Thermal Management Technology for IGBT Modules

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ABSTRACT

In power conversion systems that use IGBT modules, the thermal conductivity of the thermal grease utilized is designed as low as possible. As a result, the thermal grease thickness affects the IGBT chip temperature. This paper describes the effects of the hardness of components and the ingredients of the thermal grease on the spreading ability of the compound and the distribution of stress when tightening with screws. Additionally, in consideration of the stress distribution, we have proposed a metal mask pattern for applying the thermal grease as thinly as possible. As a result, the thermal grease can be applied at approximately 1/3rd the thickness of the conventional application technique.

1. Introduction

Recently, in response to global warming, new types of energy, such as wind and solar power, are being utilized and efforts to popularize hybrid cars are being promoted with the goal of reducing carbon dioxide emissions resulting from the use of fossil fuels. Also, as conventional electric and electronic devices are requested to provide ever higher levels of energy savings, IGBT (Insulated Gate Bipolar Transistor) modules required for power conversion and motor control are becoming more and more important. Moreover, as society becomes increasingly information-oriented, digitized data is becoming more and more prevalent, and there is renewed need for uninterruptable power supplies (UPS) and the like.

The required IGBT module characteristics differ according to the particular market, but higher efficiency and down-sizing are common requirements. For wind power generation, IGBT modules are used in the devices that convert the generated power. Power converters are often installed in limited spaces, such as inside a tower, and the IGBT modules are water-cooled to increase their mounting density and achieve a more compact size(1).

In response to requests for high density mounting, Fuji Electric has increased the performance(2) of IGBT chips. The IGBT modules have been developed with thermal management to achieve a more compact size and greater capacity simultaneously(3),(4). Fuji Electric also supplies a simulator for simulating the IGBT module loss and temperature under the operating conditions, and this simulator is necessary when designing an apparatus requested by a customer.

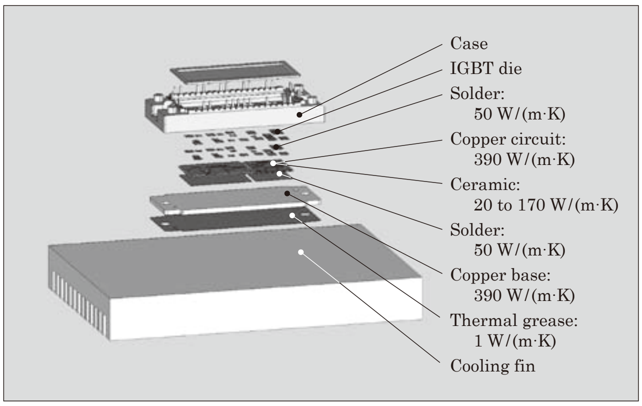
This paper introduces technology for attaining low thermal resistance by optimizing the usage of the thermal grease that thermally connects the IGBT module and cooling fin.

2. Background

The structure of a product that uses an IGBT module and the thermal conductivities of constituent components are shown in Fig. 1. So that heat generated from the die can escape, the IGBT module is used with a cooling fin attached. The cooling fin typically used with an inverter may have a surface roughness of up to about 100 μm maximum. When an IGBT module is mounted on a cooling fin, a gap is created, and this is a factor that degrades the thermal contact resistance. Generally, in order to reduce the thermal contact resistance, thermal grease is applied (printed) between the cooling fin and IGBT module.

The thermal conductivity of a typical thermal grease is approximately 1 W/(m·K), and as can be seen in Fig. 1, thermal conductivity is lowest in the path of thermal dissipation away from the IGBT mod-

Fig.1 IGBT module structure and main thermal conductivities



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ule. To increase the efficiency of the entire product that uses the IGBT module, reduction of the thickness of the thermal grease is requested. However, if the thickness of the thermal grease is reduced, spreading the thermal grease over the entire interface between the IGBT module and the fin will be difficult.

In the chapters below, we report on (1) factors affecting the spreadability of thermal grease and (2) the thermal grease printing method, and propose reducing the thermal contact resistance in a product that uses an IGBT module.

3. Factors Affecting the Spreadability of Thermal Grease

The thermal grease is printed onto the IGBT module or the cooling fin, and the force exerted by tightening the screws that secure the IGBT module to the cooling fin causes the thermal grease to spread out and fill the gap between the IGBT module and cooling fin. At this time, the IGBT module and cooling fin will be thermally connected. To observe the spreading of the thermal grease, grease was printed at a thickness of 30 μm in an area of 81 mm^2 between a glass block (having surface roughness of 5 μm or less) and a fin (having surface roughness of 5 μm or less), and screws to secure the glass block to the fin were tightened with 3.5 N·m of torque. The results are shown in Fig. 2. As can be seen in the figure, the thermal grease spread out around the screw locations, but despite using a flat fin, the spreading of thermal grease in the center area was poor. To investigate the cause, a photoelastic camera was used to measure the distribution of stress generated between the IGBT module and fin when the IGBT module and fin mounting screws are tightened. An FEM (finite element method) analysis was also performed at the same time.

Fig.2 Spreading of thermal grease

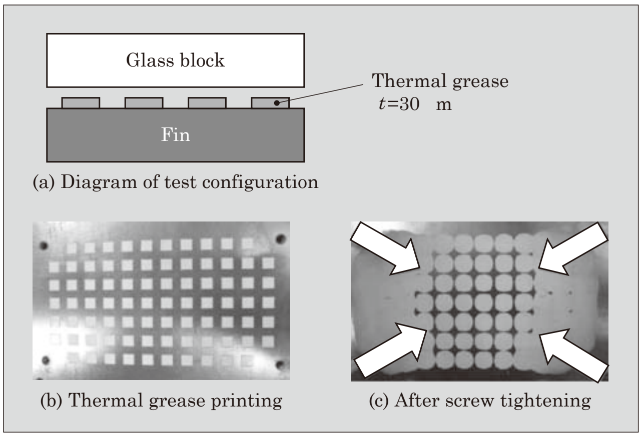


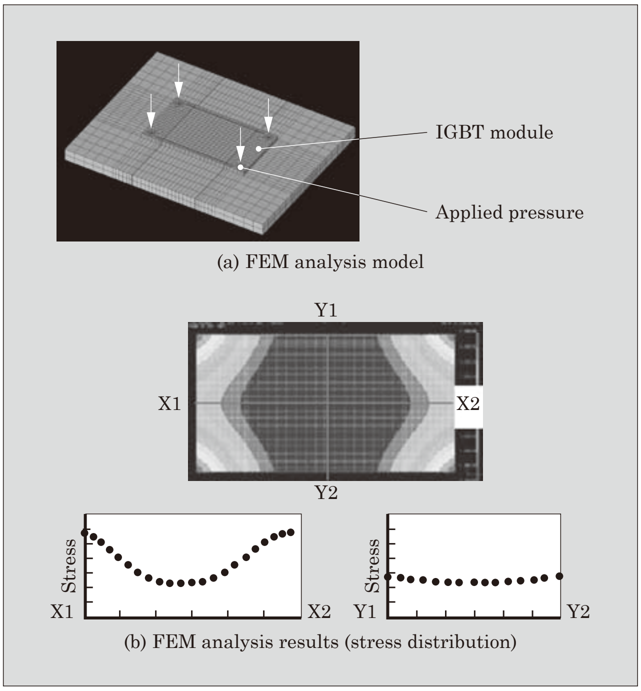
Fig.3 Results of stress distribution measurement using photoelastic camera

Figure 3 shows the results of measurement with the photoelastic camera of the distribution of stress generated between the IGBT module and fin. A large stress was found to be generated in the area surrounding the screws, and this finding exhibits a similar tendency as the grease spreading test results shown in Fig. 2.

Figure 4 shows the FEM analysis model and the analysis results. The analysis was carried out for the conditions of an IGBT module size of 119 mm×59 mm and the screws being tightened with 3.5 N·m of torque. The results of the FEM analysis showed that the stress generated between the IGBT module and fin is highest at the areas around the screws, but decreases when approaching the center area. These results clearly show that generated stress between the IGBT module and fin varies according to the distance from a screw location.

Next, the relationship between stress and the thickness of the thermal grease was investigated using grease manufactured by several different companies. The following types of thermal grease were used : Electrolube's HTC, Dow Corning's SH 340, American Oil & Supply's AOS 340 and Shin-Etsu Silicone's G747. A uniform amount of each type of grease was printed onto a flat plate, and then a glass block was laid on

Fig.4 FEM analysis model and analysis results



top, and pressure was applied. From the spread-out area of thermal grease at this time, the corresponding thickness of the thermal grease thickness was computed for each applied pressure.

Figure 5 shows the relationship between applied pressure and thermal grease thickness. It can be seen that the thermal grease thickness decreases as the applied pressure increases up to 0.1 MPa. However, at pressures above 0.1 MPa, the thickness did not fall below a certain level even if the applied pressure was increased. The reason for this behavior is thought to be attributable to the effect of the material composition of the thermal grease. The main components of ordinary thermal grease are ceramic powder and oil[6].

Figure 6 shows a SEM (scanning electron microscope) photograph of the ceramic particles used in thermal grease. It can be seen that the ceramic particles are several microns in size. The ceramic grains are believed to be the reason that the thermal grease thickness does not decrease below a certain level even if additional pressure is applied.

Thus, we examined factors that affect spreading of the thermal grease. As shown in Fig. 7 (a), in the

Fig.5 Relationship between applied pressure and grease thickness

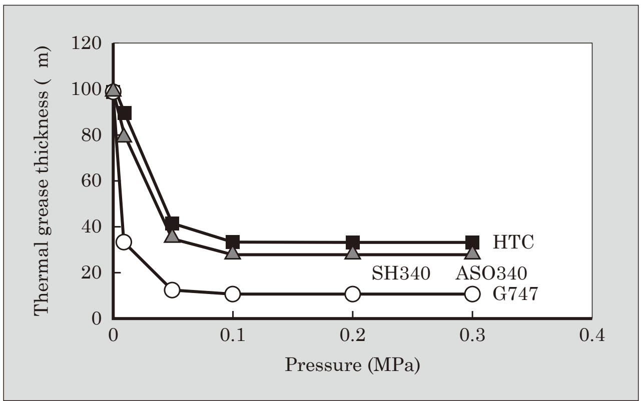
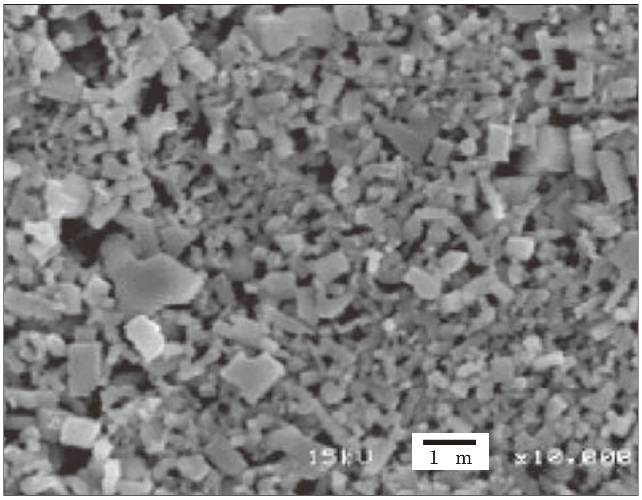


Fig.6 SEM photograph of ceramic material used in thermal grease



case where thermal grease is present at a location of high stress in the vicinity of a screw, the gap between the module and fin will be large, and there is a concern that force may not be transmitted to the center area. In other words, the printing pattern of the thermal grease is thought to affect its spreading. Therefore, we investigated the relationship between the initial pattern and the spreading of the thermal grease. Figure 8 shows how the thermal grease spreads according to whether grease is present in the areas surrounding the screws. In the case of sample A, in which thermal grease has been printed at the screw locations, the center area does not contact the fin. However, with sample B, in which thermal grease has not been printed at the screw locations, the thermal grease spreads over the entire surface.

If there exists areas to which the thermal grease has not spread, an air layer will be formed and result in a dramatic increase in thermal resistance. Therefore, until now, poor spreading of the thermal grease was counteracted by increasing the quantity of thermal grease applied.

From the above results, it is thought that the application of thermal grease at appropriate locations will enable a smaller quantity of thermal grease to be used, resulting in a lesser thickness of the thermal grease.

Fig.7 Relationship between grease location and pressure (schematic diagram)

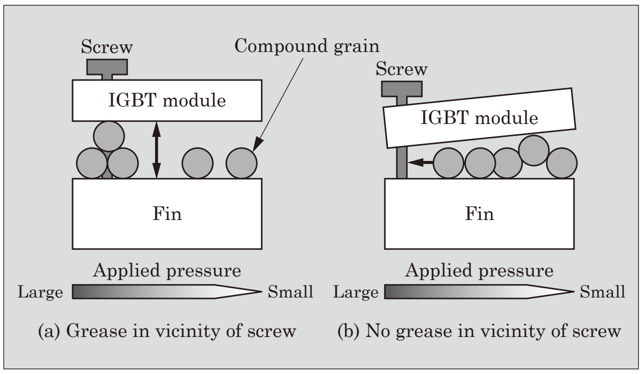
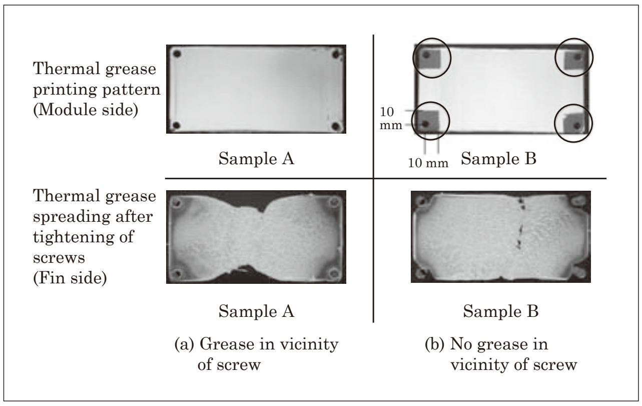


Fig.8 Relationship between thermal grease printing pattern and spreading (test results)



4. Development of Recommended Printing Method for Thermal Grease

4.1 Metal mask design

Based on the results of investigations into the causes of thermal grease spreading, we considered which method of thermal grease printing Fuji Electric should recommend. Typical methods of thermal grease printing involve the use of : (1) a dispenser, (2) a roller or spatula, and (3) a metal mask. When a dispenser is used for thermal grease printing, there is a large distance throughout which the grease can spread, and the spreading is easily affected by the viscosity of the thermal grease. In the case of thermal grease printing using a roller or spatula, there is significant variation in the application quantity and the quality will be inconsistent. For these reasons, Fuji Electric adopted the following method for controlling thickness of the thermal grease.

Fig.9 Thermal grease printing method using a metal mask

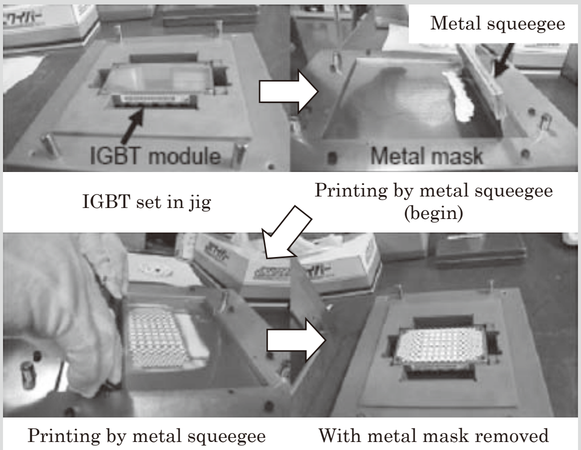
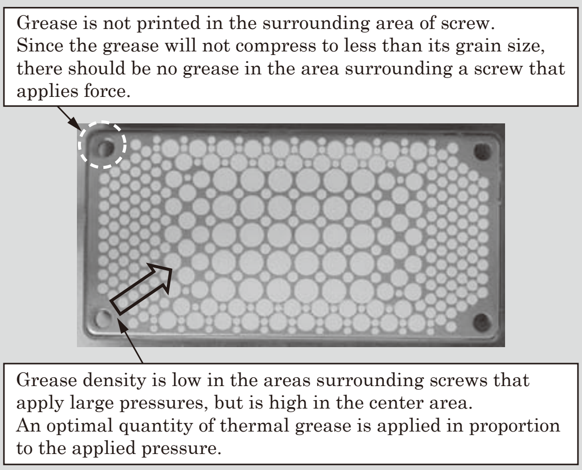


Fig.10 Recommend metal mask design



(1) Thermal grease printing shall be performed using a metal mask.
(2) Thermal grease shall be applied at appropriate locations (and no grease shall be applied in the area surrounding a screw).
(3) The quantity of grease applied shall be changed according to the level of stress generated between the IGBT module and the fin.

Figure 9 shows the method of thermal grease printing using a metal mask and Fig. 10 shows Fuji Electric's recommended metal mask design. Fuji Electric's recommended metal mask was designed so that thermal grease is not applied in the surrounding areas of screws and that the required quantity of thermal grease at each location is printed according to the stress level computed from the FEM analysis.

Next, we investigated the relationship between the printing method and the minimum thickness (printing quantity) of thermal grease required for grease spreading. For testing, a single IGBT module (having dimensions 119 mm×59 mm) and fin, and HTC thermal grease were used. Figure 11 shows the relationship between the thermal grease printing method and minimum required thickness (printing quantity). When using a roller, a mass of thermal grease corresponding to a thickness of approximately 100 μm is printed to spread over the entire surface between the IGBT module and the fin. On the other hand, it can be seen that when using Fuji Electric's recommended metal mask, a mass of thermal grease corresponding to a thickness of approximately 50 μm to spread over the entire surface between the IGBT module and the fin.

The above result demonstrates that printing using an optimal metal mask is a valid method, and that the use of Fuji Electric's recommended metal mask design

Fig.11 Relationship between thermal grease printing method and rate of spreading

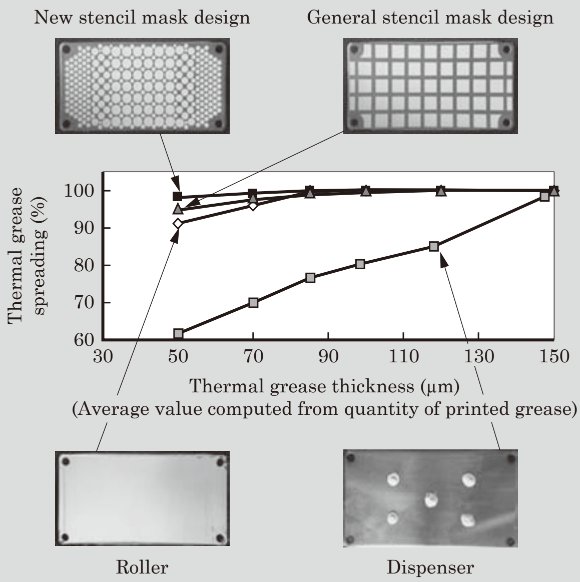
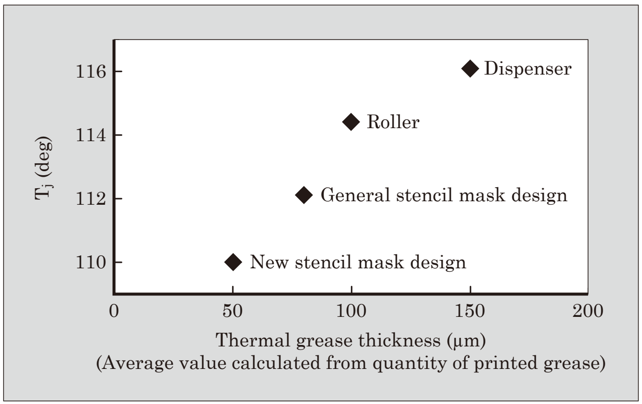


Fig.12 Relationship between thermal grease printing method and die temperature



is highly effective in optimizing the quantity of thermal grease to be printed.

4.2 Affect on die temperature

We investigated the effect of the printing method on the die temperature of the IGBT module.

In the testing, using the same IGBT module and fin, a current of 80 A was applied to the IGBT die and after 5 minutes had elapsed, the die temperature was measured with an IR camera. Figure 12 shows the required minimum thermal grease thickness for each printing method, and the measured results of the IGBT die temperature for each thickness. It can be seen that the IGBT die temperatures are different according to the thermal grease printing method.

It was verified that when using Fuji Electric's recommended metal mask, the maximum IGBT die temperature was 6 °C lower than in the case of a conventional printing method. The IGBT die temperature is the largest factor affecting the lifespan and efficiency of products that utilize IGBT modules. The use of Fuji Electric's recommended metal mask enables an appropriate quantity of thermal grease to be printed and realizes a decrease in thermal resistance in products that utilize IGBT modules.

5. Postscript

The following items were clarified in the results of our study of thermal grease printing as a thermal management method in product.

(a) The stress generated between the IGBT module and fin is affected by the printed pattern of the grease.
(b) An optimal pattern and quantity exist for the thermal grease to be printed.

From the above results, an optimal metal mask design was proposed for thermal grease printing. By disclosing the thermal grease printing method to our customers and applying Fuji Electric's IGBT modules, we aim to contribute to higher efficiency and energy savings in equipment.

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