Packaging Technologies Using Epoxy Resin Sealing

Author: *Hiroyuki Harada**

1. Introduction

Companies around the world must contribute to reducing environmental impact and achieving a low-carbon society. Along with the advances made in industrial equipment, electric railways, and automobiles, the development of power modules to be mounted onto such machines has also been accelerating. Therefore, we have further improved our packaging technologies, including heat resistance and insulation properties, to ensure the stable performance and high reliability of the power modules.

This paper introduces the epoxy resin sealing packaging technology that was adopted for the NX-type models of our T-Series seventh-generation IGBT modules for industrial applications and our J1-Series power semiconductor modules for automobiles.

2. Characteristics of the structures

2.1 Characteristics of the package structures

Figure 1 shows the appearance of the packages for the NX-type models of the T-Series seventh-generation IGBT modules for industrial applications and the J1-Series power semiconductor modules for automobiles.

As shown in Fig. 2, the conventional structure consists of a metal baseplate and ceramic insulating substrate combined with silicone gel sealing. The characteristics of the structure of the NX-type models of the industrial T-Series are an insulated metal baseplate having high heat dissipation and insulation properties, and DP resin made from epoxy resin as the sealing material. In addition, adopting DP resin reduced the risk of mismatches between the linear expansion coefficients

Fig. 1 Packages for power modules

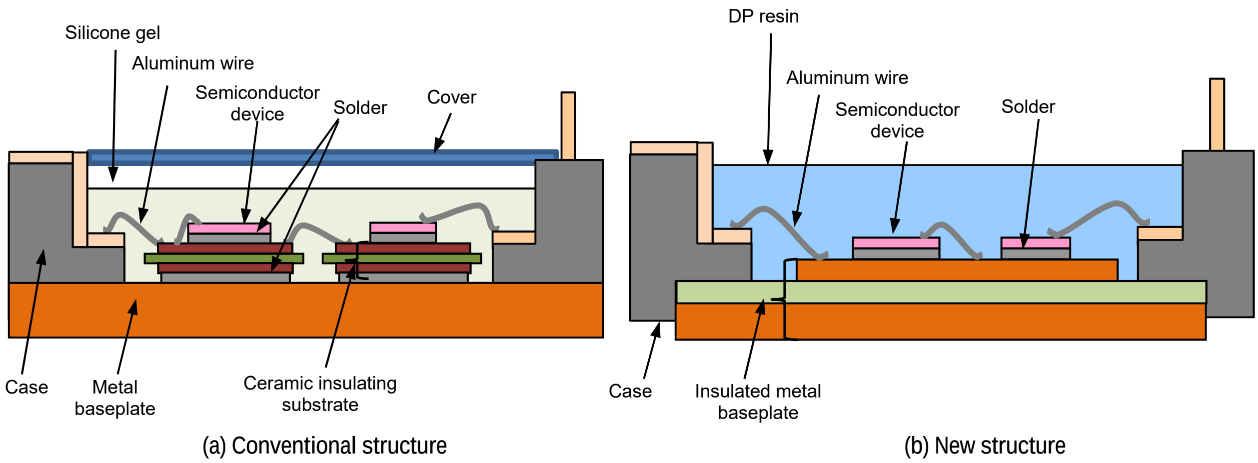

Fig. 2 Cross section of T-Series NX type

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of the components, which improved the resin's resistance to separation during thermal cycles.(1)

Figure 3 shows a cross section of the J1-Series power semiconductor module for automobiles. In the structure of the J1-Series, a ceramic insulating substrate is combined with a radiating fin, which enhances the cooling performance. The direct lead bonding (DLB) structure in which a metal frame is directly bonded to a semiconductor device with solder was adopted to improve the current-carrying capability and to reduce the wiring resistance and inductance. In addition, using DP resin as sealing resin makes the module structure as reliable as transfer-molded power modules (T-PMs) with the DLB structure. The three-phase inverter circuit configuration in which three 2-in-1 circuits are arranged was packaged into a single package to achieve a 6-in-1 circuit.(2)

2.2 Characteristics of the resin sealing technology

The package structure and components of power modules vary depending on the application, so appropriate resin sealing based on the performance of the package is required. There are three types of resin sealing: mold resin sealing using solid epoxy resin used for transfer molding, silicone gel sealing used for sealing of general case type modules, and DP resin sealing using liquid epoxy resin. The characteristics vary between the resin technologies (Table 1).

In mold resin sealing, the reliability of the power module is high thanks to sealing by transfer molding. However, an expensive mold is required, making it difficult to change the module structure. In addition, the productivity of sealing large modules deteriorates since there is a limit to the size of molds.

For silicone gel sealing, the heat resistance and insulation performance are excellent. Since silicone gel has a low viscosity, it is easy to fill the narrow gap. However, its heat resistance and reliability will need to be improved in the development of future power modules.

DP resin sealing, which uses liquid epoxy resin, solves such problems with sealing technologies. DP resin sealing does not require molds and its resistance to moisture permeability is high compared to silicone gel. It is considered that DP resin sealing could reduce the deterioration of solder materials at the bottom of semiconductor devices as a result of thermal cycles. These factors suggest that DP resin sealing can achieve

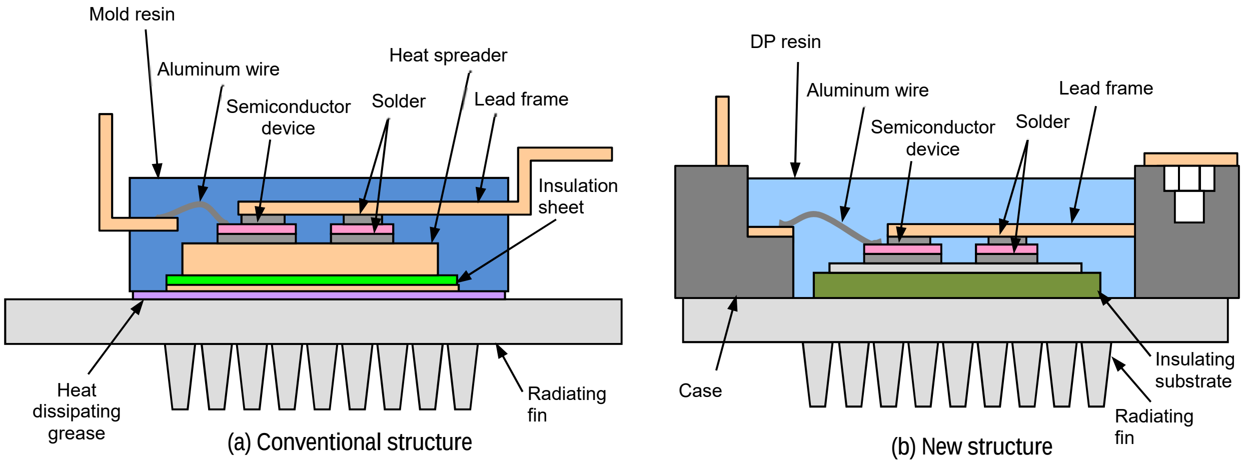
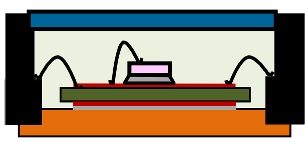
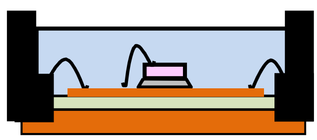
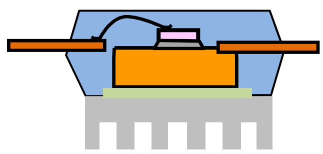


Fig. 3 Cross section of J1-Series

Table 1 Comparison of resin sealing technology

	Case type module		Transfer molding
	Silicone gel sealing	DP resin sealing	Mold resin sealing
Structure			
Reliability	Reliable	Highly reliable	Highly reliable
Larger package size	Possible	Possible	Not sufficiently possible
Linear expansion coefficient	High	Low	Low
Elastic modulus	Low	High	High

high reliability even under severe service environments. Meanwhile, its resin viscosity and elastic modulus are high, so it is difficult to fill the narrow-gap sections. The influence on separation and module warp caused by stress due to differences between the linear expansion coefficients of various components must be taken into account. Therefore, the optimum resin material design and sealing processes are important. These are discussed in detail in Chapter 3.

3. Packaging technology with resin for sealing

3.1 DP resin material design

DP resin consists of mainly epoxy resin, a ceramic filler, and various additives (e.g., flame retardant). We have developed materials with the optimum resin characteristics for each module type.

For the J1-Series for automobiles, the module structure includes a ceramic insulating substrate, so a DP resin type with a low linear expansion coefficient matching the ceramic's linear expansion coefficient had to be selected. The resin's linear expansion coefficient can be adjusted by changing the amount of filler to be added to the resin, as shown in Fig. 4. However, as the amount of filler increases, the resin viscosity also increases, thereby decreasing the liquidity. Regarding the liquidity of the resin, the liquid limit (viscosity) at which the resin can be filled even in the narrow-gap sections in modules at a high filling factor was calculated from a basic evaluation. We have identified the amounts of filler to be added (range) where the liquidity is excellent and have developed a DP resin that satisfies the required resin characteristics.

3.2 DP resin sealing process technology

Resin sealing in which the resin can be filled in the narrow-gap sections at high density requires the optimum filling processes based on determined resin characteristics. In recent years, power modules have become smaller and the density has become higher. The DLB structure and other types of structures have also been applied. These trends have resulted in an increasing number of module sections with narrow gaps of 1 mm or less. Therefore, optimization of the resin filling processes has become even more important. Regarding the processes, we filled resin under optimum conditions that were determined through evaluation, and achieved high-quality resin sealing at high density.

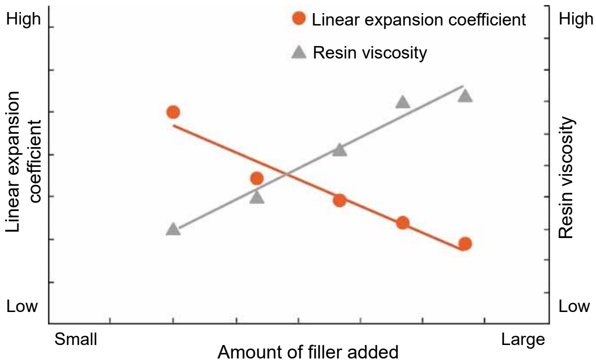
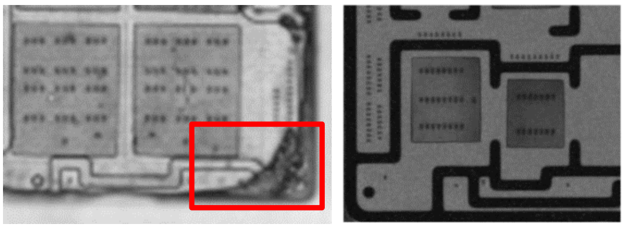


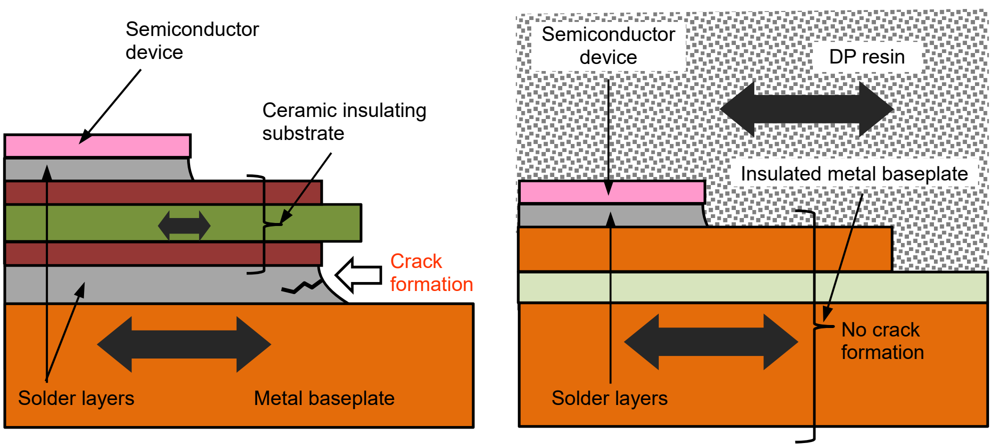
Fig. 4 Relationship between linear expansion coefficient and resin viscosity with respect to filler amount



(a) Silicone gel sealing structure

(b) DP resin sealing structure

Fig. 5 Cross section of substrate after thermal cycle test



(a) Silicone gel sealing structure

(b) DP resin sealing structure

Fig. 6 Cross section of each sealing structure

3.3 Reliability test

The conventional structure in which silicone gel sealing was applied for a ceramic insulating substrate and the new structure in which DP resin sealing was applied for an insulated metal baseplate (NX-type model of the T-Series for industrial applications) were tested in a thermal cycle test (−40°C ↔ 125°C). Figure 5 shows scanning acoustic tomography (SAT) images after 600 cycles. Figure 6 illustrates the cross sections of the two types of sealing structures (diagrams).[3]

On the silicone gel sealing structure, as the thermal cycle test proceeded, a crack advanced slightly from the end of the solder layer in the lower section of the ceramic insulating substrate. On the other hand, the DP resin sealing structure has no solder joint layer between the baseplate because an integral-type substrate is used, so no component degradation was seen after the thermal cycle test. For both structures, no degradation was observed on the solder joint layers in the lower sections of the semiconductor devices after the thermal cycle test.

For the silicone gel sealing structure, the linear expansion coefficient of the ceramic insulating substrate is relatively close to that of the semiconductor device, so the stress on the solder joint layer is not so high. On the other hand, for the DP resin sealing structure, the difference between the linear expansion coefficient of the semiconductor device and that of the insulated metal baseplate is large, so the stress applied to the solder joint layer is high. However, the high-modulus DP resin with excellent adhesiveness covering the solder joint layer may have reduced the stress working on the solder joint layer.

In addition, the results of a power cycle test showed that the power cycle life of the new structure is equal to or longer than that of the conventional structure. This is further evidence of the high reliability of the resin sealing technology using DP resin sealing.

4. Conclusion

For the NX-type models of our T-Series seventh-generation IGBT modules for industrial applications and our J1-Series power semiconductor modules for automobiles, DP resin sealing using epoxy resin was adopted in place of silicone gel sealing which was mainly used in the conventional case type modules, thus improving the reliability of the power modules. We will accelerate the development of the next-generation power modules by improving the performance of the sealing technologies, including materials and production processes, to contribute to an energy-saving society.

5. References

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(3) Kaji Y., et al.: Novel IGBT Modules with Epoxy Resin Encapsulation and Insulating Metal Baseplate, Proc. 28th International Symposium on Power Semiconductor Devices and ICs (ISPSD), 475–478 (2016)