MASTERBOND®
CASE STUDY

Biocompatible Epoxies for Medical Device Manufacturing

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Microelectronics devices composed of integrated circuits are complex and pose many engineering challenges. A careful design must be employed to allow heat to be dissipated from the device and mitigate thermally induced stresses. Adhesive encapsulants have been developed to seal and protect the sensitive electrical components and connections from contaminants and assist with thermal management. Encapsulants provide mechanical support, distribute stresses, and protect sensitive connections from mechanical shock. Typically, encapsulants with ceramic fillers provide enhanced thermal conductivity and improve the heat transfer and heat dissipation properties of the design, while a reduction in the thermal coefficient of expansion of the encapsulant mitigates stresses from thermal mismatch. Depending on application demands, encapsulant adhesives can be formulated for a wide range of viscosities and provide various thermal, mechanical and environmental resistance properties. Products may be engineered for application specific approvals like ISO 10993-5 and USP Class VI for use in medical devices, NASA low outgassing requirements, and cryogenic serviceability.

Uses and Thermal Properties of Encapsulants for Chip-on-Board Assemblies

In microelectronics, methods are used to form the electrical connection between an integrated circuit chip, also called a die, and the substrate. The methods of wire-bonding and flip-chip are predominantly used today. (1) An adhesive encapsulant is commonly used in these assemblies to protect the integrity of the electrical connections. The potential for thermal mismatch can be assessed by evaluating the coefficient of thermal expansion (CTE) of the materials used in the assembly. CTE may be conveniently measured as ppm/°C. Of relevance are the CTE of silicon used in the die (2.6-3.0 ppm/°C), solder (21.5-24.6 ppm/°C), and the substrate itself. A widely used organic substrate such as FR-4 exhibits a CTE of 14-17 ppm/°C. As different materials thermally expand at different rates, stresses can accumulate. Even small differences in CTE can result in premature device failure during temperature excursions. Encapsulants and underfill provide a means to mitigate thermal mismatch by distributing stresses across the coupled area and thereby minimizing the magnitude of stresses at critical solder joints. The CTE of the encapsulant itself can be optimized depending on the design requirements. Encapsulants must be electrically non-conductive and provide strong adhesion to the substrates. For demanding applications, a low CTE and moderate thermal conductivity aid in thermal management.

The function of the adhesive encapsulant can be visualized in Figure 1 for a wire bonded assembly. The die is physically bonded to the substrate often with a suitable die adhesive; the connections between the die contact pads and the underlying board circuitry is then made through the wire bonding process. This particular case sees the use of a dam to contain the uncured encapsulant adhesive prior to final cure. From this diagram it can be seen that the encapsulant effectively seals the chip and protects the fragile wire bonded connections between the chip and the board substrate. The encapsulant utilizes physical mass to seal and mechanically secure the assembly while distributing any mechanical stresses resulting from thermal mismatch of the components.

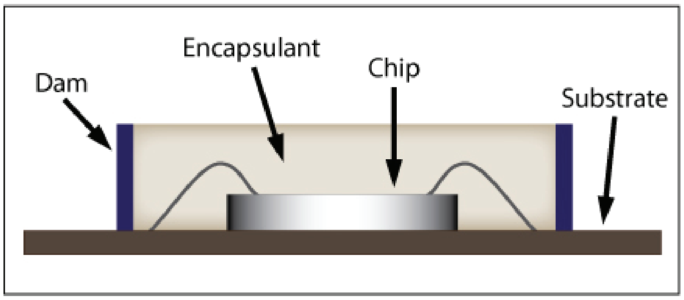

Figure 1. Wire Bonded Assembly with Glob Top Epoxy Encapsulant, Dam and Fill (2)

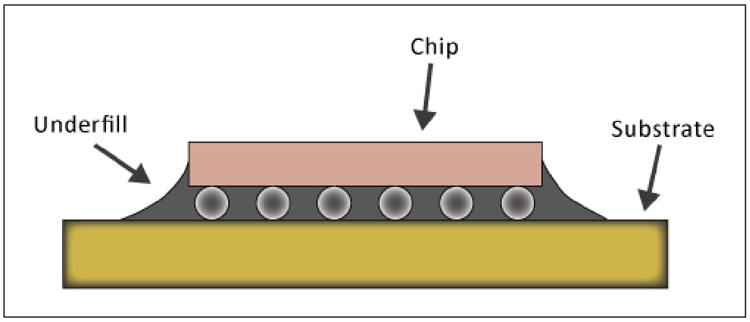

Figure 2. Flip Chip Assembly with Underfill (1)

Flip-chip assemblies offer many advantages over wire-bonding including higher interconnect density and speed improvements owing to the shorter interconnect lengths. Other benefits include smaller size, greater ruggedness, and lower cost when manufactured at high volume. An example of a flip-chip assembly is shown in Figure 2—in this fabrication method the chip is flipped or inverted with its solder balls facing the contacts of the substrate; thereafter, the solder is remelted to form the electrical connection. The gap present beneath the chip is then underfilled with adhesive encapsulant often through capillary action. For these applications, a viscosity less than that used in encapsulation of wire-bonded assemblies is necessary to enable a fast flow-rate and prevent entrapment of air. The stiffness or modulus of the underfill must be optimized; too low a modulus may result in excess strain at the solder joint while too high a modulus may overly redistribute stresses to the chip and result in cracking. (3)

As with many organic materials, an unfilled epoxy has a high CTE of 66-72 ppm/°C, but it can be reduced by compounding with fillers such as aluminum oxide (8.1 ppm/°C) or silica (0.5 ppm/°C). Addition of either filler increases modulus with silica providing a more potent affect. Due to its higher thermal conductivity, 35 W/m-K for Al_2O_3 versus 0.363 W/m-K of epoxy, Al_2O_3 filler increases the thermal conductivity of the composite while maintaining a suitable degree of electrical non-conductance. (4) Aluminum oxide is then preferred for applications requiring greater thermal conductivity, while silica is preferred if higher modulus is required at reduced filler loading. For epoxy filled with Al_2O_3, above a threshold volume fraction, thermally conductive paths form between the filler particles leading to an abrupt increase in thermal conductivity. This is similar to the percolation threshold that is observed in electrically conductive adhesive systems loaded with electrically conductive particles. The particle size of the filler also impacts the loading response of the composite; at a fixed volume fraction, smaller particles of silica result in a greater decrease in CTE for an epoxy-silica composite. (5) The mechanism of this can be attributed to the greater interfacial surface area that comes with a decreased particle size at constant loading. As particle size decreases, the interfacial area between the high CTE epoxy matrix and the low CTE filler increases resulting in a greater restriction of the epoxy and less thermally induced expansion of the bulk composite. (6) Overall, optimization with respect to particle size and desired viscosity is necessary as viscosity generally increases with decreased particle size due to similar reasoning with regard to interfacial area and friction forces in the uncured resin. The aspect ratio or shape factor of the filler particles influences the degree of CTE isotropy; spherical particles generally result in an isotropic thermal expansion, whereas fiber or disc-like particles, especially when aligned in the matrix, result in anisotropic expansion properties. (7) For flip-chip underfill, maximum particle size is restricted by the gap size between the chip and substrate, the maximum particle size must be selected, often below 1/3 of the gap size, to prevent impeded flow during the underfill process. (1)

Master Bond EP42HT-4AOMed Black

Master Bond EP42HT-4AOMed Black is a two-component ceramic-filled epoxy adhesive, sealant, coating, and casting system. The objective for this product was to improve upon a previous legacy system, EP42HT-2Med, by including a carefully selected filler package at appropriate loading to reduce the CTE while maintaining ISO 10993-5 and USP Class VI compliance for use in medical device applications. This product has exceptional thermal and chemical resistance properties standing up to repeated autoclaving, radiation, and chemical sterilants. Figure 3 demonstrates an almost four-fold improvement in weight loss when subjected to 100 autoclave cycles when compared with a standard, two-component ambient cure epoxy. Filled with aluminum oxide, this product has increased thermal conductivity (>1 W/m-K) and lower CTE (18-21 ppm/°C) than an unfilled epoxy while maintaining electrically non-conductive properties (volume resistivity: >1014 ohm-cm). The addition of filler provides enhanced dimensional stability, very low cure-induced shrinkage, and high modulus. The wide service temperature range of 4K to +400°F [4K to +204°C] is an additional benefit of the product. When bonding surfaces are appropriately prepared, EP42HT-4AOMED Black bonds well to a wide variety of substrates including metals, composites, glass, ceramics, rubber, and plastics. For ease of use, the product employs a forgiving 100:40 by weight mix ratio, and it readily cures at ambient temperature or more rapidly at elevated temperatures. The optimum cure schedule is overnight at ambient temperature (75°F / 24°C) followed by 2-3 hours at 150-200°F [66-93°C]. The working life or open-time after mixing is 75-120 minutes allowing for flexibility on the production line.

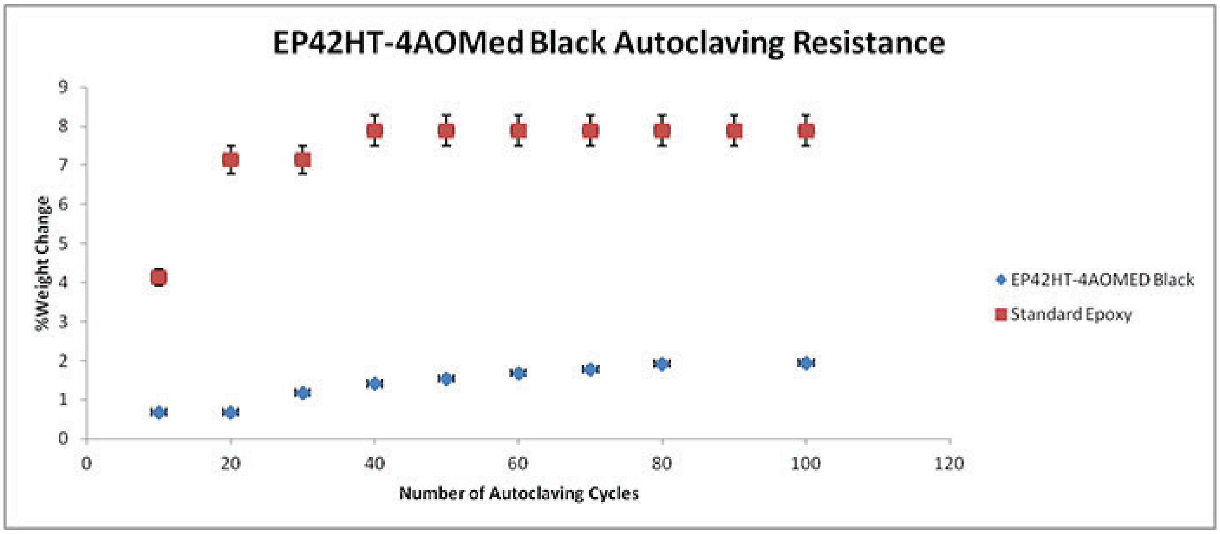

Figure 3. Resistance to repeated autoclave cycles measured by percent weight loss for EP42HT-4OMed Black versus standard two-component, ambient cure epoxy.

Application Example:
Implantable neural probe with bond-wires sealed via biocompatible epoxy encapsulant

In this application, Raducanu et al.(8) constructed an implantable, active neural probe capable of performing in-vivo neuroscientific studies on laboratory animals. The etch process used to form the electrodes on the chip's implantable shank was optimized to provide a high degree of smoothness to avoid damage to the animal's neural tissue. The high uniformity and electrode density of the recording sites coupled with the small electrode size allowed the researchers to capture the signal from individual neurons with high spatial resolution. The chip's probe shank, 8 mm in length, 100 μm in width, and 50 μm in thickness contained a 4 x 336 array of 20 x 20 μm electrodes with 12 larger reference electrodes measuring 20 x 80 μm to provide improved recording quality.

Implantable devices such as these face limitations with regard to power dissipation—heat dissipated from the device into the animal's neural tissue should be kept at or below 1°C for long-term studies. To mitigate these constraints, auxillary circuitry was moved off-chip to a small, lightweight printed circuit board (PCB) headstage unit weighing 1.25 grams. The headstage unit was then connected via a flexible and lightweight cable to a back-end field programmable gate array enabling data capture while allowing the animal to easily move about during experiments. Connections from the chip probe were wire-bonded to a small, thin PCB that was then connected to the headstage. The bond wires were finally protected and sealed with Master Bond EP42HT-2Med a biocompatible epoxy used as an encapsulant for wire-bonded chip-on-board applications requiring ISO 10993-5 or USP Class VI compliance. Master Bond EP42HT-2Med is a legacy version of EP42HT-4AOMed Black; the latter product having been formulated with aluminum oxide to further improve the CTE and thermal conductivity while maintaining biocompatibility and not compromising on sterilization resistance.

Summary

Master Bond EP42HT-4AOMed Black and the legacy product EP42HT-2Med are biocompatible two-part epoxy adhesive systems for use as encapsulants in wire-bonded, chip-on-board microelectronic assemblies. Master Bond products are formulated to provide the desired thermal, electrical and mechanical properties needed to protect sensitive wire-bonded chip-on-board assemblies from moisture, dust and other contaminants while providing mechanical and thermal support to assure reliable, long-term performance. In addition to these products, Master Bond offers a full line of products for the electronics industry including those with properties and viscosities optimized for capillary underfill, conformal coatings, die attachment and more.

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