Composite materials for electrical applications

4.1 Introduction

Composite materials are traditionally designed for use as structural materials. With the rapid growth of the electronics industry, composite materials are finding more and more electronic applications. Owing to the vast difference in property requirements between structural composites and electronic composites, the design criteria for these two groups of composites are different. While structural composites emphasize high strength and high modulus, electronic composites emphasize high thermal conductivity, low thermal expansion, low dielectric constant, high/low electrical conductivity and/or electromagnetic interference (EMI) shielding effectiveness, depending on the particular electronic application. Low density is desirable for both aerospace structures and aerospace electronics. Structural composites emphasize processability into large parts, such as panels, whereas electronic composites emphasize processability into small parts, such as stand-alone films and coatings. Owing to the small size of the parts, material costs tend to be less of a concern for electronic composites than structural composites. For example, electronic composites can use expensive fillers, such as silver particles, which serve to provide high electrical conductivity.

The electrical applications for composites pertain to microelectronics and resistance heating (such as the deicing of aircraft).

4.2 Applications in microelectronics

The applications of polymer–matrix composites in microelectronics include interconnections, printed circuit boards, substrates, encapsulations, interlayer dielectrics, die attach, electrical contacts, connectors, thermal interface materials, heat sinks, lids and housings. In general, the integrated circuit chips (dies) are attached to a substrate or a printed circuit board on which the interconnection lines have been written (usually by screen printing) on each layer of the multilayer substrate or board. In order to increase the interconnection density, another multilayer involving thinner layers of conductors and interlayer dielectrics may be applied to the substrate before attachment of the chip. By means of soldered joints, wires connect between electrical contact pads on the chip and electrical contact pads on the substrate or board. The chip may be encapsulated with a dielectric for protection. It may also be covered by a thermally conducting (metal)
lid. The substrate (or board) is attached to a heat sink. A thermal interface material may be placed between the substrate (or board) and the heat sink to enhance the quality of the thermal contact. The whole assembly may be placed in a thermally conducting housing.

A printed circuit board is a sheet for the attachment of chips, whether mounted on substrates, chip carriers or otherwise, and for the drawing of interconnections. It is a polymer–matrix composite that is electrically insulating and has four conductor lines (interconnections) on one or both sides. Multilayer boards have lines on each inside layer so that interconnections on different layers may be connected by short conductor columns called electrical vias. Printed circuit boards (or cards) for the mounting of pin-inserting-type packages need to have lead insertion holes punched through the circuit board. Printed circuit boards for the mounting of surface-mounting-type packages need no holes. Surface-mounting-type packages, whether with leads (leaded chip carriers) or without leads (leadless chip carriers, LLCCs), can be mounted on both sides of a circuit board (i.e., a card), whereas pin-inserting-type packages can only be mounted on one side of a circuit board. In surface mounting technology (SMT), the surfaces of conductor patterns are connected together electrically without employing holes. Solder is typically used to make electrical connections between a surface-mounting-type package (whether leaded or leadless) and a circuit board. A lead insertion hole for pin-inserting-type packages is a plated-through hole, a hole on whose wall a metal is deposited to form a conducting penetrating connection. After pin insertion, the space between the wall and the pin is filled by solder to form a solder joint. Another type of plated-through hole is a via hole, which serves to connect different conductor layers together without the insertion of a lead.

A substrate, also called a chip carrier, is a sheet on which one or more chips are attached and interconnections are drawn. In the case of a multilayer substrate, interconnections are also drawn on each layer inside the substrate, such that interconnections in different layers are connected, if desired, by electrical vias. A substrate is usually an electrical insulator. Substrate materials include ceramics (e.g., Al₂O₃, AlN, mullite, glass–ceramics), polymers (e.g., polyimide), semiconductors (e.g., silicon) and metals (e.g., aluminum). The most common substrate material is Al₂O₃. As the sintering of Al₂O₃ requires temperatures greater than 1000°C, the metal interconnections need to be refractory, such as tungsten or molybdenum. The disadvantage of tungsten or molybdenum lies in the higher electrical resistivity compared to copper. In order to make use of more conductive metals (e.g., Cu, Au, Ag–Pd) as the interconnections, ceramics that sinter at temperatures below 1000°C ("low temperature") can be used in place of Al₂O₃. The competition between ceramics and polymers for substrates is increasingly keen. Ceramics and polymers are both electrically insulating; ceramics are advantageous in that they tend to have a higher thermal conductivity than polymers; polymers are advantageous in that they tend to have a lower dielectric constant than ceramics. A high thermal conductivity is attractive for heat dissipation; a low dielectric constant is attractive for a smaller capacitive effect, hence a smaller signal delay. Metals are attractive for their very high thermal conductivity compared to ceramics and polymers.

An interconnection is a conductor line for signal transmission, power or ground. It is usually in the form of a thick film of thickness > 1 μm. It can be on a chip, a substrate or a printed circuit board. The thick film is made by either screen printing or plating. Thick-film conductor pastes containing silver particles