SiC die attach based on sintered for Wide Band Gap semiconductor

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Abstract

Silver sintered die attach materials offer a new interconnect technology. Hybrid sintering die attach paste is resin-based and has the same application as standard die attach paste, but does not require high pressure and high temperature for sintering. It features excellent workability that enables stable application for 24 hours continuously without silver sedimentation or separation. Lead-free die attach materials that offer simplified processing, robust reliability, and best-in-class thermal and electrical performance for high-power semiconductor packages.

SiC is the next generation wide bandgap semiconductor material for high temperature power electronics for automotive and telecommunications. We would like to introduce a SiC die attach based sintering solution for WBG packages. Features include thermal conductivity >200 W/m.k, pressure less die attach process, low temperature cure under nitrogen atmosphere and excellent adhesion to all treated surfaces.

Key words

Silicon Carbide (SiC) , Gallium Nitride (GaN), sintering material, WGB semiconductor

I. Introduction

The introduction of improved semiconductor devices, namely wide bandgap types such as Silicon Carbide (SiC) and Gallium Nitride (GaN) will enable significantly higher performance power switching applications, especially in applications such as automotive traction inverters.

SiC power semiconductor technology offers significant advantages over traditional silicon-based devices in power applications requiring low losses, high frequency switching and/or high temperature environments [1].

Some of the advantages of these technologies have been demonstrated and deployed, especially with Silicon Carbide in standalone charging station applications (high voltage) and more recently in traction inverter assemblies (high temperature, high switching frequency), emerging as a cutting edge application" in the realm of automotive electrification.

With the potential for drastically improved performance, a challenge for the any remains. How we might modified die attach material to realize the full performance advantages of these promising semiconductor devices?

Accommodating the coefficient of thermal expansion (CTE) mismatch between the die and its substrate to ensure physical integrity and long-term reliability exacerbates the situation. Additionally, WBG semiconductors can operate at significantly higher operating temperatures (around 200 °C) that conventional die attach and packaging materials cannot withstand [2]. Higher operating temperatures also amplify thermal stresses caused by CTE mismatch, delamination risk increase and premature failure. In order to take advantage of the characteristics of these WBG devices, effective heat dissipation has become an increasingly important issue.

II. Emergence sintered materials

Table 1: Comparison of bulk material

Specification	solder	sintering	hybrid sintering
Workability	poor	fair	good
Adhesion	fair	fair	fair
Reliability	good	good	good
thermal conductivity	fair	good	good
lead free	poor	good	good
Cost	good	poor	poor
Functionalization	poor	fair	good

Compared to solder, conductive adhesives have a very low thermal conductivity due to the presence of resins. Solder has the characteristic of having a very high mechanical strength due to metal bonding. In order to compensate the low thermal conductivity of conductive adhesives, increasing the content of silver powder is one of the approaches to obtain high thermal conductivity. In other words, high thermal conductivity can be achieved by controlling the packing density by combining the shape and size of the silver powder. Although high thermal conductivity type conductive adhesives were put to practical use, their applications in semiconductor packaging and applications were limited due to their inferior electrical properties, heat dissipation properties and reliability results when compared to solder.

Recently, applied technology of sintering silver has led to the development of conductive adhesives having properties equal to or better than those of solder, and this conductive adhesive composed of sintered silver is called a sintering agent. Initially, a curing temperature of about 250°C to 350°C was required, but sintering at around 200°C is now possible. In addition, sufficient sintering is possible even in a nitrogen atmosphere, which meet the requirements of the semiconductor manufacturing processes. At present, conductive adhesives using sintering agents can be utilized for both pressurized and non-pressurized equipment types depending on the package. The non-pressurized equipment can utilize conductive adhesive w/ sintering agents with conventional equipment, so the equipment investment and process are simple. On the other hand, the pressurized type requires unconventional equipment, which may cause investment difficulties; moreover, the process becomes complicated due to the pressurization. However, since sintering can be accelerated by pressurization, it is possible to improve metal bonding and form a dense film, which is advantageous in terms of heat dissipation characteristics. Semiconductor manufacturers use both materials depending on the package structure and process.

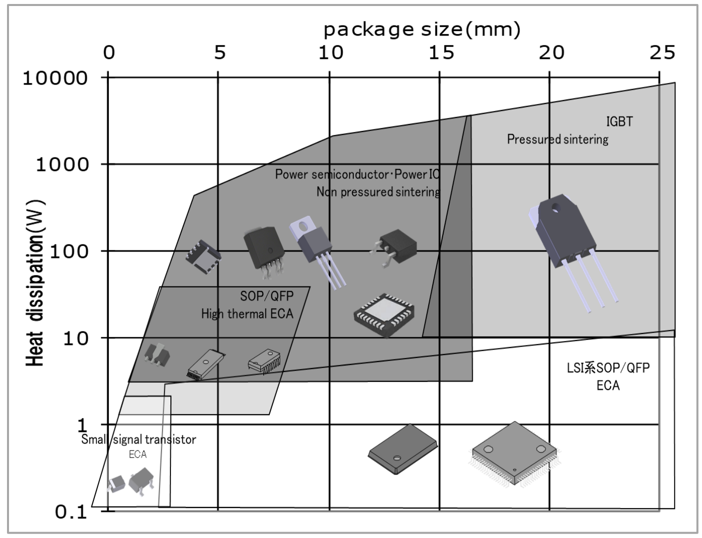


Fig 1: Scope of die attach material [3]

AuSn eutectic solder has been used as a die bonding material, but sintering material is now a new option to be used for bonding small chip parts such as communications and LEDs. With a thermal conductivity of 100 to 200 W/m.k or more and high heat dissipation features, sintering material is capable of dramatically improving the product performance. In addition, although sintering material is one of the candidates to alter solder for automobile applications, but since the RoHS/ELV has been postponed until 2027, it can inferred that no alternative materials that can be put into practical use for a while.

A semiconductor manufacturing process using a sintering material was described earlier. There are cases where a conductive adhesive is required according to the process, and there are cases where the manufacturing process is determined by characteristics and cost, as in the case of sintering agents. For example, to improve productivity, we provide conductive adhesives that can handle high-speed die bonding, and to improve heat dissipation properties, we provide die attach film for semiconductors designed for thin wafers. Although the example given here is just one example of how conductive adhesives have made technological progress according to market needs and have contributed to improving the convenience of the world through semiconductors. Semiconductor packages have been made smaller, lighter, and more functional through development that incorporates not only the properties of conductive adhesives but also processes.

Because sintering material are superior to conventional solders and conductive adhesives in terms of heat resistance, heat dissipation, and bonding, they are expected to be used in new applications. In addition, hybrid sintering material, which are sintering agents mixed with resin, are attracting attention as an approach to solve reliability issues due to differences in linear expansion coefficients of SiC and GaN wafers for IGBT modules and WGB packages [4].

Table 2: Properties of key material

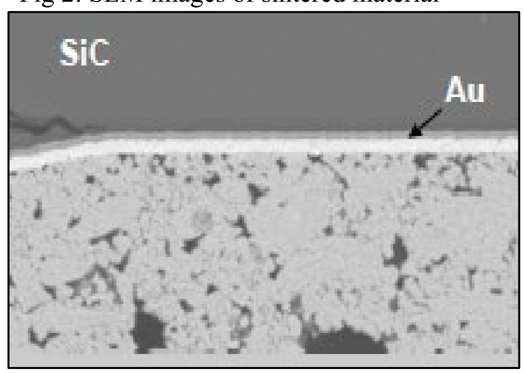
Properties	conventional	Hybrid sintering
Technology	Die attach paste	Hybrid sintering paste
Resin system	Epoxy	Epoxy
Filler type	Silver	Silver
Thermal Conductivity (W/mK)	13	150
Volume Resistivity (Ω･cm)	32×10^{-6}	6×10^{-6}
Die Shear Strength(N/mm^2)	20	55
Cure	R.T. →175deg, 60min under air/N2	R.T. →200℃ 60min + 250℃60min under N2/Air
E' Modulus(Mpa@25℃)	6,000	16,500
Tg by TMA(℃)	50	Tg less
CTE1 (ppm/ºC)	40	19
CTE2 (ppm/ºC)	60	19

Hybrid sintering die attach paste uses specially selected fine filler which can achieve silver sintering at a low temperature. The bonding strength of hybrid sintering bond line is primarily provided by the sintered silver structure, as opposed to the cured resin matrix. Re-melting silver would require an extremely high temperature, since the melting point of silver is above 1000º C; however, this feature makes up for the high operating temperatures and delivers excellent creep resistance.

In addition, the porous metal structure offers a significantly lower modulus as compared to solid metal, which makes it a potential solution for assemblies with large CTE mismatch components. In addition, the higher thermal performance of hybrid sintering reduce CTE mismatch-induced thermal stress. Hybrid sintering die attach material can be applied stencil or screen printing, dispensing which makes it compatible with most standard assembly processes and equipment.

Key properties of hybrid sintering and die attach material are shown in Table 1. To demonstrate the performance advantages of hybrid sintering, a widely used die attach epoxy paste was chosen as the control material and its key properties are also shown in Table 1. Compared to the epoxy paste, hybrid sintering offers much higher thermal and electrical conductivities and significantly lower CTEs, which makes it a potential candidate for WBG semiconductor.

Fig 2: SEM images of sintered material



The interface between hybrid sintering and backside of Sic die is shown in Figure 2. As sintering progresses, metallic bonding with Au on the back side is observed. This is a very good bonding condition, which shows that sintering has progressed sufficiently in the presence of resin. SiC wafers are used for WGC packages, and thick substrates are used. Sufficient bonding strength and stress relaxation ensure reliability and maximize package performance.

-Bond strength

For die attach material, ensuring good and reliable bond strength is a key requirement. Bonding strength evaluation was conducted with 2 mm x 2 mm Si die, back side Ag plating, Ag plating lead frame. Since the semi-sintered paste is silver-based, a silver or gold surface metallization was expected for superior strength. As expected, it showed excellent strength. Table 2 shows the results of the die shear test. A typical conductive adhesive has a 2 mm x 2 mm die shear strength of $20 N/mm^2$. This shows that the strength has increased not only by the resin but also by the metallic bond obtained by sintering.

-Thermal performance

Die shear tests demonstrate that the sintering die attach material exhibits excellent adhesive strength to Ag-plated lead frames. However, the high thermal performance of the package must be proven before the semi-sintered material can be used for WGB semiconductors. In addition, thermal performance is a good indicator of sintering quality, as good sintering tends to form larger and stronger silver grain interconnects. Thermal conductivity was evaluated using the laser flash method. It was shown that sintered silver approaches bulk and has dramatically improved thermal conductivity compared to general silver adhesives.

-Elastic modulus

Table 3: Coefficient of thermal expansion [4].

type	Material	CTE(ppm/℃)
die	Si	2.6
	SiC	2.8
	GaN	3.2
substrate	CuW	8.0
	CuMo	7.6
	Cu	17
	Al	23

SiC, GaN chip, and Cu-based substrates used in WGB semiconductors have different CTEs; therefore, stress is applied to the die bonding material. Elastic modulus of the hybrid sintering material becomes a very important factor. Since sintered silver approaches bulk, it tends to have a higher elastic modulus than general conductive adhesives. Actual values are shown in Table 3. Since the elastic modulus also changes with temperature, the behavior at low and high temperatures affects thermal cycle test.

III. Conclusion

Comprehensive experimental tests were conducted to evaluate the die shear strength and thermal performance of hybrid sintering die attach material. In house results show that hybrid sintering can maintain high bond strength and achieve high thermal performance over traditional die attach pastes and solders. SEM showed a high sintering quality between the silver particles and the SiC backside Au surface. In the future, we need to focus on reliability evaluation in SiC devices. As explained at the beginning, the most important issue is how the stress caused by the difference in coefficient of linear expansion between SiC, GaN, and thick substrates used in WGB semiconductor packages will affect thermal cycle testing.

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