Component Packages for IMSE™ (Injection Molded Structural Electronics)

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Abstract—TactoTek has developed and commercialized an advanced platform of Injection Molded Structural Electronics (IMSE). IMSE is an innovative technology and significantly different from the conventional electronics in which components are reflow soldered onto printed circuit boards. Many of the packages optimized for conventional electronics can be used with IMSE technology. However, they are not ideal. In this paper we present the ideal component package for IMSE integration. We also present the TactoTek internal component qualification process. It verifies that component packages do not lower IMSE manufacturing yield and are reliable in IMSE designs.

Keywords—IMSE, structural electronics, component packages, reliability qualification process

I. Introduction to IMSE Technology

Injection Molded Structural Electronics (IMSE) technology enables design innovation by adding electronic functions into formed plastic structures. Features, such as controls, sensors, illumination and communications, are embedded in thin 3D structures with plastic, wood and other surfaces (Fig 1).

TactoTek smart molded structures are light, thin and durable. In conventional use cases, such as an in-vehicle control panel, a single IMSE part replaces a multi-part conventional electronics structure and eliminates labor-intensive electro-mechanical assembly. The IMSE part also weighs less and is significantly thinner. TactoTek has demonstrated IMSE designs with 70% weight and 90% thickness reduction when compared with conventional multi-part assemblies (Fig 2).

Fig. 1. TactoTek IMSE is also available for natural surface finishes, such as wood veneer.

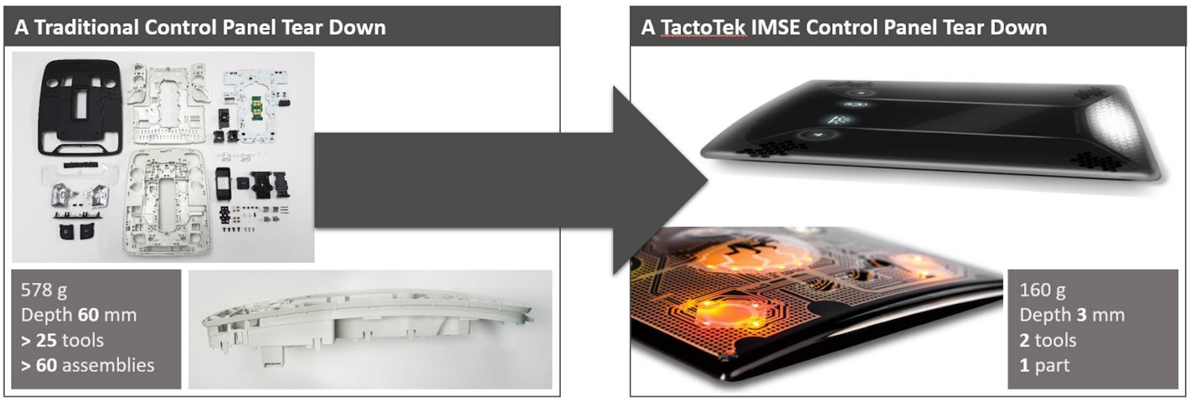

Fig. 2. TactoTek has demonstrated IMSE designs with 70% weight and 90% thickness reduction when compared with conventional multi-part assemblies [1].

II. Introduction to IMSE Manufacturing

IMSE structures are made by integrating and encapsulating printed electronics and standard electronic components within durable three-dimensional (3D) injection-molded plastics. Manufacturing processes are mature and TactoTek uses standard manufacturing equipment suitable for mass production. However, the standard processes are combined in a unique way when manufacturing IMSE. Core IMSE manufacturing processes are printing, surface mounting, forming and injection molding (Fig. 3).

Printing is the first IMSE manufacturing process. Decoration (graphic inks) and electronics (electrically conductive and dielectric inks) are printed onto plastic film or other suitable material. Electronics are typically printed using silver (Ag) conductive inks and dielectric materials to insulate between layers of circuitry. The output is In Mold Labeling (IML)/IMSE film (optionally wood veneer in some designs) with decoration/electric printing.

Surface mounting, also known as SMT, is the second IMSE process. Components are bonded, mechanically and electrically, onto electronic films. The output is 2D (two-dimensional) IMSE film with components.

Forming is the third IMSE process. Two-dimensional electric and/or graphic films are formed into three-dimensional shape and/or cut. Outputs are 3D graphic films and 3D electric films with components.

Injection molding is the fourth IMSE manufacturing process. Three-dimensional electric films and 3D graphic films are inserted into the injection mold and molded. The output is injection molded IMSE part (or structure) in which electronics are encapsulated within the molded plastic.

IMSE manufacturing often includes also Pre-Assembly and Final Assembly of control electronics. However, these processes are not IMSE-specific and thus beyond the scope of this paper.

III. IMSE Manufacturing Processes

IMSE manufacturing is significantly different from the conventional electronics where components are reflow-soldered onto printed circuit boards. Many of the component packages optimized for conventional electronics can be used with IMSE technology. However, they are not ideal. In this chapter we present how IMSE manufacturing processes affect requirements for the ideal component package. The requirements are only referenced here and are listed in the following chapter.

A. Printing

IMSE structures have printed conductors and contact pads on polymer film. Polymer film shrinkage during subsequent processes cannot be fully controlled. The printing process minimum feature sizes are also larger than in printed circuit boards. Thus, component packages do not need small pitches, please see requirement 1.

B. Surface Mounting

IMSE structures rely on conductive adhesives for component bonding instead of solder paste. Adhesive bonding has lower processing temperatures than reflow soldering. Curing temperatures remain below 150 C, which can be “good news” for the component suppliers. However, for optimal results and design flexibility, adhesive bonding causes new requirements for component contact pads. This is because conductive adhesives:

- Do not self-align. Thus, the risk of short-circuiting is higher than with solder and requirement 1 is re-enforced. However, the risk of short-circuiting can be minimized with the use of anisotropically conductive adhesives.
- Do not wet the sides of contact pad/lead. This decreases the bonding area when compared with solder. Please see requirement 2.
- Do not contain cleaning agents (fluxes). Please see requirement 3.

C. Forming

Forming is not used in conventional electronics manufacturing. TactoTek uses a high-pressure thermoforming process. 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). Thus, during forming component packages may soften or even deform. Please see requirement 4.

D. Injection Molding

Injection molding is not used in conventional electronics manufacturing, either. From the component packaging point, it is the most demanding IMSE process. This is because during injection molding, components are subjected to elevated temperatures and pressures as well as polymer flow. As the molded IMSE structure cools to room temperature, thermal expansion mismatch causes stresses to components and their interconnections.

TactoTek uses different polymer types; typical molding temperatures are listed in Table 1. Some molding temperatures are higher than peak temperature during reflow soldering. In addition, heat transfer during injection molding is through conduction. Thus, heat transfer is more efficient than during reflow soldering (through convection and radiation). Rapid temperature rise can be stressful for the components. Please see requirement 5.

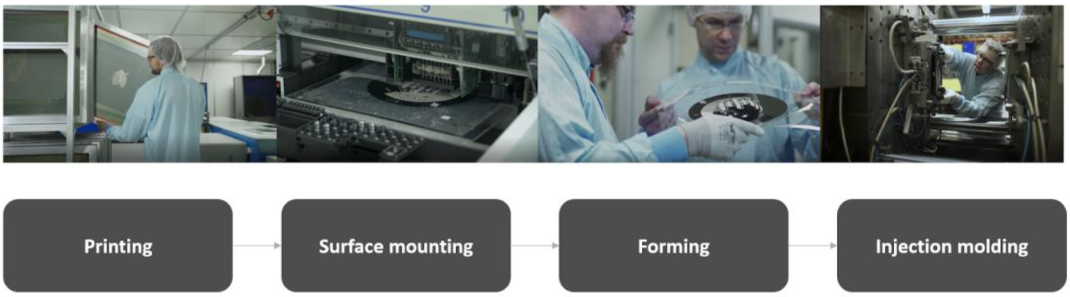

Fig. 3. Core IMSE manufacturing processes.

TABLE I. TYPICAL POLYMER TYPES USED AT TACTOTEK.

Polymer type	**Typical molding temperature**
PC (Polycarbonate)	260 - 340 C
PMMA (Poly methyl methacrylate)	240 - 280 C
TPU (Thermoplastic polyurethane)	190 - 210 C

Maximum pressures during injection molding are around 100 MPa (1000 Bar). Component packages are typically subjected to less than half of the maximum pressure. Most solids will not significantly compress at those pressures, but gases, such as air, can do so. When air inside component package compresses, the package can deform or even crack. Please see requirement 6.

Flow of viscous polymer causes shear stresses to the component. The shear stress is largest when polymer flow front hits component package. Once the flow front moves on, the components remain in the "frozen" zone of the flow and shear stresses decrease. However, the shear stress can detach a component from the film-substrate. Please see requirements 7-10.

As the molded IMSE structure cools to room temperature, thermal expansion mismatch between materials causes more stresses to components. Small component size is an advantage and reduces these stresses. In addition, good adhesion between injected polymer and component package improves interconnection reliability. Silicones in component packages are not suitable because poor adhesion to injected polymers may trap air inside IMSE structure. Please see requirements 11 and 12.

Injection molded polymers around components have limited thermal conductivity, which can raise component temperature during operation. Please see requirement 14. However, injection molded polymer also protects electrical components from harsh environmental conditions, such as mechanical impacts, moisture and dust. This is a significant benefit for many use cases, such as automotive electronics.

IV. REQUIREMENTS FOR THE IDEAL IMSE COMPONENT PACKAGE

By ideal component package we mean that it does not lower IMSE manufacturing yield, product reliability or impose significant design constraints. The requirements for the ideal component package are listed below and partly illustrated in Figure 4.

1. Minimum contact spacing is 500 μm.
2. Minimum contact area is 500 μm x 300 μm.
3. Contact surfaces are clean. For example, there are no mold release agents or oils.
4. Component package substrate is structurally strong, such as glass fiber laminate or copper/bronze baseplate.
5. No package materials are sensitive to moisture. The moisture sensitivity level (MSL) is 0 or 1.
6. Component package does not have any cavities or hollow parts. The use of porous materials, such as low-fired ceramics, is also minimized.
7. Maximum package overall height is 1.0 mm.
8. Bottom of component package is flat and has room for bonding. Structural adhesives, such as epoxies, have good adhesion to bottom of component package.
9. Package shapes are simple, such as cuboids, cylinders or domes. All corners are rounded.
10. No wire bonding is exposed.
11. Maximum package size is 16 mm^2.
12. Package material has good adhesion to injected polymer, see types in Table 1.
13. Maximum amount of contact pads is 16. (This requirement is a combination from requirements 1, 2 and 11.)

14. Component package allows use of external heat sink or printed heat spreading pads.

When we look at the current supply of components, we find ideal LED and passive components. For example, the package type 0603 for resistor/capacitor/LED is optimal for IMSE, Fig 5. However, Integrated-Circuit (IC) packages do not always fulfill our wish list. Fortunately, IC package types Land-Grid-Arrays (LGA) and sparse Quad-Flat-No-Lead (QFN) are well suited. Also, some Chip-Scale-Packages (CSP) with few contacts are well applicable. Please see Figs 5-8.

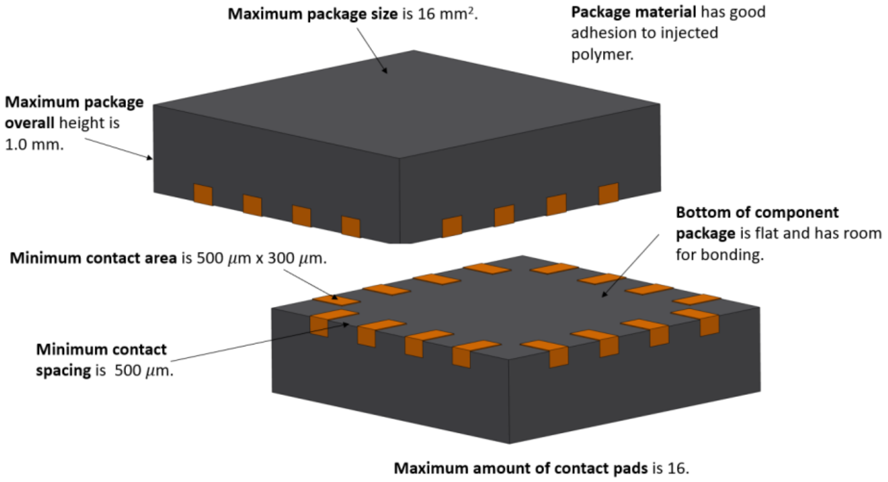

Fig. 4. Requirements for ideal component package.

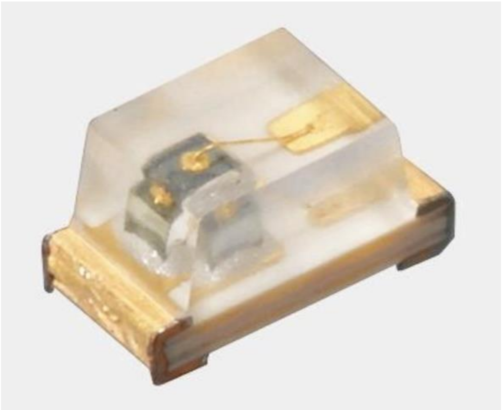

Fig. 5. The package type 0603 for resistor/capacitor/LED is well suited for IMSE technology [2].

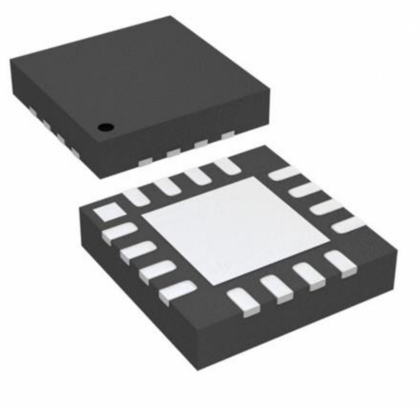

Fig. 7. Quad-Flat-No-Lead (QFN) package is well suited for IMSE technology [4].

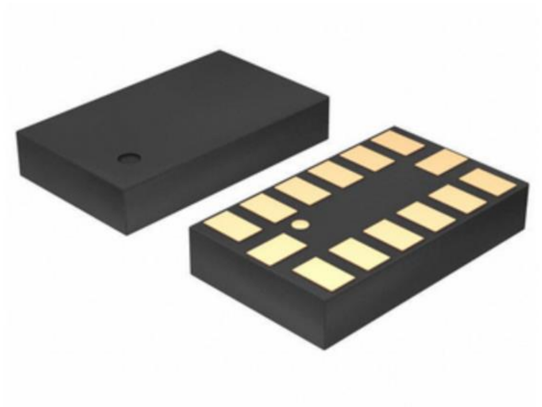

Fig. 6. Land-Grid-Array (LGA) package is well suited for IMSE technology [3].

Fig. 8. Chip-Scale-Package with few contacts is well suited for IMSE technology [5].

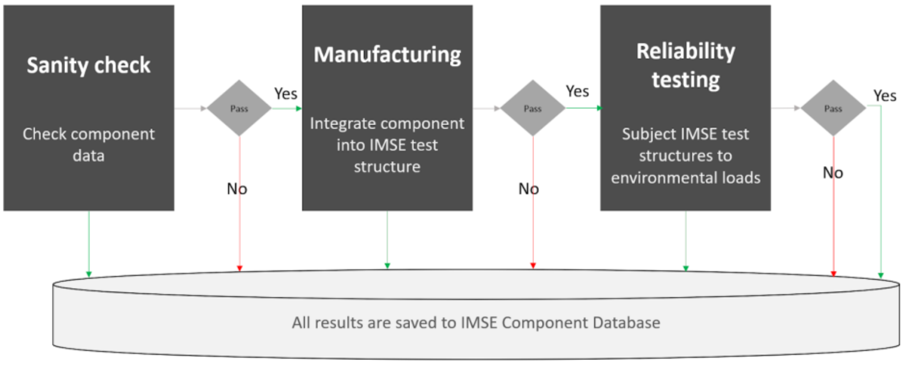

Fig. 9. Component qualification process flow.

V. TactoTek Internal Component Qualification Process

Currently most electronic components are optimized for conventional electronics manufacturing. Thus, TactoTek qualifies all electronic components that are embedded within its IMSE solutions, i.e., inside injection molded polymers. Qualification has three steps (Fig. 9).

The sanity check is a pre-screening phase, in which component data is compared with ideal IMSE package. The component package does not need to fulfill all requirements to pass this step. However, there are some items that cause qualification failure. Examples are:

- Component geometry is too complex. For example, package has cavities or hollowed-out parts.
- Package overall height is 1.2 mm or more.
- Package Moisture Sensitivity Level (MSL) is 4 or higher.

If a component passes the sanity check, TactoTek manufactures IMSE test structures. TactoTek has developed internal standards for qualification layout and material stack. Components undergo surface mounting, forming and injection molding and they are tested after each process step. The testing system is also standardized.

If the manufacturing yield is sufficient, IMSE test structures are subjected to reliability testing. Typical environmental loads are thermal shock and damp heat. Examples of tests are IEC 60068-2-14, Change of temperature, for 1000 hours as well as JEDEC JESD22-A101, Highly accelerated temperature and humidity, for 1000 hours. Based on testing results and physical failure analysis, components can be qualified for IMSE.

To date, approximately 40 percent of the tested components have failed qualification in manufacturing or reliability testing phase. Typical reasons for failure include:

- Component geometry does not allow sufficient bonding. Thus, shear stress during injection molding has detached component.
- Elevated pressure during injection molding has deformed or cracked component.
- Reliability testing has caused cracks and fractures in components or surrounding injection molded resin.

VI. Market Prospects for IMSE Technology

Industry analysts forecast that IMSE markets and use cases will expand significantly in the coming years, Fig. 10. When component suppliers develop packages that are well suited also for IMSE, they too can benefit from this growth.

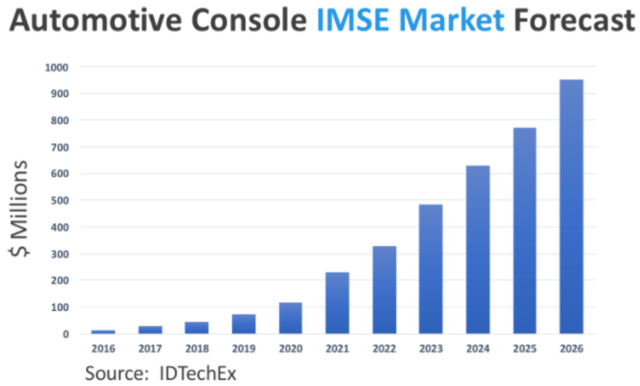

Fig. 10. IdTechEx forecast for the automotive console IMSE market [6].

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