
PLASTIC-ENCAPSULATED MICROELECTRONICS

Materials, Processes, Quality, Reliability, and Applications

Edited by

**Michael G. Pecht
Luu T. Nguyen
Edward B. Hakim**



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formed into various shapes, including dual in-line, gull-wing, or J-leads. Details of these processes are presented in Sections 3.6, 3.7, and 3.8.

3.2 DIE ATTACHMENT

The integrated circuit diced from the wafer is attached to the center pad of the leadframe, called the die-attach pad or die-paddle, with a soft solder, a gold-silicon eutectic, or, most commonly, a polymer adhesive. The common polymer adhesives are epoxy and polyimide, often filled with silver or alumina to make them more thermally conductive.

The physical process of transferring dies to the die pad requires a collet or a surface pickup tool at the end of the transfer arm that picks up the die and deposits it precisely on the die pad. The collet is typically metal and machined to the exact die size. The surface pickup tool is often of rubber, teflon, or delrin, and may be used over a range of die sizes. It is predominantly used for applying dies to polymer or silver-loaded, glass-resin, die-attachment materials; the collet is used only for high-temperature, eutectic, die-attachment applications. Soft-solder die-attachment may use either collets or surface pickup tools, but latter will require special high-temperature materials (good up to processing temperatures of about 340°C). Otherwise, contamination of the die surface may result from the breakdown of the pickup tool surface, causing package delamination at the die surface during temperature cycling and creating long-term reliability problems. This effect has been analyzed with scanning acoustic microscopy by Olson and Owens [1991].

Gold-silicon eutectic bonding is accomplished by cutting a preform, generally of the 94Au/6Si alloy, placing it on the die-attach pad of the leadframe (Alloy-42), then putting the chip on the preform and heating above the melting temperature of the eutectic (300°C). This forms a rigid joint between the leadframe and the silicon that is not prone to solder fatigue. However, thermal mismatch stresses may be transmitted to the die, sometimes producing horizontal die cracks. Furthermore, gold-silicon eutectic die attachment is a low-throughput manual method that cannot be reliably adapted for high-speed automation [Nguyen et al. 1994].

Polymer die-attach adhesives require curing subsequent to chip placement, usually for about 1 hr at 150°C for epoxies, and longer at higher temperatures for polyimides. The curing schedule is usually determined by differential scanning calorimetry.

Polymer die-attach materials are normally used in low-power PEM parts in plastic dual in-line package (PDIP), plastic-leaded chip carrier (PLCC), small

outline integrated circuit (SOIC), and plastic quad flatpack (PQFP) packages. Polymer die-attach materials are widely used, due to their relative cost-effectiveness (compared with solder and eutectic die-attach) and their adhesive compliance under thermal cycling conditions. The major concerns about their use are related to very long-term degradation, especially under high-temperature storage; and interfacial void formation can cause die cracking, and high thermal resistance in the voided area, which can cause parametric shifts due to a local increase in junction temperature. Since polymer adhesives absorb moisture under high-humidity conditions, they have been tentatively correlated with horizontal PEM case cracking during soldering to a substrate or circuit card (see Chapter 4).

The properties of polymeric die-attach materials also dictate manufacturing decisions, such as whether to use a single-component or two-component system. In the latter, the resin or resin-filler is combined with the hardener just prior to use, which results in an excellent shelf life at room temperature. On the other hand, single-component materials avoid problems associated with reproducible mixing and component ratios, but even when stored below 5°C, they are guaranteed for only six months.

The polymer die-attach material can be dispensed with a needle or syringe, or by stamping or screen printing. The viscosity must be selected by the manufacturer for the particular application, with machine adjustments to control the proper thickness and fillet. The fillet provides significant strength for small dies, but must not be allowed near the surface of the die because of the potential for silver migration, when silver is used as a filler. Formation of voids, due to improper dispensing of the adhesive or the release of solvents during cure, is the major concern in polymer die attachment. The effect of voids on the quality and reliability of plastic packages has been extensively studied [van Kessel et al. 1983, Edwards 1987, Mahalingam et al. 1984], and C-mode scanning acoustic microscope has been effectively used for their characterization [Kessler et al. 1987] (see Chapter 6). However, problems caused by improper dispensing have largely been solved by the use of multiple nozzles; void-free results have been demonstrated on chips as large as 20 x 20 mm, using fully automatic process control, made possible through image processing of the dispensing pattern.

The next step in the die bonding process is to place the chip on the adhesive-coated die pad. When large chips are involved, placement errors of less than 25 μm (1 mil) and angular errors of less than 0.3° are maintained by stable pick-and-place units, accurate positioning, and image-processing techniques. Bonding

pressures of up to 5 N/cm^2 are required to achieve 15-to 30- μm -thick adhesive layers and acceptable visible protrusion of fillets around the edges of the chips. Inaccurate die placement may lead to several manufacturing problems such as high die stress from voiding; epoxy bridging to leadfingers, resulting in inner-lead bonding problems; lead sweep at the wirebond, resulting in low stresses on the bonding wires on one side of the package and high stresses on the opposite side; and low wirebond yield and throughput, due to the extra time needed to search the die position.

A priority of die-bonding manufacturing methods is the reduction of chip stresses caused by the different coefficients of thermal expansion of the chip, molding mass, and die pad. While the stress is mainly bending stress, tensile stress develops at the chip surface, which can cause chip cracking. In some cases, especially when quick-setting adhesives with poor stress relaxation properties are used, stresses can lead to delamination or cracking. Major manufacturers have addressed this by choosing either suitable adhesives and process parameters, or an improved leadframe design (e.g., dividing the die pad into several decoupled subareas).

3.3 WIREBONDING

In PEM manufacture, wirebonding is the dominant interconnection technology, although it has changed substantially since it was first introduced. Gold wire is the common material for interconnects in plastic-encapsulated microcircuits. It is bonded using thermocompression and thermosonic bonding because of its easy ball formation and oxidation resistance.

To reduce plastic package costs, studies have been conducted to develop the use of other wire materials, including aluminum, copper, silver, and palladium. While the focus of this section is on gold wirebonding processes, process modifications to extend the bonding processes to copper, aluminum, and palladium are also presented.

3.3.1 Thermocompression Bonding

Thermocompression bonds occur when two metal surfaces are brought into intimate contact in a controlled time, temperature, and pressure cycle. During the process (Figure 3.3), the wire and the underlying metallization undergo both plastic deformation and atomic interdiffusion. The plastic deformation at the mating surfaces ensures close contact between the bonding elements, an increase in the bonding area, and the breakdown of the interface film layers. Interdiffusion

DEVICE: A single discrete electronic element such as a transistor or resistor or a number of elements integrated within one die, which cannot be further reduced or divided without eliminating its stated function. Preferred usage is die or dice, bare or prepackaged.

DEW POINT: The temperature at which liquid first condenses when a vapor is cooled.

DEWETTING: The condition in a soldered area in which liquid solder has not adhered intimately and has pulled back from the conductor area.

DIE: (plural, dies or dice): The individual semiconductor element or integrated circuit after it has been cut or separated out of the processed semiconductor wafer, distinct from a completely packaged or encapsulated integrated circuit with leads attached. A semiconductor chip. See also *chip*.

DIE ATTACH: The technique of mounting chip to a substrate. Methods include AuSi eutectic bonding, various solders, and conductive (and nonconductive) epoxies, polyimides, or thermoplastics.

DIE BOND: The interface of the die to some other entity (substrate, header, etc.)

DIE PAD, DIE-ATTACH PAD, DIE-MOUNT PAD, OR PADDLE: The portion of the leadframe on which the IC die is mounted during the assembly process.

DIELECTRIC LAYER: A layer of dielectric material between two conductor plates.

DIELECTRIC: (1) Any insulating medium which intervenes, between two conductors. (2) A material with the property that energy required to establish an electric field is recoverable in whole or in part as electric energy.

DIELECTRIC PROPERTIES: The electrical properties of a material, such as insulation resistance, and breakdown voltage.

DIFFUSION: The phenomenon of movement of matter at the atomic level from regions of high concentration to regions of low concentration. A thermal process by which minute amounts of impurities are deliberately impregnated and distributed into semiconductor material.

DIFFUSION CONSTANT: The rate at which diffusion takes place under specific conditions.

DIMENSIONAL STABILITY: A measurement of dimensional change of a material due to various environmental factors.

DIP SOLDERING: Soldering process for populated printed boards accomplished by dipping the exposed leads and conductive pattern in a bath of static molten solder.

DRY PACKING: Protecting moisture-sensitive plastic packages in metallized plastic