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

Tatsuo Oomori

Mitsubishi Electric Corporation
Chief Technical Adviser, Corporate Research and Development Group

Profile

Tatsuo Oomori 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. Create a center for common basic technology development related to SiC

To promote the development of basic technologies underlying SiC (silicon carbide) power electronics devices, we will set up a R&D center that brings together the public, private and academic sectors to design the next generation of SiC wafers, devices and modules. These advancements will produce more compact, more reliable technologies capable of handling higher voltages with minimal losses. The new center will also provide researcher training programs.

Ⅱ. Create a center for common basic technology development related to GaN

To bolster basic technologies for gallium nitride (GaN) power electronics, the program will construct a research center as a home for a network of industry-academia-government experts. The center will focus on developing reliable production systems for next-generation GaN wafers for power devices with minimal defect rates as well as vertical GaN power devices.

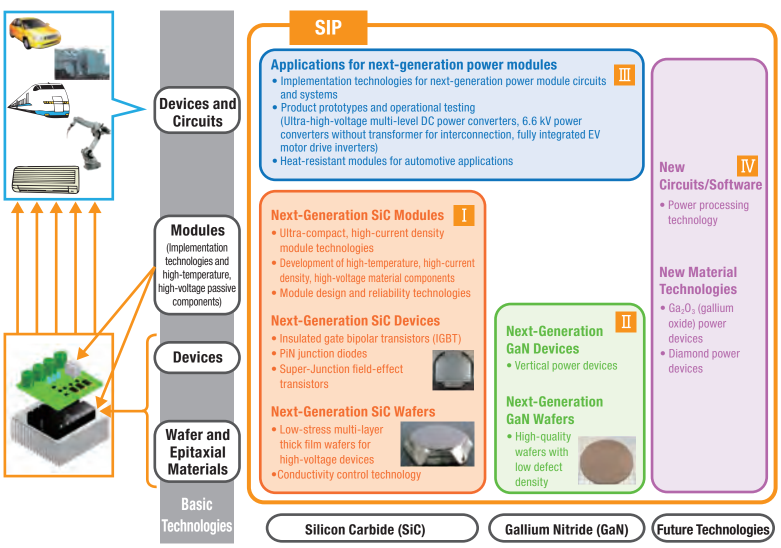
Ⅲ. Conduct basic research and development for next-generation power module application

To promote the use of next-generation power modules and broaden the scope of potential applications, the program will develop implementation technologies for more efficient high-performance power converter systems and more efficient motor drive systems that offer high power density. In addition, the program will use simulation technologies to enable the efficient integration of these systems into power modules and to aid in the design of product prototypes.

Ⅳ. Conduct basic research and development to support future power electronics

To produce high-performance power devices that surpass SiC and GaN, the program will conduct research for innovative performance improvements. This will include pioneering Ga_2O_3 (gallium oxide), diamond, and other new materials, as well as developing new structures and circuits supporting foundational technologies beyond traditional power electronics. The goal of this work is to achieve commercialization within the next 10 to 15 years.

•R&D Conceptual Diagram: Next-Generation Power Electronics



Exit Strategies

Consider and formulate strategy

Consider and formulate a strategy for activities toward creating an ideal society, as well as for finding new applications and implementation of power electronics technologies geared towards the world of 2030. Create new industries and markets based on power electronics, and pursue intellectual property and standardization strategies. Utilize NEDO studies to pursue new market opportunities by envisaging the future world of 2030, designing the applications needed to achieve this vision. Work backwards (backcasting) from performance specifications in applications to produce a roadmap for a seamlessly integrated technology hierarchy that encompasses all stages from input materials through final products.

Prove required performance levels through prototyping

Prove performance, quality, and manufacturability using prototypes to demonstrate successful development of technologies that meet performance and specification requirements identified via backcasting from the applications. Promote the development of product commercialization in industry.

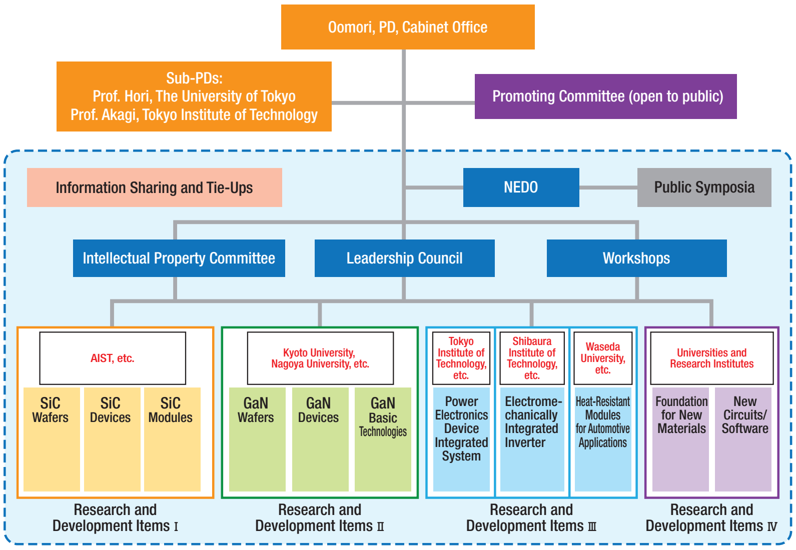
Engage in activities to promote adoption of results

Conduct standardization and other activities to promote the adoption of program results. Research the best standardized test methods for assessing the performance of component parts to promote standardization. Promote research of a performance certification system for each component and material. Set up a research consortium to develop related technologies and promote the wider adoption of research outcomes.

Implementation Structure

Establish a Promoting Committee consisting of representatives of government ministries and experts guided by the Program Director (PD) and the Cabinet Office. Utilize the resources of NEDO and leverage the NEDO relationship with JST to help in selecting research project leaders and to assist the PD and Promoting Committee.

Set up an Intellectual Property Committee, a Leadership Council, and workshops at the underlying levels. With the exception of public symposiums, these organizations will be run under a closed structure, while inside cross-pollination, frank discussion, and horizontal partnerships are encouraged. These organizations will coordinate materials assessment in conjunction with AIST and universities, separate from the SIP. This will enable discussion and debate throughout the organization as a whole.

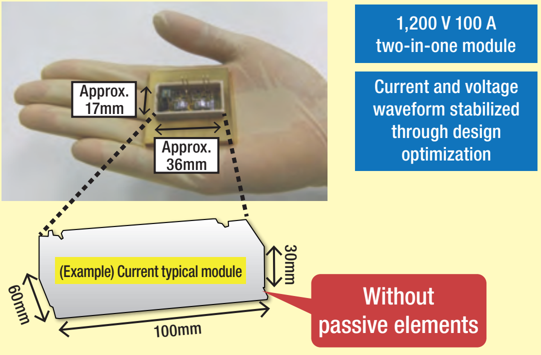


Progress to Date

Reliability testing commenced for some technologies

Several SiC (silicon carbide) power electronics device designs are already at the product development stage. However, there is still room for further improvement in SiC performance characteristics. In the area of wafers, through a co-doping technique of adding two kinds of impurities, we achieved an improvement in quality and lowering of resistivity to less than half of the current level. In the area of devices, having shed light on the mechanism of current degradation at times of high current density operation, we developed technology enabling stable high current density operation and synchronous rectification, and by eliminating the need for parallel diodes previously required in modules, we achieved our goals of making main circuits simpler and making modules more compact and less costly. In the area of modules, having developed and satisfactorily completed reliability testing for passive elements capable of high-temperature operation and high-frequency operation, we have built prototypes for next-generation high-temperature, high-speed SiC modules (figure on right) that are about one-third the size of conventional modules, and we have commenced reliability testing. Finally, in the area of applications, we have completed a scaled-down model of a 6.6 kV power converter without transformer for interconnection that is one-quarter the size of a standard factory power converter. We are conducting a series of tests on the model ahead of the final year's demonstration testing of a mock grid connection.

•A power module with embedded passive elements



Program Director **Tatsuo Oomori** Interview

Developing Technologies for New Materials beyond Silicon

Power electronics represents a key technology for electronic device energy savings in everything from home appliances to trains. SIP has had a number of successes in the development of technologies for new materials beyond Si (silicon), to strengthen this area where Japanese research has already been well advanced.

SiC Devices on the Path to Commercialization

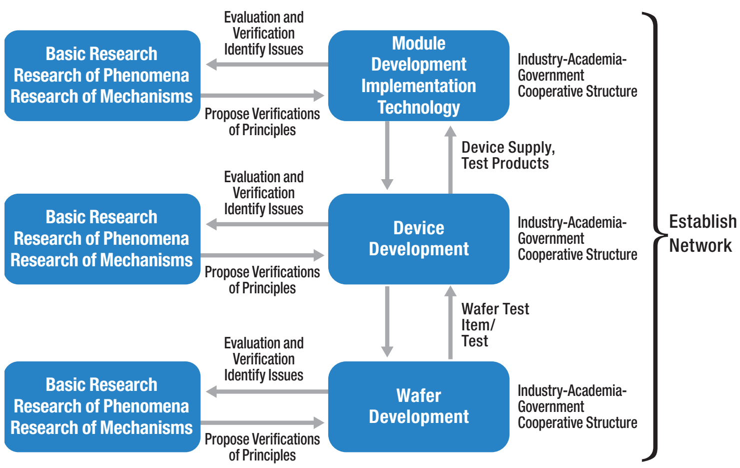
Next-generation power electronics represents a key technology for the energy-conscious world of the future. Program Director Tatsuo Oomori reflected on the achievements over the last three years.

"This was the first real attempt at a genuine collaboration between government, private enterprise and the academic sector in Japan. There were some difficulties at the initial stage, not the least of which was a sort of language barrier between the universities and the private-sector companies. But once we started talking properly together, we were able to coordinate our ideas and begin pulling in the same direction. Asking the universities to produce concrete results actually made it easier for them to come up with concepts and drive the R&D work."

Let's take a look at some of the achievements in each domain thus far, early in the fourth year of the program.

A number of compact high-performance power electronics products featuring the next-generation SiC (silicon carbide) materials are already at the product development stage. Even so, there is still room for further improvement in SiC performance characteristics. In the area of next-generation SiC power devices, after unraveling the problematic mechanism of current degradation at times of high current density operation, we achieved our goals of high current density operation and synchronous rectification operation. We also successfully scaled down high-speed SiC modules, which are developed based on high-voltage devices with passive elements embedded, to about one-third the size of conventional modules. We have commenced reliability testing with a view to commercialization by the year 2020 or so. We have also completed a scaled-down prototype of a 6.6 kV power converter without transformer for interconnection designed for industrial applications. Having verified its basic operations, we aim to conduct a system-based demonstration in the final year of the project.

•Conceptual diagram of creating a center for common basic technology development related to SiC



Next-generation GaN Materials Now at the Validation Testing Stage

GaN (gallium nitride) is another exciting next-generation material. Researchers are working to enhance quality standards for GaN wafers as the core technology in vertical power devices. Advances are also currently being made in the development of device processes with respect to operational stability and efficiency.

"Core technologies for improving the quality standards of GaN wafers are also taking shape, and overall we are ahead of schedule. For vertical power devices, we have moved on from verifying feasibility to setting targets for better performance."

We are working on futuristic power devices designed to operate at very high voltages with minimal losses. At this stage, we are identifying the main challenges we need to overcome to commercialize power electronics featuring new materials such as Ga2O3 (gallium oxide) and diamond. Meanwhile, advances are being made in research designed to yield revolutionary performance improvements, such as new structures and circuits that constitute the core future technologies that go beyond conventional power electronics. These advancements will lead to power processing systems capable of computing electrical power based on finite power sources. This, in turn, will drive a significant increase in potential applications for power electronics. We expect commercialization in this field by the year 2030 or thereabout.

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Energy-saving Technology Ideas for the Super Smart Society of the Future

At the beginning of the fourth year of this program, we conducted a review of program content, systems, etc. Reflecting the exit strategies for the remaining two years of the program, we have shaped the program structure to ensure balanced progress, boosting the number of Sub-PDs to two.

Echoing the progress made in heat-resistant modules for automotive applications, we have also transferred this topic from Item I (development of common core technology related to next-generation SiC) to Item III (application of next-generation modules).

In terms of operating structures, we provide a variety of forums for demonstration, assessment, and discussion. These include workshops, venues for discussion among researchers from various fields, and a consortium-style body that encompasses universities and AIST.

As far as human resources training, we are conducting practical sessions and university classes in conjunction with NEDO to provide younger researchers with hands-on experience in building and operating power electronics devices.

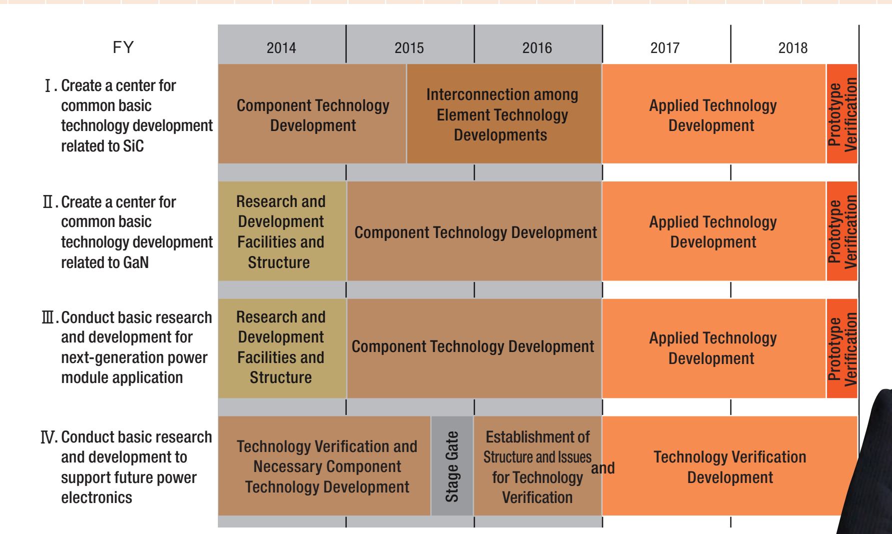
Power electronics is also expected to make an important contribution to the upcoming Society 5.0.

Says Oomori, “We are seeing the advent of a super smart society built on Big Data. But there is always the issue of power in operating devices once the information has been processed. The potential applications of power electronics are not limited to data centers. Next-generation power processing can be used to minimize power losses even further.”

While Japan is making steady advancements in energy-saving home appliances, there is still much room to contribute to power electronics across the world. By broadening the scope of applications of low-cost high-performance power electronics devices, our nation could establish a dominant market position through SiC devices and modules alone. This market is potentially worth hundreds of billions of yen. At the same time, we can make a significant contribution to addressing global energy issues.

Future Plans

As we head towards the last year of the program, we are conducting validation tests of SiC modules for fully integrated in-wheel motors used in cars, looking to develop products ultimately. We will also complete demonstration testing of a mock grid connection for the 6.6 kV power converter without transformer for interconnection. At the same time, we are making advancements in more sophisticated vertical power devices based on high-quality GaN wafers, as well as in the development of technologies for new materials, structures, and circuits.



Develop compact high-performance power electronics devices to establish a competitive edge in global markets and contribute to solutions for energy issues.