Next-generation Power Electronics

Power Electronics Devices Everywhere, for an Energy-efficient Society and More Affluent Lifestyles

Power Electronics Technologies Supporting Power in the Super Smart Society of the Future

Anyone could wish for a future society that balances the environment with lifestyle conveniences. And power electronics is a key technology to realize such a future. Already, improvements in power electronics development have resulted in energy savings for everything from home appliances to trains. The global market of power electronics is poised for significant future growth, and Japan has the opportunity to develop world-leading, next-generation power electronics technologies that will provide both competitive industry advantage and an energy-efficient society enjoying more affluent lifestyles.

Program Director

OOMORI Tatsuo

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* The affiliation and title of PD shall be as of the end of the 1st period (the end of FY2018).

Profile

OOMORI Tatsuo graduated from the University of Tokyo with an MS degree in Electronic Engineering in 1980, after which he joined Mitsubishi Electric Corporation Central Research Laboratory. He was promoted to manager of the company's Advanced Device Technology Department, Advanced Technology R&D Center in 2003. Named SiC Device Development Group Manager in 2005, OOMORI was next promoted to Power Device Works Deputy General Manager in 2010. He was appointed Corporate Research and Development Group Fellow in 2013, and then to Chief Technical Adviser of the Corporate Research and Development Group in 2016.

Research and Development Topics

Ⅰ. Development of fundamental basic technologies related to silicon carbide (SiC) (higher voltage ratings, downsizing, smaller loss, and higher reliability)

Promotion of the development of basic technologies underlying SiC power electronic devices, for which we set up a research and development (R&D) center that has brought together the industrial, academic, and government sectors for technology development of the next-generation SiC wafers, devices, and modules that are more compact and reliable, capable of handling higher voltages with minimal losses. The new center has also incorporated various training programs for researchers.

Ⅱ. Development of common fundamental technologies related to GaN (improvement of wafers and development of vertical power devices)

Bolstering of basic technologies for gallium nitride (GaN) power electronics, for which the program has constructed/provisioned a research center, which facilitates collaborations between a network of experts from industrial, academic, and government bodies. The center has focused on developing reliable production systems for the manufacture of next-generation GaN wafers for power devices with minimal defect rates, along with vertical GaN power devices.

Ⅲ. Basic research and development concerning applications of the next-generation power modules

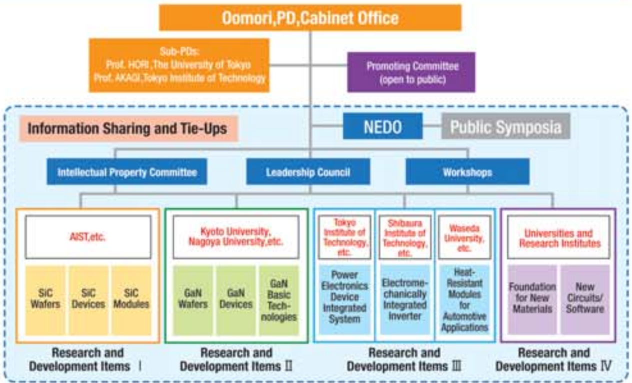
Promotion of the use of next-generation power modules and broadening of the scope of potential applications, for which the program developed implementation technologies to achieve more efficient high-performance power converter systems and motor drive systems that offer high power densities. Additionally, the program employed simulation technologies to enable the efficient integration of these systems into the power modules and aid the design of product prototypes.

Ⅳ. Basic research and development for future power electronics

Production of high-performance power devices that surpass SiC and GaN, for which the program will promote research to achieve innovative performance improvements. This will include pioneering studies of gallium oxide (Ga_2O_3), diamond, and other new materials, along with the development of new structures and circuits supporting foundational technologies beyond traditional power electronics. The goal of this project is to achieve commercialization within the next 10 to 15 years.

Implementation Structure

Establishment of a Promoting Committee comprising representatives from government ministries and experts guided by the Program Director (PD) and Cabinet Office. We utilized the resources of NEDO and leveraged NEDO's relationship with JST to help select research project leaders and assist the PD and Promoting Committee. We set up an Intellectual Property Committee, Leadership Council, and workshops at the underlying levels. With the exception of public symposiums, these organizations were run under a closed structure, while internal cross-pollination, frank discussions, and horizontal partnerships were encouraged. These organizations coordinated material assessment in conjunction with the AIST and universities—separate from the SIP—that enabled discussion and debate throughout the organization as a whole.

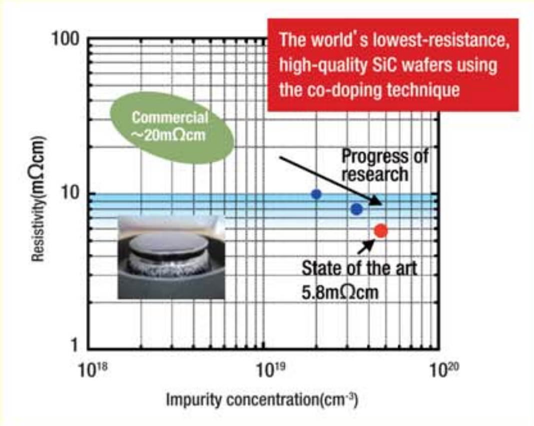


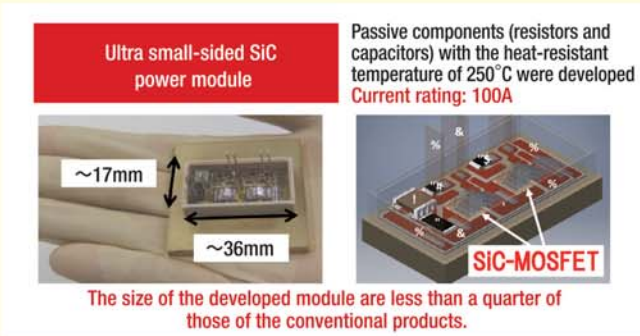
* It shows the structure and organization at the end of the 1st period (the end of FY2018).

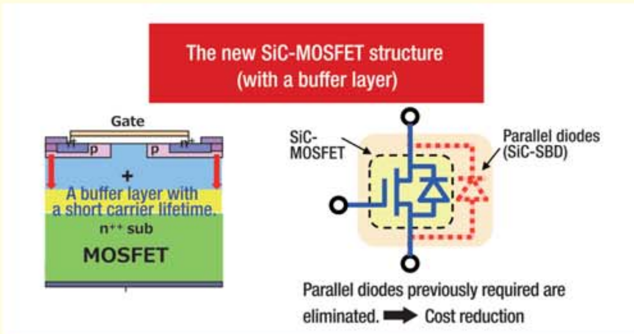
Achievement over the last 5 years

Major result (1): Low-resistance SiC wafers, the new SiC-MOSFET structure, and Ultra small-sized power modules

Several designs of the SiC (silicon carbide) power devices are already in the product development stage. However, there is room for further improvement regarding SiC performance. In the field of wafers, using a co-doping technique involving the addition of two types of impurities, we achieved high-quality wafers, which had about a quarter of the resistance of commercial wafers (upper right figure). In the field of devices, having shed light on the mechanism of current degradation during high current density operation, we developed a new SiC-MOSFET structure (lower right figure) to suppress defects by inserting a buffer layer with a short carrier lifetime. This led to a stable high current density operation and eliminated the need for parallel diodes, which were previously required in the modules. As a result, we achieved simplifying the main circuits and building more compact and less cost modules. Additionally, to reduce the module size, we developed passive components and materials with a heat-resistant temperature of 250 °C (175–200 °C for the conventional components and materials), thereby achieving the next-generation high temperature and high speed SiC module. The size of the developed module are less than a quarter of those of the conventional products (1.25 kV - 100 A, 2-in-1 type) (lower left figure).

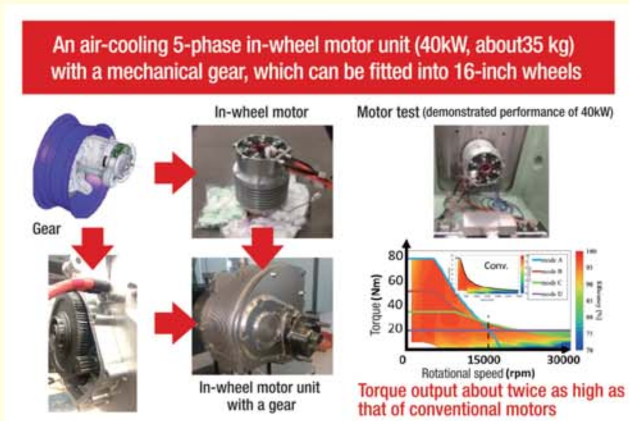






Major result (2): An in-wheel motor-inverter integrated system for EVs

An air-cooling motor-inverter integrated system in a five-phase drive and motor-winding switching method using SiC power modules was developed resulting in the smaller size and reduced losses, due to the high-temperature drive and high-speed switching characteristic of the SiC modules. Additionally, the developed motor-inverter integrated system was converted into an air-cooling five-phase in-wheel motor unit (approximately 35 kg in weight) with a mechanical gear, which can be fitted into 16-inch wheels. The motor bench test demonstrated a system performance of up to 40 kW, with about twice the torque and half the inverter loss, as compared to the conventional motors. Furthermore, the winding switching behavior of the motor proved stable, and it was demonstrated that the developed system could be applied to motors to enable the EV/FCV drive, thus illustrating an application of the SiC motors.



Major result (3): 6.6kV transformerless power converter for interconnection

A 6.6kV transformerless power converter for interconnection (200 kVA) (a static synchronous compensator) based on the modular multilevel cascade converter (MMCC) was developed with establishing applied technologies such as the high-frequency stable operation of the 3.3kV SiC power modules. The delta connection method, which outputs the reversed-phase power and reduces the number of bridge cells, and the newly developed DC voltage balance control method were adopted. We conducted a verification test using a power system in the factory to reveal/demonstrate the stability of the behavior and control performance at the time of interconnection, and the power conversion efficiency of ≥98.5% (with less than half the conventional loss). High efficiency was realized by reducing the power loss in the power conversion system via the SiC device and eliminating the use of transformers for interconnection.