Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp1071-1072

PS-14-08

High Temperature SiC Power Module Enhanced with Transient Thermal Characteristic by Al-bump Technology

Hidekazu Tanisawa[1, 2], Fumiki Kato [1], Kenichi Koui[1, 3], Shinji Sato[1], Kinuyo Watanabe[1], Hiroki Takahashi[4], Yoshinori Murakami[5], and Hiroshi Sato [1]

[1] National Institute of Advanced Industrial Science and Technology, [2]Sanken Electric Co., Ltd.,
[3]Calsonic Kansei Corporation, [4]FUJI ELECTRIC CO., LTD., [5]NISSAN MOTOR CO., LTD., Japan.
National Institute of Advanced Industrial Science and Technology Tsukuba Central 2, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8560, Japan
Phone: +81- 29-861-2858 E-mail: fupet-tanisawa@aist.go.jp

Abstract

The SiC power device can operate with low ON resistance, high speed switching, contributing to low loss of the power converter. Furthermore, the SiC power device can operate at a higher temperature than the Si power device. Utilizing this characteristic, the temperature difference between the inverter and the ambient temperature can be increased, and the cooling efficiency is improved. As a result, the cooling system can be simplified, and a small and high power density power converter can be manufactured.

In designing the cooling system, not only steady state temperature rise but also transient temperature rise is important. Suppressing this transient temperature rise indicates toughness against high load for a short time.

In this paper, we developed a module to suppress temperature rise against transient heat generation. This module is realized by placing a heat capacity near the heat source. The developed module was able to demonstrate the transient thermal resistance reduction effect in 0.03 to 3 seconds compared to the general wire bonding type module.

1. Introduction

In recent years, demands for energy saving are increasing against the backdrop of global warming and the rise in oil prices. For the reason, energy saving air conditioners and electric vehicles equipped with inverters have become widespread. Although Si devices have been conventionally used as the main switching devices of these motor driving power converters, application of SiC devices is being studied for further energy saving.

Besides having low loss, the SiC device can operate at a high temperature of 150 °C or higher, which cannot be used in general Si devices. When module using forced air cooling or natural air cooling operate semiconductor junction temperature at a high temperature (for example Tj = 200 to 250 °C), efficient heat dissipation is possible due to a large temperature difference from the outside air temperature, It is possible to realize miniaturization of the cooling system occupying a large volume in the cooling system. We made forced air cooling type inverter which can operate at 200 °C or higher in the past **[1-4]**.

Furthermore, while maintaining such miniaturization, we

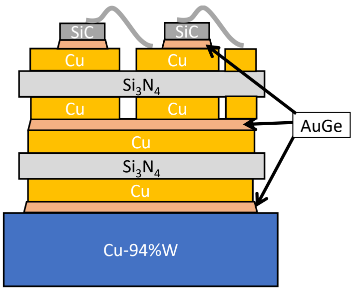

Fig. 1 Cross-sectional image of wire bond type.

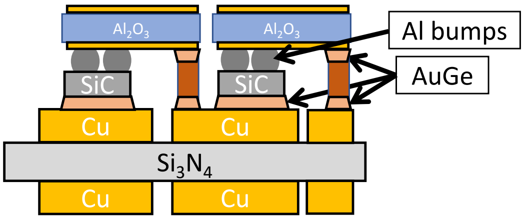

Fig. 2 Cross-sectional image near device in wiring board type.

think that a power module that can cope with a short-time load like an existing inverter is necessary. In that case, it is important to place a heat capacity in the vicinity of the power device, which is a heat source, to relax the temperature rise.

We have developed a flip chip mounting technology using Al bumps corresponding to 250 °C **[5]**. In this paper, we applied this technology and developed a power module with reduced transient thermal resistance by adding heat capacity at flip chip bonding near the junction which is the heat generating part of the device. We introduce how the transient thermal resistance tendency differs between developed module and module using general wire bonding.

2. Module structure and evaluation method

Module structure

Fig. 1 shows a sectional structure image of a wire bonding type module to be compared. As in the Reference [6], the structure has a structure in which two heat dissipation substrates using silicon nitride on the Cu - W base plate are stacked. SiC devices are mounted thereon and all are bonded with Au - Ge solder.

Fig. 2 shows the structure image of the power module near the device developed in this research. Since the lower part from the heat dissipating board has the same structure as the wire bonding type, the image is omitted. In this structure, the device and the wiring board are joined by flip chip mounting using Al bumps, not by wire bonding. Joining from the wiring board to the heat radiation board is joined with Au - Ge solder via the Cu-W block.

Fig. 3 shows the actual appearance of the module. Both modules used Cree's SiC-MOS, CPM 2 - 12000 - 0025B.

Evaluation method

Transient thermal resistance was measured for the fabricated module using T3Ster from Mentor. The measurement method is in accordance with the Reference [7].

3. Results and discussion

Fig. 4 shows the measurement results of the transient thermal resistance of wire bonding type and wiring board type. In both module structures, it turned out that after 3 seconds it was in steady state. However, it can be seen that the thermal resistance of the wiring board type is about 0.4 K / W at the timing of 0.1 ms, which is lower than 0.57 K / W of the wire bonding type. Fig. 5 shows the ratio of the transient thermal resistance of the wiring board type when the transient thermal resistance of the wire bonding type is 1. Values are normalized in steady state. It cannot be determined until about 2 ms because the measurement noise is large. It can be seen that transient thermal resistance of the wiring board type is excellent in the region from 3 ms to 3 s. The timing at which the ratio of the transient thermal resistance was the largest was about 15% at the timing of about 81.3 ms.

3. Conclusions

Using Al bump flip chip mounting technology, we fabricated a power module with heat capacity added close to the device. In this module, the transient thermal resistance was reduced in 3 ms to 3 s compared to the wire bond type that is generally used. The maximum transient thermal resistance reduction was about 15% reduction at 81.3 ms. We will further enhance heat capacity in the vicinity of the device and aim for further improvement of transient thermal characteristics.

Acknowledgements

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Next-generation power electronics/Consistent R&D of next-generation SiC power electronics" (funding agency: NEDO)

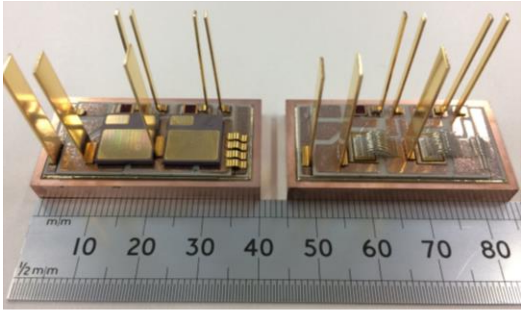

Fig. 3 Photograph of the power modules.

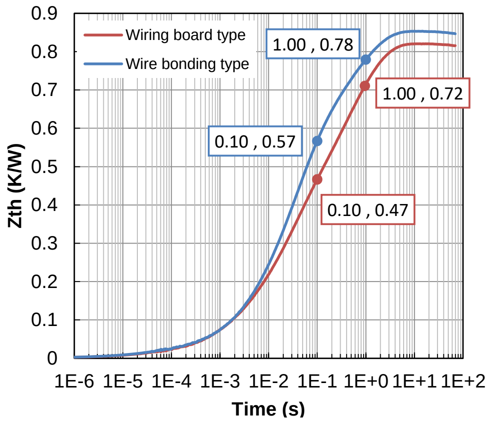

Fig. 4 Measurement result of transient thermal resistance.

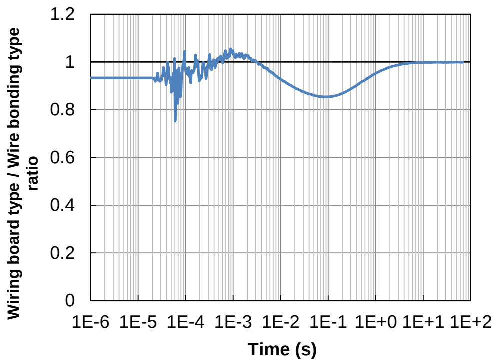

Fig.5 Transient thermal resistance ratio of wiring board type based on wire bond type.

References

[1] Kohei Matsui, et al., "A compact 5-nH one-phase-leg SiC power module for a 600V-40W/cc inverter", Silicon Carbide and Related Materials 2011 Part2, pp.1233-1236 (2011)

[2] Shinji Sato, et al., "Development of High Power Density All-SiC Three-Phase Inverter" , ECS Transactions, Volume 50, No. 3, pp. 15-24 (2012)

[3] Takeshi Anzai, et al., "Sandwich Structure Power Module for High Temperature SiC Power Semiconductor Devices", 47th International Symposium on Microelectronics, International Microelectronics Assembly and Packaging Society (IMAPS) Proceedings, pp.757-762 (2014)

[4] Shinji Sato et al., "Switching Analysis for a Full SiC Module", ECSCRM2016, 11, Sep. 2016.

[5]Hidekazu Tanisawa, et al., "Reliability Assessment of Flip-chip Assembly of Al Bumps", Journal of Microelectronics and Electronic Packaging April 2015, Vol. 12, No. 2, pp. 92-97

[6] Kenichi KOUI, et al., "Development of High Temperature and High Speed Switching Power Module by Double Layer Active Metal brazing Copper Substrate Structure", MES2016, 26, pp. 159–162, Mar. 2014. [in Japanese]

[7] F. Kato, et al., "Thermal transient measurement using body diode of SiC-MOSFET for thermal resistance analysis of power module package," ADPS 3rd meeting, pp. 300-301 (2016) [in Japanese].