SiC Lecture Series

2. The History of Research and Development of SiC Power Devices at Mitsubishi Electric

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In the 1990s, Mitsubishi Electric began research and development of SiC (Silicon Carbide) that directly led to today's various SiC power device products. Initially, the quality of SiC crystals was inadequate, and the device structures and manufacturing processes suitable for SiC were still being explored. However, we dedicated ourselves to research and development with the belief that the SiC MOSFET would be the device that could maximize the advantages of SiC's excellent physical properties.

Utilizing support from national projects, Mitsubishi Electric developed a small SiC MOSFET chip with a breakdown voltage of 2kV in 2003, and a prototype SiC MOSFET with a breakdown voltage of 1200V and a current rating of 10A in 2005. By evaluating the dynamic characteristics of the 10A class SiC MOSFET, we demonstrated that switching losses could be dramatically reduced compared to Si IGBTs. Subsequently, we continued to develop high-current chips, high-voltage chips with a breakdown voltage of 3.3kV, and SiC MOSFETs with various integrated functions. Mitsubishi Electric has been consistently advancing the development of high-performance, highly reliable, and user-friendly SiC MOSFETs.

Mitsubishi Electric has internal divisions for device development, power electronics application development, and system development. Leveraging this advantage, we grappled with the development of SiC MOSFET inverters in parallel with the development of SiC chips. In 2007, we succeeded in making a prototype of a 3.7kW-class inverter using SiC MOSFETs, which demonstrated a 50% reduction in inverter losses. By 2009, we had also made 11kW-class and 20kW-class inverters, showing that inverter losses could be reduced by 70-90% depending on the driving conditions. During this period, the quality of SiC wafers improved rapidly, and technical knowledge regarding various SiC processes accumulated, leading to a growing realistic expectation for SiC power devices. However, some manufacturers remained skeptical about SiC MOSFETs due to concerns over the reliability of the gate oxide film.

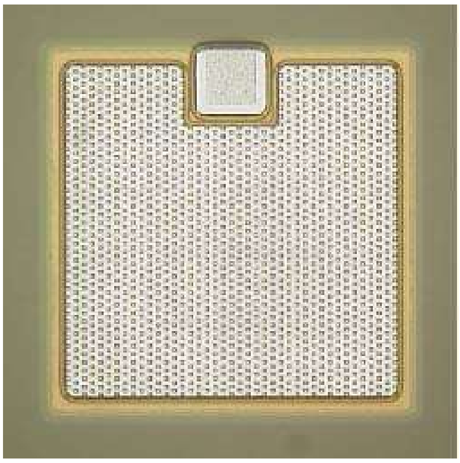

Figure 1 Mitsubishi Electric's SiC MOSFET chip in the early stages of development

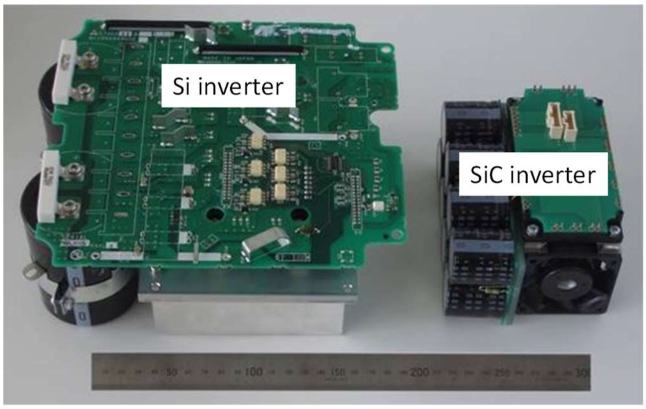

Figure 2 Size comparison of 11kW-class Si inverter and SiC inverter

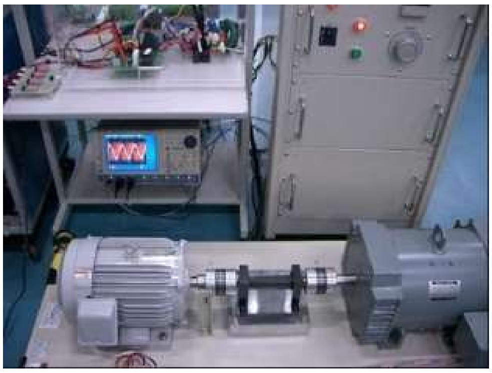

Figure 3:
Motor drive test using a SiC inverter

Mitsubishi Electric has been actively working on the development of systems applying SiC devices from an early stage. In 2010, we were quick to commercialize air conditioners equipped with hybrid DIPIPM™ using SiC SBDs. In 2011, we developed a high-capacity hybrid SiC module rated at 1200A/1700V and applied it to drive inverters for subway vehicles. Regarding SiC MOSFETs, we succeeded in commercializing an inverter for railway vehicles using a 3.3kV-rated full SiC module in 2013. The 3.3kV full SiC module has been applied to drive inverters for many railway vehicles, including high-speed trains, and is used in commercial operations. Additionally, Mitsubishi Electric introduced SiC MOSFETs into industrial IPMs in 2015 and into consumer DIPIPM™ in 2016, contributing to the reduction of losses in applied systems. The application of SiC MOSFETs to railway vehicle inverters, in particular, had a significant impact on the industry, accelerating the commercialization and widespread adoption of SiC MOSFETs, leading to the present day.

Figure 4
Full SiC Module 3.3kV/750A

Figure 5
Full SiC Power Module NX Type
1.7kV/600A

Figure 6
Full SiC DIPIPM
600V/15A、25A

Mitsubishi Electric developed and established production lines for SiC devices starting with 2-inch and 3-inch lines in the 2000s, followed by the construction of a 4-inch line in 2009, which marked the beginning of product commercialization. In the late 2010s, we established our current main production line, the 6-inch line. Looking ahead, both wafer vendors and device manufacturers are considering the transition to 8-inch wafer lines, and Mitsubishi Electric is also progressing with development plans to commence operation of an 8-inch line by 2026. The market for SiC devices is expected to significantly expand in the future, particularly for applications in electric vehicles (EVs) and renewable energy. The transition to 8-inch wafers is anticipated to drive cost reductions and improvements in productivity, which are highly anticipated to be key factors in this market growth.

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