Reliable Smart Molded Structures

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Abstract — IMSE (Injection Molded Structural Electronics) solutions are made by integrating and encapsulating printed electronics and standard electronic components within durable 3D injection-molded plastics. Part of the technology development is to ensure that electric components and materials, such as polymer substrates, functional inks, and surface mounting adhesives, form a reliable solution. The technology verification includes stringent reliability testing. The used tests are rapid change of temperature, high temperature ageing and steady-state temperature-humidity. Here we present an additional testing case: 3000 cycles of thermal cycling (-30 °C …. 80 °C).

Keywords—IMSE; reliability; structural electronics

I. Introduction

A. Injection Molded Structural Electronics

Injection molded structural electronics (IMSE) enables design innovation by integrating electronic functions into 3-dimensional (3D) injection molded plastic parts. Features, such as controls, sensors, illumination, and communications, are embedded in thin 3D structures with plastic, wood, and other surfaces. The structures are light, thin and durable.

IMSE design can be illustrated as a material stack. The stack is a combination of films, inks, electronic components, surface mounting adhesives and injection molding (IM) resin. Fig. 1 shows an illustration of a material stack in a 2-film design.

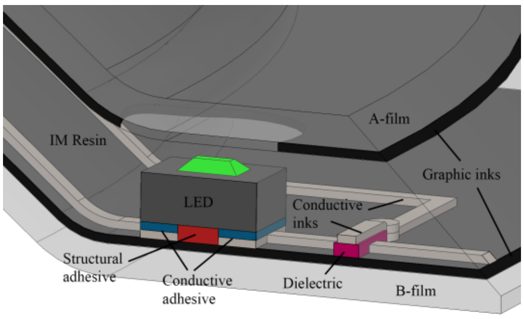

Fig. 1 Illustration of a material stack in two-film design

B. Manufacturing Processes

IMSE manufacturing differs from conventional electronics, where components are reflow-soldered to printed circuit boards. IMSE solutions are made by integrating and encapsulating printed electronics and standard electronic components within durable 3D injection-molded plastics. Core manufacturing processes are printing, surface mounting, forming and injection molding, Fig. 2. Fig. 3 shows the injection molding materials in more detail. Taken individually, the core processes are mature and use standard equipment suitable for mass production. However, standard processes are combined in a unique way during manufacturing.

Printing is the first core manufacturing process. Screen printing is used because it is suitable for mass-production and enables appropriate layer thickness (range of 10 µm). Electronics (functional inks) and decorations (graphic inks) are screen printed onto plastic film or another suitable substrate material. Electronics are typically printed using silver (Ag) conductive inks and dielectric inks to insulate between layers of circuitry.

Surface mounting is the second core process. Components are placed and bonded onto electronic films. Conductive and structural adhesives are used for electrical and mechanical bonding. The output is a two-dimensional film substrate with components.

Forming is the third core process. Two-dimensional electric and decorative films are thermoformed into three-dimensional shape and trimmed as needed. Outputs are 3D electric films with components and 3D decorative films. Forming is not used in conventional electronics manufacturing. During forming, component packages are subjected to elevated temperatures and pressures. The maximum temperature depends on the polymer film and is typically below 150 °C. Maximum pressure is typically below 8 MPa (80 bar).

Injection molding is the fourth core manufacturing process. Three-dimensional electric films and 3D decorative films are used as inserts in an injection molding tool. Resin, such as polycarbonate, is injected between the films resulting in a single molded part. The output is a strong and durable structure in which electronics are overmolded. Injection molding is not used in conventional electronics manufacturing, either. Some molding temperatures are higher than peak temperature during reflow soldering of SAC-solders (SAC = tin, silver, copper). In addition, heat transfer from hot resin to electric films is through conduction. Thus, heat transfer to components and other materials is more efficient than during reflow soldering. Maximum pressures during injection molding are around 100 MPa (1000 Bar). Reference [1] gives a more detailed description of the structural electronics manufacturing process. It also outlines requirements for components that are ideal for structural electronics.

C. Structural Electronics Applications

Automotive, appliances, building automation and IoT (Internet of Things) have been the most common applications. The technology benefits are especially suited for automotive interior use cases, for example in center console modules and trim parts. Fig. 4 shows photos of car interior applications.

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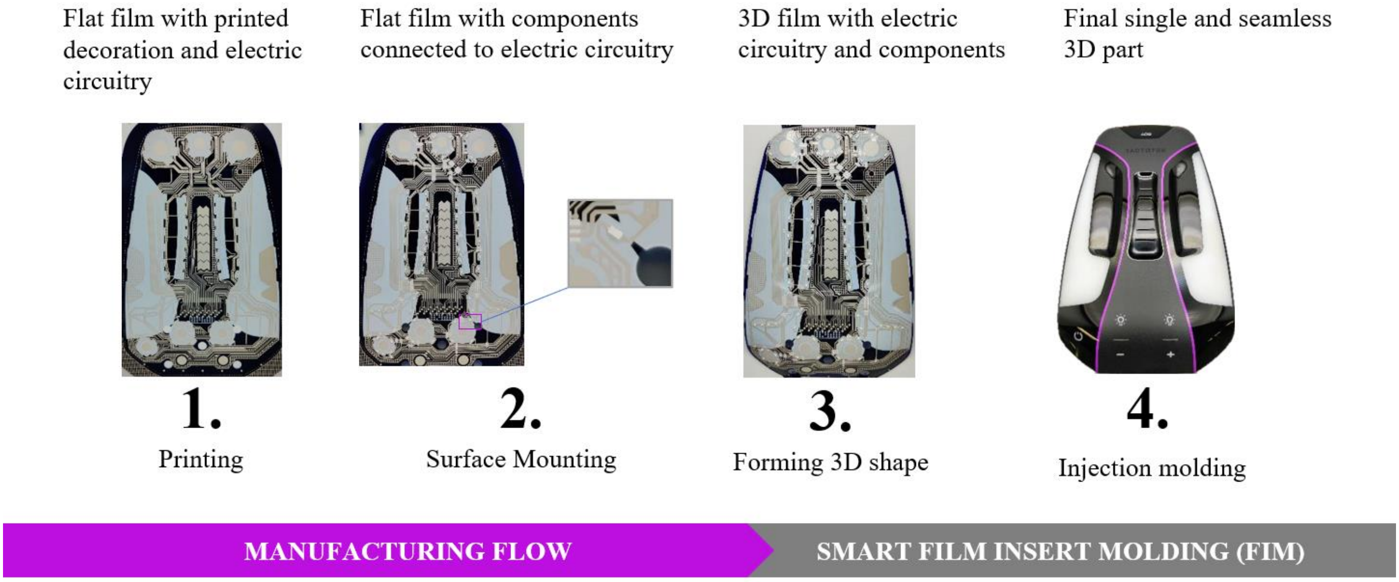

Fig. 2 Core manufacturing processes are printing, surface mounting, forming and injection molding.

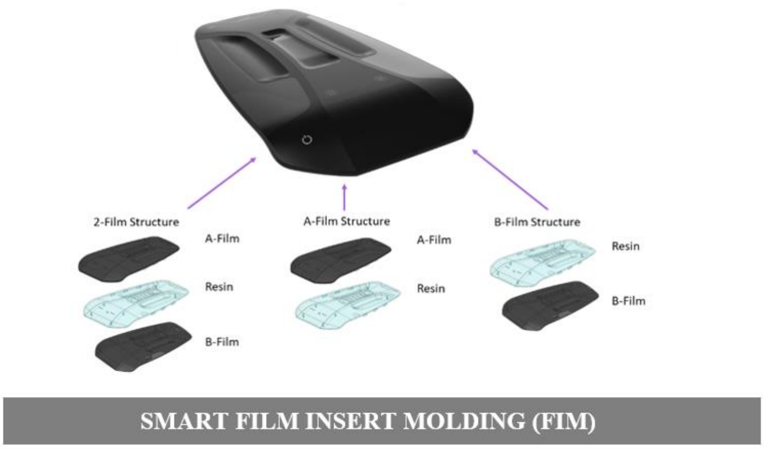

Fig. 3 The illustration shows the injection molded materials for 1 and 2-film designs. The films are used as inserts in injection molding tools and resin is injected as an overmold.

Fig. 4 The top-left photo shows a seat controller and bottom- right photo its electric film. Bottom-left photo shows a center console. The middle photo shows an overhead control panel. Top-right photo shows a technology demonstrator.

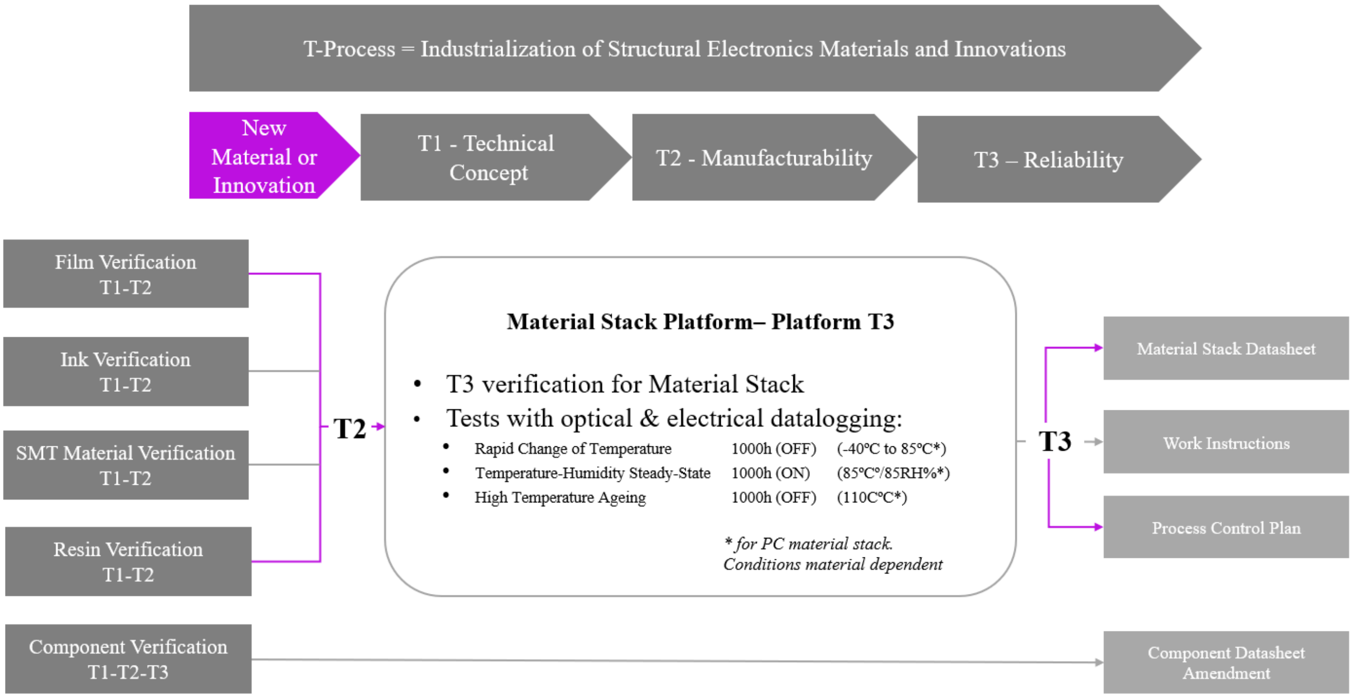

Fig. 5 Technology verification T-process, the overview is on top and more detailed description on bottom

II. EXPERIMENTAL

A. Technology Verification Process

Before product validation, the company ensures that electric components and materials, such as polymer substrates, functional inks, and surface mounting adhesives, form a reliable solution. This technology verification is done in a T-process that has three review gates, Fig. 5.

The T3 material verification is typically made using Material Stack Platforms. T3 verification includes three different reliability tests. Those are rapid change of temperature, high temperature aging and steady-state temperature-humidity, Table 1. (The test temperatures in Table 1 are selected for polycarbonate automotive stacks.)

Table 1 Reliability tests in technology verification

Test	Temperature range	Duration	DUT Mode
Rapid Change of Temperature (IEC 600068-2-14)	-40 °C…. +85 °C 30 min dwell with 10 s transition time	1000 h (977 cycles)	OFF
High Temperature Aging (IEC 600068-2-2 (110 °C))	110 °C	1000	OFF
Steady-State Temperature-Humidity (JEDEC 22-A101)	85 °C / 85 %RH	1000 h	ON (50 %) OFF (50 %)

When materials and components pass the T3 review gate, they are verified for IMSE product use. The product design is later subjected also to validation testing according to application and use case requirements. Experience has shown that passing the technology verification testing forms an excellent base for passing product validation testing [2].

B. *Excample Case of Additional Reliability Testing*

Product validation testing varies a great deal according to applications and companies. Thus, Material Stack Platforms (MSP) may be subjected also to additional reliability testing. Here we describe such a case.

The device-under-test (DUT) was Material Stack Platform (MSP) design. It included four top-emitting LEDs and a structure for measuring resin transparency. The design was a two-film structure and has transparent overmold resin. Fig. 6 shows a photo of two samples.

The additional reliability test was a change of temperature (−30 °C …. 80 °C), MSPs were powered off. Test duration was 3000 cycles. Each cycle included 0,5 h dwell times at extreme temperatures and about 6 min transition times between them. Thus, the test lasted for 150 days.

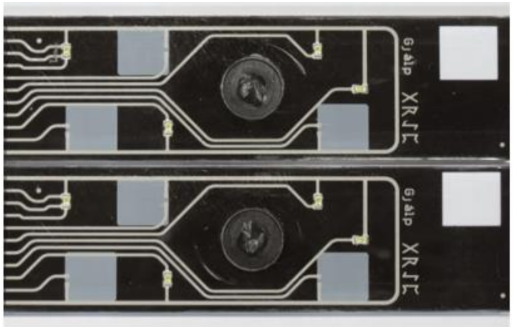

Fig. 6 Photo of Material Stack Platform samples that were tested in change of temperature test

III. RESULTS

A. *Electrical and Optical Measurements*

We performed functional testing for all the LEDs before and after thermal cycling. We did not observe any significant changes in the parameters, such as forward voltage (V_f). We also optically measured the LEDs before and after thermal cycling, LED luminance and colors had remained constant. Fig. 7 shows a comparison chart of average LED luminance before and after thermal cycling. When looking at the LEDs individually, the typical luminance change was less than ±2 %. Measurements showed also that color coordinates passed 1-step MacAdam criteria, Fig.8.

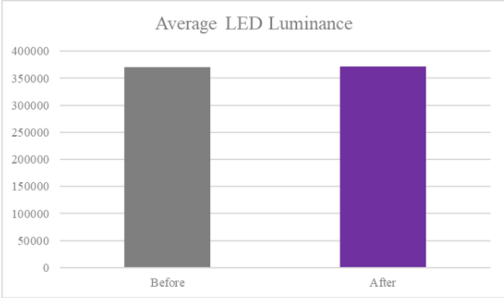

Fig. 7 Average LED luminance before and after thermal cycling

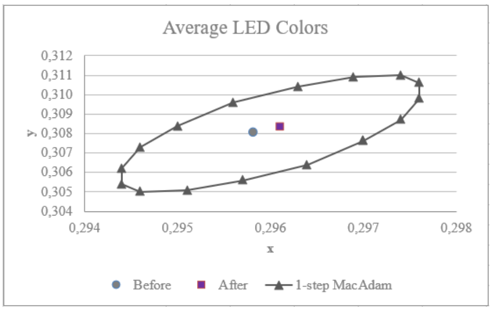

Fig 8. Average color coordinates before and after thermal cycling

B. Cross-section Analysis

We made cross-sections from some of the LEDs and analyzed those with Scanning Electron Microscope (SEM). The analysis showed that contacts between LED terminals and conductive ink were intact, Fig. 9. Thermal cycling had not caused cracks in conductive adhesive that would affect LED performance. This was in line with the electrical and optical measurements that had not seen any changes in LED performance after thermal cycling.

The cross-section showed a small gap between the LED surface and overmold. The gap is not part of the contact paths and thus has no effect on LED performance.

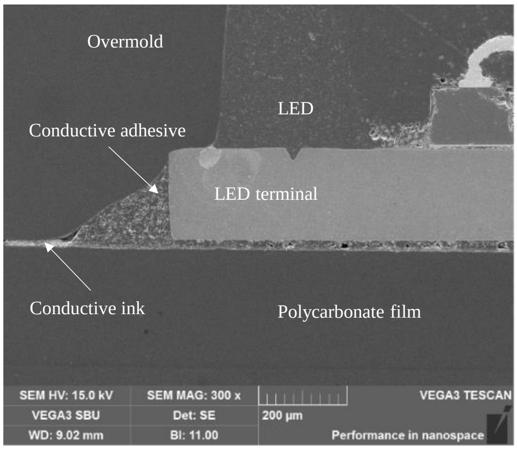

Fig. 9 Cross-section from a LED after thermal cycling

Table 2 Thermal Expansion (CTE) and Modulus of Elasticity Values for IMSE Stack Materials

Material	CTE in ppm/K	E-Mod in GPa	Comment
Polycarbonate overmold and film	65...80	2,4	These are room temperature values, and they change as a function of temperature.
LED terminal	17	115	We have used values of copper.
Conductive adhesive	150	0,2	These are room temperature values, and they change as a function of temperature.
Conductive ink	Data not available	Data not available	Thin conductive ink layers follow polycarbonate film expansion.

IV. Discussion

Change of temperature test causes thermomechanical stresses in the samples due to differences in thermal expansion of stack materials. Table 2 lists coefficient of thermal expansion (CTE) as well as modulus of elasticity values for the materials. Thermomechanical stresses can potentially cause:

- Cracks in surface mount adhesives,
- Cracks in functional or graphic inks,
- Delamination within material stack.

Cross-section of tested sample showed minor delamination at the interphase between conductive ink/adhesive and polycarbonate overmold. No delamination was detected between LED terminal and conductive adhesive. No cracking in conductive adhesive was detected, either.

Fatigue of isotropically conductive adhesives (ICA) has not been researched to the same extent as of solder. However, the research at VTT suggests that the lifetime of ICA bonds is influenced less by plastic strain than the lifetime of tin-lead solders [3]. Furthermore, overmold strengthens IMSE structures and reduces plastic strain in the conductive adhesive during temperature cycling. Overmolding protects the electric components also from environmental loads such as moisture, dust, and mechanical impacts.

V. Conclusion

We have presented an additional IMSE technology verification test case: 3000 cycles of thermal cycling (-30 ℃ …. 80 ℃). Thermal cycling did not change LED electrical or optical performance. Cross-section analysis of the thermally cycled LEDs showed that interconnections were intact. Overmolding strengthens IMSE structures and reduces plastic strain in the conductive adhesive during temperature cycling.

Acknowledgment

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References

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