Preface

Power Devices and Peripheral Technologies

FUNAKI, Tsuyoshi*

It is believed that the evolution of power devices is driven by the requirement of improving power electronics performance. The material and process for Si semiconductor material has been matured, and power devices employing Si are approaching performance limitation of material. Accordingly, wide bandgap semiconductors SiC (silicon carbide) and GaN (gallium nitride) are believed to invoke game change in power device development. News report simply addresses that the replacement of Si device to wide band gap semiconductor device, e.g. SiC device, achieves loss reduction. However, the replacement of device structure from bipolar to unipolar realizes loss reduction. Though, conventional Si semiconductor material employs a bipolar structure to realize both high breakdown voltage and low conduction loss at high voltages, but SiC semiconductor material can employ unipolar structure. Unipolar devices, such as metal-oxide-semiconductor field-effect transistor (MOSFET), have no loss due to knee voltage of PN junction. Moreover, unipolar devices do not employ conductivity modulation, then fast switching operation is achieved, and there is almost no loss resulting from reverse recovery or tail current. The wide bandgap is beneficial in maintaining breakdown voltage at high temperatures.

A large distance between conductors is required to secure insulation for high voltage circuit. This increases parasitic inductance in wiring. Fast switching operations increase the time rate of change in circuit current and increase surge voltage with interacting parasitic inductance. In this way, there is a trade-off between employing higher circuit voltage and adopting high-speed switching. Modularization of multiple power devices and circuit components is necessary to improve this trade-off.

Passive components such as inductors, transformers, and capacitors dominate large volumes and weights in power electronics systems, and high-frequency switching operation is required to miniaturize them. The fast switching capability of MOSFET enables high-frequency switching operations. But, it must be careful about high-frequency switching operation of MOSFET with hard switching. It is believed that the faster the switching speed is, the lower the switching loss is. However, during MOSFET is turning-on, the stored electric charge in the depletion layer is shorted via a channel, resulting in switching loss. This loss is constant, regardless of switching speed. Therefore, the loss increases in proportion to switching frequency in hard switching operation, which makes it difficult to increase the switching frequency. It is therefore necessary to apply soft switching with zero voltage turn-on to increase switching frequency. It is necessary to detect zero cross timing of voltage and current to ensure reliable soft switching, and sensing devices must also be integrated into power modules.

The miniaturization of power modules to reduce parasitic inductance also leads to an increase in heat generation density due to loss at power devices, and it is therefore necessary to improve heat dissipation and thermal resistance. Power device die*1 are attached to a module substrate for current output and heat dissipation. Die attachment*2 with solder offers high thermal resistance, however, mitigates the stress generated as a result of the difference in thermal expansion coefficient with the copper plate on the module substrate, and by temperature changes. The process temperature of sintered metal die attach, such as silver, is lower than the melting point, and it results in low thermal resistance. However, thin bonding layers to ensure low thermal resistance is difficult to mitigate thermal stress. There are many difficulties in sintering die attach process to be overcome such as requiring pressurization in the bonding process in order to ensure sufficient bonding strength and reliability. Moreover, the miniaturization of high-voltage power modules results in high electric field inside module. Consequently, in addition to power devices, insulating substrate materials and sealing material must also have high critical electric field. Insulating materials are required to have not only high dielectric breakdown capability, but also electrical characteristics such as no space charge accumulation and maintain volume resistivity at high temperatures, as well as free from partial discharge due to void formation. We must therefore simultaneously satisfy mechanical and chemical properties such as degassing in the sealing process and substrate material adhesion. Furthermore, the miniaturization

* Ph.D (Engineering), Professor, Graduate School of Engineering, Osaka University

*1: Die: semiconductor chip

*2: Die attachment: bonding semiconductor chips to a substrate of power modules reduces the thermal conduction area. Consequently, further improvements in cooling performance using methods such as double side cooling or direct water cooling are also required at the same time.

As discussed above, we must simultaneously develop and apply a variety of peripheral technologies to effectively utilize the performance of evolving power devices. In other words, we need to integrate technologies and knowledges across different fields such as power devices, metallurgy and dielectric materials, as well as thermodynamics and mechanical engineering. To achieve this, we need to see development from the perspective of these issues involving the cooperation of industry, government, and university.

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