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RESEARCH REGARDING PROTOTYPE OF AN ELECTRONIC HYBRID POLYMER STRUCTURE

Beniamin-Constantin VĂLIMĂREANU, Constantin Gheorghe OPRAN

Abstract: *An electronic hybrid polymer structure enables the creation of devices and interfaces that are not only visually appealing but also lightweight, durable, and highly efficient. By minimizing the number of moving components, this technology can lower production, assembly, and maintenance costs while also reducing the likelihood of malfunctions or failures. This paper presents research regarding a product from the automotive industry, a structure that makes possible an easy communication between the human and the machine with a low-cost of fabrication. This research product with automotive applied has an electric layer that makes possible communication by a simple touch. The original contribution in this work consists in obtaining a polymeric product with electronic hybrid structure and manufacturing the prototype by additive manufacturing. An electronic circuit with touch sensors will be presented to make sure that the material or thickness will not affect the main function of the product.*

Key words: *polymeric hybrid structure; advanced electronic circuit; additive manufacturing; automotive market; prototype manufacturing.*

1. INTRODUCTION

For large-scale automotive production, an electronic hybrid polymer structure will be manufactured using IME (in-mold electronics), with all electrical components embedded directly into the mold so that the final part is obtained after the first injection cycle. For the prototype, electrical components consist in capacitive touch button, electrical wires and LEDs to figure out that the circuit is working properly. This product may be intended to control the windows and mirrors of a car, but for the moment, in this study will be made research about the influence of thickness and material properties on the main function of the product and the circuit.

2. HYBRID IN-MOULD INTERGRATION

The hybrid in-mold integration concept combines roll-to-roll printing on flexible substrates with component placement, film forming, and injection overmolding/in-mold labeling (IML) techniques. Bringing these cost-efficient manufacturing methods together provides advantages such as reduced size and weight, lower production expenses, and greater design flexibility compared to traditional approaches. The main idea is to mount bare dies or SMD components onto a substrate or circuit board and then use this sub-assembly as an insert during the injection-molding stage. In this process, mechanical and optical features are shaped, and the bare chips become encapsulated, ensuring both the necessary mechanical and optical functions as well as proper device protection. Converged manufacturing process flow is shown in next figure. [8]

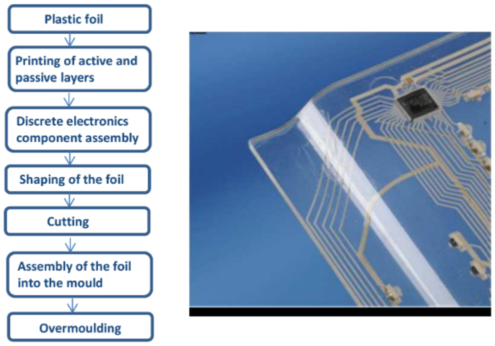

Fig. 1. Hybrid in-mould integration process flow and an example of overmoulded optical touch panel [8]

In-molded touchscreen technology offers major advantages, including excellent light transmission since no additional layers are placed between the display and the user, as well as the ability to form complex 3D shapes that enable touch functionality to extend across device covers within a single assembly. This capability stems from new integration approaches that allow touch sensing to become part of the device's outer surface. The control electronics can also be embedded during molding, while the components may still be mounted on flat films using standard pick-and-place techniques. [3].

3. SYSTEMS-IN-FOIL

A well-known category of flexible electronics is flexible printed circuits, which are already broadly used in products such as print heads, mobile phones, and laptops. More recently, a new generation of flexible electronic systems has emerged, where entire functional systems are integrated to produce a fully flexible end product. These system-in-foil devices offer multiple benefits. They provide users with greater freedom, as their bendable nature enhances ease of use, and they are ideal for conformal applications in which the electronics must adapt to the contours of a rigid object. Flexible devices may be designed to bend only once—just enough to fit into their final application.

Figure 2 shows an example demonstrator of a stretchable circuit demonstrator device with small LEDs incorporated in it. [4]

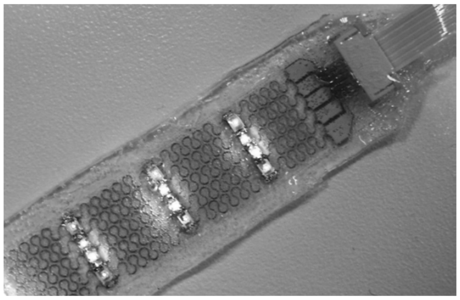

Fig. 2. Complete OLED demonstrator [4]

To ensure a reliable, flexible circuit, it is important to carefully choose the mechanical properties of the embedded material. Because the circuitry will experience deformation in its application, an important selection criterion for the embedded material will be its elastic modulus. Finite element modelling (FEM) is useful to study the effect of the elastic modulus of the embedding material on the stresses in the final circuitry [4].

4. 3D PRINTED ELECTRONICS CIRCUITS

Today, additive manufacturing is extensively utilized across a variety of industries, ranging from aerospace and automotive to bioengineering and architecture [9,2].

In 3D-printed electronics, electrically conductive traces and components are typically made from polymer composites filled with carbon or metal for FDM (which have relatively high resistivity) or from silver pastes for Direct Write (which are costly). Bartlomiej P. a.o. [1] proposed a new method using fusible alloys to create conductive paths within 3D-printed polymer structures, aimed at high-performance structural electronics.

The objective is to study the interactions between the molten alloy and the 3D-printed polymer substrate during deposition [1]

The overall concept of the FDMm technique and the creation of embedded electrical circuits within a 3D-printed polymer substrate is illustrated in Figure 3. In the first step, the polymer substrate is printed along with grooves designed for the conductive alloy material (Figure 3a). Next, liquid fusible alloy is deposited into these grooves using an additional printhead (Figure 3b).

These steps can be repeated to produce a fully 3D-printed structural circuit. For the metal deposition tests on polymer substrates, ABS substrates were printed using standard FDM, with typical parameters: nozzle temperature 230°C, bed temperature 60°C, print speed 50 mm/s, layer height 0.2 mm, and 70% infill. Subsequently, FDMm printing tests were performed on these substrates using two solder alloys, Sn60Pb40 and Sn99Ag0.3Cu0.7, which have different melting points of 183°C and 216°C, respectively. [1]

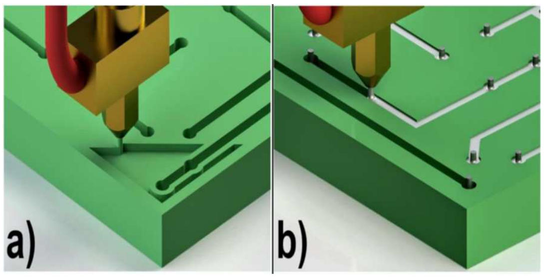

Fig. 3. Schematic illustration of an additive process for fabricating 3D-printed structural circuits from fusible alloys. (a) Preparation of a polymer substrate with the standard FDM printing process using thermoplastic polymers or composites. (b) Fabrication of condutctive metallic paths from fusible alloys with a modified FDM technique adapted for low-temperature metals and alloys (FDMm) [1]

5. 3D PRINTED MANUFACTURING OF AN ELECTRONIC HYBRID POLYMER STRUCTURE

The own contribution in this work consists in obtaining a polymeric product with electronic hybrid structure by In mold Electronics (IME) technology and manufacturing the prototype by 3D printing technology.

For several years, electronics manufacturers have been exploring a breakthrough technology set to transform the devices we use and how they are designed: eliminating mechanical buttons and switches, reducing thickness to just 2 mm, cutting weight by around 70%, and lowering costs by roughly 30%.

Capacitive touch technology is widely applied in IME systems, replacing the need to press physical buttons with a simple touch of a finger.

The circuit board tracks beneath the touchpoint detect changes in the electrostatic field, and when a user touches the panel, a small charge is drawn to that spot, with the finger acting as a functional capacitor.

For example, in a car, such interfaces are used to turn on the headlights, power, or adjust the volume. Here's how the American chemical company Dupont, one of the world's developers of conductive inks for IMEs, is presenting interfaces for cars of the present and future: [9]

	Standart design	IME Design	Difference
Weight	650 g	150 g	−77%
Thickness	45 mm	3 mm (flat version)	−93%
Mechanical parts	64 pcs.	2 pcs.	−96%
PCBA size	10 x 4 sm	10 x 3 sm	−25%

Fig. 4. Significant reduction of a part manufactured by standard process vs IME [9]

The automotive industry is just one of the many applications of IME that we have already mentioned above. I will use this field for a case study to illustrate the topic of this article. Let's take as an example the control panel for electric windows in a vehicle, which was designed with a circuit board and a plastic casing, consisting of several prefabricated parts, and compare it with a new concept developed using IME technology, where the final product is produced after the first injection. There is a significant reduction in weight, size, number of parts, and, ultimately, the cost of the assembly. Considering the current development of this technology, due not only to the reduction in cost but also to the attractive design, and taking into account analysts' reports, which predict an increase in IME implementations, a new trend is emerging in the electronics and polymer market. In the near future, we will see a transition from flat, rigid printed circuit boards inside a box-shaped enclosure to three-dimensional structured electronics.

The part designed is an automotive part, namely an electric window control panel, located on the driver's front door, whose main function is to open and close windows, control mirrors and close and open doors. Operation is done manually by the operator by touching the icons specific to each function.

The innovative part of this application is the replacement of the electrical connectors with tactile sensors, which leads to a reduction in the mass of the part, the price and the number of components.

Fig. 5. 3D Part design in CATIAV5 and location of the part inside of the car

As can be seen in the picture, the part has some bumps to allow the operator to feel the areas where he has to use his finger, without having to look at the area.

The design of the part was made in a special software, namely CATIA V5, and no fixings are provided at this time. The main objective is to obtain a transparent prototype, apply a foil on the design side, which contains some perforations that name each function of the part, and then introduce on the technical side of the TTP223 touch sensors with LEDs at their ends and connect them to a 5V battery. The idea is to control the closing and opening of the LED lights by touching the sensor button area with your finger.

The role of this prototype is to observe whether light passes easily through the material and whether the 3 mm thickness of the piece affects the functionality of the capacitive buttons.

The principle scheme is relatively simple, each capacitive button being connected to a 5V power supply, and a different colour LED being mounted on each of them. The TTP223 button has several functions, including opening and closing the circuit when touched by the operator. Another function is to close the circuit when the operator presses and holds it. These functions can be controlled from the technical side of this button.

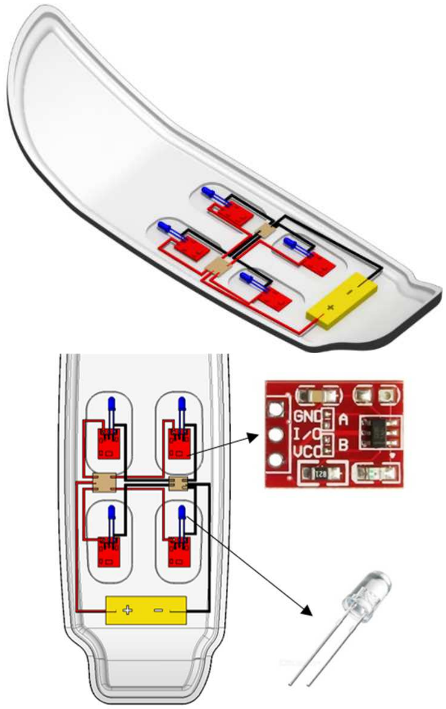

Fig. 6. Part design with assembled components

To obtain the prototype, a transparent material is needed, through which light can easily penetrate, which is why we chose 3D printing with resin (SLA - Stereolithography), a more expensive process than a normal one but which gives better results.

Fig. 7. SLA process components and SLA printer machine ELEGOO SATURN S

Resins are chosen for SLA printing because they offer high resolution and smooth surface finishes, allowing for precise and detailed parts. They can also be formulated with a variety of mechanical, thermal, and optical properties to suit different applications. The properties of the resin are shown in the table below.

Table 1. Properties of the resin used for SLA

Ultimate Tensile Strength	65 MPa
Tensile modulus	2.8 GPa
Elongation	6 %
Flexural Modulus	2.2 GPa
Notched Izod	25 J/m
Heat deflection Temp 0.45MPa	73°C

Given the small working dimensions of the printer, in order to be able to produce the piece, it was placed diagonally as shown in the figure below. This placement generates a higher material consumption because it introduces supports for placement that will be removed after the process.

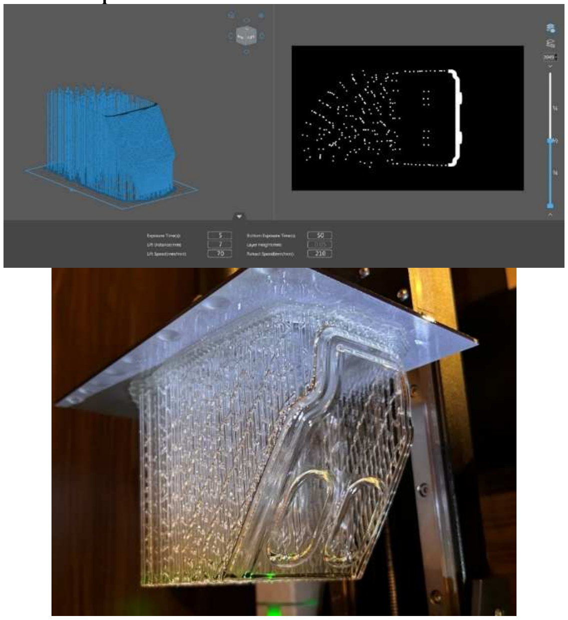

Fig. 8. SLA process simulation (with Chitubox software) and part result 50%

The seating supports are easily removed to obtain the finished piece. As you can see from the pictures above the process was done on the vertical axis from bottom to top, the last printed part being at the top end of the piece. The whole printing process took 14 hours and a consumption of 150 ml of resin.

A post-print UV curing process is used after SLA printing to further harden the resin and enhance the part's mechanical stiffness. This additional curing step helps the material reach its full strength and improves long-term dimensional stability. As a result, the final component becomes more durable and better suited for functional applications.

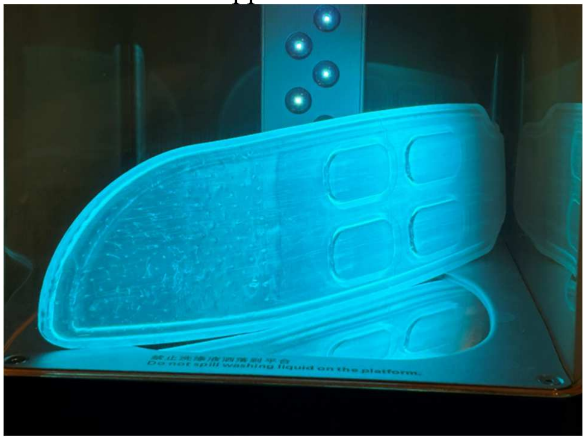

Fig. 9. UV process for increased stiffness on the part

To make the process easier, a foil was perforated in the LED action areas on the design side, the perforations having the shape of windows.

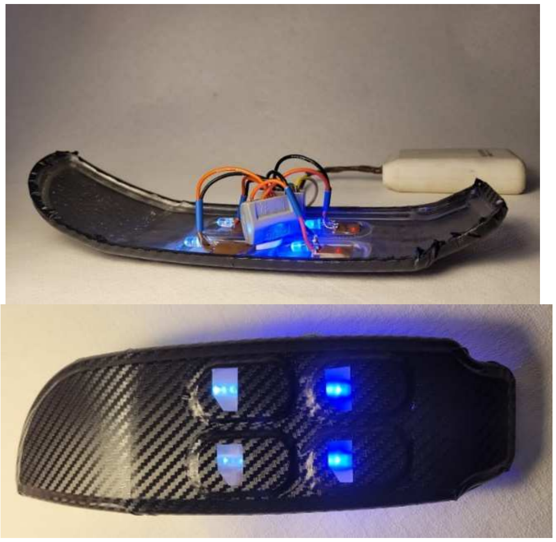

Fig. 10. Final part result with a design foil perforated that allows the light to pass through it

The prototype will be a test to see if the printed material allows light to pass through it and if its thickness is sufficient to give the piece good rigidity. It will also be studied whether tactile sensors can be assembled on the technical surface of the part and whether they function correctly when the operator acts. These will be connected to an LED bulb and will be controlled to open and close on operator action. The part, 3 mm thick, will be covered with a 0.2 mm thick adhesive tape that will be perforated in the LED areas to allow the functionality of the sensors to be seen.

6. CONCLUSIONS

It is observed that the process works in optimal parameters, as touching the buttons turns the LEDs on or off, and the energy source is sufficient to keep them on. The foil does not prevent the capacitive buttons from working properly and neither does the thickness of the part.

The button assembly on the track is a removable type so that it can be easily replaced and leaves no marks on the track area. The thickness of the material does not affect the way the sensors work and the transparency of the material allows the LED light to pass through it.

The next prototype will consist in integrating some electrical circuits inside the part so that its functional role is to control a small electric motor, which will lead to the opening and closing of some windows, thus fulfilling the main role of the part. The behaviour of the part to touch will be observed and resistance simulations will be made in a special software, simulating the force exerted by the operator with a single finger.

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Cercetări privind prototipul unei structuri electronice polimerice hibride

Beniamin-Constantin VĂLIMĂREANU, PhD student, National University of Science and Technology POLITEHNICA Bucharest, Doctoral School of Industrial Engineering and Robotics, 313 Splaiul Independentei, 060042, Bucharest, Romania, valimareanubeny@gmail.com, +40754455367

Constantin Gheorghe OPRAN, prof.univ., PhD coordinator, National University of Science and Technology POLITEHNICA Bucharest, Doctoral School of Industrial Engineering and Robotics, 313 Splaiul Independentei, 060042, Bucharest, Romania, constantin.opran@upb.ro