Hybrid In-Mould Integration

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Abstract

Next generation of electronic modules and systems in different application areas such as automotive, medical and home appliances will utilize various electronic, optical and mechanical functions integrated in freeform intelligent products with benefits such as decreased volume and weight, lower costs and higher freedom of design when compared to currently available electronics manufacturing and packaging methods. The hybrid in-mould integration technology concept is based on combination of roll-to-roll (R2R) printed electronics, discrete component assembly, film forming and injection overmoulding/in-mould labelling (IML) processes. In this study, compatibility and feasibility of the technology for low-cost disposable healthcare sensor applications, especially pulse oximeters, was investigated. Flexible printed circuit (FPC) substrates for pulse oximeter applications were manufactured in high-volume and low cost fashion by R2R printing and etching processes. Surface mount technology (SMT) and leadframe components were assembled on FPCs by using adhesive bonding technology. The assembly process was also demonstrated using automated, high-volume capable machine. It was proven that SMD components and their interconnections on flex withstand the injection overmoulding process and can thus be embedded seamlessly inside plastic parts. By the use of the same injection moulding process it was also demonstrated that rigid mechanical locking features manufactured by film overmoulding can be combined with the flexibility of FPC. In order to speed up the iteration cycles of the hybrid integration design flow, a new method was developed for rapid prototyping of in-mould integrated products. In the method, 3D printing was used to create a master for a silicone mould, and assembled FPC was overmolded in vacuum casting process with polyurethane material. This paper presents also other research activities at VTT Technical Research Centre of Finland in the field of hybrid system integration carried out in various collaborative projects with companies and research institutes in Europe. The demonstrators realised in these projects include autonomous, intelligent lighting and signaling systems for automotive and traffic signs, in-molded optical touch panel and flexible printed organic light-emitting diode (OLED) embedded into 3D plastic structure using IML-like process in which active OLED foils are used instead of graphic foils. The demonstrators prove that hybrid in-mould integration could be a feasible technology enabling seamless integration of optical, electrical and mechanical features into 3D plastic products.

Key words

Printed electronics, hybrid integration, injection overmoulding, in-mould labelling, smart system integration

I. Introduction

System-in-foil approach has been seen as a way to realize next generation of seamless and unobtrusive smart systems. In this concept, a flexible polymer substrate is used as a base where functions such as energy, sensing and communication are built by using different manufacturing methods and organic or inorganic materials [1]. Such flexible system-in-foil devices have several advantages. Firstly, the consumer will experience more freedom in usage when the device is bendable. Secondly, flexible devices are also suitable for conformal applications where they have to follow the shape of a given rigid body. Flexible devices can either be one-time-flexible, so bended once to be able to fit in their final application. Or, alternatively, they are applied in applications where they should survive multiple bendings [2]. A potential way to realize the conformal integration of flexible system-in-foil devices where they have to be embedded in a seamless fashion to 3D shaped plastic products is the use of injection overmoulding process. Furthermore, intelligent combination of injection moulded parts and flexible circuits can lead to very low costs when R2R processes are utilised [3].

II. Hybrid In-Mould Integration Concept and Examples

A. Concept

The hybrid in-mould integration concept idea is to assemble electronic components or bare dies on a circuit carrier, and use the sub-assembly as an insert in injection overmoulding process. After the overmoulding, the sub-assembly becomes an integral part of the final plastic product. The use injection moulding process to overmould rigid electronic modules has been studied for instance in [4] - [6].The sub-assembly can also be single or multilayer FPC, offering a possibility to use 3D forming techniques for the assembled foil if needed. Integration of multilayer FPCs into plastic parts by injection overmoulding was investigated for instance in [7] – [10]. In these papers the basic issues such as the adhesion between substrate and overmoulding material and reliability of the embedded components were investigated. In the *B-D* parts of this chapter, some previously published research examples of more integrated hybrid systems realised at VTT are presented in more detail.

B. Autonomous Systems in Automotive Lighting

Autonomous systems are pursued in automotive and signage applications due to easy installation and achieved energy savings. System-in-foil approach provides possibility to implement thin and light-weight solutions with potential for conformal integration. Technology capability was verified by designing and implementing large area automotive and signage demonstrators. It was shown that it is feasible to interconnect flexible batteries, solar cells and driving electronics by using conductive adhesives onto flexible polycarbonate (PC) backplane substrate with silver-ink printed wirings. Manufactured demonstrators were operational after assembly and bonding processes. The energy produced by the solar cells was guided to the Li-Ion batteries by a charge regulator. Batteries were able to supply power to the automotive and signage LED elements so that the systems autonomous operation was successfully demonstrated [11]. The automotive demonstrator is shown in Fig. 1. The next step in the work could be 3D shaping and overmoulding of the flexible LED element in order to seamlessly integrate it to plastic parts.

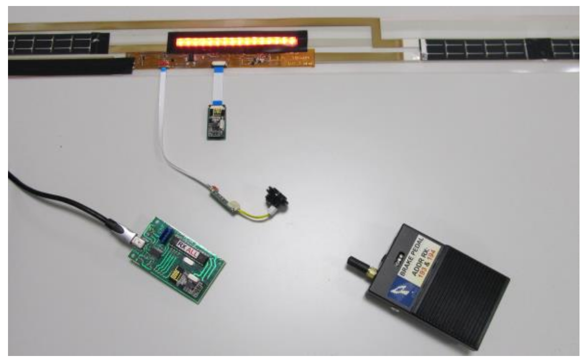


Figure 1. Autonomous automotive lighting system demonstrator.

C. Flexible OLED Foil Embedded in 3D Shaped Plastic Structure

In this research example thin, flexible and R2R fabricated OLEDs were successfully integrated into 3D shaped polymer products using IML-like process in which active OLED foils are used instead of graphic foils. This synthesis of low-cost manufacturing technologies offers potential to add novel display and lighting elements to plastic products in different application fields, such as packaging, consumer electronics and healthcare. The benefits are decreased volume and weight, lower costs and higher freedom of design when compared to conventional methods. OLED foil was fabricated by printing and evaporation processes on indium tin oxide-polyethylene terephthalate (ITO-PET) substrate. Electrical wirings were realized by double-sided screen-printing with conductive silver-ink and filled electrical vias. Organic layers of the OLED were gravure printed. Cathode was fabricated by Ba/Ag evaporation. In the IML process, the overmoulding PC polymer material was casted over the OLED foil and it thus became an integral part of the final 3D shaped polymer structure of the demonstrator. Samples were tested before and after the overmoulding for injected current and visually observed OLED emission, and it was found out that the emitted light remained on the same level after overmoulding [12]. A working demonstrator sample is shown in Fig. 2.

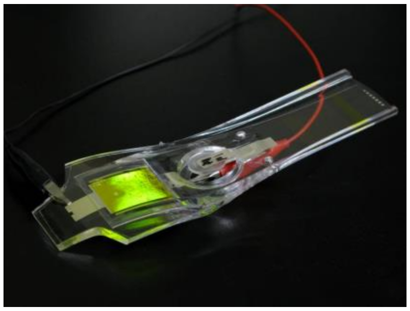


Figure 2. Plastic embedded OLED demonstrator

D. Overmoulded Optical Touch Panel

The overmoulded optical touch panel research example is based on a plastic structure that operates as a lightguide. A series of infrared LEDs are positioned on one side of the structure and a series of detector components on the other side. The light travelling in the lightguide 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 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. Due to the fact that optoelectronic components are embedded into plastic structure, the touch panel is highly environment proof and durable. This technology is most suitable for small to midsize terminals, such as mobile phones and industrial and medical terminals [13], [14]. Overmoulded optical touch panel is shown in Fig. 3.

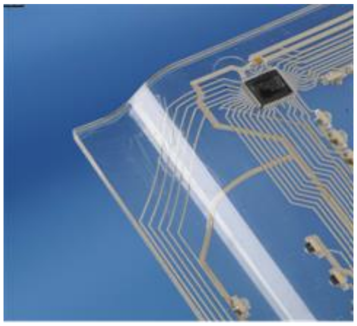


Figure 3. Optical touch panel.

III. Disposable Healthcare Sensor Demonstrator

A. Concept

In this chapter, the work towards utilising hybrid in-mould integration technology for low-cost single-patient use disposable healthcare sensor applications is presented. In this application field there's a strong demand for lower manufacturing cost, in the same time keeping the performance and reliability of the sensor at acceptable level. Pulse oximeter was chosen as the demonstrator, because today some disposable pulse oximeters in the commercial markets already utilise FPCs, but often packaging and interconnection issues are a limiting factor for potential cost benefits. Disposable pulse oximeters typically measure pulse and oxygen level of the blood from the finger tip of a patient using an optical transmittance measurement.

The demonstrator construction is based on FPC with assembled SMT and leadframe components: a leadframe LED emitter and a photodiode detector, and two SMT passive components. The other end of the FPC is injection over-moulded to realise mechanical and electrical connector for the monitor equipment cable. The SMT components are located in the overmoulding area and thus are embedded inside the plastic structure of the connector. The connector was designed keeping in mind the typical specification requirements associated with disposable healthcare sensor applications, for instance, water ingress and spillage. Fig. 4 illustrates the mechanical schematics of the demonstrator. FPC with assembled components is shown with light green colour, overmoulded part with purple and monitor cable part of the connector with yellow.

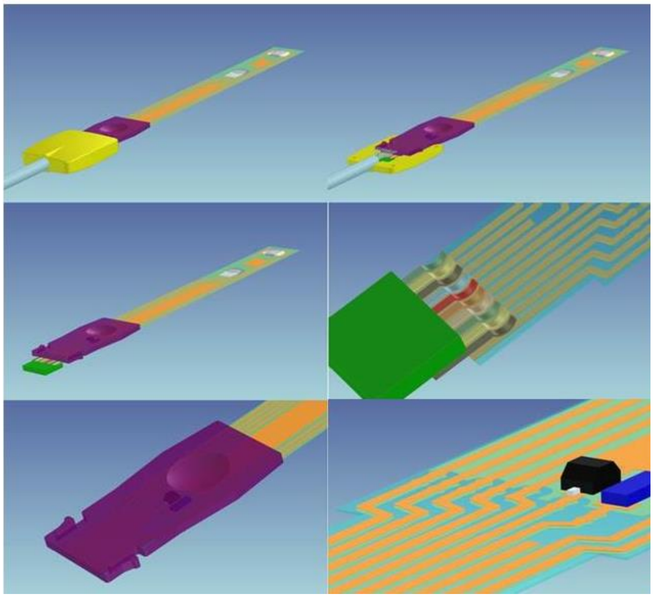


Figure 4. Mechanical schematics of the demonstrator.

Fig. 5 shows the schematic cross-section of the demonstrator. Dimensions are not to scale.

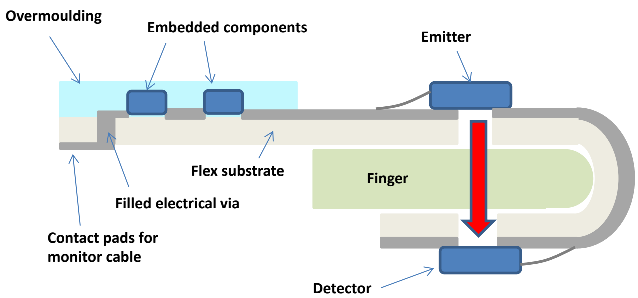


Figure 5. Cross-section of the demonstrator.

B. Fabrication of the Flexible Printed Circuits of the Demonstrators

In the fabrication of the demonstrator FPCs through-substrate vias were first punched on125 µm thick PC film substrate and filled with conductive silver paste Asahi LS-411AW by using sheet-to-sheet screen printing machine. Then conductive wirings were patterned on both sides of the film by screen-printing with the same conductive silver paste. SMT and leadframe components were assembled by using silver-filled conductive adhesive Epotek H20E.

C. Overmoulding Prototyping of the Demonstrator

Fabrication of injection moulding tools is a time-consuming and expensive process. Typically, rapid prototyping methods are used in plastic product design processes to realise potential design changes before the actual production tool is fabricated. Therefore, it would be beneficial to have a feasible rapid prototyping technique also for the hybrid in-mould integration concept. In this work a new method was implemented in realising foil overmoulding prototypes. First, a master was created from a CAD-file by using standard 3D printing technology with Object Eden 260 V machine. Then, a silicone mould tool was fabricated from this master. Flex with assembled components was inserted into the mould and liquid polyurethane material casted into the mould and over the flex in vacuum casting process. The method was found out to be working fine: all the assembled components were functional and adhesion between the foil and the polyurethane material good. The method is suitable for fabrication of prototype series of 10-50 samples in hybrid in-mould integration projects.

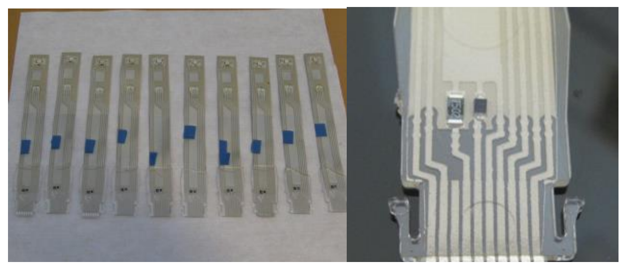
D. Overmoulding in Injection Moulding Process

Conventional injection moulding machine Engel ES200 / 50 HL was used for the overmoulding. Foil with assembled components was overmoulded with commercially available polycarbonate material Bayer Makrolon 2407 in a way that mechanical lockings for the connector were realized and two SMT components embedded inside the plastic material. Injection moulding parameters are shown in Table 1.

Table 1. Injection moulding process parameters for the flat connector demonstrator.

Temperature of the IM material	300ºC
Temperature of the mould	80ºC
Pressure limit	250 bar
Rate of injection	60 mm/s
Packing pressure	400 bar
Dose	18 mm

Fig. 6 (a) shows 10 overmoulded demonstrator samples. Some samples show partial filling etc. problems but when the right parameters were found, the mechanical features were properly moulded and embedded components were functional as shown in Fig. 6 (b).



(a) (b)

Figure 6. Demonstrator samples (a) and a close-up (b).

However, later it was found out that even the successfully overmoulded demonstrators cannot withstand moderate bending of the flex but the conductors broke down from the edge of the overmoulding. Therefore, a new flex design was made in order to overcome this problem. Fig. 7 illustrates the problem and the new flex design. With the new design, the problem of conductor breaking was solved. The future work will include thorough reliability testing of the demonstrator samples for their flexural properties.

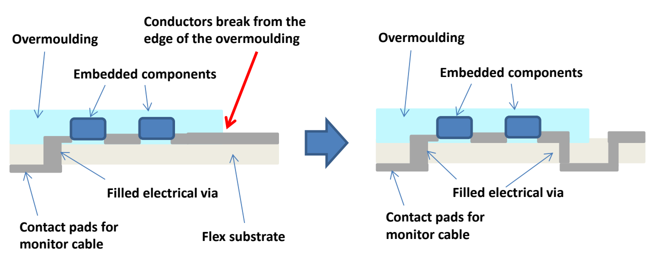


Figure 7. New flex design.

The monitor cable connector was fabricated using 3D printing process. Metal contact springs were machined and assembled on printed circuit board (PCB) by soldering. Wires of the monitor cable where also soldered to the PCB. Fig. 8 and Fig. 9 show the monitor cable connector.

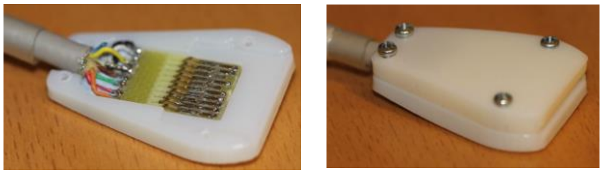


Figure 8. Assembly of the monitor cable connector of the demonstrator.

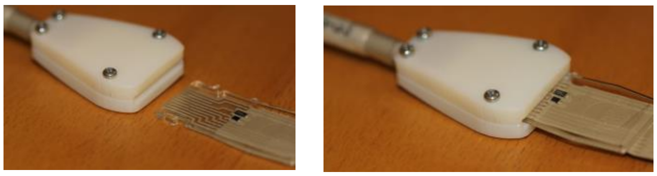
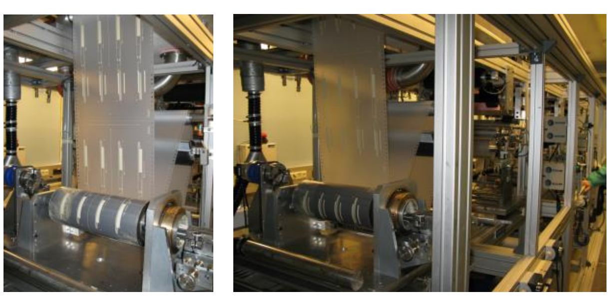


Figure 9. Insertion of the overmoulded connector.

IV. High-volume Production Assessment

A. Roll-to-Roll Manufacturing of Printed Flexible Circuits

Use of R2R processes is one of the key issues to achieve lower costs which are critical for disposable healthcare sensor applications. In this work high-volume production was assessed by investigating four different R2R manufactured FPC types: Silver ink (Asahi LS-411AW) rotary screen-printed conductors on 75 µm thick PC substrate; 20 µm thick etched bulk copper conductors on 50 µm thick polyethylene naphthalate **(**PEN) substrate (Cu20/PEN50); 35µm thick etched bulk copper conductors on 25 µm thick polyimide PI substrate (Cu35/PI25); and 30µm thick etched bulk aluminium conductors on 36 µm thick PET substrate (Al30/PET36). The conductor patterning was carried out for one side only for all FPC types. The screen-printed version was fabricated by using VTT’s R2R pilot production machine. The machine and the rotary screen printing unit of it are shown in Fig. 10. The etched versions were commercially available from a high-volume electronics manufacturer.



(a) **(b)**

Figure 10. Rotary screen printing unit (a) in R2R pilot production machine (b).

The actual vs. nominal widths of the conductors were measured from samples using SmartScope measuring microscope (Fig. 11). Five samples were taken from all four FPC types.

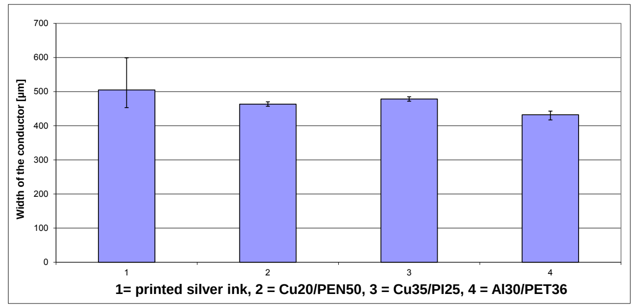


Figure 11. Average width of the conductor for different flexible circuit types. Error limits are shown as the minimum and maximum values of the width.

It can be seen that the width deviation of the printed conductors is much higher than of the etched ones. Square resistance of the conductors were measured by using 4-wire resistance measurement and conductor widths (Fig. 12). Five samples were taken from all four flexible circuit types.

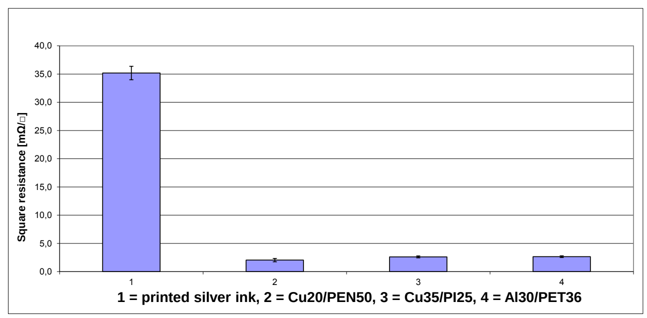


Figure 12. Square resistance for different flexible circuit types. Error limits are shown as ± stdev.

The resistance of the printed conductors is roughly ten times higher than of the etched ones. As a conclusion, both the line quality and the conductivity are much better with the mature R2R etching processes. However, if the design requires electrical vias, screen-printing becomes a much more feasible choice since via filling can be carried out without a separate process step (vs. plated through-holes). In addition, R2R screen-printing is much easier process to establish than R2R etching which requires quite delicate chemical processes.

B. Automated Assembly

Another key issue for lower costs in disposable healthcare sensor applications is the automated assembly of different components on flexible substrates. In this work it was studied by using VTT’s automated hybrid integration pilot line based on 2200 EVO machine from Datacon. The capability of the line includes assembly and bonding of various types of components on flexible substrates in continuous 200 mm wide web stop & go process. Fig. 13 shows a picture of the pilot line.

Figure 13. Automated chip & component bonder Datacon 2200 EVO with R2R transport system.

An assembly routine was created to preliminary test feasibility of automated assembly for pulse oximeter demonstrator. A simplified layout with one-sided R2R silver-ink screen-printed PC film was used in these tests, as well as the same components ie. leadframe emitter and detector, and SMT passive components.

The main structure of the created assembly routine is:

1. Inspection of conductor features for alignment with machine vision
2. Dispensing of conductive adhesive on contact pads
3. Stamping of non-conductive adhesive for attaching the body of leadframe components on flex
4. Pick-up of components from gelpack holder (leadframe) and tape holder (SMT)
5. UV and thermal cure of the adhesives

Steps 4 and 5 are repeated for each component. Final cure of the adhesives could be made as a batch process in thermal and/or UV oven. The automated assembly process was successfully demonstrated, although machine vision could not yet reliably distinguish the unusual shape of the leadframe optoelectronic components.

V. Conclusion

In this work hybrid in-mould integration concept was studied to be utilised in low-cost disposable healthcare applications. The work included the design, prototyping and fabrication of a pulse oximeter demonstrator using flexible electronics for sensor part and injection overmoulding to create a connector for monitor cable. High-volume manufacturing issues were also investigated by comparison of different R2R manufacturing methods for FPC as well as R2R compatible automated assembly of discrete components on flexible substrates. The hybrid in-mould integration concept was proven to be a potentially feasible concept for healthcare applications as well as for other cost-sensitive 3D integrated smart systems. Future work will include reliability and clinical testing of the pulse oximeter demonstrators and further development on automated assembly routines.

Acknowledgment

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