SiC Lecture series

1. History of Mitsubishi Electric Power Devices

History of Mitsubishi Electric Power Devices

Semiconductor devices are indispensable in today's rapidly developing power electronics equipment, playing a crucial role in advancing science, technology, and societal progress. Mitsubishi Electric, as an innovator in many technical fields, holds a significant position in the semiconductor industry. The keys to Mitsubishi Electric's success are its superior technology, state-of-the-art manufacturing processes, and ample production capacity. The history of Mitsubishi Electric's power devices is illustrated in Figure 1 below.

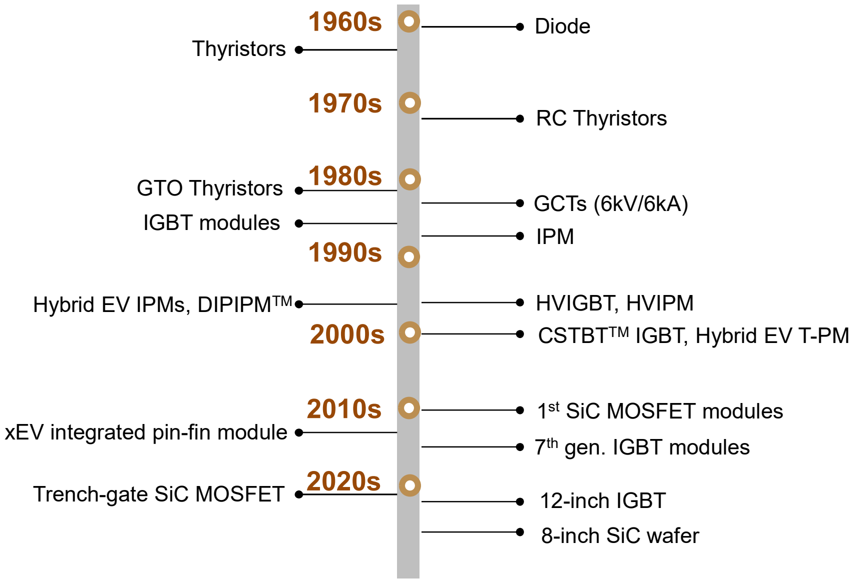

Figure 1 History of Mitsubishi Electric Power Devices

In the 1960s, Mitsubishi Electric introduced high-power diodes and thyristor products. Thyristors have played a role in the modernization of power electronics, continuously moving towards higher withstanding voltage and higher current. In the 1980s, GTO (Gate Turn Off) thyristors were developed, evolving from reverse-blocking thyristors without self-turn-off capabilities. These GTO thyristors can change from an on state to an off state by applying a negative voltage signal to the gate. Additionally, GCT (Gate Commutated Turn off) thyristors inherited the basic structure of GTO thyristors and achieved high-speed operation and superior shutdown performance by significantly reducing gate impedance. This design enables rapid extraction of gate current during turn-off, although it requires a gate driver capable of handling high peak currents due to the low gate impedance. The SGCT (Symmetrical Gate Commutated Turn off) thyristor unit, which integrates an optimized gate driver, fully harnesses the performance of GCT thyristors with reverse blocking capability, while simplifying system design.

In the 1980s, Mitsubishi Electric developed MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) modules and IGBT (Insulated Gate Bipolar Transistor) modules. MOSFETs, known for their high-speed switching, voltage-driven operation, and low loss, have been widely used in various medium and small power electronics conversion circuits. IGBTs combine the advantages of BJTs, such as low drive power, fast switching speed, low on-state voltage drop, and high current capacity, making them the main devices in modern power electronics technology and occupying an important position in medium to high-power supply applications.

■IGBT and IGBT module

The development history of Mitsubishi Electric's IGBT chips is illustrated in Figure 2. The structure of the fourth-generation IGBT chips has evolved from a planar gate structure to a trench gate structure. The fifth-generation IGBT chips, based on trench gate IGBTs, incorporate a charge storage layer, known as the CSTBT™ structure. This addition improves the trade-off relationship between shutdown losses and collector-emitter saturation voltage drop, thereby reducing power losses. Building on this, the sixth and seventh-generation IGBT chips continue to optimize the chip structure, reduce wafer thickness, and further minimize losses.

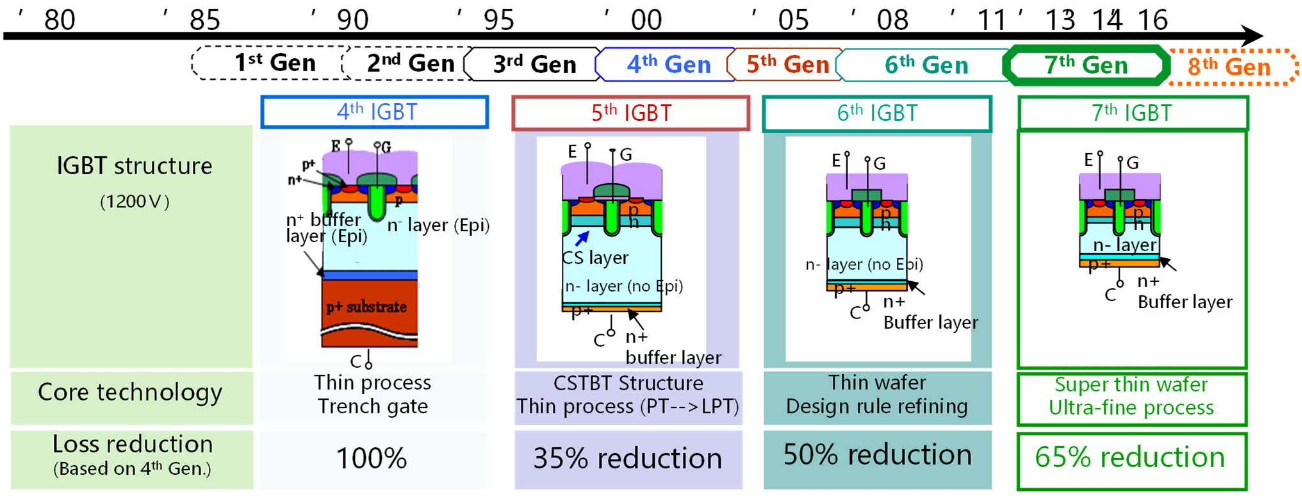

Figure 2 IGBT Chip Development Roadmap

As shown in Figure 3, the structure of the seventh-generation IGBT modules adopts direct epoxy potting resin and integrated insulated metal substrate (IMB), eliminating the solder layer between the insulation layer and the metal base plate, thereby significantly enhancing the thermal cycle capability of the IGBT modules. Based on this, the industrial LV100 package IGBT (Figure 4) has been developed to cover multiple voltage levels (1.2kV, 1.7kV, 2kV), featuring higher current density and high reliability, making it suitable for applications such as solar power generation, wind power generation, hydrogen electrolyzer, and motor drives.

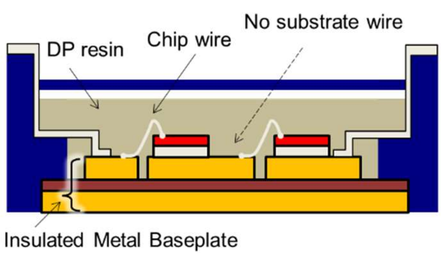

Figure 3 New Structure of Seventh-Generation IGBT Module

Figure 4 Industrial LV100 Package IGBT module

■IPM

In 1989, Mitsubishi Electric originally proposed the concept of the Intelligent Power Module (IPM). As shown in Figure 5, the integrated solution of the inverter, drive circuit, and protection circuit significantly reduces the size, cost, and development time of the system.

As shown in Figure 6, the latest G1 series IPM achieves very low losses by using the same IGBT chip and diode chip technology as the seventh-generation IGBT modules. In addition to the conventional IPM features of low voltage protection (UV), short circuit protection (SC), and overheating protection (OT), the G1 series also includes switching speed control functions and fault identification functions, contributing to improved performance and reliability of inverter equipment.

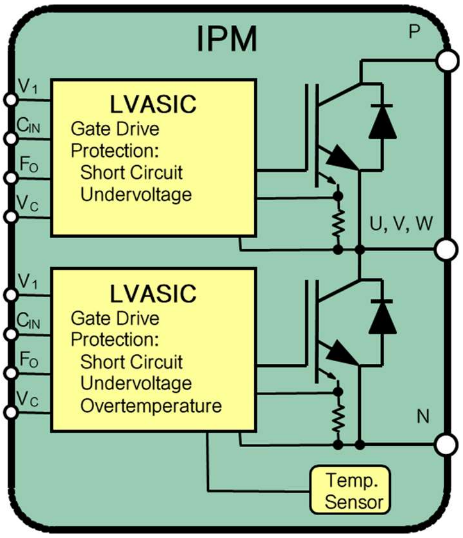

Figure 5 Internal Block Diagram of IPM

Figure 6 G1 Series IPM

■HVIGBT Modules

In 1996, Mitsubishi Electric's HVIGBT was introduced to the market, and due to its excellent performance and high reliability, it has been widely used in fields such as railways and power transmission. After continuous optimization and improvement, Mitsubishi Electric has successively launched the H series, R series, and X series, covering a voltage range from 1.7kV to 6.5kV, and has continuously expanded the current ratings of IGBTs.

Mitsubishi Electric's latest X series HVIGBT modules have a maximum operating junction temperature of 150°C and improve product operational reliability by optimizing the chip terminal design and the internal structure of the package, enhancing heat dissipation, moisture resistance, and flame retardance. There are two types of packages: the standard package HVIGBT shown in Figure 7 and the LV100/HV100 package shown in Figure 8.

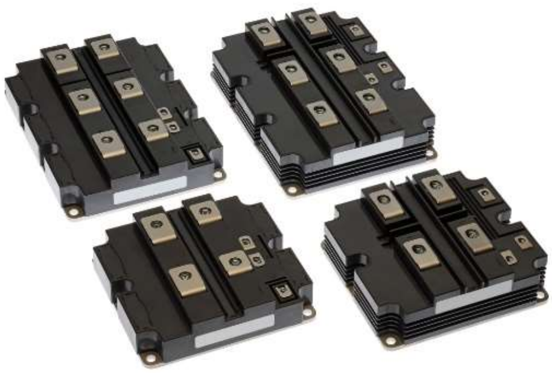

Figure 7 Standard Package

Figure 8 LV100/HV100 Package

■DIPIPM™

In 1997, Mitsubishi Electric developed the DIPIPM™ as shown in Figure 9 and 10. This module integrates a driver chip, achieving single power drive, and incorporates protection functions such as undervoltage, overtemperature, and overcurrent, reducing the design difficulty of converters and enhancing the reliability of converters.

Since the birth of the first-generation DIPIPM™, Mitsubishi Electric has continuously upgraded its DIPIPM™ products through the development of IGBT chip technology and continuous improvement of packaging technology. This has led to the evolution of the seventh-generation DIPIPM™, with packaging forms developing into small, ultra-small, SLIMDIP™, SOPIPM™, and DIPIPM+ formats. Mitsubishi Electric is committed to providing customers with higher energy efficiency, greater integration, more intelligent solutions, higher power density, and more cost-effective products.

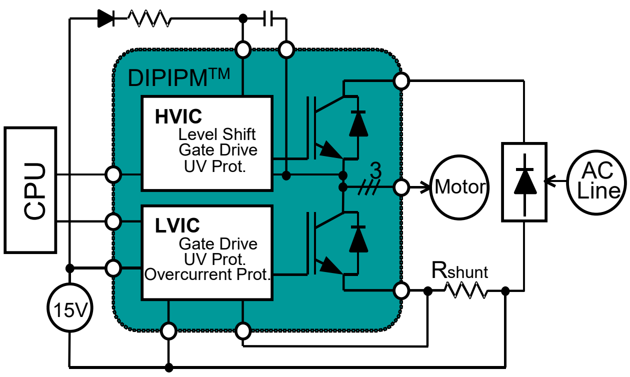

Figure 9 Block Diagram of DIPIPM™

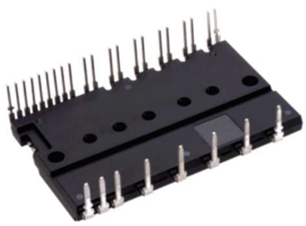
Figure 10 Appearance of DIPIPM™

■Modules for xEV

In 1997, Mitsubishi Electric successfully applied power modules for electric vehicles to HEVs (Hybrid Electric Vehicles), building a track record of mass production and application. To date, over 26 million electric vehicles equipped with Mitsubishi Electric power chips and power modules are in operation. Starting from the fifth generation, Mitsubishi Electric adopted T-PM (Transfer Mold Power Module) technology, replacing the conventional silicone gel potting with epoxy resin, thereby improving vibration resistance and module mounting flexibility.

The J1A series IGBT modules use the DLB (Direct Lead Bonding) connection process to bond copper terminals (copper frames) to the chip, resulting in more uniform temperature distribution, lower maximum temperature, and improved power cycle life. Additionally, the latest automotive power modules, the "J3 series," feature a high-reliability, mass-production press injection molded package compatible with RC-IGBT and SiC MOSFET, accommodating high-speed switching and parallelization. This contributes to further improvements in power density and driving range of electric vehicles. The J3-HEXA-S contains three J3-T-PMs, and the J3-HEXA-L contains six J3-T-PMs, both equipped with unique copper heat sinks to support various power segment designs of xEV inverters.

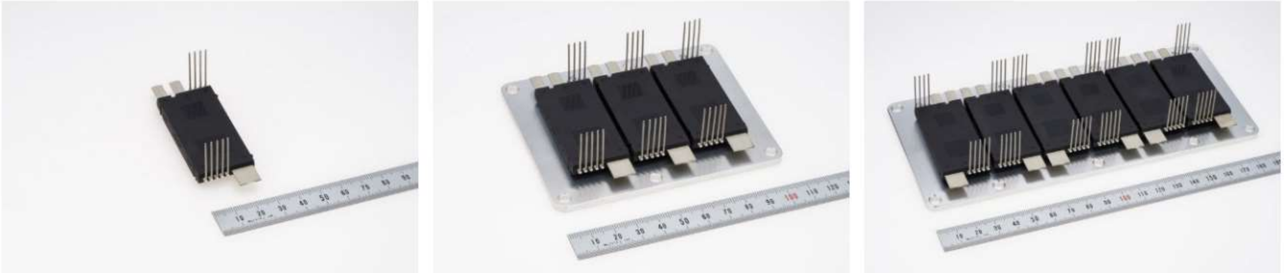

Figure 11 J3 T-PM、J3-HEXA-S、J3-HEXA-L

■SiC Modules

Mitsubishi Electric has been engaged in research on SiC-related technologies since 1994, accumulating 30 years of experience. The first decade, from 1994 to 2004, focused on the research and development of chip technologies such as SiC MOSFETs and SiC SBDs. From 2005 to 2009, Mitsubishi Electric concentrated on the application development of SiC power modules, designing and evaluating inverters based on SiC power devices for various applications. The commercialization of SiC power modules began between 2010 and 2014, with Mitsubishi Electric releasing several types of first-generation all-SiC power modules and hybrid SiC power modules.

By 2025, the second-generation planar gate SiC MOSFETs are being mass-produced stably, and the third-generation trench gate low-voltage SiC MOSFETs and high-voltage SiC MOSFETs embedded with SBDs are scheduled for sequential adoption. Tens of SiC power modules, ranging from 600V to 3300V, have been commercialized for applications in home appliances, industrial, new energy, automotive, and traction fields. The new 3300V, 200A/400A/800A Unifull™ series adopts SBD embedding technology, which significantly reduces switching losses and improves the performance of SiC modules.

Figure 12 Unifull™ 3300V
SBD Embedded SiC MOSFET

January 2025
Power Device Works