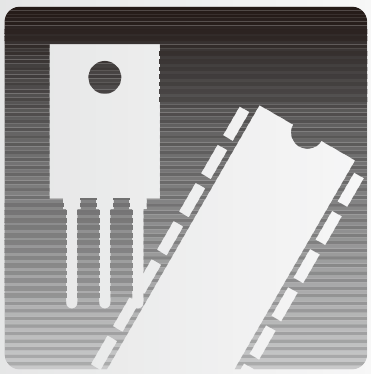
Electronic Devices



Power Semiconductors
Photoconductors
Disk Media

Outlook

Power Semiconductors

In order to achieve a safe, secure and sustainable society, there are extremely high public expectations and needs for the widespread use of renewable energy and for power electronics technologies to use such energy efficiently. As these needs increase, Fuji Electric is working on the development of power semiconductor products that provide high energy conversion efficiency, reduce noises and are friendly to the global environment. These products have been applied in various fields to contribute to the world, including the environment/energy, industrial machinery, automobiles and home appliances fields.

For the environment/energy field, we expanded a line-up of reverse-blocking insulated gate bipolar transistors (RB-IGBTs) that can be used in 3-level power conversion circuits. In addition to the conventional series of 600 V and 1,200 V types, we have developed a chip that can withstand a voltage of 900 V. This will expand the range of applications for module and discrete products, and enable us to offer best-suited products that satisfy the conditions of customer applications. We also have developed 2-in-1 products of 1,200 V/1,400 A and 1,700 V/1,400 A by forming a layer of phase-change type thermal interface material (TIM) on the back of IGBT module products. A material offering high thermal conductivity and reliability was selected for the TIM and the printing pattern of the formed TIM was designed to allow TIM to extend and spread uniformly and thinly in an optimum pattern when the module is mounted on customer's equipment. This ensures the IGBT module has the maximum heat dissipation performance.

For the industrial machinery field, we have developed a 1,700 V withstand voltage SiC hybrid product for high voltage inverters (1,700 V/400 A 2-in-1). It improves inverter outputs by 30% compared with the conventional products and thus contributes to a reduction of system costs. We have also developed a small-capacity intelligent power module (IPM) for industrial use to be used for small-capacity servo systems and inverters. We applied the latest 6th-generation "V-Series" IGBT and adopted a low-power-loss small package. Furthermore, product series of 600 V/100, 150, 200 A and 1,200 V/50, 75, 100 A have been developed through the application of high-heat dissipating packaging technologies to the IPM, to which the latest 6th-generation IGBT technology has also been applied. The adoption of high-heat dissipation direct copper bonding (DCB) to the conventional package has improved the power density by 30%.

For the automobile field, we have developed a 4th-generation intelligent power switch (IPS) that can help improve the fuel consumption and comfort of vehicles by enabling accurate detection of electric current.

For the power supply field, a 2nd-generation LLC current resonant control IC has been developed. This product contributes to efficiency improvement, noise reduction and profile lowering of power supplies for equipment such as LCDs, reduces standby power and improves protective functions compared with the 1st-generation products. In addition, we have developed the "Super J-MOS FRED Series" that has greatly improved the reverse-recovery parasitic diodes loss, which contributes to improve efficiency of server power supplies for which demand has been growing in recent years.

Photoconductors

The total demand for photoconductors is predicted to have tendency to decrease slightly and some manufacturers of photoconductors and photoconductor materials have decided to withdraw from the business. The business environment is growing increasingly difficult. On the other hand, photoconductors are expected to offer higher performance that enables response to the trend for providing higher speed and longer life on the equipment side.

Fuji Electric developed photoconductors that had improved the sensitivity and durability by 30% compared with the conventional products and started mass producing them to meet the demands of equipment manufacturers, in FY2013. We will further improve performance by developing new materials through uti-

lizing simulations.

Disk Media

With the advancement of cloud computing, perpendicular magnetic recording media for hard disk drives (HDDs) is required subsequently to provide with larger capacity and lower cost.

In FY2013, Fuji Electric developed more advanced characteristics products of a 3.5-inch aluminum substrate medium and a 2.5-inch glass substrate medium offering a storage capacity of 1 TB and 500 GB per disk respectively, and started mass producing them. They will contribute to the improvement of customers' manufacturing yield by enhancing the media performance due to the optimization of material compositions and the manufacturing process. We will push forward with the development of large-capacity media to contribute to the advancement of the IT society.

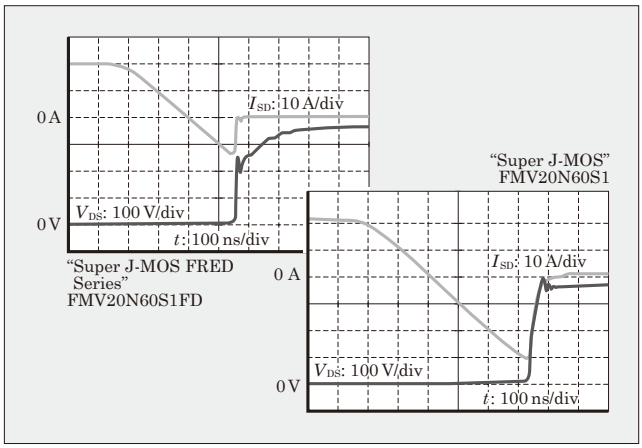
Power Semiconductors

1 "Super J-MOS FRED Series"

The resonant circuit and inverter circuit for uninterruptible power supplies (UPSs), servers, communication power supplies and power conditioners (PCSs) require metal-oxide semiconductor field-effect transistor (MOSFET) that has a built-in diode providing low-reverse recovery loss and high-reverse recovery withstand capability. Fuji Electric has developed the "Super J-MOS FRED Series" to meet such a requirement. While the low on-resistance and low switching loss properties of the conventional Super J-MOS are kept the same, the built-in diode has been improved to provide less reverse-recovery loss and significantly higher reverse-recovery withstand capability. The main features are as follows:

(1) Reverse-recovery time T_{rr}: Reduced by approx. 60 % (compared with conventional products)
(2) Reverse-recovery charge quantity Q_{rr}: Reduced by approx. 80 % (compared with conventional products.)
(3) Withstand voltage: 600 V
(4) On-resistance (max.): 42, 74, 132, 200 mΩ

Fig.1 Reverse-recovery waveform examples



2 Small IPM for Industrial Use

In recent years, the need for system energy saving has been growing and the demand for general inverters and servo systems is expanding in the industrial field.

For small-capacity industrial applications, Fuji Electric has started mass producing small intelligent power modules (IPMs) of the 600 V/15, 20, 30 A that have a built-in a 3-phase inverter bridge circuit and control ICs.

This product has achieved energy savings with optimized low loss dissipation devices and also has enabled system downsizing and usability improvement by applying ultra-compact package adopting a high thermal conductivity aluminum insulated substrate and by incorporating various protection functions.

Moreover, it satisfies the demand for safety by applying UL-certified (UL1557).

Fig.2 Small IPM for industrial use

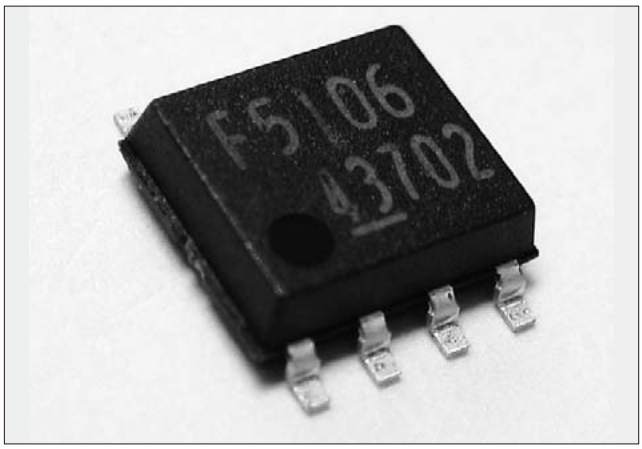
3 One-Chip Linear Control IPS "F5106H"

In the field of vehicle electrical components, the demands for smaller system size, higher reliability and higher functionality are increasing. To meet these demands, Fuji Electric has developed a one-chip linear control intelligent power switch (IPS) "F5106H" that is equipped with a high-precision current detection amplifier in the conventional IPS.

The output stage power metal-oxide semiconductor field-effect transistor (MOSFET) has been changed from the planar gate type to the trench gate type, and the 4th-generation IPS device/process technology using smaller control/protection circuits and multi metal layer technology has been applied. This allows one-chip design and mounting onto the SOP-8 package. In addition, the maximum rating of the junction temperature was set to 175 °C to improve the durability in harsh temperature environments while low power-voltage operation is possible down to 4.5 V.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 251

Fig.3 "F5106H"



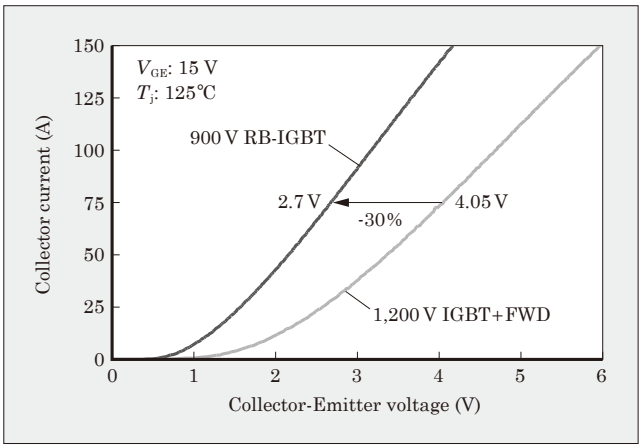
4 900 V Reverse-Blocking IGBT (RB-IGBT)

The demand for reverse-blocking insulated gate bipolar transistors (RB-IGBTs) has been increasing in recent years, including the use as a neutral clamp device of a 3-level power conversion circuit. Fuji Electric has been working on the development of RB-IGBTs that lead to higher efficiency of power converters.

RB-IGBTs of 600 V class are hard to apply to large scale 1,000 V DC (maximum) solar converters, because the larger stray inductance inside/outside IGBT module results critical spike voltage. On the contrary, 1,200 V RB-IGBTs have higher switching loss. To solve these issues, we have developed a 900 V class RB-IGBT.

By reducing the number of devices, we have achieved a 30% reduction of the on-state voltage drop compared with that of 1,200 V IGBT+FWD alternative solution.

Fig.4 Comparison of IV characteristics

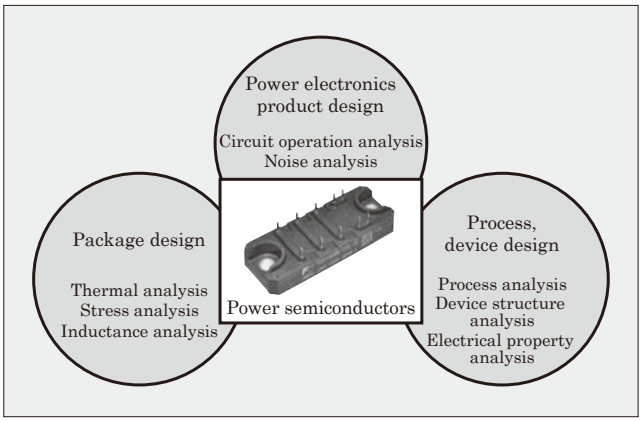


5 Power Semiconductor Simulation Technologies

Fuji Electric is developing simulation technologies for designing devices and packages, and for designing power electronics products equipped with power semiconductors. The combinations of the following simulation technologies are the backbone of the functionality enhancement and quality improvement of Fuji Electric products:

(1) Process, device design: Optimized design of the performance and quality of devices based on analysis of the process and device structure
(2) Package design: Optimization of the structure based on thermal, stress and inductance analyses
(3) Power electronics product design: High-accuracy circuit operation analysis based on precise modeling of the electrical properties of devices or the LCR components of packages; and noise reduction through noise analysis

Fig.5 Simulation technologies used in the development of power semiconductors

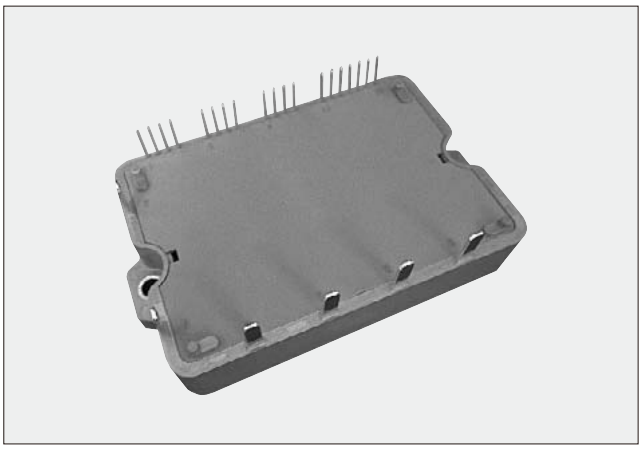


6 Medium-Capacity Small Package of "V-Series" IPM

In recent years, there has been increasing demand for further downsizing and expansion of the rated current value range of the intelligent power modules (IPMs) used in servo control or other equipment. Fuji Electric has now completed the series of "P636 Packages" targeted for servo control equipment; they cover the capacity range of 600 V/100 A and 1,200 V/50 A, incorporate brake circuits and have achieved a footprint size 26% smaller than the conventional products. The main features are as follows:

(1) Outline dimensions: W90×D55×H18.5 (mm)
(2) Rating: 600 V/50, 75, 100 A; 1,200 V/25, 35, 50 A
(3) Circuit configuration: 7-in-1 and 6-in-1 series
(4) Thermal resistance: 20% reduction (compared with conventional products)
(5) Performance/functionality: The 6th generation insulated gate bipolar transistor (IGBT) mounted, built-in IGBT gate drive circuit and protection circuit, alarm identification function, dead time reduction

Fig.6 "P636 Package"



7 1,700 V Withstand Voltage SiC Hybrid Module

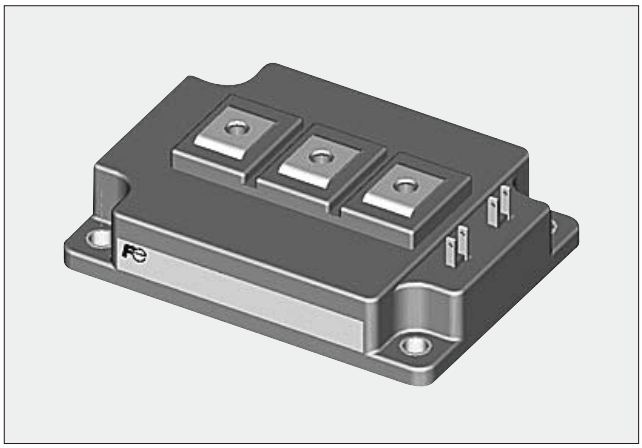
In place of Si devices, SiC devices having heat resistance and high breakdown electric field tolerance are raising expectations to be new devices that achieve efficiency improvement and downsizing of equipment. Fuji Electric is promoting the development of 1,700 V withstand voltage SiC hybrid module intended for high efficiency inverters (690 V series) that contribute to energy conservation.

To Free Wheeling Diode (FWD), we applied the SiC-Schottky barrier diode (SiC-SBD) chip which had been developed jointly with the National Institute of Advanced Industrial Science And Technology and which are set to be mass produced by Fuji Electric. To insulated gate bipolar transistor (IGBT), Fuji Electric's latest product, the 6th-generation "V-Series" IGBT chip has been applied.

By improving leakage current and switching properties, we confirmed that the chip can reduce generated loss in the 300 A product module by approximately 26% compared with the conventional Si modules.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 218

Fig.7 1,700 V withstand voltage SiC hybrid module



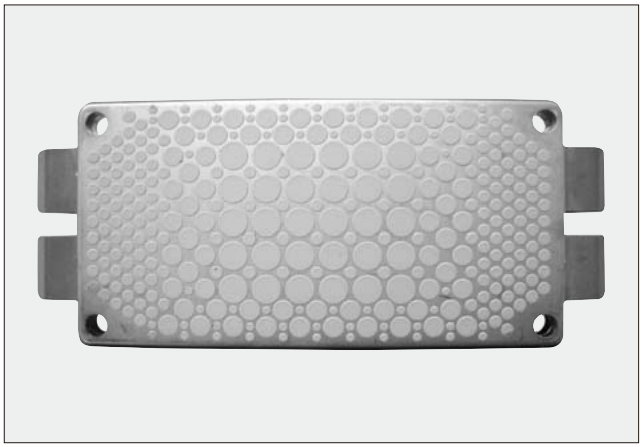
8 IGBT Module with Pre-Applied TIM

When an insulated gate bipolar transistor (IGBT) module is mounted, thermal grease is applied between the cooling fin and the IGBT module to encourage quick transfer of the heat generated from the IGBT module. An increasing number of customers request IGBT suppliers to do this thermal grease application.

To meet this requirement, Fuji Electric has developed a family of IGBT modules with pre-applied thermal interface material (TIM) of phase change type. The adopted TIM features heat dissipation performance that is over three times as good as that of the conventional thermal greases. Its transportability is great because it maintains a solid state under a temperature of around 45 °C, though it liquefies above that temperature. This resulted in developing an IGBT module with improved heat dissipation properties and reliability.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 241

Fig.8 IGBT module with pre-applied TIM (rear view)



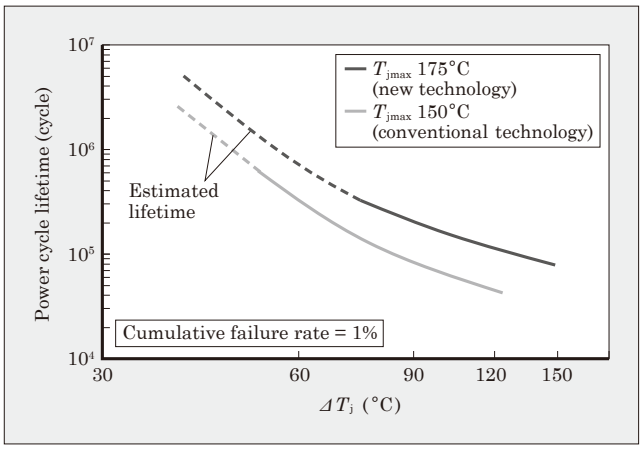
9 New Assembly Technologies for T_{jmax} 175°C Continuous Operation Guaranty of IGBT Module

In order to achieve further downsizing and higher power density of insulated gate bipolar transistor (IGBT) modules, it is required to raise the upper limit of the device temperature T_{jmax} during continuous operation from the current limit of 150 °C to 175 °C.

To guarantee the continuous operation of IGBT modules at 175 °C, Fuji Electric has developed three new bonding technologies: High thermal-resistance aluminum wire; high-strength solder at high temperature; and a structure with Ni layer formed on the chip surface electrode. These packaging technologies have increased power density and achieved doubled power cycle lifetime at all temperature regions compared with the conventional products.

These technologies can be applied to the current manufacturing processes. Hence, conventional facilities can be used to mass producing products that guarantee continuous operation at 175 °C without modification.

Fig. 9 Power cycle test results (T_{jmax} = 175 °C)



10 Packaging Technology of IPMs for Hybrid Electric Vehicles

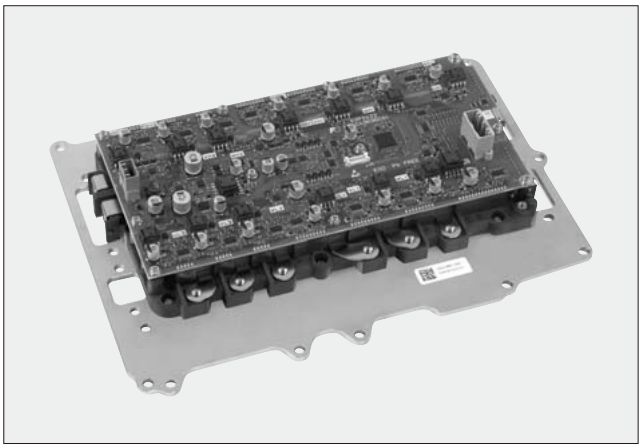
The popularization of hybrid electric vehicles (HEVs) and electric vehicles (EVs) is accelerating in order to comply with environmental regulations. Fuji Electric started mass producing new intelligent power module (IPM) for HEVs.

This product integrates two inverter units controlling two motors and a buck-boost converter unit. It adopts an aluminum direct water-cooling structure for a compact design, light weight and high output power density. Two new technologies have been developed:

(1) High cooling design based on this direct water cooling structure
(2) High-strength solder material that makes it possible to joint between aluminum heat sink and a ceramic insulating substrate, having large mismatch in coefficients of thermal expansion.

This product is an all-in-one package integrating the inverter/converter circuits and a controller, resulting in a 30% reduction in volume ratio and 60% reduction in mass ratio compared with the conventional indirect water cooling type.

Fig.10 IPM for hybrid electric vehicles



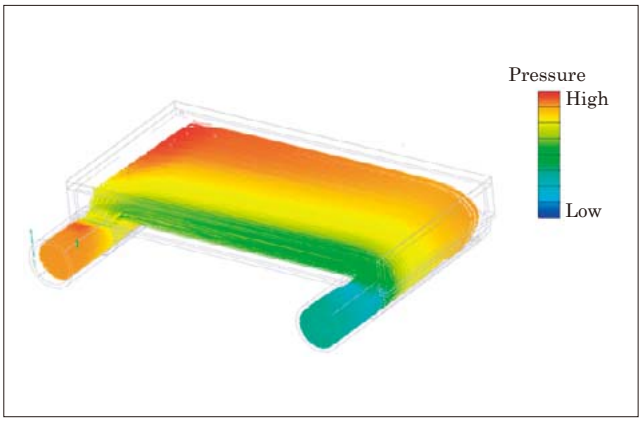
11 Thermal Fluid Simulation Technology

Power semiconductors are used for controlling the motor of hybrid electric vehicles (HEVs) and electric vehicles (EVs). For the purpose of downsizing and lightweight, applications of a liquid-cooling system has been progressing for power semiconductors mounted on HEVs and EVs.

Fuji Electric has established technology for designing the direct-liquid cooling system of power semiconductors. It can determine the coolant flow using thermal fluid analysis and analyze the cooling properties of the coolant in a consistent way.

We have used these technologies for equalizing the coolant flow speed and attempting to design a cooler that has no coolant stagnation points that may cause corrosion by conducting thermal fluid simulation analysis. Furthermore, by offering a total design for cooling systems that are different among individual customers with consideration given to pump performance, we aim to optimize and improve the efficiency of the HEV/EV systems.

Fig.11 Example of coolant flow analysis of the power semiconductor cooling system



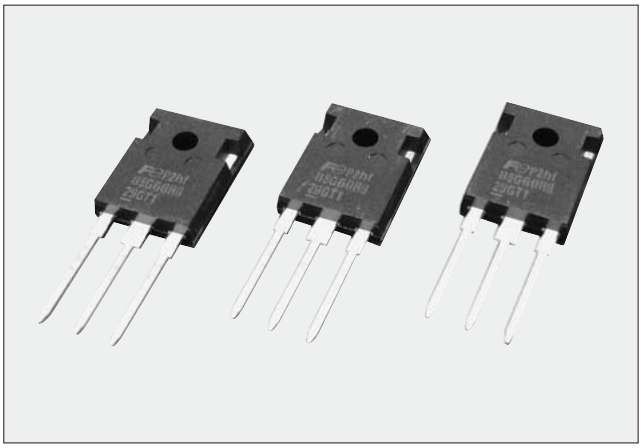
12 600 V Discrete RB-IGBT “FGW85N60RB”

Advanced T-type neutral point clamped (AT-NPC) power conversion circuits including a neutral-point clamp are attracting attention because they improve the efficiency of power conversion equipment. Applying reverse-blocking insulated gate bipolar transistors (RB-IGBTs) that withstand voltage for both forward- and reverse-biases makes it possible to reduce the number of elements used for a neutral-point clamp, allowing for further efficiency improvement.

Fuji Electric has developed proprietary technologies for mass production of RB-IGBT. Following the AT-NPC IGBT module incorporating RB-IGBT, we have commercialized “FGW85N60RB” that incorporates the RB-IGBT developed for discrete products into a TO-247 package. Since the inductances inside the package and of the main circuit are lower than those of module products, a reduction in power dissipation and high-frequency operation can be achieved.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 262

Fig.12 “FGW85N60RB”



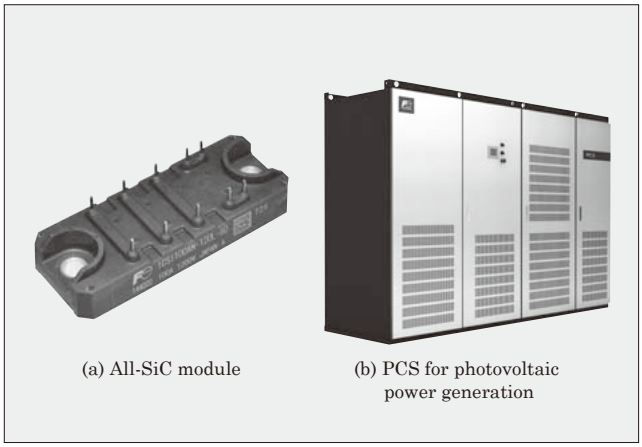
Power Semiconductors

13 All-SiC Module for Power Conditioners

Fuji Electric is moving forward with the product development of All-SiC modules incorporating metal-oxide-semiconductor field-effect transistor (MOSFET) and Schottky barrier diode (SBD) which are SiC devices jointly developed with the National Institute of Advanced Industrial Science And Technology. We are considering their applications to various types of power electronics equipment including power conditioners (PCSs). Figure (a) shows a picture of the All-SiC module that is rated 1,200 V/100 A. We have reduced the module internal inductance to almost one-fourth and the footprint size to almost half compared with Si- insulated gate bipolar transistor (IGBT) modules of the same rating. In addition, the resin sealed structure provides high reliability. Moreover, both the reduction of power dissipation and downsizing of the power module have been achieved simultaneously, which help to improve the power density of PCS for photovoltaic power generation.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 221

Fig.13 All-SiC module and PCS for photovoltaic power generation



(a) All-SiC module (b) PCS for photovoltaic power generation

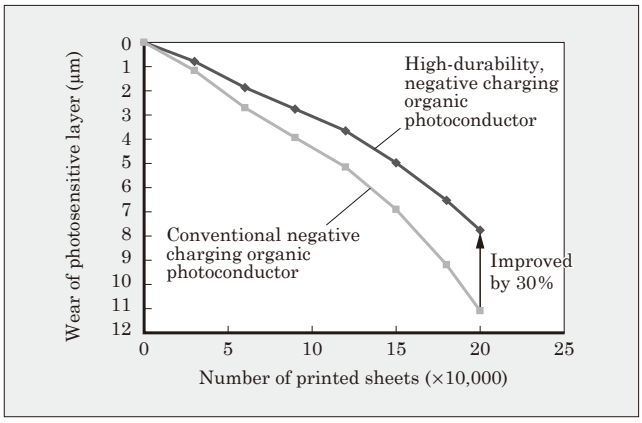
Photoconductors

1 High-Durability, Negative Charging Organic Photoconductors

As the life of printers and copiers extends, there is a growing demand for photoconductors to be highly durable. Inside the equipment, however, the load placed on a photoconductor is increasing and wear is further accelerated due to the increase of various contact processes.

To develop high-durability, negative charging organic photoconductors to meet the needs of such processes, Fuji Electric is developing a binder that is a main component of the charge transport layer on the surface of a photoconductive layer. We succeeded in developing a new binder whose properties far exceed conventional products. This was achieved by working out the molecular design from proprietary simulations focused on hardness and toughness and by conducting tests based on an assumption of various external stresses. The photoconductor to which this binder was applied has improved wear resistance of the photosensitive layer by 30% compared with the conventional products, achieving higher durability.

Fig.14 Printing durability property of high-durability, negative charging organic photoconductor



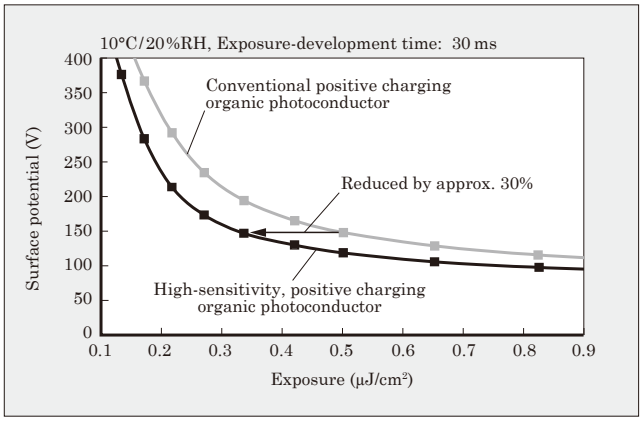
2 High-Sensitivity, Positive Charging Organic Photoconductors

Electrophotography-based laser printers and copiers are designed to be faster, smaller and more power-saving. In tandem with this, there is growing demand for a highly sensitive organic photoconductor that can respond to less exposure in shorter time, so that the design margin of the exposure system can be widened.

Fuji Electric provides positive charging organic photoconductors that have sensitivity properties equivalent to negative charging organic photoconductors by developing a multilayer positive charging organic photoconductor based on proprietary technologies.

This time, by seeking to optimize the combination and compounding ratio of various functional materials including charge transport materials and electron transport materials, we have developed a high-sensitivity, positive charging organic photoconductor. It works with about 30% less exposure even under low-temperature and low-humidity conditions where response speed tends to be slower. We will provide organic photoconductors based on this technology from now on.

Fig.15 Photo-induced discharge characteristics of high-sensitivity, positive charging organic photoconductors

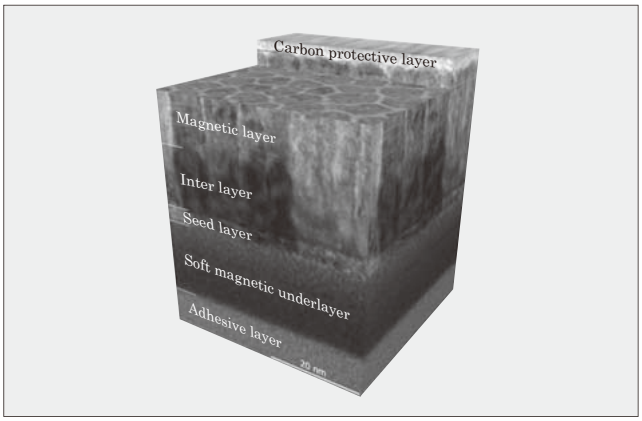


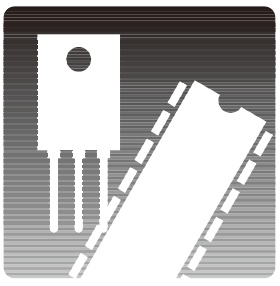
Disk Media

1 Large-Capacity, High-Reliability Perpendicular Magnetic Recording Media

With the expansion of cloud computing, the main driving force in the HDD market is shifting from PCs to the demand of data centers. The market is growing steadily and the demands for magnetic recording media with a larger recording capacity are still high. Fuji Electric has pursued both high reliability and reduction of magnetic spacing through optimization of the lubricant and the carbon protective layer. We have also achieved finer and more uniform crystal grains by optimizing the composition/deposition conditions of a medium layer structure including a multilayer granular layer. Moreover, we have established a system to allow HDD to be evaluated in-house using actual equipment to achieve more accurate and faster evaluations of medium properties. By implementing these measures, we succeeded in achieving a recording density of 1,064 Gbits/in^2 (712 GB per 2.5-inch medium) ahead of other companies. This technology is scheduled to be applied to the media for HDD that will be commercialized in FY2014.

Fig.16 Cross-sectional and top views of TEM image of developed magnetic recording medium





* All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.