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Systematic analysis of microelectronic chip packaging materials

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Abstract. Microelectronics is a recent hot field, and packaging is an indispensable part of making microelectronic chips. This article introduces the commonly used materials in the field of microelectronic chip packaging. It first presents two complex polymer raw materials recently becoming hot topics, namely epoxy resin and silicone. Then the article presents these two materials from the perspectives of their characteristics, advantages in packaging, and further research directions, allowing readers to have a basic understanding of them while also gaining a general understanding of their research progress. Afterward, the article introduces three crucial types of functional materials in packaging. The article not only presents their respective uses, but also classifies them from the main material types. The article not only analyzes the characteristics and application fields of each material, but also provides some existing in-depth research directions for reference. This article helps readers quickly understand the relevant knowledge of some microelectronic chip packaging materials, especially in determining their future research direction.

Keywords: Electronic Packaging, Epoxy Resin, Organic Silicon, Conductive Adhesive, Electromagnetic Shielding.

1. Introduction

In the field of electronics, packaging refers to the process of assembling integrated circuits into the final product of a chip. The specific form is to connect the circuit pins on a silicon chip with wires to external connectors. Packaging provides environmental protection for precision electronic components, protecting them from environmental factors such as moisture, dust, and temperature. Packaging facilitates electrical connection and allows electronic components to integrate with printed circuit boards or other devices [1]. It also helps dissipate the heat generated during operation, ensuring optimal thermal management, and preventing overheating. In addition, electronic packaging can achieve miniaturization because it provides a way to integrate multiple components into a compact and portable form factor, thereby achieving a compact and portable design for electronic devices. Overall, electronic packaging is crucial as it can protect components, achieve connectivity, manage heat dissipation, and support the miniaturization of electronic products, which determines a lot in improving the functionality, reliability, and performance of electronic devices. The importance of selecting appropriate packaging materials to meet these various functions is self-evident.

The article introduces two commonly used polymer materials. We present three functional materials with different substrates, as various conductive adhesives, thermal interface materials, and electrical shielding materials. The respective advantages, disadvantages, and application areas of each kind of materials are shown. The specific classification is shown in the figure 1 below.

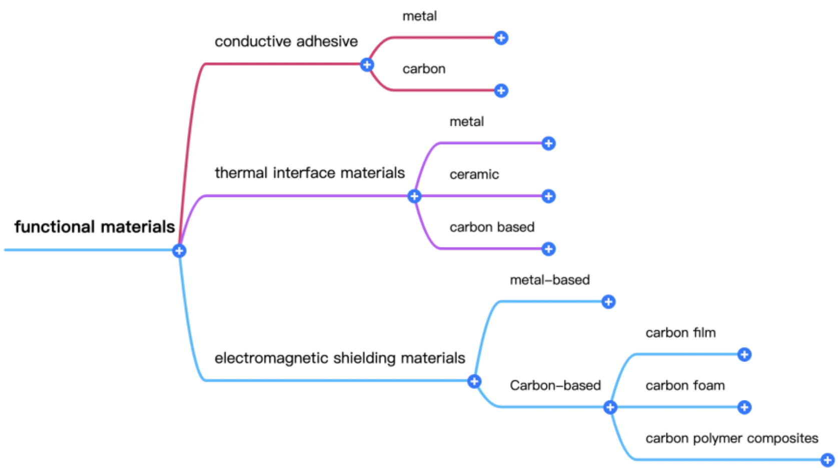

Figure 1. Packaging materials and their classification.

2. Packaging raw materials

The selection of electronic packaging materials has a significant impact on the performance, reliability, and cost-effectiveness of packaging. According to the packaging structure, it is divided into substrate, wiring, frame, interlayer medium, and sealing material. Substrates are mainly divided into rigid substrates, flexible film substrates, and co fired ceramic substrates. The materials of wiring and framework require low resistance and good solderability. The interlayer medium plays a role in protecting the circuit, isolating insulation, and preventing signal distortion, requiring materials with high insulation resistance and low dielectric constant. Sealing materials have gradually shifted from ceramic based to polymer-based packaging. Suitable electronic packaging materials require high reliability, yield, applicability, manufacturability, and low cost. This paragraph mainly introduces two core polymers in electronic packaging.

2.1. Epoxy resin

Epoxy resin refers to a chemical substance that contains two or more epoxy groups in its molecules and can form a three-dimensional cross-linked structure in the presence of appropriate chemical additives such as curing agents [2].

The advantage of using epoxy resin as encapsulation and packaging materials is its low viscosity, achieving bubble free pouring. At the same time, it has high adhesive strength, good electrical performance, high chemical corrosion resistance, extensive temperature resistance range, and low shrinkage rate. The fully cured shrinkage of epoxy resin is 1.5-2%. During the curing process, no volatile substances are generated, so epoxy resin is less prone to bubbles, cracks, and peeling. At present, the primary epoxy molding materials used for integrated circuits and semiconductor chips are ortho cresol formaldehyde epoxy resin systems.

2.2. Organic silicon

There are four main categories of organic silicon products: rubber, resin, oil, and silane coupling agents. Due to the partial ionic bonding characteristics of the Si-O bond of organic silicon, it combines the properties of both inorganic and organic materials [3]. Organic silicon materials have high thermal

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stability, oxidation resistance, weather resistance, flame resistance, corrosion resistance, as well as stable electrical properties and biological activity.

In the early days of packaging, organic silicon was mainly used to interact with epoxy resin to improve its heat resistance and toughness. K. K et al. used siloxanes with epoxide groups to hydrolyze and condense under alkaline catalysts to produce oligomers of organic silicon and epoxy resin [4]. The outstanding advantage of this material after vulcanization molding is that the mass fraction of potassium and sodium plasma is lower than 0.000002. Thus the insulation performance is improved.

3. Packaging functional materials

In the design and packaging process of electronic devices, conductive adhesives, thermal interface materials, and electromagnetic shielding materials are crucial components. Conductive adhesive provides reliable electrical connections, thermal interface materials are used to optimize thermal conductivity and heat dissipation performance, and electromagnetic shielding materials are used to reduce external electromagnetic interference received by electronic devices. This paragraph introduces several conductive adhesives, thermal interface materials, and electromagnetic shielding materials processed based on the raw materials.

3.1. Conductive adhesive

Conductive adhesive is an adhesive that has specific conductivity, thermal conductivity, and mechanical properties after curing. It is usually used to fill small gaps or connect circuits between electronic devices, forming reliable conductive channels. The main components are matrix resin and conductive fillers, which bind conductive particles together through the binding effect of the matrix resin. Conductive fillers mainly consist of metals, carbon-based materials, and nonconductive materials coated with metal chemical coatings [5].

3.1.1. Metal conductive adhesive. Commonly used metal conductive fillers include Ag, Au, Ni, Cu, and Al. Among them, silver conductive adhesive has the lowest resistivity and highest usage rate for conductive adhesive. However, it can cause electromigration when there is an electric field, resulting in a decrease in conductivity and affecting its service life. Copper, due to its active chemical properties compared to silver, is rapidly oxidized in the air, resulting in a rapid decrease in its conductivity, thereby limiting its application. Nickel has similar problems to copper.

3.1.2. Carbon conductive adhesive. Carbon based conductive fillers, especially graphene and carbon nanotubes, have excellent performance. Mixing them with silver powder as conductive fillers can improve the conductivity and mechanical properties of conductive adhesives.

YIM et al. prepared epoxy based conductive adhesive using carbon nanotubes and Sn-58Bi alloy as conductive fillers [6]. This material has better conductivity and mechanical properties than conductive adhesives using traditional silver sheets as conductive fillers.

3.2. Thermal interface materials

TIM are used for bonding and heat dissipation at two interfaces. It can reduce the thermal resistance between interfaces, thus achieving rapid heat transfer of chips-the thermal resistance of contact between interfaces. An ideal thermal interface material generally requires high thermal conductivity, flexibility, and insulation properties. Common thermal interface materials include metals, ceramics, and carbon based.

3.2.1. Metal. They have a high thermal conductivity and are a common type of thermal interface material. They are mainly used in the form of liquid metals and metal nanoparticles. In high-power functional components such as RF and IGBT modules, metal materials based on gallium, mercury, indium, tin, and bismuth are commonly used [7, 8].

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However, metals can conduct electricity, which limits their application in thermal insulation materials. And metal particles and metal fibers have poor compatibility with polymers. Composite materials containing metals are easy to separate and have lower thermal conductivity.

3.2.2. Ceramic. Common ceramic high thermal conductive filler particles include Al2O3, AlN, BN, SiO2, ZnO, SiC, etc. Compared to other thermal interface materials, they typically provide better thermal performance and shorter manufacturing cycles. The smaller viscosity allows them to fill the interface voids quickly [9]. At the same time, it also has a minimal adhesive layer thickness, which brings a meager thermal resistance. But it is susceptible to external environmental influences and fails. For example, when an electronic device is connected to a power source, it can cause relative motion between the chip and the heat dissipation device. It will allow the thermal conductive filler to overflow, contaminating the circuit board and causing a short circuit.

3.2.3. Carbon based. These materials possess higher intrinsic thermal conductivity than ceramic materials. Common carbon-based materials include carbon nanotubes and graphene. Carbon nanotubes are one-dimensional fillers of carbon. Generally, a carbon nanotube comprises several to dozens of layers of carbon atoms arranged in a hexagonal shape, and has a relatively high thermal conductivity. Multiple vertically arranged carbon nanotube arrays have low density and thermal expansion coefficient. Meanwhile, carbon nanotubes have excellent flexibility, which enables carbon nanotubes to eliminate all interfaces. It is considered an ideal thermal interface material.

The thermal conductivity of carbon nanotubes is determined by factors such as diameter and distribution density. These factors can be controlled by adjusting the catalyst and growth conditions [10]. Its disadvantage is that it can lead to excessive contact thermal resistance, which must be studied [11].

3.3. Electromagnetic shielding materials

Electromagnetic shielding refers to using materials or structures to block or reduce the electromagnetic interference generated by external sources from affecting electronic devices [12]. Electromagnetic shielding materials are designed to attenuate or redirect electromagnetic waves, preventing their penetration into sensitive electronic components. These materials are typically conductive or magnetically permeable, allowing them to absorb or reflect electromagnetic radiation. At present, electromagnetic shielding materials are mainly divided into two types: metal based and carbon based.

3.3.1. Metal-based. Metal based electromagnetic shielding materials are the earliest and most widely used. This material is usually composed of metal materials and other auxiliary materials. Its use is traditionally applied externally to the component as a conductive coating. They have high magnetic saturation magnetic induction intensity and residual magnetism, which can provide a strong magnetic field shielding effect.

Metal based electromagnetic shielding materials have drawbacks such as high density, inflexibility, and poor chemical stability, which greatly limit their application in the current era of higher precision requirements for components. However, in environments that require hardness, metal based electromagnetic shielding materials still have significant advantages.

The most common type of coating material is ferrite. This compound absorbs electromagnetic waves in the form of magnetic loss. The main drawbacks limiting its use are poor stability and narrow absorption frequency band. At present, the research direction of ferrite mainly focuses on the combination with other ions or elements. For example, combining Ba and Ca plasmas with unary ferrite will produce a more stable hexagonal crystal structure, thereby improving thermal stability [13]. Composite bubble structure electromagnetic shielding materials are also a research direction, focusing on reducing the density of electromagnetic shielding materials and improving sound insulation performance. This material often uses metals such as aluminum, iron, and nickel as the basic skeleton. Yin et al. prepared AgNWs/Ti3C2T composite foam films using positive pressure filtration technology

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[14]. The density of this material is 1 g/cm3, the conductivity is 15.038S/cm, and it achieve an electromagnetic shielding effectiveness of 41.3 decibels with a thickness of 1.2 micron.

3.3.2. Carbon-based. Carbon based materials are superior to metal-based materials in many aspects. The various allotropes of carbon not only have high conductivity, but also have the characteristics of light weight, good thermal stability, good chemical stability, and soft texture. This enables them to prepare electromagnetic shielding materials that are easy to process, lightweight, and highly stable. Carbon based electromagnetic shielding materials have been widely used in sophisticated fields such as wearable devices and electronic device casings [15]. According to morphological classification, carbon based electromagnetic shielding can be divided into carbon film materials, carbon foam materials and carbon polymer composites.

Carbon based electromagnetic shielding materials in carbon films can be applied by preparing carbon materials such as carbon nanotubes or graphene into thin films or coatings. This carbon film type has a dense structure and a thickness of about 10μ m. It is often used in instruments with small precision, such as aircraft radars [16]. Song et al. used suction filtration method to peel graphene nanosheet films with a conductivity of up to 20000S/m from graphite [17]. They also conducted further research by mixing ferric oxide into the film. They conclude that adding magnetic materials can sacrifice their ability to reflect electromagnetic waves and improve their absorption ability.

Carbon foam is a porous structural material composed of carbon nanotubes with multiple surface areas, graphene, and other carbon materials. Among the many advantages of carbon based electromagnetic shielding materials, its most prominent advantage is its extremely low density. This makes it have excellent application prospects in the aerospace field.

The carbon content and reduction degree of carbon foam materials can be adjusted according to the conductivity needs. Under the same conditions, the carbon foam sample with the highest filling density or reduction degree usually has the highest conductivity, thus having the best electromagnetic shielding performance [18].

Carbon matrix composite electromagnetic shielding material is produced by filling nonconductive polymers into the pores of carbon foam materials. Therefore, it has similar shielding performance with carbon foam. Its characteristic is good mechanical properties and low cost of mass manufacturing. This type of material is often used in scenarios with high demand, such as in the construction industry.

4. Conclusion

Exploring low-cost and mass production solutions for complex composite materials demands a more in-depth investigation. Specifically, within the realm of thermal interface materials, there is a notable scarcity of research pertaining to the fusion of polymers and other raw materials. Concerning electromagnetic shielding materials, scholars are passionately engaged in finding ways to reduce material weight while moving away from traditional reflective shielding methods and towards absorption shielding techniques that inflict lesser harm.

As the microelectronics industry continues to advance, along with packaging technology, traditional materials are progressively falling short of meeting current packaging requirements. Composite materials built upon polymers offer significant advantages in terms of both thermal conductivity and insulation. Therefore, extensive research into polymers like epoxy resins is expected to remain a prominent and enduring area of interest.

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