Fuji Electric's Semiconductors: Current Status and Future Outlook

Toru Hosen † **Kuniaki Yanagisawa** †

ABSTRACT

With the growth of new energy sectors, such as wind power and mega solar, large-capacity modules are being developed and commer-cialized and Fuji Electric's line-up of IGBT (insulated gate bipolar transistor) modules is rated up to 1,700 V/3,600 A. Wide bandgap semicon-ductors are being developed jointly with third-parties. High-speed discrete IGBTs for fast switching have been developed and are contributing to the realization of higher efficiency equipment. Power supply control ICs utilize a proprietary control method more energy efficient, smaller size and lower noise, and are contributing to the realization of higher performance equipment. Automotive devices such as IPS (intelligent power switch) and pressure sensors are being commercialized.

1. Introduction

Following the global recession of 2008, as a result of economic stimulus measures such as subsidies centering on the environmental sector as enacted by each country, the economic environment showed a sudden recovery in 2010. Recently, business relating to new types of energy, i.e., energy saving devices, environmentally-friendly vehicles, solar and wind power generation and the like, has expanded rapidly. Moreover, in Japan, record-setting heat waves continue, localized heavy rains are causing damage, and the phenomenon of extreme weather is being felt directly and concern about the environment is increasing more and more.

Since 2009, Fuji Electric has concentrated on a new 3-year plan for its "energy and environment business," and has announced its aim to contribute to society through this business. Power electronics technology is central to efforts to protect the global environment such as CO_2 reduction and to expand the field of renewable energy, and Fuji Electric has been working to innovate power electronics technology for many years. Power electronics technology is a key technology for converting energy into motive power, and power semiconductors, which are essential components, are becoming more and more important.

This paper focuses on the power semiconductors that Fuji Electric is working on and that will contribute to the energy and environmental field, and discusses the present status and future outlook for such representative power semiconductors as power modules, next-generation devices, power discretes, power supply ICs and devices for use in automobiles.

† Fuji Electric Co., Ltd.

2 . Power Modules

In the field of power modules, the development of IGBT (insulated gate bipolar transistor) power modules has been advanced based upon the keywords of "energy" and "environment." Many product series have been introduced for applications in the conventional field of medium-capacity power generation, but with the expansion of the field of large-scale new energy power generation, including wind and mega-solar power generation and the like, the development and commercialization of large-capacity modules is being advanced. A 1,700 V series of IGBT modules with current ratings of up to 3,600 A has been produced, and samples of 3,300 V IGBT modules are being deployed.

The IGBT chips presently being used to configure IGBT power modules are mainly the "V Series" of 6th generation IGBT chips. The V Series uses microfabrication technology and the optimzed FS (field stop) structure, and features an improved trade-off between low on-voltage, high-speed switching and resistance to breakdown in order to achieve performance close to the theoretical limit. Fuji Electric is expanding its lineup of new power modules using this V Series chip and a new package structure. In particular, Fuji Electric's new PIM (power integrated module) and 6-in-1 module both use a PCB (printed circuit board) insertion method for connecting external terminals that enables the elimination of the soldering process. Additionally, with the new-structure 2-in-1 and 1-in-1 IGBT modules, the stray inductance inside the package has been reduced by 50%, and high reliability has been achieved. Furthermore, lead-free (RoHS*[1] compliant) materials are used, and high-temperature operation is possible up to 175 °C.

In addition, Fuji Electric has its proprietary technology to develop a RB-IGBT (reverse blocking IGBT)

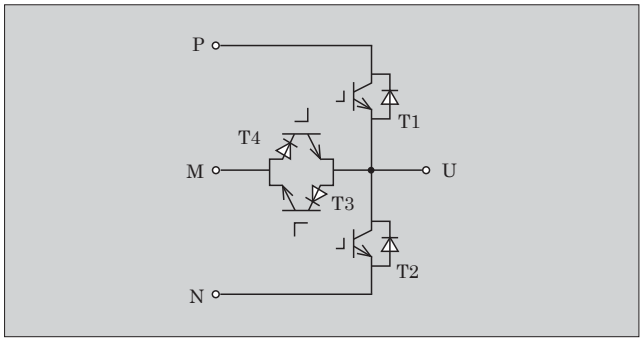

Fig.1 A-NPC inverter equivalent circuit

chip having reverse blocking capability for use in matrix converters and advanced NPC (A-NPC: advanced neutral-point-clamped) type inverters*2 that can be used to realize higher efficiency in equipment. Using this chip, an IGBT module for use in an A-NPC circuit in combination with a conventional IGBT as shown in Fig. 1, and a bidirectional switching IGBT module for use in a matrix converter have been developed.

Fuji Electric has developed IGBT modules and IPMs (intelligent power modules) for applying to hybrid vehicles, a plated IGBT having twice the current density of a general-purpose IGBT using a double-sided cooling package structure, a diode chip, and the like. All of these devices are either 600 V or 1,200 V products. In recent years, the motor capacities of hybrid and electric vehicles have increased, and with the increase in motor output current, higher efficiency through optimizing the module voltage has increasingly been demanded. In response to this demand, Fuji Electric has developed a 750 V IGBT module for mild hybrid vehicles that realizes an approximate 30% reduction in loss compared to previous modules.

In the field of power modules, technical development to improve further the performance of IGBTs as key devices in the "energy and environment" field, and product development to meet customer needs are being carried out.

3. Next-generation Devices

As 6th generation IGBTs, which are the mainstream devices of today, are approaching the theoretical performance limit of silicon, dramatic performance improvements as in the past are no longer expected. Therefore, attention has shifted to next-generation devices that use silicon carbide (SiC) and gallium nitride (GaN) materials. Since 2009, Fuji Electric has actively been developing these next-generation devices jointly with outside organizations, and is endeavoring to accelerate development aiming for practical application.

Using SiC material, in joint development with the National Institute of Advanced Science and Technology, Fuji Electric is advancing the development of MOSFETs (metal oxide semiconductor field effect transistors) and schottky barrier diodes. Through using SiC devices, loss can be reduced by 50% or more compared to conventional silicon, and SiC technology is considered to hold promise for making significant contributions to technical innovation in power electronic devices.

Meanwhile, for GaN device development, Fuji Electric and the Furukawa Electric Co. have jointly established the Technical Research Association for Next-Generation Power Devices, and are advancing research toward practical applications. GaN can be formed on a silicon wafer, and is therefore potentially less expensive than SiC.

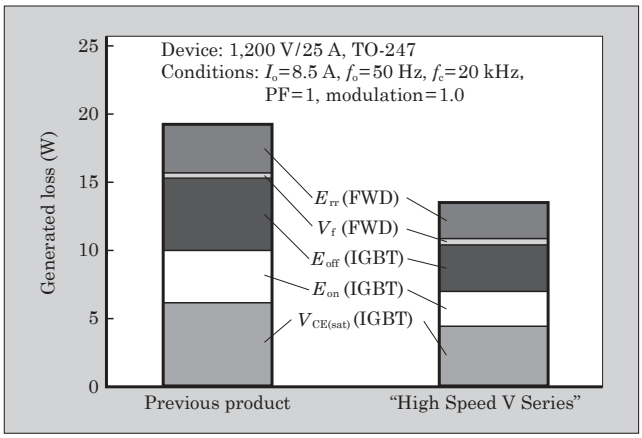

Fig.2 Loss breakdowns in 1,200 V series discrete IGBTs

4. Power Discretes

As a result of the increasing popularity of the Internet in recent years, and for such purposes as storing digital photographs or other digital data, there has been an increase in small computer applied systems and the importance of small UPS (uninterruptible power supplies) has been recognized. Additionally, as solar power has become more popular, power conditioners have also been used increasingly. Because these UPSs and power conditioners are running at all times, higher efficiency to conserve resources and reduce operating costs is strongly demanded. To meet these demands, Fuji Electric has applied 6th generation IGBT technology to develop a "High Speed V Series" of high-speed discrete IGBTs that are capable of high-speed switching. An internal FWD (free wheeling diode) also aims for higher speed, and in the 1,200 V product, achieves an approximate 30% reduction in loss compared to the conventional product as shown in Fig. 2.

Fuji Electric is also developing various devices for use in switching power supplies in flat-screen TVs,

*1: RoHS directive: EU (European Union) directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

*2: 3-level inverter technology: See explanation on page 108

PCs, servers and the like. For high-voltage MOSFETs, Fuji Electric has developed and deployed the "SuperFAP-E^3 Series" of planar MOSFETs featuring the world's best $R_{on}\times A$ (normalized on-state resistance per unit area) performance. The SuperFAP-E^3 Series achieves low loss and low noise, and has contributed to the higher efficiency of equipment. In addition, Fuji Electric is also moving ahead with the development of a Super Junction MOSFET (SJ-MOSFET) having the world's best $R_{on}\times A$ performance of approximately one-quarter that of the "SuperFAP-E^3 Series." The SJ-MOSFET, with its low on-state resistance, enables loss to be reduced by approximately 15% when used in the power factor correction circuit of a power supply. Development continues to accelerate toward early commercialization.

Meanwhile, super low I_R Schottky barrier diodes and large capacity diodes of greater than 30 A are being developed into product lines, and are being deployed in solar power and large capacity power supply applications.

To comply with increasingly severe demands for higher efficiency, smaller size and so on, Fuji Electric seeks not only innovation with conventional silicon technology, but is also accelerating the development of next-generation devices made from materials such as SiC and GaN and that realize dramatically lower loss compared to silicon.

5. Power Supply LCs

For power supply ICs, Fuji Electric has developed a proprietary control method that, when applied to products, realizes low energy consumption, small-size and lower noise in switching power supplies, and contributes to the higher performance of devices. Switching power supplies are commonly used to reduce the energy consumption of devices, but because a capacitor-input type rectification and smoothing method is employed, there arises a problem of higher harmonics on the power line, which is subject to regulatory oversight. To solve this problem, a power factor correction (PFC) circuit is often used. Meanwhile, energy-saving regulations for electronic devices are becoming stricter year-by-year and lower standby power consumption and higher efficiency during light-load operation are sought, and compliance in the PFC circuit is also important. Responding to these requests, Fuji Electric has developed the "FA5590 Series" of 2nd generation critical-mode PFC control ICs that realize higher efficiency as shown in Fig. 3 by limiting the maximum oscillation frequency of switching during light-load operation and that enable a reduction in peripheral circuit components.

Additionally, Fuji Electric has also developed technology for a high voltage IC (HVIC) that contains a built-in high-side driver for relatively high-capacity power supplies such as for servers. The HVIC technology developed by Fuji Electric has a breakdown voltage of 800 V, and because this is a higher breakdown voltage than that of the driving MOSFET, there is little risk of damage. Furthermore, the turn-on and turn-off propagation delay time has been set to less than 100 ns, which contributes to higher efficiency. In the future, this newly developed technology will be applied to make commercial products.

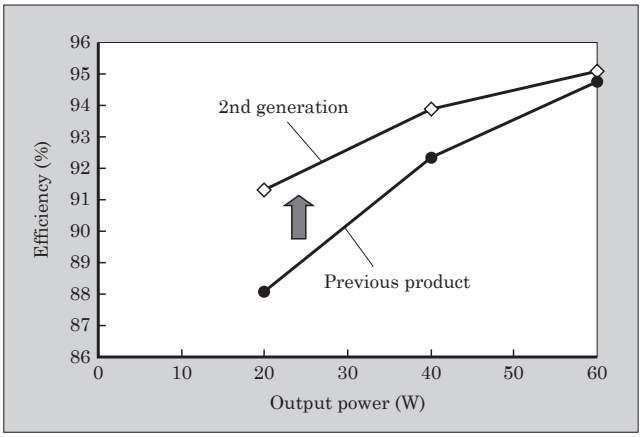

Fig.3 Efficiency of power supply control ICs

Fuji Electric is also endeavoring to advance simulation technology that will support product development. To improve design efficiency, ample verification through simulation is essential, and this special issue of the Fuji Electric Review introduces one aspect of the simulation technology.

To support requests for higher efficiency, lower energy consumption, smaller size and so on for power supply control ICs, Fuji Electric will continue to research and develop proprietary control technology and distinctive process technology.

6. Semiconductor Devices for Automobiles

Based on competitive and advanced device technology developed for industrial and power supply applications, Fuji Electric has applied high reliability technology to deploy IPSs (intelligent power switches), pressure sensors, IGBTs for ignitors, IGBT drive ICs for hybrid vehicles, and so on for the automotive field. With "environmental friendliness," "safety" and "comfort" as key words, products capable of realizing these concepts are desired. An intelligent power switch (IPS) for linear control and a 6th generation small pressure sensor that support such requests are introduced below.

(1) IPS "F5064H" for linear control

For automatic transmissions, linear control systems capable of varying the oil pressure linearly have been increasing in usage, and the detection of current flowing through a linear solenoid coil must be performed with high accuracy. For this purpose, a new circuit, device optimization and the like is carried out for the recently developed IPS, and the device is

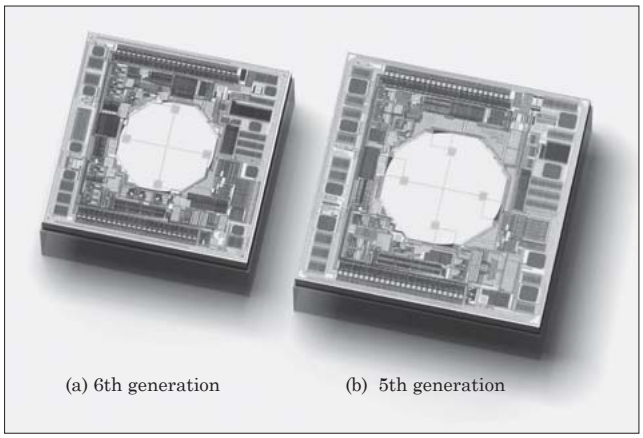

Fig.4 Pressure sensor chips

equipped with an op-amp for high accuracy detection.

Additionally, to protect the input stage of the op-amp, the device is provided internally with a protection element having ESD (electrostatic discharge) tolerance of 30 kV or higher, and also a function that turns off the output when the input terminal is in an open state. By using QPJ (quasi plane junction) technology, commonly used in high voltage MOSFETs, in the output stage MOSFET, 25% lower $R_{on} \times A$ than previous device was realized. Because of the high accuracy detection and low loss, this device can contribute to miniaturization of the ECU (engine control unit).

(2) 6th generation small pressure sensors

In the automotive field, as well, environmentally friendly initiatives such as fuel-efficient cars are also being advanced. Pressure sensors are key devices for making engines more efficient (higher fuel efficiency) and cleaner, and are used to measure the intake air pressure, atmospheric pressure and so on. Fuji Electric is mass-producing a 5th generation pressure sensor based on a CMOS (complementary metal-oxide semiconductor) process and incorporating high reliability circuit technology and advanced MEMS (microelectromechanical system) technology, and that is applied to automobiles and motorcycles both in Japan and overseas.

The newly developed 6th generation pressure sensor has an optimized sensing part shape (diaphragm) and a miniaturized circuit to maintain the functions and performance of the 5th generation while reducing the chip size to 70%. Fig. 4 shows a comparison of the external appearances. Fuji Electric plans to apply this technology to expand its product lineup in the future.

In addition to the products introduced herein, Fuji Electric's other automotive devices include a single-chip ignitor that uses Fuji Electric's proprietary technology. By levering its proprietary technology in the future and also incorporating new technologies, Fuji Electric will continue to develop high reliability and high performance products to satisfy customer needs.

7. Postscript

Based on the key words of "energy" and "environment," Fuji Electric has established the goal of contributing to society as a business objective. Power electronics technology will form the basis for achieving this goal, and technical innovation in power semiconductors, which are critical components, will also be needed.

As described in this paper, Fuji Electric is endeavoring to develop distinctive power semiconductor products that will contribute to the energy and environmental field, and will realize lower loss, higher functionality, smaller size, lower noise and higher reliability with innovative proprietary technology. Hereinafter, so as to be able to respond quickly to customer demands, Fuji Electric will continuously develop technology and will develop products from the customer's perspective.