Relaxing Thermal Stress by Using SLC Technology and New PC-TIM

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1. Introduction

Solid cover (SLC) technology is applied to the structure of the LV100 (Fig. 1) to reduce the thermal stress. In addition, combining the SLC technology with a new type of phase change (PC)-thermal interface material (TIM), which has a high thermal conductivity, has made it possible to further enhance performance. The characteristics of the LV100 and the new PC-TIM are described below:

(1) The SLC technology increases the capacity and chip mounting area.
(2) Changes in the shape of the baseplate (warps) due to temperature changes are reduced.
(3) The new type of PC-TIM has high thermal conductivity and high heat resistance.
(4) The SLC technology combined with the new PC-TIM reduces the thermal resistance.

Fig. 1 LV100

2. SLC technology

Figure 2 shows schematic drawings comparing the structure with the conventional technology that uses a "conventional structure" and the structure with the SLC technology that uses an integrated substrate with resin insulation. Table 1 lists the features of the SLC technology for large-capacity modules. The adopted SLC technology increased the capacity and power density of the LV100 for industrial applications.

For power modules in the conventional structure, in cases when the rated current exceeds 1,000 A, the ceramic substrate must be divided into multiple sections to prevent cracking of the substrate. On the other hand, when the SLC technology is applied, there is no need to divide the substrate, so the area of the metal pattern on the substrate can be larger. As shown in Fig. 3, the pattern area of the industrial LV100 was increased by

Table 1 Features of SLC technology

#	Item	Advantage
1	Integrated substrate	Enlarges the chip mounting area
2	Optimization of the constituent materials' linear expansion coefficients	Reduces the thermal stress due to differences between the materials' linear expansion coefficients
3	Resin insulation material with high thermal conductivity	Reduces the thermal resistance

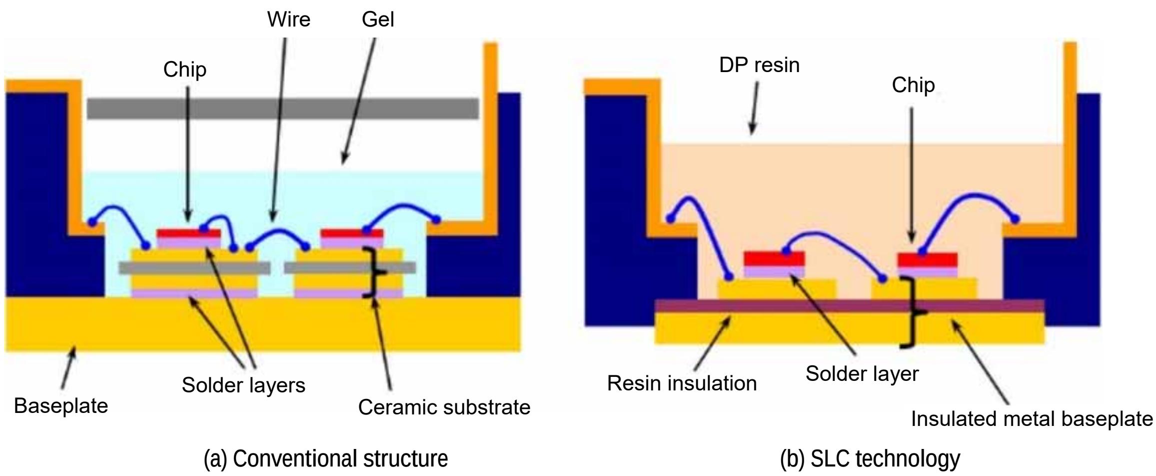

Fig. 2 Comparison of structures

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approximately 20% for the outline size of the LV100. Also, an undivided single substrate made it possible to reduce the area of the terminal joints, which allowed a further increase in the area ratio of the chip mounting section on the surface of the metal pattern. The increased chip mounting area can reduce the thermal resistance and increase the output from modules compared to the conventional structure.

In addition, in the SLC technology, the thermal expansion coefficients of the constituent materials have been optimized. The ceramic substrate and the solder under the substrate are eliminated and materials with similar thermal expansion coefficients are used to compose a module, which improves the heat cycle resistance.[3] Figure 4 shows the measured flatness of a baseplate in relation to temperature changes. Even for the LV100 with a large baseplate area, the SLC technology reduces the displacement of the baseplate due to temperature changes. This reduction of displacement improves the pumping-out resistant and makes it possible to reduce the thickness of the heat radiation materials, such as silicone grease and PC-TIM.

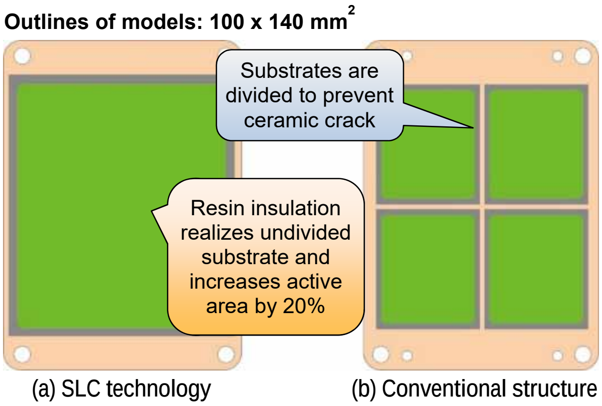

Fig. 3 Comparison of active area for Cu pattern

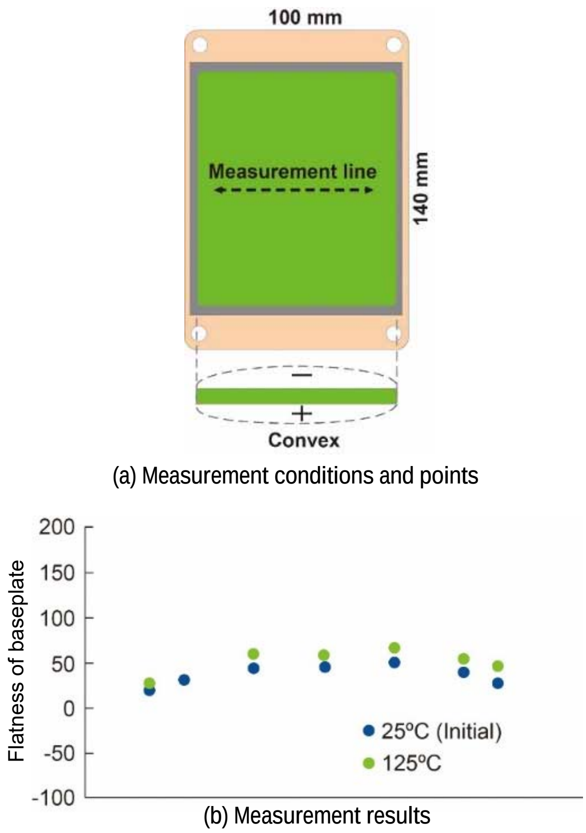

Fig. 4 Measurement results for baseplate flatness

Furthermore, the thermal conductivity of the resin insulation sheet was improved compared to the conventional sheet material used for our seventh-generation NX-type 1,200 V series. As shown in Table 2, the improvement in the sheet material's thermal conductivity reduced the thermal resistance by 6% while the isolation voltage was increased from 2.5 to 4.0 kV by increasing the thickness of the sheet.(4) Realization of the isolation voltage of 4.0 kV has made it possible to apply the SLC technology to 1.7 kV power modules. This sheet type with such high thermal conductivity has been used for the NX-type seventh-generation 1.7 kV system.

3. PC-TIM with high thermal conductivity and high heat resistance

To reduce thermal stress, it is important to improve the power module's heat dissipation and reduce the thermal contact resistance between the baseplate and the heatsink. We started applying the PC-TIM to the seventh-generation NX-type and std-type and are considering adopting a new type of PC-TIM for which the thermal conductivity and heat resistance have been improved. Table 3 compares the PC-TIM with the conventional specifications and those of the new type with high thermal conductivity and high heat resistance.

Table 2 Comparison of resin insulation sheets

Applied product	Resin insulation sheet	Withstand voltage	Ratio of thermal resistance (Rthj-c)*
Seventh-generation 1,200 V NX-type series, etc.	Conventional specifications	2.5 kV	1.0
Seventh-generation 1.7 kV NX-type series, industrial LV100, etc.	High thermal conductivity specifications	4.0 kV	0.94

Note: Thermal resistance ratio between the junction and the case for the same chip size

Table 3 Comparison of PC-TIMs

PC-TIM	Thermal conductivity [W/(m·K)]	Maximum service temperature (°C)
Conventional specifications	3.4	125
Specifications with high thermal conductivity and high heat resistance	4.0	150

The thermal conductivity of the new PC-TIM was improved to 4.0 W/(m·K) and can be used at 150°C. Figure 5 shows the results of evaluating the wet-spreading properties of the two types of PC-TIMs. The wet-spreading property has a trade-off relationship with the thermal conductivity based on the amount of filler content (Fig. 6 shows a conceptual drawing): when the thermal conductivity is improved, the wet-spreading property may decrease. To solve this, the constituent materials and filler diameter were optimized for the new PC-TIM, which improved the thermal conductivity without impairing the wet-spreading property.

Figure 7 shows the weight change rates of the two types of PC-TIMs in a high-temperature storage test at 150°C. For the specifications of high thermal conductivity and high heat resistance, the weight change rate at high temperatures was reduced by increasing the thermal decomposition temperature. This improvement allows the PC-TIM to be used at 150°C.

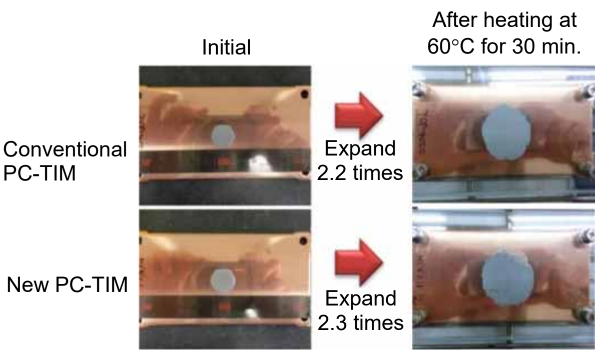

Fig. 5 Measurement results for wet-spreading property

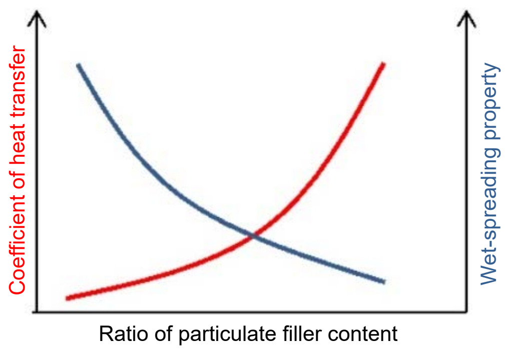

Fig. 6 Conceptual drawing of PC-TIM trade-off relationship

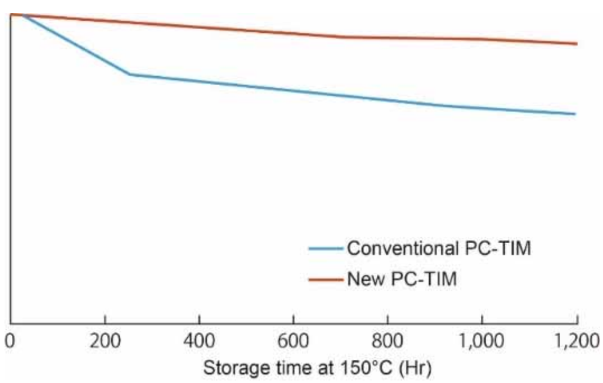

Fig. 7 Comparison results for weight change during storage test at 150°C

4. Reduction of thermal resistance

Combining the SLC technology with the new PC-TIM with high thermal conductivity and high heat resistance can reduce the thermal resistance. Table 4 shows the modelling conditions of the steady-state thermal analysis performed to check the heat dissipation. The outline size of the industrial LV100 was used for the analysis. For comparison, another model for which silicone grease was used as the heat radiation material with an Al_2O_3 substrate as the module structure was analyzed. In addition, the thickness of the heat radiation material in the SLC structure was decided at 50 μm because the displacement of the baseplate due to temperature changes was reduced. Figure 8 compares the thermal resistance of the two models calculated by the steady-state thermal analysis. The analysis results show that the thermal resistance of the model with the new technology is approximately half that of the model with the conventional technology. This demonstrates that the heat dissipation was improved by combining the new PC-TIM having high thermal conductivity and high heat resistance with the SLC technology.

Table 4 Conditions of thermal resistance calculation

Model	Structure	Heat radiation material*	Outline size (mm^2)
New technology	SLC structure	PC-TIM 4.0 W/(m·K) 50 μm	100 × 140
Conventional technology	Conventional structure (Cu baseplate + thin Al_2O_3 substrate)	Silicone grease 0.9 W/(m·K) 100 μm	

Note: The thickness of the heat radiation material is as recommended for each structure.

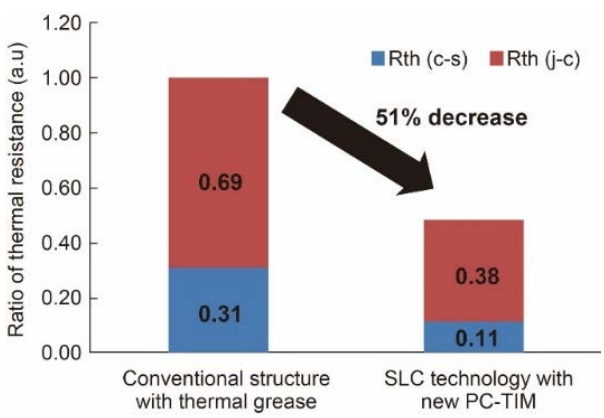

Fig. 8 Thermal resistance calculation results

5. References

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(4) Takahashi T., et al.: “A 1700V-IGBT module and IPM with new insulated metal baseplate (IMB) featuring enhanced isolation properties and thermal conductivity,” Proc. PCIM Europe, Nuremberg, Germany (2016)