printed hybrid systems technology. VTT has responded to this interest by creating plans of a new pilot manufacturing line that could be concentrated solely in the production of hybrid systems. The line may contain new manufacturing equipment like pick-and-place, foil manipulation and injection molding machines. The purpose is to take the next step towards the production process concept. The line will be built as a back-end process to the existing PrintoCent pilot factory, which is a world-class facility for development of printed electronics located in Oulu, Finland. Main emphasis in the research conducted with the planned equipment would be the study of mass production feasibility. Key issues like manufacturing costs, reliability and yield will need to be tested in practice with small pilot production series of novel polymer based hybrid components, modules and systems. VTT has unique rapid prototyping and hybrid manufacturing capabilities for creating 3D plastic products based on roll-to-roll printing, assembly over-moulding of flexible hybrid electronics systems.

6. SUMMARY AND CONCLUSIONS

This paper reviews the results obtained by VTT in the field of printed electronics and hybrid manufacturing of smart systems. The research focuses on combining manufacturing technologies, such as, roll-to-roll-printing, injection molding and traditional component assembly to enable seamless integration of new functionalities into products still maintaining comparatively low manufacturing cost. This approach is called Printed Hybrid Systems (PHS) that was depicted with several demonstrator examples, which have been used in testing the feasibility and showing the potential of the technology. By utilizing the good properties of printed electronics, namely the substrate flexibility and low cost, totally new types of product structures can be created. VTT is also investing in further efforts to the development of manufacturing facilities that will be used in testing the feasibility of printed hybrid systems in mass-production.

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REFERENCES

[1] Jaakola, T., Lahti, M. Petäjä, J., Kautio, K., Rönkä, K. and Lenkkeri, J., “Low cost printed flexible multilayer substrates,“ 10th Electronics Packaging Technology Conference EPTC, 344-349 (2008).

[2] Tuomikoski, M. and Suhonen, R., “Pursuing the Printed OLED,” posted on Tue Apr 05, 2011, http://www.industrial-printing.net/content/pursuing-printed-oled?page=0%2C0 (2011)

[3] Kopola, P., Aernouts, T., Guillerez, S., Jin, H., Tuomikoski, M., Maaninen, A. and Hast, J., “High efficient plastic solar cells fabricated with a high-throughput gravure printing method,“ Solar Energy Materials and Solar Cells, v 94, n 10, 1673-80 (2010).

[4] Liedert, R., Amundsen, L.K., Hokkanen, A., Mäki, M., Aittakorpi, A., Pakanen, M., Scherer, J.R., Mathies, R.A., Kurkinen, M., Uusitalo, S., Hakalahti, L., Nevanen, T.K., Siitari H. and Soderlund, H., “Disposable roll-to-roll hot embossed electrophoresis chip for detection of antibiotic resistance gene mecA in bacteria,” Lab Chip, 12, 333–339 (2012).

[5] Hiltunen, J., Hiltunen, M., Karioja, P., Puustinen, J. and Lappalainen, J., “Fabrication of optical waveguides by imprinting: usage of positive tone resist as a mould for UV-curable polymer,” Optics Express Vol. 17, No: 25, 22813–22822 (2009)

[6] Mäkinen, J-T., Keränen, K., Hakkarainen, J., Silvennoinen, M., Salmi, T., Syrjänen, S., Ojapalo, A., Schorpp, M, Hoskio, P. and Karioja P., “Inmould integration of a microscope add-on system to a 1.3 Mpix camera phone,” SPIE 6585 (2007).

[7] Bäumer S. (ed.), Handbook of Plastic Optics, 2nd ed., Wiley-VCH, Weinheim, Germany, pp. 266-268 (2010).

[8] Keränen, K., Mäkinen, J.-T., Heikkinen, M., Hiltunen, M., Lahti, M., Sunnari, A. and Rönkä, K., “Backlight illumination structure based on embedded inorganic LED chips and hot laminated multilayer polymer,” SMTA Microelectronic Symposium, Kona, 18-20 January, THA3/1, (2011)

[9] Mäkinen, J.-T., Keränen, K., Alajoki, T., Koponen, M., Keränen, A., Kemppainen, A. and Rönkä, K., “Over-molded electronics and printed hybrid systems,” SMTA Microelectronic Symposium, Kona, 18-20 January, TA1/2, (2011).

[10] Aikio, J. and Keränen A., “Arrangement for a touchscreen and related method of manufacture,“ WIPO Patent Application WO/2010/046539, April 29, (2010).