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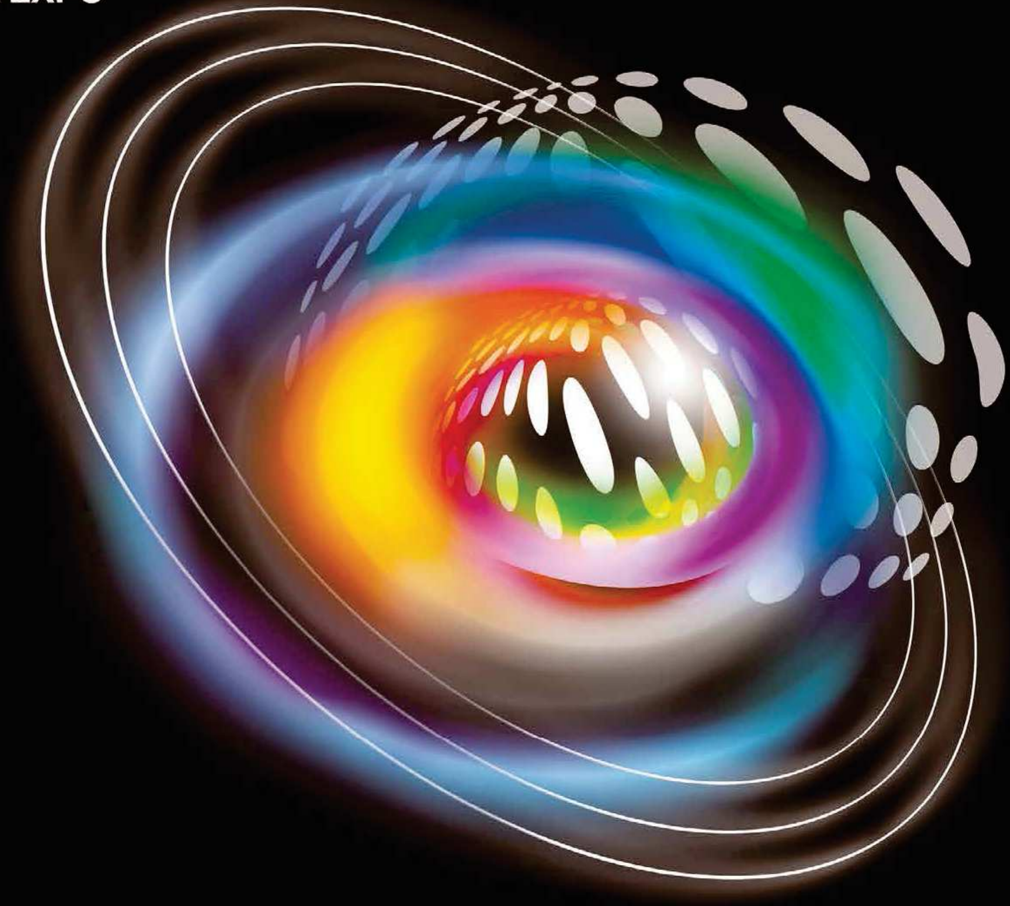

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Customized LED and Optical Device Packaging

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Abstract

The traditional semiconductor industry provides packaging solutions using transfer moulding that are suitable for high volume and low cost and can be customized to fulfil many of the unique requirements of LEDs and optical devices. Advanced Packaging Center BV (APC) has developed dedicated technologies (Film Assisted Moulding and Dynamic Insert Technology) that expand the capability of transfer moulding technology to encapsulate optical devices in black, white or clear compound materials and keep designated areas of the device free of any compound to facilitate sensing or emitting elements. Many different substrates can be used and additional functionality can be added into the package such as lens structures. This paper explains the technology and shows several examples. At the same time two interesting new die-attach technologies are discussed (Silver-sintering and ultrasonic soldering) that offer capabilities with superior thermal conductivity. Both technologies offer interesting advantaged over traditional die-attach technologies, depending on the specific applications.

Introduction

Transfer moulding has been the primary process method for microelectronic encapsulation using epoxy moulding compound (EMC). The technology can easily be industrialized to meet high volume - low cost requirements. Tradition transfer moulding has disadvantages such as EMC bleed and resin flash, time consuming mould cleaning, mould wear, package deformation during the ejection process and lead frame deformation or (ceramic) substrate cracking due to clamping. Film Assisted Moulding (FAM) deals with these challenges of releasing the compound from the mould and keeping certain surfaces (“windows”) clean from moulding compound. These windows can facilitate emitting or sensing areas of an optical chip. Additionally a Dynamic Insert Technology (DIT) has been developed to further optimize the performance of FAM to automatically and dynamically control pressure on one or multiple surfaces while adjusting for height differences and tilt (compensating most of the tolerances). Figure 1 shows a schematic representation of the application of FAM and DIT in transfer moulding. A more detailed description of FAM and DIT can be found in Bos et al [1]. These technologies enable the use of many different compound materials (epoxy, silicone) that can be applied in different versions (black, white, clear and combinations thereof). The base materials can also be solid or fluid. Combined with the ability to use different die-carrier materials such as lead-frames and different substrates (ceramic, metal, FR4, wafer-level) and the option to design exposed open windows in the package (eg to facilitate sensing or emitting areas), a large variety of packages can be designed to meet the needs of different applications, including optical applications.

Packaging Solutions for Optical Applications

Recent developments in solid state lighting, communication technology, (medical) sensor technology and others require optical packaging solutions that

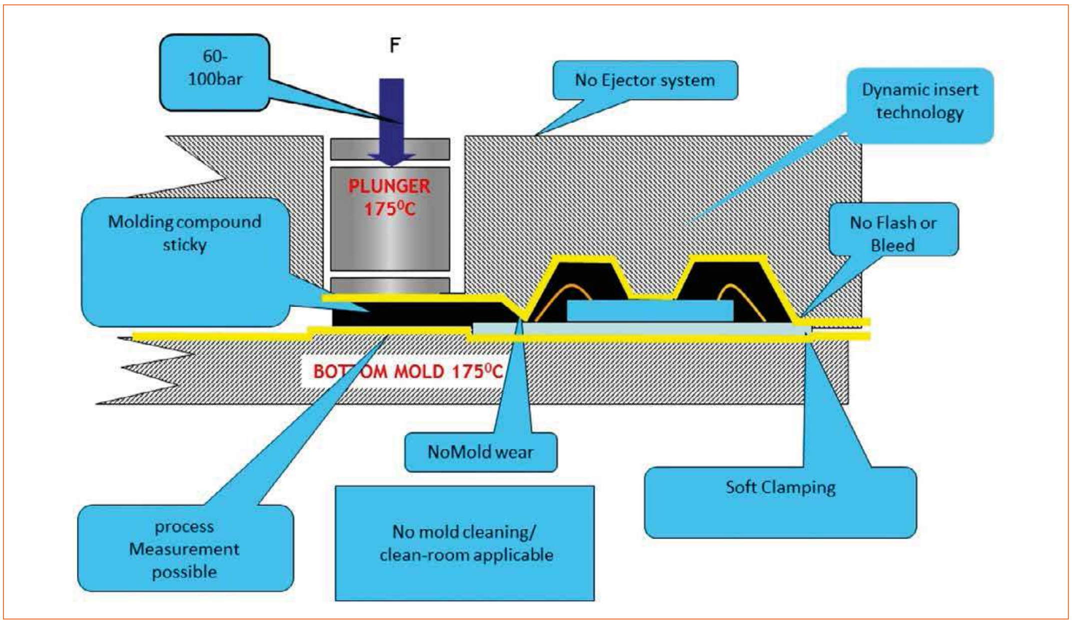

Figure 1: Schematic overview of the application of Film Assisted Moulding (FAM) Technology and Dynamic Insert Technology in transfer moulding. For further reference see text

meet both the electrical and optical requirements and allow for high volume production at reasonable costs. Typical products may contain in addition to one or more optical components (laser, LEDs, detectors) several electrical components (ASICs, drivers, passives). Optical requirements may include total encapsulation (environmental ruggedness) but with defined optical transparency. In other cases the optical components should be fully exposed to the environment (exposed window). Also some optical interfacing to the environment might me desirable (connections to optical fibres, lenses for enhanced field of view). Electrical requirements may include the number of IOs, (high) voltage ruggedness, Mechanical requirement may include a defined package layout (e.g. QFN, SO, DFN, BGA, LGA or customized) a defined operational temperature range and mechanical ruggedness. Design need to meet different standards, such as automotive or industrial. All these combinations are well within range of the technology presented.

Different compound materials

Transfer moulding using FAM/DIT allows for many different compound materials and even combinations of different materials. Epoxy based and silicones are most widely used and come in black, white and transparent. Traditionally for microelectronic encapsulation a black compound is used. Black compound consists of an epoxy resin filled with a possible variety of materials (graphite, metal oxides, glass, silicon oxides, etc) that create the color and a matching coefficient of thermal expansion (CTE) to semiconductor materials. The color black is preferred because various electronic components are sensitive to light. Similarly white compound can be used. White compound consists of a similar epoxy resin containing fillers such as TiO_2. These materials can be used to enhance reflectivity of a package or influence the direction of emission patterns of optical sources. An epoxy resin without fillers can be used as transparent compound. These materials can be used to encapsulate optical components while maintaining optical

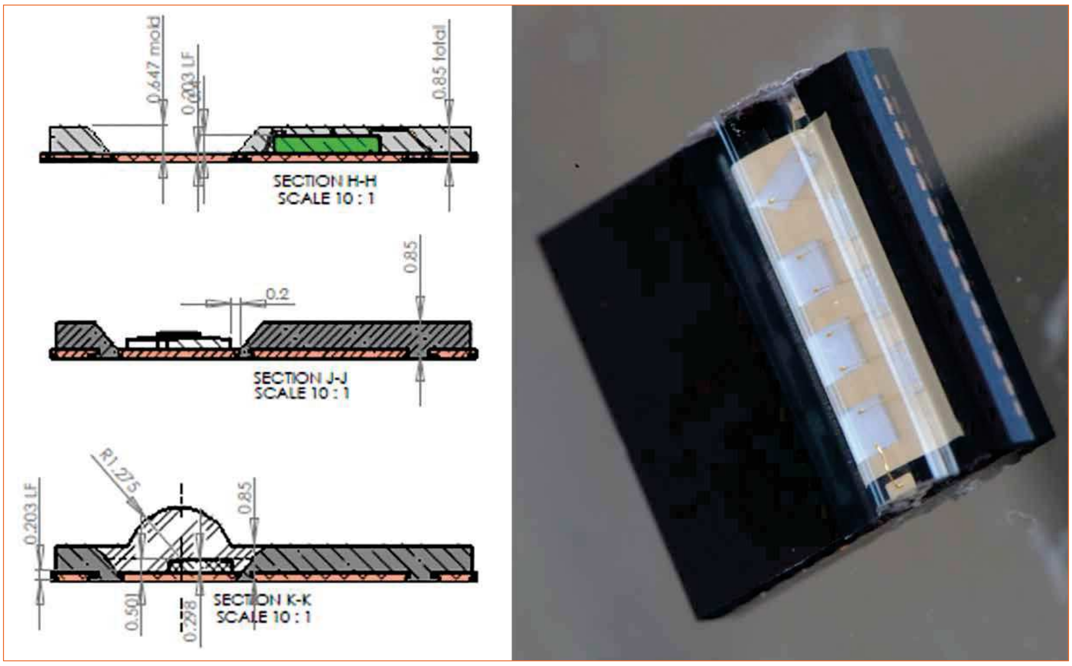

Figure 2: An LED system design using a black epoxy to encapsulate an ASIC (green) and wire bonds and a transparent silicone compound with incorporated lens shape

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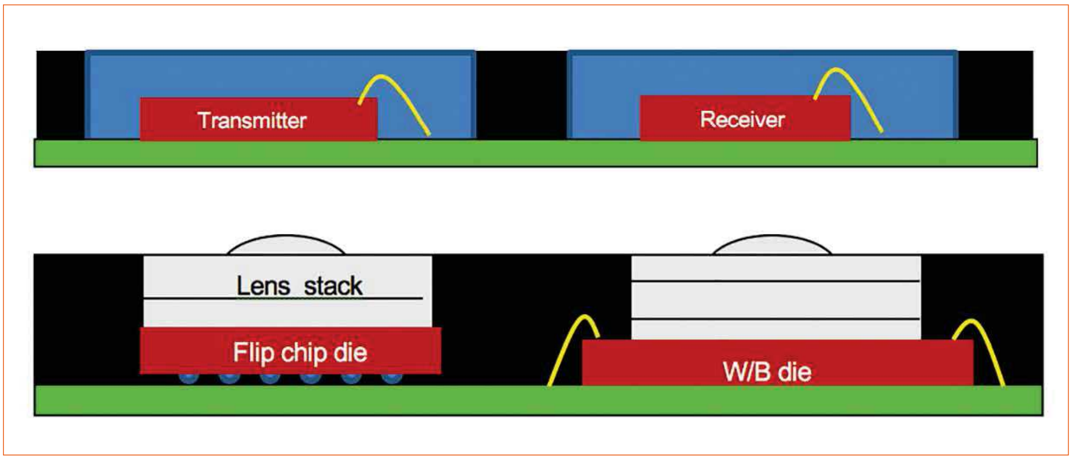

Figure 3: Schematic design examples showing (left) the combination of a black and transparent compound where the black compound serves as a block for optical cross-talk and (right) the combination of a flip-chip die or wire bonded die with the combination of a black and transparent epoxy and a lens stack

transparency. However, epoxy resins have usually a large CTE mismatch compared to semiconductor materials, which requires sufficient attention in the design phase to avoid thermo-mechanical stress. An alternative to epoxy resin can be silicone compound, it has some interesting properties. It is a much softer material than epoxy resin, leading to much less thermos-mechanical stress. It is much less susceptible to optical (UV) degradation, making it ideal for applications with long life-time requirements and high radiation levels (e.g. Concentrated Photo Voltaic). However, because the materials is soft, it can be hard to saw, which can be difficult for high-volume production.

Silicon compound is a fluid base material which makes it difficult to use and absolute requires double-film based moulding (FAM). Figure 2 shows as an example an LED system design using a black epoxy to encapsulate an ASIC with wire bonds and a transparent silicone compound. Figure 3 shows two schematic design examples with (above) the combination of a black and transparent compound where the black compound serves as a block for optical cross-talk and (below) a flip-chip die or wire bonded die with the combination of a black and transparent epoxy and a lens stack. Figure 4 shows a design of a solar detector (CPV) in a white compound.

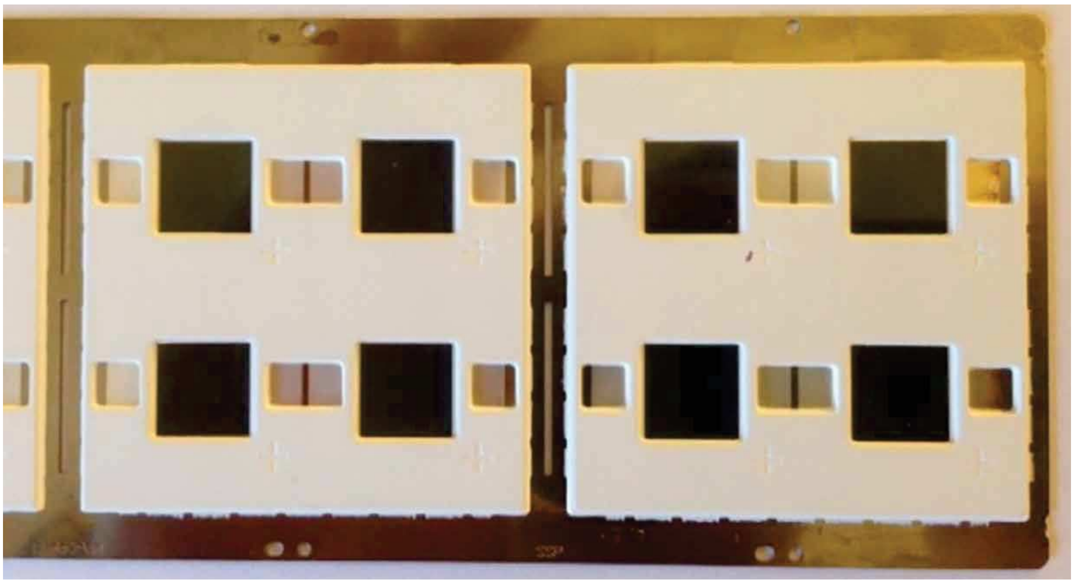

Figure 4: An example showing a solar collector (Concentrated Photo Voltaic) in a white compound

Different substrates and package layouts

Transfer moulding is a flexible technology which allows for many different substrates to be used. The traditional lead-frame technology has many advantages, it is a well-known technology, has good adhesion properties to compound materials, it is cost effective in mass production and allows many different technologies for die-attach (gluing, soldering, welding, sintering etc). Alternatively also different substrate materials can be used: metal, ceramic, flex-foils, FR4 or wafer-level. FR4 materials (or similar) can be tricky: at elevated temperatures they can outgas leading to decreasing adhesion. The use of double-film based moulding (FAM) enables large areas of substrates to be free of compound which can be advantages for secondary level packaging or thermal constrains. Wafer-level moulding has attracted significant interest over the last couple of years. Combined with the affordable use of Through Wafer Via technology in the front-end semiconductor design, wafer-level moulding allows for very cost efficient package designs.

All compound and substrate materials can be combined in a range of standard or customized package layouts. This includes package layouts such as DIP, QFP, QFN, DFN, SOP, BGA, PGA and more. Leaded packages such as DIP and SOP are often used in automotive application because of their proven reliability. However, based on their cost efficiency leadless packages such as QFN are increasingly used not only in automotive but also in avionics and other demanding industrial areas. In addition to these standard packages, both customized versions of these standards package layouts as well as fully customized packages are easily feasible. Figure 5 shows an example of a lead frame based design of an automotive transceiver with alignment bumps to facilitate e.g. the in coupling of light into optical fibres. Figure 6 shows an example of a device using a wafer-level substrate.

New Die-Attach Technologies.

Numerous die-attach technologies are available that can be combined with transfer moulding, including epoxy,

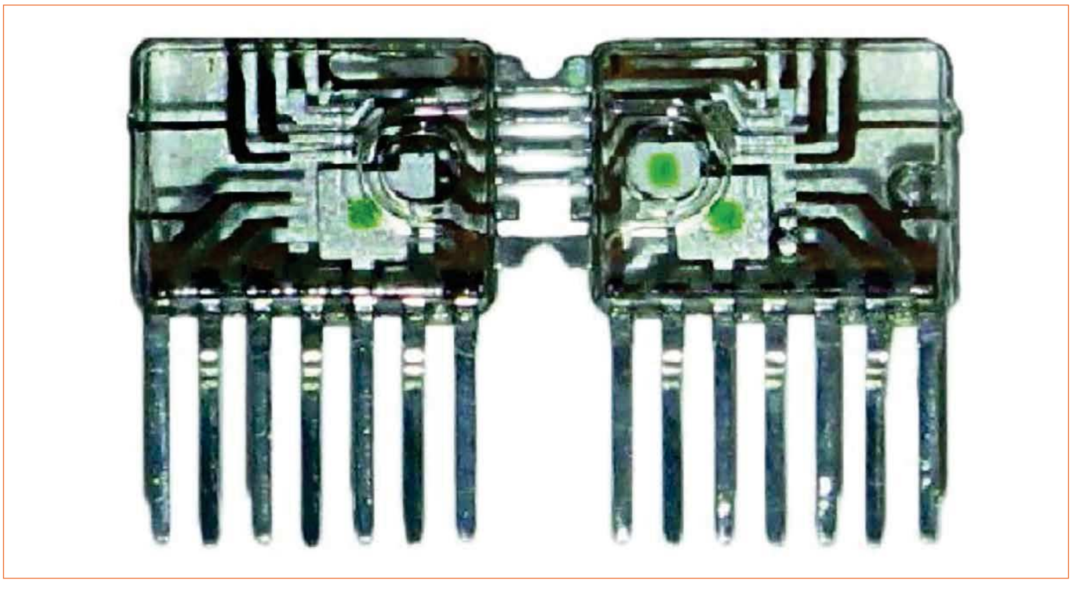

Figure 5: A lead-frame bases design for an automotive optical trans-ceiver. The device is fully encap-sulated in clear compound with integrated align-ment bumps to facilitate the in-coupling of light into an optical (plastic) fibre

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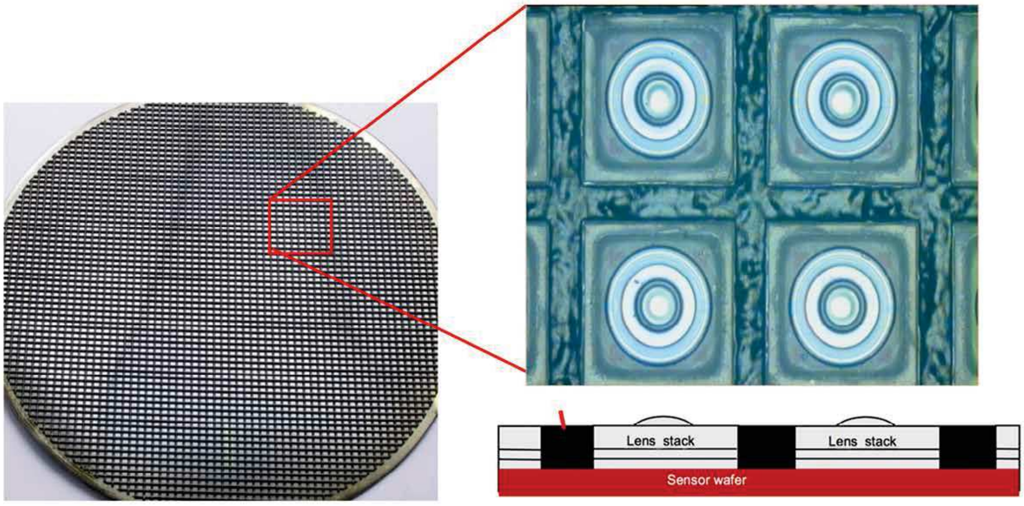
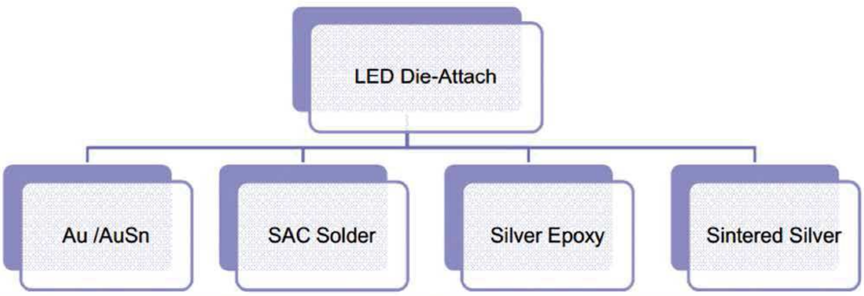


Figure 6: An example of a device on a wafer-level substrate. After moulding (combination of compounds) the individual devices can be sawn from the wafer

eutectic and soft-solder. However, recently two new technologies have become available that are of particular interest in demanding thermal applications (high power or high power-density): Silver (Ag) sintering and ultrasonic soldering. Ag-sintering is a new die-attach and bonding technology offering a void-free, strong bond, superior thermal (> 200 W/mK) and electrical conductivity resulting in high yield and increase the output of your device and increase lifetime at the same time. The sinter process takes place at 200-250 °C, but the resulting bond does not melt until 962 °C (melting point of silver). This allows for many subsequent reflow processes. A relative comparison of different (LED) die-attach technologies is shown in figure 7. See also Dutt [2]. Research in Ag-sinter materials has been ongoing for several decades and over the last 2-3 years the technology has been industrialized. It is rapidly being adapted by e.g. suppliers of automotive power electronics (for electrical cars), but has also great potential for automotive LED head-lighting, LED street lighting, high power lasers and more. Ag-sintering requires all surfaces to be metallized with preferbly either silver or gold. This limits the application area somewhat.



	Au /AuSn	SAC Solder	Silver Epoxy	Sintered Silver
Second Reflow Possible	Yes	No	Yes	Yes
Thermal performance	Medium-High	Medium	Low-Medium	High
Cost of Ownership	High	Low	Medium	Medium-High

Figure 7: Relative comparison of different die-attach technologies suitable for LED applications. Courtesy of Gyan Dutt, ALPHA, LED A.R.T Conference, Nov 17-19 2015, Atlanta USA

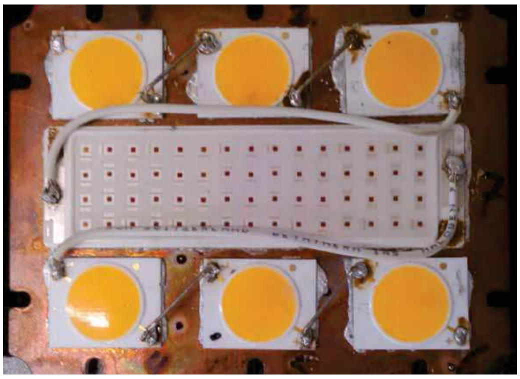
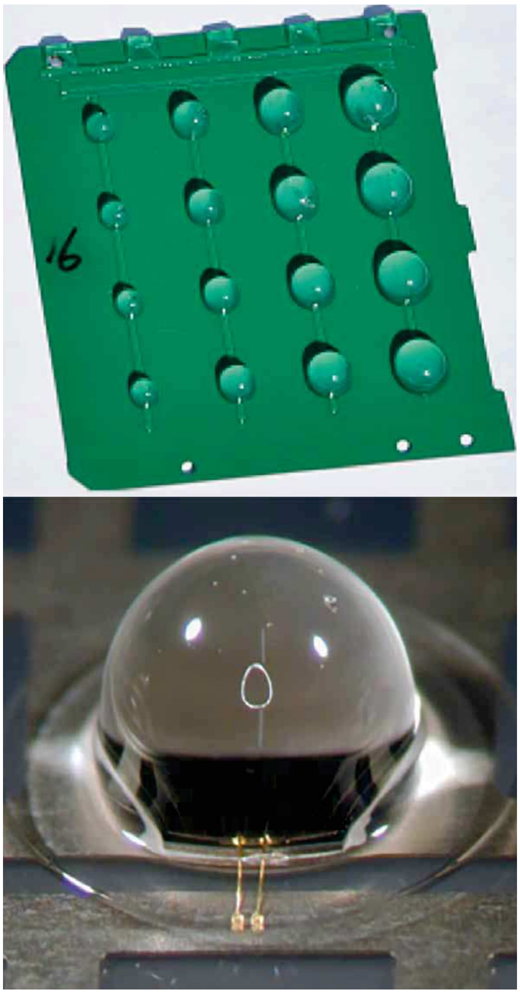


Figure 8: Prototype LED module where ultrasonic soldering is used to bond a ceramic Chip-on-Board directly to copper. The final product should be over-moulded with white compound and exposed windows for the LEDs. Courtesy of Wim van Vliet, NGES Next Generation Energy Solutions BV and Ino J. Rass, Euromat GmbH

Recent developments in ultrasonic soldering, especially in the formulation of new advanced solder materials, have created very intersting opportunties to solder many different materials (metals, ceramics, glasses), in a large temperature range (140 ˚C up to 450 ˚C) without the use of any flux or additional metallization. See Rass [3]. In figure 8 a prototype LED module is shown where an un-metalized ceramic Chip-on-Board (COB) device was soldered to a copper substrate without the use of any flux at 150 ˚C. The lack of metalization on the back-side of the COB limits traditional die-attach technologies to e.g. (silver) epoxy at temperatures below 150 ˚C (max case tempereture for these kind of devices). These new ultrasonic soldering materials have a thermal conductivity (50-100 W/mK) that outperform these epoxys. They are already being used in several industrial and power-electronics cooling and are now being tested for applciatons in optical (semiconductor) pacakging. Initial results are looking very promising.

Added functionality in the package

Packaging is traditionally solely used to protect the internal device from external influences, such as impact and corrosion, holds the leads or connections in place and transfers the heat from the interior to the environment. Transfer moulding using FAM and DIT provides the opportunity to create additional functionality. In clear compound lens shapes can be created to enlarge the field of view of e.g. detectors or create structures ("alignment bumps") to facilitate e.g. the in coupling of light into optical fibres. The absorption spectra of different (transparent) compound materials vary, allowing the ability to design "optical filters" for over-moulded devices. Mixing a defined concentration of TiO_2 particles into a clear compound also creates the opportunity to design diffusive filters for over-moulded devices. Finally, channels can be created in the package (micro-fluidic) that can be used in combination with optical devices. Figure 9 shows different design studies to create lenses in packages.



Figures 9: Different design studies to create lens structures in packages. The smallest diameter that can be achieved is well below 1 mm

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Limitations

Unfortunately transfer moulding cannot address all possible requirements for LED - and optical device applications. The hermeticity that can be achieved using moulding compounds is limited to approximately Moisture Sensitivity Level three (MSL 3). Stricter requirements for hermetic packages require other materials such as metal packages. Also encapsulation of pig-tailed devices (using SM or MM glass fibres) is not possible on industrial scale. Although it might in theory be possible to industrialize the process of pig-tailing followed by encapsulation by transfer moulding, it is very hard to overcome the necessary investments and justify the business case. Finally some medical (optical) applications that expose packages to in-vivo situations require biocompatibility that can also not always be met with existing compounds.

Conclusions

Transfer moulding has been the primary process method for microelectronic encapsulation and allows for high-volume and low-cost industrialization solutions. In this paper an overview is given on several different package solutions that can be created for LEDs and optical devices using traditional transfer moulding The transfer moulding technology from Advanced Packaging Center BV has been augmented with Film Assisted Moulding (FAM) and Dynamic Insert Technology (DIT), which further expands the range of design solutions. An important feature of FAM is the ability to keep certain surfaces ("windows") clean from moulding compound. These windows can facilitate emitting or sensing areas of an optical chip. Several design solutions are discussed and examples are given, including the use of different and combinations of moulding compounds (black, white, transparent in both epoxies and silicones) and different substrates (lead frames, substrates such as metals, ceramics, FR4 and wafer-level). These materials can be combined in standard packages (industry standards), variations thereof and complete customized packages. Features such as lens-shapes can be included in the package design which gives the package additional functionality such as enlarging the field-of-view of e.g. detectors or enabling the in-coupling of light into an optical fibre. Two new developments in die-attach technologies are discussed, offering interesting opportunities for high-power or high-power-density applications:
Silver (Ag)-sintering and ultrasonic soldering. Some limitations of the transfer moulding technology are discussed.

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