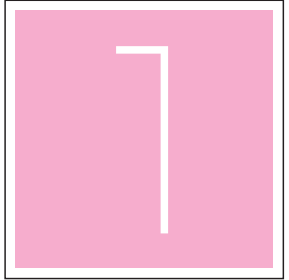
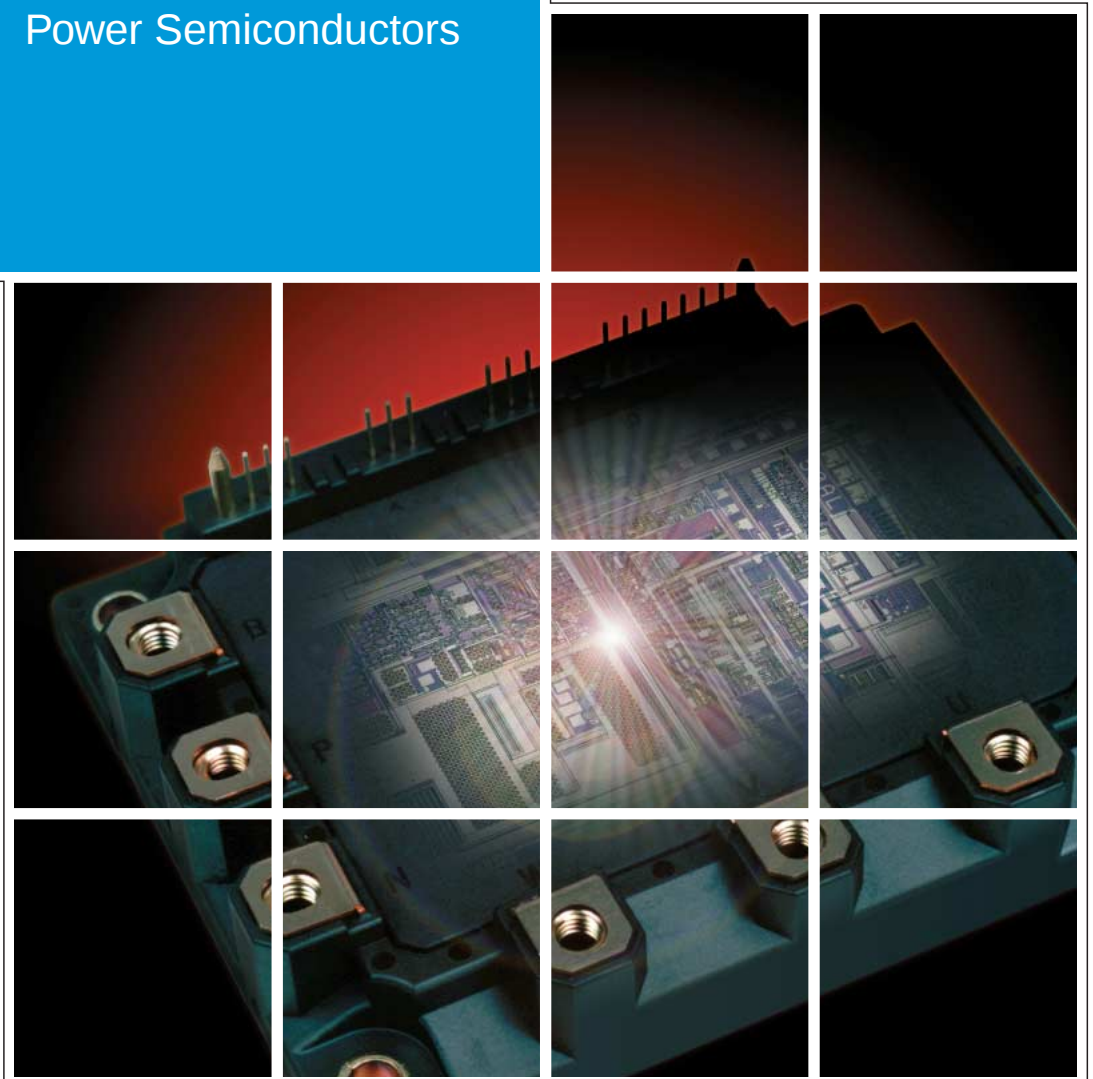


FUJI ELECTRIC REVIEW



1998 VOL.44

Power Semiconductors



Power MOSFET “FAP-II S Series” Ensures Ruggedness for Repetitive Avalanche.



FAP-II S series					
Package \ V _{DSS}	450V	500V	600V	800V	900V
T-pack	2SK2754-01 (10, 0.65)	2SK2758-01 (10, 0.90)		2SK2762-01 (4, 4.00)	2SK2768-01 (3.5, 5.50)
TO-220AB		2SK2757-01 (10, 0.90)		2SK2646-01 (4, 4.00)	2SK2767-01 (3.5, 5.50)
TO-220F15	2SK2638-01MR (10, 0.65)	2SK2640-01MR (10, 0.90)	2SK2645-01MR (9, 1.20) 2SK2761-01MR (10, 1.00)	2SK2647-01MR (4, 4.00)	2SK2769-01MR (3.5, 5.50) 2SK2651-01MR (6, 2.50)
TO-3P	2SK2639-01 (10, 0.65)	2SK2641-01 (10, 0.90)	2SK2760-01MR (9, 1.20)	2SK2763-01 (4, 4.00)	2SK2770-01 (3.5, 5.50)
	2SK2755-01 (18, 0.45)	2SK2643-01 (15, 0.55)		2SK2765-01 (7, 2.00)	2SK2652-01 (6, 2.50)
				2SK2648-01 (9, 1.50)	2SK2654-01 (8, 2.00)
TO-3PF	2SK2756-01R (18, 0.45)	2SK2759-01R (15, 0.55)		2SK2764-01R (4, 4.00)	2SK2653-01R (6, 2.50)
				2SK2766-01R (7, 2.00)	2SK2655-01R (8, 2.00)
				2SK2649-01R (9, 1.50)	

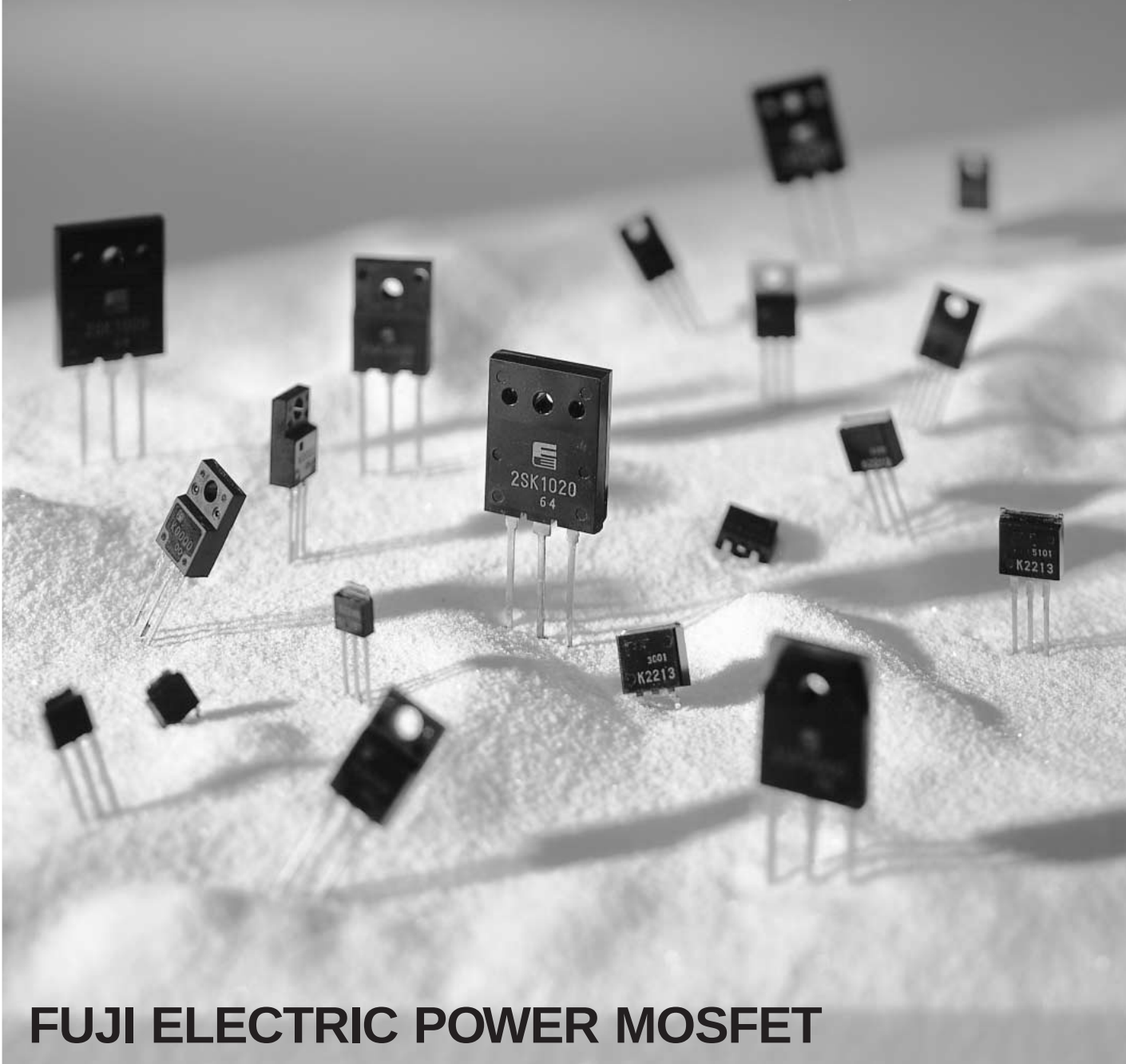
2SK2754-01(10, 0.65)

Type name

RD(ON)(Ω)

ID(A)

Uses:
Switching power supply for
OA equipment, etc.



FUJI ELECTRIC POWER MOSFET

FUJI ELECTRIC REVIEW

Power Semiconductors

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Cover Photo:

As energy consumption increases, the protection of environment and the effective use of resources become more and more important. There are increasing demands for higher efficiency, advanced functions, and lower noise of electronic equipment and its key component semiconductor devices.

To meet these requirements, Fuji Electric is always in pursuit of low power consumption, intelligent devices, and low noise to offer more advanced devices.

The cover photo which shows an R-IPM intelligent power module with a component control LSI chip images an advance in the function by marrying a power device with LSI.

Present Status and Future Prospects for Power Semiconductors

Ken'ya Sakurai

1. Introduction

From the viewpoint of a highly information-oriented society in the coming 21st century, the social infrastructure will undergo rapid repairs and reformations. What will bring us to a society where computers and communications are closely intertwined? Technical innovations have always brought us advantages as well as disadvantages. Any future technical innovations must definitely exclude disadvantages.

A highly information-oriented society will result in a great increase in electric energy consumption. Problems of the global environment, social environment, and energy resources must be improved through more serious consideration, with electrical manufactures leading these technical innovations. Development of high power generation and conversion efficiency and energy-saving technology for electron devices are core technologies. More specifically, power electronics that control electric energy increases in importance, and especially power semiconductor devices as the key devices are required for further advances in performance and functions. The major directions of the research and development are:

- (1) low power dissipation devices
(reduction in conduction and switching losses)
- (2) system-integrated devices
(system-on-a-chip devices and system-integrated modules)

Under these circumstances, Fuji Electric plans to work with a leading company of power devices for intelligent motion control and intelligent power management.

In particular, power MOSFETs (metal oxide semiconductor field effect transistors), IGBTs (insulated gate bipolar transistors), IPMs (intelligent power modules), and power ICs (integrated circuits) with advanced performance and functions will rapidly enlarge the market.

This special issue describes the present status and future prospects for Fuji Electric's power semiconductor devices in the highly information-oriented society of the future. Listed below are the device items classified by application fields.

- (1) Devices related to multimedia

- ① High-voltage silicon diodes and damper diodes with high-speed switching performance to improve the picture quality of the CRT (cathode ray tube) display monitors and televisions
- ② Low on-resistance SOP-8 power MOSFETs that extend the battery life of portable electronic appliances such as notebook computers

- (2) Vehicles and rolling stock

- ① Intelligent power MOSFETs that decrease the size and improve reliability of car electronics systems
- ② High-voltage, high-power NPT (non punch-through)-IGBT modules and flat IGBTs that reduce rolling stock size, weight, and energy consumption

- (3) Power conversion (inverter control)

- ① Molded IGBTs, IGBT modules, and IGBT-IPMs for applications including NC (numerical control) equipment, general-purpose inverters, servo mechanisms, welding machines, and UPSs (uninterruptible power system)

2. Technical Trends of Power Semiconductor Devices

These applications extend over a wide range of equipment including power systems, transportation, industries, information, communications, and household appliances. Major technical developments follow the trend toward decreased power loss, high speed, high reliability, and advanced functions.

2.1 Technical trends

Figure 1 shows the progress of improvement in power MOSFET on-resistance. In low-voltage devices (100V or less), their on-resistance has been greatly reduced by fine patterning technology for LSIs (large-scale integrated circuits). It is further reduced by adopting trench gate technology. On the other hand, no great improvement has been made in high-voltage devices. The reason is that the main on-resistance component of high-voltage MOSFETs is in the drift region and therefore, great reductions cannot be ex-

Fig. 1 Improvements in on-resistance

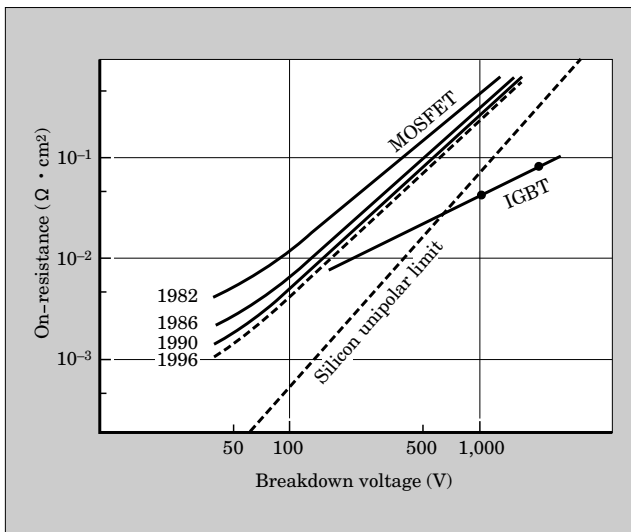
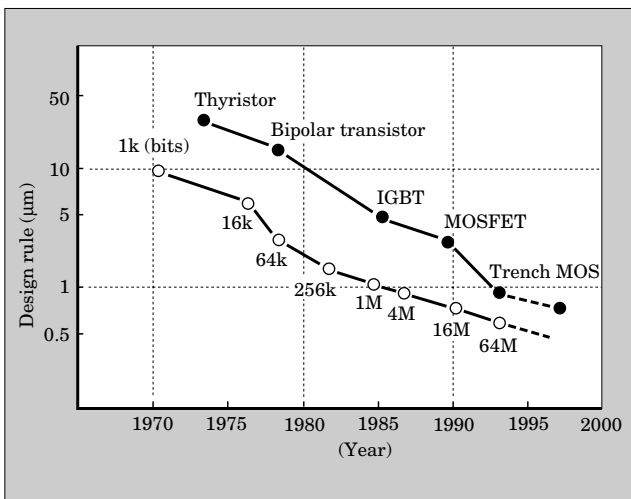


Fig. 2 Development of process design rules



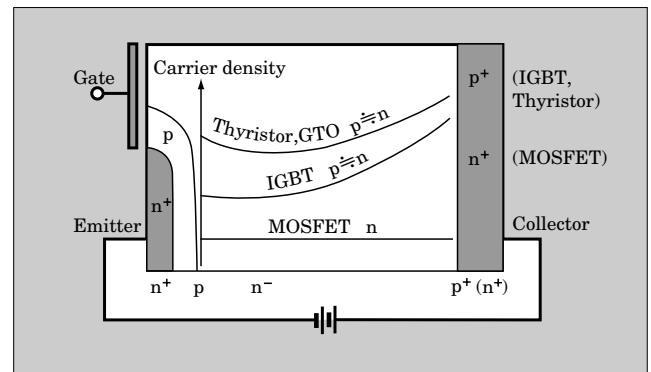
pected by adopting finely patterned cells. To reduce the on-resistance of high-voltage devices, an IGBT was developed. As shown in the figure, the IGBT on-resistance is much lower than the silicon unipolar limit due to the conductivity modulation effect. From the viewpoint of on-resistance, the application range is thought to be less than 150V for power MOSFETs and more than 150V for IGBTs.

The performance of power semiconductors will improve with the following technical innovations:

- (1) A merger of semiconductor action physics and the application of new concept devices
- (2) A breakthrough in a trade-off with intelligent functions (drive, protection, sensor functions, etc.)
- (3) Application of LSI process technology
- (4) Notable advances in the performance of devices using new semiconductor material

Figure 2 shows the transition of design rules for power devices in comparison with that for DRAMs (dynamic random access memories). When compared with DRAMs, the application of fine patterning tech-

Fig. 3 Carrier distribution of typical devices



nology to power devices was delayed by about two generations. The fine patterning level of the power devices has greatly advanced by application of the trench process. In particular, the on-resistance of low-voltage MOSFETs has been greatly reduced by the trench gate application. As for the new concept devices, the application of trench gates will also result in further improvement. The application of various LSI process technology as well as the submicron-level patterning technology to power semiconductors will be rapidly promoted in the future, and a positive influence on their performance is expected.

Next we will describe the merger of action physics. Figure 3 shows the on-state carrier distribution of various power devices. The carrier distribution of a device determines its on-voltage drop and switching speed performance. The next goal is the merger of MOSFET and thyristor actions. More than ten years have passed since an MCT (MOS-controlled thyristor) was announced. However, because of low controllable current density, its weakest point, it has not been widely accepted. Various new-concept devices for improvement have been announced, such as the EST (emitter switched thyristor), IGCT (insulated gate controlled thyristor), and BRT (base resistance controlled thyristor). In addition, an attempt at easier application of the thyristor and attainment of high performance by introducing dual gate control has begun. However, it is not yet marketable. It is difficult to efficiently remove excess carriers at turn-off, and the excess carriers necessarily prolong the switching time. To improve these problems, various means have been contrived in the LSI process technology and the parasitic thyristor for prevention of latch-up.

Another movement is toward intelligent devices. The rapidly developed ICs were motive power to the current social reformation. In the future, they are expected to continue to play a role. However, in the mid-1980s, Dr. Adler et al. of General Electric Co. predicted that a second reformation would be caused by intelligent power devices. We feel that the technical innovation toward them has been quite remarkable. These power ICs have developed remarkably, especial-

ly toward large capacities and advanced functions. On the market are high-side and low-side switching, high cost performance, advanced function power MOSFETs for automobiles and power ICs for igniters up to 400V and tens of amperes. The one-chip inverter IC that incorporates a power supply, various protective circuits, and PWM control circuits has also been commercialized. The biggest problem of these devices is high-cost isolation technology. Recently, direct bonded SOI (silicon on insulator) technology has gained attention. The age of on-a-chip systems with an integrated power device is not very far in the future. System-integrated modules will be mainstream in comparatively large capacities. Fuji Electric plans to complete them all with silicon devices and silicon sensors concurrently realizing compactness, advanced functions, and high cost performance. We intend to promote the commercialization of the next generation IPM series and power supply devices. Figure 4 shows a power system block diagram. The target of Fuji Electric's power semiconductors are the smart discrete, IPM, and SIM (system-integrated module). Their definitions are shown in the figure.

2.2 Technical trends for the power MOSFET

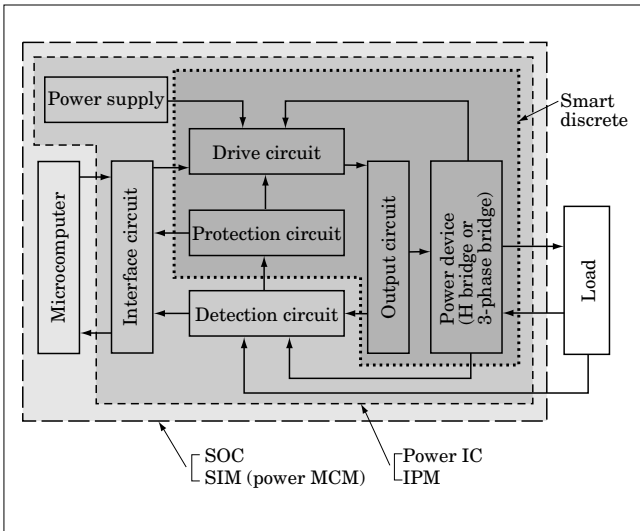
The driver for power MOSFET technology is cost/ampere. The performance index is given by $1/[R_{ds(on)} \times C \text{ (capacitance)}]$, and more advanced technology gives lower $R_{ds(on)} \times \text{Area}$.

Loss reduction for the power MOSFET is promoted by the following:

- (1) Application of VLSI (very large scale integrated circuit) technology (trench-gate, etc.)
- (2) A structure that reduces parasitic capacitance
- (3) A structure that improves avalanche withstand capacity
- (4) New-concept devices (carrier injection control, etc.)

As mentioned previously, the on-resistance of low-

Fig. 4 Block diagram of a power system



voltage MOSFETs is greatly reduced by adopting trench gates. However, trench gate MOSFETs have the following problems:

- ① a complicated process (high process cost)
- ② the reliability of MOS gates and the yield rate of chips

Many efforts have been made to solve these problems. Table 1 shows a comparison of power MOSFET performances. Overall, judging from these, manufacturers are promoting commercialization under their own technical strategies.

Intelligent low-voltage MOSFETs using power MOSFETs as output devices are expected to be widely used for automobiles and power supply systems. In response to this, we are promoting development and manufacture of the smart discrete (such as advanced function MOSFETs and IGBTs). These have driver, overcurrent and overheating protection functions and are expected to be used in many applications due to their high reliability and cost performance. To advance the functions even further, we will promote commercialization of the IPS (intelligent power switch) and development of system-on-a-chip devices using BCD (bipolar, CMOS and DMOS transistor) and SOI technologies.

2.3 Technical trends of the IGBT

The IGBT aims at reduction in power loss, system-integrated modules, downsizing, and high cost performance. To realize these goals, we strive for the following innovative technologies:

- (1) Approaching the limits of IGBTs

Table 1 Comparison of power MOSFET performances

Item Type	$R_{ds(on)}$ $\times$ area	Gate SiO ₂ relia- bility	Process	Yield rate	Cost/ ampere
VDMOSFET ^{*1}	△	◎	◎ (easy)	◎	○
Trench-gate MOSFET	◎	△	△ (complicated) trench process	○	◎
LDMOSFET ^{*2}	○	○	△ (complicated) multilayer	○	?

^{*1} VDMOSFET : Vertical double diffused MOSFET

^{*2} LDMOSFET : Lateral double diffused MOSFET

Table 2 Comparison of IGBT performances

Device structure	On- resist- ance	Switch- ing loss	RBSOA	SC perform- ance	High V _{ces}	Parallel
PT-IGBT	○	○	○	○	○	○
Trench-gate IGBT	◎	○	○	×	△	×
NPT-IGBT	△	◎	◎	◎	◎	◎
AS-PT-IGBT [*]	×	△	◎	◎	◎	◎

^{*} AS-PT-IGBT : Anode short-punch through-IGBT

- (2) Application of VLSI technology
- (3) Low-loss NPT-IGBT technology
- (4) Smart IGBT technology (high-precision sensing)
- (5) Exclusive, comprehensive, high-voltage driver IC technology
- (6) New module-package assembly technology (based on all silicon-chip technology)
- (7) Realization of new-concept devices

Using these core technologies, we plan to produce a series for low-loss 4th generation modules (600V, 1,200V, 1,800V, etc.), high-cost-performance, all-silicon 3rd generation IPMs (R-IPMs), and advanced function 4th generation IPMs. Furthermore, we plan to develop 2,500V and 3,300V-class, high-voltage, high-power IGBT modules. In addition, we plan to apply these core technologies to small capacities to produce high cost performance IGBTs.

Table 2 shows the comparison of various IGBT performances. With regard to the trench-gate IGBT and in addition to the MOSFET problems mentioned previously, there is a serious problem of withstand capability against excessive current in a short-circuit condition. It will be indispensable to add a self-protective function in practical applications. The NPT-IGBT leaves room for improvement, and we believe that it has the most suitable structure among the high-voltage IGBTs.

As mentioned above, we regard the trend toward intelligent devices as major. Based on the medium and long-term strategy for following this trend, we will promote commercialization of high-value-added IPMs.

2.4 New-concept device technology

The limit of reduction in on-voltage for a 600V IGBT (with turn-off loss equivalent to the 3rd generation) is thought to be about 1.5V (assuming the various withstand capabilities are at the necessary levels for hard switching applications).

Therefore, the development of low-loss next-generation devices exceeding IGBTs has attracted notice and many new-concept devices have been announced. These can be roughly classified into MOS-controlled thyristors and action-mode-shift types using a dual gate or the like. Among the MOS-controlled thyristors are nonsaturated (MCT) and saturated thyristors (EST). The turn-off types for these are emitter-shortened, emitter-open, and action-mode-selection types. In any case, the basic action uses thyristor action by MOS control. Device performance is dependent on the way in which to increase turn-off controllable current by operating efficiently and conquering parasitic actions with excess carriers in a latch-up state. Both emitter short-circuiting and opening are the responsibility of the MOSFET, and it is indispensable in minimizing the MOSFET on-resistance. The mode-shift type changes the thyristor action (during forward conduction) into the IGBT action just before turn-off and aims to increase controllable current and switch-

ing speed with a turn-off in the IGBT action. The point is the prevention of the parasitic thyristor from activating at an IGBT turn-off action. For that purpose we are investigating device structures that can attain the application of LSI process technology and the uniformity of current.

As IGBT performance improves, a target on-voltage of the next-generation device is required to be about 1.0V. In actual applications, there is a demand for devices that have not only low loss but also well-balanced characteristics with various withstand capabilities. We are making efforts to realize them and believe we can do so in the near future.

3. Power Semiconductor Devices for Equipment Related to Multimedia

3.1 Power semiconductor devices for the CRT

CRTs are used as displays for personal computers and workstations as well as televisions. They are becoming popular on a more personal level. There is an intense need for high-resolution pictures that make the viewer feel as if he were actually there. In response to this, the horizontal deflection circuit operating frequency is increasing year by year. At the same time, a need for energy reduction is also strong. To satisfy both, high-performance diodes with low switching loss in the high-frequency operation range are required.

To meet this requirement, in addition to the former damper diode series, we have developed and marketed new damper diodes which have greatly improved transient forward characteristics and can drive as high horizontal deflection frequency as 120kHz.

We have also developed and marketed high-voltage silicon diodes in which the high-speed switching characteristics and reverse-spike voltage withstand capability during CRT discharge have been improved.

In the future, Fuji Electric will strive to complete a line of devices such as CRT main power supply devices, S-shaped capacitor selector devices for compensating display distortion, and switching devices for horizontal deflection so that we can offer comprehensive proposals for CRT power semiconductor devices.

3.2 Power semiconductor devices for portable electronic appliances

The common problem of portable electronic appliances typically represented by personal notebook computers, mobile phones, and PDAs (personal digital assistants) is to extend service time by prolonging battery life. For this purpose, although the high performance of batteries is important, the key is to reduce power consumption for longer battery use.

From this point of view, the power MOSFET used for charging and discharging the safety circuit of long-life lithium ion batteries and the DC-DC converter must have low on-resistance to improve efficiency and

must also be utilized in the synchronous rectifier circuit. In addition, in order to be mounted in the limited space of portable electronic appliances, it must be assembled in a small surface-mount package.

To meet these requirements, we have realized a low on-resistance chip utilizing fine patterning technology and have developed and marketed n-channel SOP-8 power MOSFETs with the chip mounted on a SOP-8 package.

To prolong battery life, a management power MOSFET that cuts off power for unused peripheral equipment is also important. In the future, we plan to complete a series of p-channel SOP-8 power MOSFETs for this purpose.

4. Power Semiconductor Devices for Vehicles and Rolling Stock

4.1 Power semiconductor devices for car electronics

To meet the requirements for automobiles regarding “safety”, “environmentally friendly”, and “energy-saving”, the mounting of electronic equipment such as anti-skid brake systems (ABS) and air bags is rapidly increasing. External circuit components added to these power MOSFETs in the electronic equipment are protective circuits that protect the devices from various surge voltages and short circuits generated in automobiles and gate drive circuits.

The number of electronic parts has increased yearly and has resulted in a fear of lowered reliability and difficulties in mounting parts in the limited space of an automobile. To solve these problems, Fuji Electric marketed an IPS using a power MOSFET with built-in protective, driver, and self-diagnostic circuits on a single chip.

In addition, we have developed and marketed an advanced function MOSFET by simplifying the IPS and facilitating its use. This new MOSFET is expected to be used not only in car electronics but also in uses that demand system downsizing and high reliability.

4.2 Power devices for rolling stock and electric vehicles

The improvement of drive performance is directly connected with power conversion technology. IGBT-applied control has rapidly spread in response to recent demands for rolling stock such as improvement in energy efficiency, size reduction, and comfort. Especially high-voltage, large-power, flat IGBTs such as the 2.5kV/1,000A originally developed by Fuji Electric are expected to greatly improve equipment efficiency and size not only in rolling stock but also in high power industries.

Further focusing on devices for urban transportation use, we have developed 1,800V/800A and 3,300V/1,200A IGBT modules using new NPT-IGBTs. A through investigation into loss reduction and reliability improvement of the chips, packages, etc. was carried out to obtain optimum conditions for the rolling stock.

To protect the global environment from air pollution due to automobile exhaust gas, the development of practical and nonpolluting electric vehicles (EV) has been taken up in earnest. At present, the IGBT is top-rated as an EV inverter power device, and the IGBT-IPM is especially thought to be important because of its real-time protection and reliability. However, IGBT loss is still high and further improvement is desired. In the future, high-efficiency inverters using new-concept devices will be applied.

5. Power Semiconductor Devices for Industrial Power Converters

5.1 Power semiconductor devices for small capacity (several kilowatts or less) power converters

Small capacity power converters, typically represented by inverters for variable-speed motors and UPSs, require a reduction in size, weight, and price for further use. In this field, aiming to minimize the mounting cost in applications, Fuji Electric has offered IGBT modules with six IGBTs built into a package and PIMs (power integrated modules) with a built-in power supply converter.

Recently, small capacity power converters have been used in various fields, and requirements for IGBT mounting methods have diversified. In response, in addition to the previous approach by modules and with the concept of minimizing device cost and free mounting in applications, we have developed and marketed discrete molded-package IGBTs.

The molded IGBTs based on 3rd generation IGBT technology has low-loss and a resistance to high breakdowns and is expected to contribute to a reduction in equipment size and weight.

5.2 Power semiconductor devices for power converters

Following are uses of these devices, generally classified by the field of application. In the generation and conversion of electric power and energy, utilization of new energy resources such as photovoltaic power generation and fuel cells is expected to develop rapidly. In the industrial field, inverters used for motor control in motor applications such as pumps, blowers, and machine tools are expected to greatly increase to include a wide range of equipment. In the field of information and communications, they are expected to be utilized as devices for computer systems' power supply; the UPS is one example. Power MOSFETs and IGBTs used for the PWM (pulse width modulation) converters and PWM inverters are expected to expand. In household appliances, the use of energy-saving inverters is expected to give impetus to the development of power semiconductor devices. Inverters will be applied to the motor control of air conditioners, refrigerators, etc., resulting in high efficiency, downsizing, and advanced functions.

Up to now, Fuji Electric has been highly rated in

the field of medium capacity (up to several tens of kilowatts) inverter control. In the future, by applying the new technologies mentioned above, we plan to develop timely devices to match broadening fields. In the range less than several kilowatts, we will aim at the development of special modules and IPMs and at expansion of integrated devices (PIMs and IPMs) for a transition period. The 4th generation modules up to several hundred amperes and from several hundred to nearly two thousand volts, new NPT-IGBT modules, 3rd generation IPMs, and advanced-function 4th generation IPM series are all under development.

6. Conclusion

As stated in the Introduction, there are many problems to be solved by technology on the road to a highly information-oriented society. Unlike in the

past, there should be increased recognition of problems of the environment and resources. Specially, the goals will include “user-friendly inverters”, “energy-saving electronic appliances”, and “new energy resources development”. The role played by power semiconductor devices in pursuit of these goals will increase in importance. Fuji Electric will make a continuous effort to play a vital role in their attainment.

The present status and future prospects of Fuji Electric's power semiconductor devices have been described above. In particular, we intended to focus on our attitude towards their development. Although the descriptions may be somewhat rough, we appreciate your understanding of our intentions. We will continue our technical innovations in developing characteristic products in response to the needs of the market and contribute to the further development of electronics.



High-Speed, High-Voltage Diodes for High Resolution Monitors

Hiroyuki Ota
Taketo Watashima

1. Introduction

In today's multimedia orientated society, display devices used as man-to-machine interfaces to facilitate communication have become an indispensable part of daily life in both the public and industrial sectors. CRTs (cathode ray tubes) are the most widely used electric display devices because they provide a low cost, large screen, full-color image with high resolution, high brightness, and quick response.

The demand for large sized CRT tubes with high resolution to display high density and large capacity graphics has increased year by year, especially in the recent field of monitors, due to the popularization of CAD, computer graphics and Windows* software. Prior to the appearance of Windows 95 software, the standard size and horizontal deflection frequency of CRTs were 14 through 15 inches and about 48kHz respectively. However, since the introduction of Windows 95, the standard size and frequency have tended

* Windows is a registered trade mark of Microsoft Corporation, USA.

to increase to 17 inches and approximately 70kHz, respectively. Furthermore, demand in the monitor market for greater than 100kHz frequency and 17 through 21-inch class CRTs will increase if device costs are reduced.

In addition to personal computers, devices that can connect TVs to the internet have appeared in response to the increasing number of users who are interested in the internet. TVs larger than 20 inches in size, with horizontal deflection frequencies of 16 through 48kHz, and having the same operating frequency as standard monitors already exist and future advances are expected.

The larger size and higher resolution CRT display needs operation at higher frequency and larger current for high-voltage diode to scan larger beam with higher speed.

This paper outlines the high-speed, high-voltage diode ESJA18-08 for large screen and high resolution monitors, developed to satisfy such market requirements.

2. Applications of High-Voltage Diodes

High-voltage diodes are applied in the voltage output circuit for the horizontal deflection of a monitor display. Figure 1 shows a horizontal deflection circuit for a CRT monitor.

A horizontal deflection circuit horizontally deflects and scans the CRT beam current. The high-voltage output circuit supplies a high voltage to the CRT anode. The beam is scanned to the CRT fluorescence screen synchronizing with the horizontally deflection. The high-voltage diode is mounted in a flyback transformer (FBT) which generates the high voltage.

3. Improving The ESJA18-08 High-Speed High-Voltage Diode

3.1 Low loss, high frequency operation

In order to be able to operate the diode at high frequency, it is necessary to reduce the loss. Total loss (W_t) consists of forward loss (W_f), reverse loss (W_r), and switching loss (W_{sw}) when operating the FBT. As

Fig.1 Horizontal deflection circuit for CRT monitor

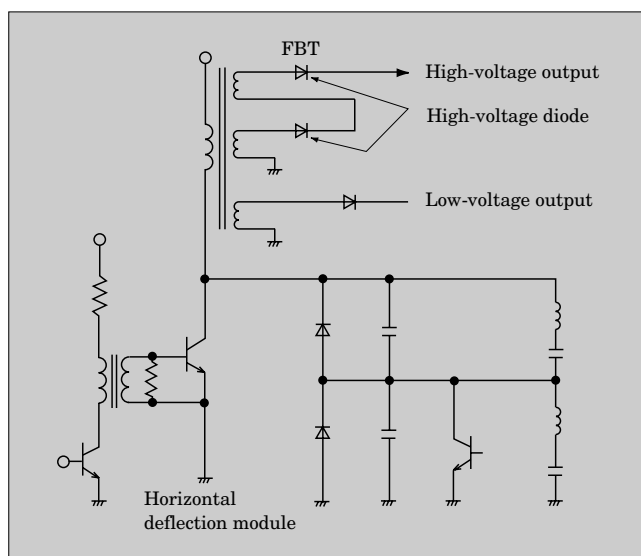
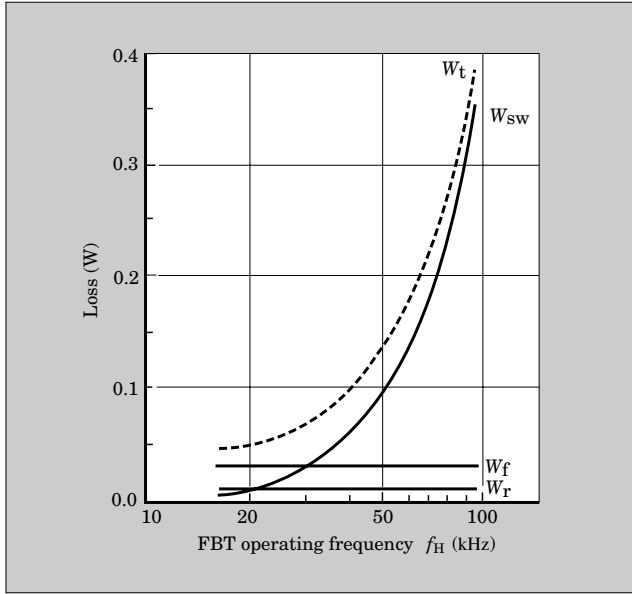


Fig.2 FBT operating frequency versus loss



shown in the graph of Fig. 2 (loss versus operating frequency), W_f and W_r remain constant, while W_{sw} increases suddenly with increasing frequencies.

Therefore, reduction of W_{sw} is crucial to enabling operation of the diode at high frequencies. The goal in developing the ESJA18-08 diode was to operate at higher than 80kHz and to reduce reverse recovery time (t_{rr}) compared to the former ESJA08-08 diode. Reverse recovery time has a trade-off in the relation between forward voltage (V_F) and reverse current (I_R). Assuming an improvement in the trade-off, the goal was to develop a new diode with V_F and I_R at the same level as the former diode.

3.2 Large reverse surge capability

The FBT structure was changed from the former slot type into a multilayer type, suitable for high frequency. In the case of multilayer type FBTs, there is a problem in applying the reverse surge voltage to the high-voltage diode when flash-over is generated in the CRT. Furthermore, today's severe price competition has created a need to lower the manufacturing cost of FBTs, and as a result, protective resistance that reduces the surge voltage of flash-over in CRTs has tended to be omitted in FBT.

Moreover, larger sized CRT screens have caused the FBT voltage output to increase. This has been accompanied by corresponding increases in generated surge voltage. Therefore, obtaining large surge capability is as important as low loss at high frequency operation in the development of higher-voltage diode. During development, a flash-over test circuit as shown in Fig. 3 was used for the simulation of flash-over in the CRT.

Usually, when flash-over is generated in a CRT that uses a layer type FBT, the structure of the secondary circuit of FBT is so that the highest reverse

Fig.3 Flash-over test circuit

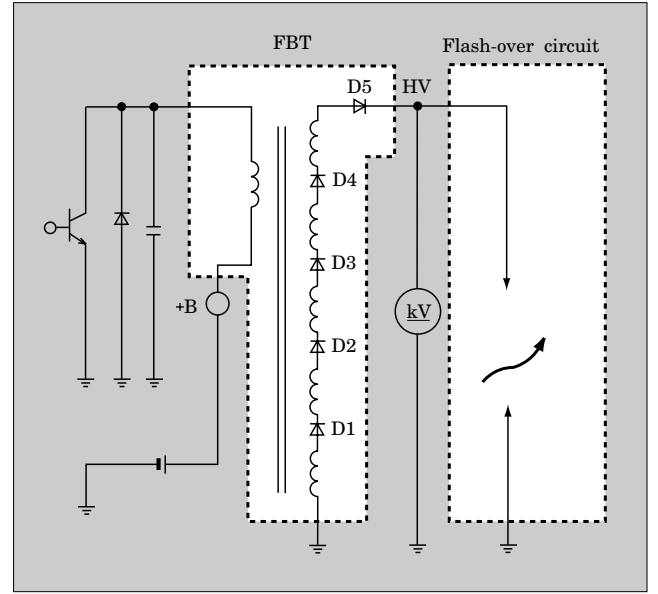
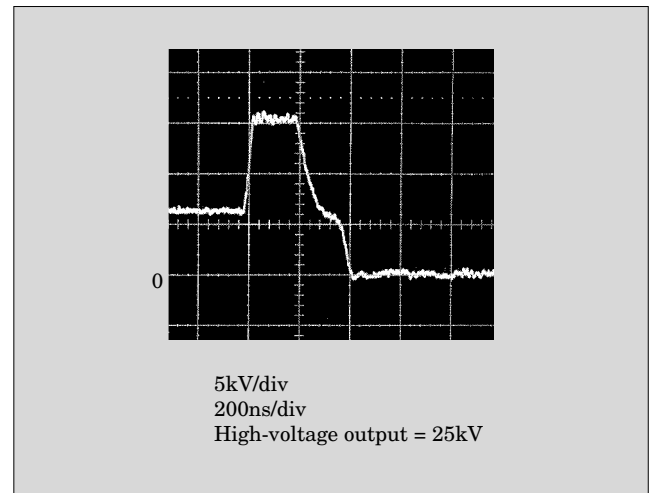


Fig.4 Waveform of flash-over obtained from high-voltage diode



surge voltage is applied to the second diode from the high-voltage output. The value of this reverse surge voltage depends on the composition and the high-voltage output of the FBT. In this case this reverse surge just under 20kVp-p was observed for a 5-layer, 5-diode type FBT (secondary windings of the FBT are wound one above the other into 5 sections with high-voltage diodes) when the output voltage was 25kV. Although it is extremely effective to use high-voltage diodes that have higher voltages than the surge voltage, in consideration of manufacturing costs, space constraints, and the applied voltage during regular operation, high-voltage diodes have 8kV of reverse voltage (V_{rm}) are normally used in layer type FBTs. Figure 4 shows a typical waveform of the diode at the secondary step ($V_{rm} > 8kV$) from the high-voltage output side during flash-over of the CRT.

It is understood that the high-voltage diode can

operate in the avalanche area because the applied surge voltage is clamped at avalanche breakdown voltage. Furthermore, since dv/dt (250kV/ μ s) of the applied reverse surge voltage is very sharp, the capability to withstand both avalanching and dv/dt is necessary for surge protection.

4. Design Goals

To achieve low loss under high frequency operation and to preserve the large reverse surge capability described in section 3.1 and 3.2, the design had the following goals.

Fig.5 Appearance of ESJA18-08 high-speed, high-voltage diodes

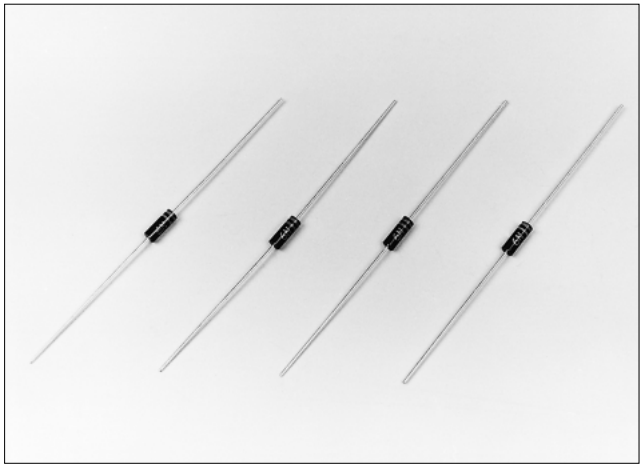


Table 1 Absolute maximum ratings of the ESJA18-08 high-speed, high-voltage diode

Item	Symbol	Rating	Units
Repetitive peak reverse voltage	V_{RM}	8	kV _{peak}
Average forward current	I_O	5	mA
Non-repetitive peak forward current (10ms)	I_{surge}	0.5	A _{peak}
(Allowable) Junction temperature	T_j	120	°C
Storage temperature range	T_{stg}	- 40 to +120	°C
(Allowable) Case temperature	T_c	100	°C

Table 2 Electric characteristics of the ESJA18-08 high-speed, high-voltage diode

Item	Symbol	Condition	Rating	Units
Forward voltage drop	V_F	$I_F=10mA$	≤ 28	V
Reverse current	I_{R1}	$V_R=8kV$	≤ 2	μA
	I_{R2}	at 100°C, $V_R=8kV$	≤ 5	μA
Reverse recovery time	t_{rr}	$I_F/I_R=2/4mA$	≤ 45	ns
Junction capacitance	C_j	$f=1MHz, V_R=0V$	≤ 2	pF

- (1) To optimize resistance and number of layers of Si chips
- (2) To redevelop the lifetime control
- (3) To optimize the base width and diffusion depths of p⁺ and n⁺ layers
- (4) To improve Si surface etching technology

Fuji Electric has developed a high-speed high-voltage diode that processes enhanced high speed switching characteristics, a low forward voltage drop, and enhanced large reverse surge capability.

An overview of the ESJA18-08 diode is presented below.

5. Overview

Figure 5 shows the appearance of the ESJA18-08 diodes. Table 1 and Table 2 list absolute maximum ratings and electric characteristics, respectively.

Fig.6 Comparison of switching waveforms

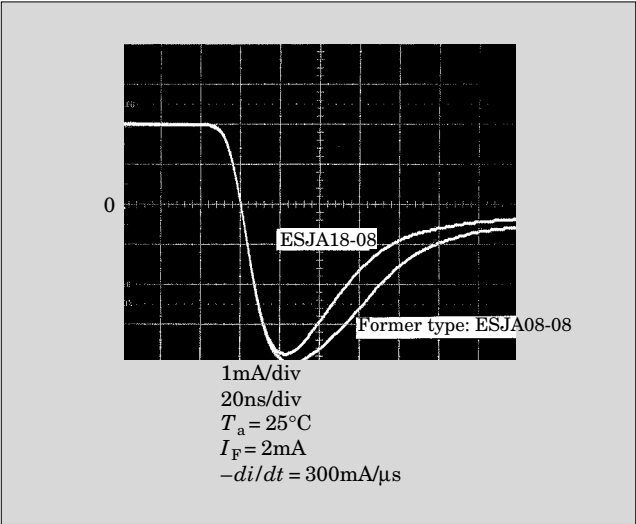


Fig.7 Temperature dependence of reverse recovery time

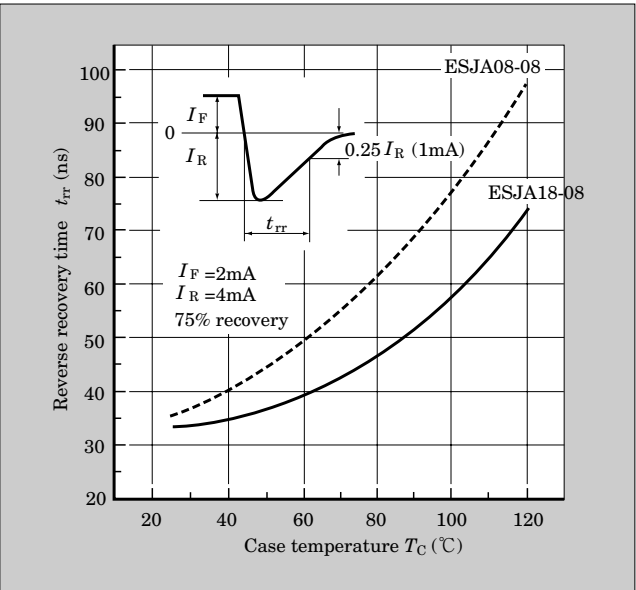
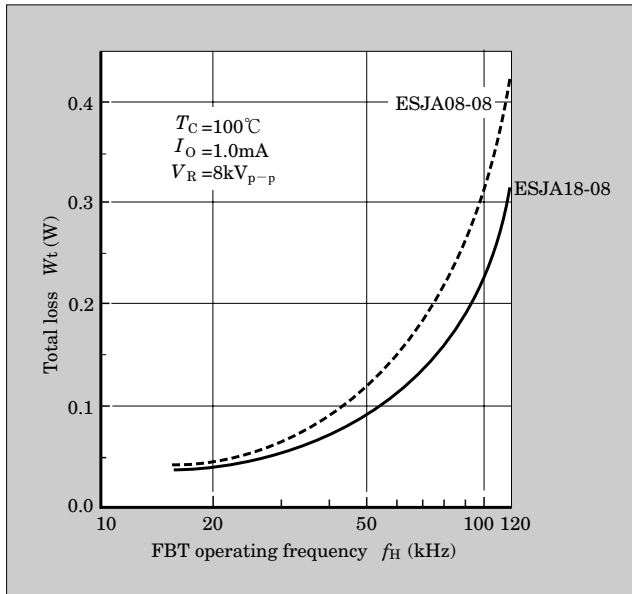


Fig.8 FBT operating frequency versus total loss



A comparison of the main characteristics of the ESJA18-08 and the former ESJA08-08 will also be presented.

5.1 Switching

Figures 6 and 7 compare the switching waveforms of the ESJA18-08 and ESJA08-08 and their temperature dependence versus reverse recovery time, respectively.

Reverse recovery time of ESJA18-08 is less than that of the ESJA08-08 in the high temperature region. Therefore, the switching characteristic of the ESJA18-08 is sharply improved. Figure 8 shows total loss versus FBT operating frequency for the ESJA18-08 and ESJA08-08. The ESJA18-08 may be operated at higher frequencies because its loss in the high frequency region is lower than that of the ESJA08-08.

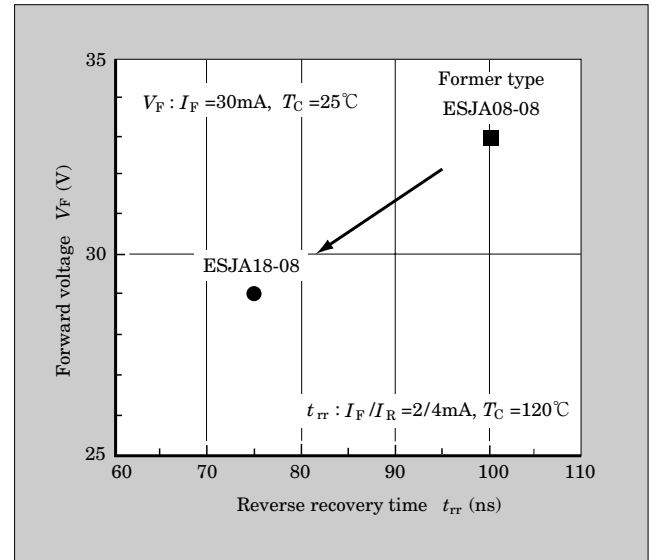
5.2 Forward voltage

Figure 9 shows reverse recovery time versus forward voltage for ESJA18-08 and ESJA08-08. As described above, there is a trade-off between forward voltage and reverse recovery time. The characteristics of this trade-off have been greatly improved.

5.3 Reverse characteristic

Due to the above improvements, avalanche breakdown voltage and reverse current at higher temperatures remain the same as those of the ESJA08-08.

Fig.9 Reverse recovery time versus forward voltage



5.4 Reverse surge voltage capability

The reverse surge voltage capability of the ESJA18-08 has been evaluated using a standard 5-layer, 5-diode type FBT (non-protecting resistance) and the aforementioned flash-over test circuit for CRTs. The result have been very favorable, with no degradation of FBT output even after more than 40,000 flash-over tests with a FBT high-voltage output of 30kV.

5.5 Summary

As described above, the ESJA18-08 diode has been developed with excellent high-speed switching characteristics, compatible with the demands for high reverse surge voltage capability required in most important market applications. The ESJA18-08 diode will also be suitable with the future technology for high resolution CRT monitors.

6. Conclusion

This paper has presented the ESJA18-08 high-speed high-voltage diode that was developed for large size and super high resolution CRT monitors. This high-speed, high-voltage diode will contribute to the development of larger sized and higher resolution CRT monitors. Based on these developed technologies, Fuji Electric will continue to provide improved devices and technology.

New Power MOSFET

Naoto Fujisawa
Toshihiro Arai
Tadanori Yamada

1. Introduction

Due to the finer patterns and higher integration of LSIs, functions that were used a few years ago in mini-computers have now been realized in personal computers. The popularity of the internet has also spread the use of personal computers. In particular, because of their compact size, notebook type hand-held computers are widely used in the office. In addition, portable electronic devices such as LCD TVs or personal handy phones are also widely used.

These portable devices require batteries and a battery charger (AC adapter). Because portable devices are most beneficial when they can be operated for a long time, batteries must be small and have a high-energy density. Instead of the conventional Ni-Cd battery, Li-ion batteries have begun to be utilized as a new second battery for these devices. Because the charging and discharging of Li-ion batteries must be precisely controlled to prevent degradation, ICs (integrated circuits) and power MOSFETs (metal-oxide-semiconductor field-effect-transistors) have been used to control them. The necessary characteristics of the power MOSFET are low on-resistance and a small surface mounting package. To lengthen the discharge time for each charge of the battery, it is important to increase the DC-DC converter efficiency which stabilizes the output voltage. To increase the efficiency, a synchronous rectifier circuit that uses a power MOSFET is being used in the rectifying circuit of DC-DC converters.

Fuji Electric has developed a SOP (small outline package) -8 series power MOSFET suited for the power control of portable devices. In this paper, an outline of the power MOSFET will be presented.

2. Application of Power MOSFETs

2.1 Li-ion battery

Figure 1 shows the charge-discharge control circuit of a Li-ion battery used in portable devices. As shown in Fig. 1, individual power MOSFETs are used to control the charging and discharging of the battery. An SOP-8 package, effective as a small sized battery

pack, is used as the IC package and contains 2 power MOSFETs.

2.2 DC-DC converter

Although the output voltage of the battery is high when fully charged, the voltage is reduced as it is discharged. In certain situations, semiconducting parts such as ICs that control devices will not operate correctly when the supply voltage is unstable. To stabilize the supply voltage, a DC-DC converter is used.

Fig.1 Internal circuit of Li-ion battery

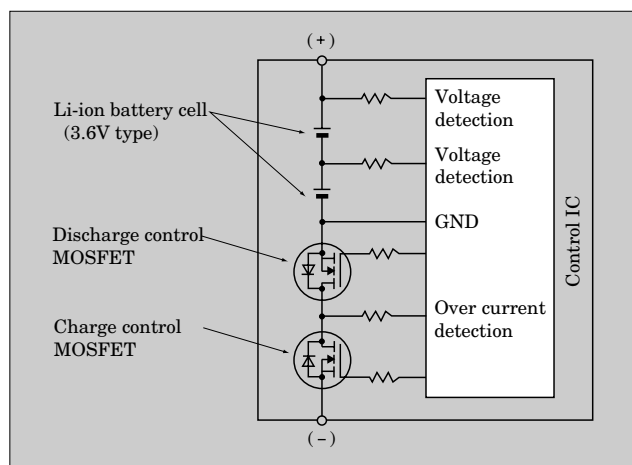
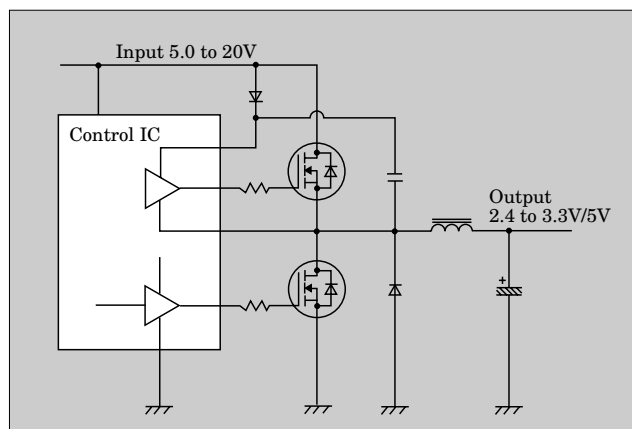


Fig.2 Synchronous rectifier circuit



The output voltage of DC-DC converters has decreased from 5V to 3.3V and 2.9V to 2.4V due to lower operating voltages of ICs and LSIs in portable devices. Because the forward voltage drop of the rectifying diode has a large effect on efficiency, lowering the output voltage of DC-DC converter reduces the

Fig.3 Comparison of forward voltage characteristics

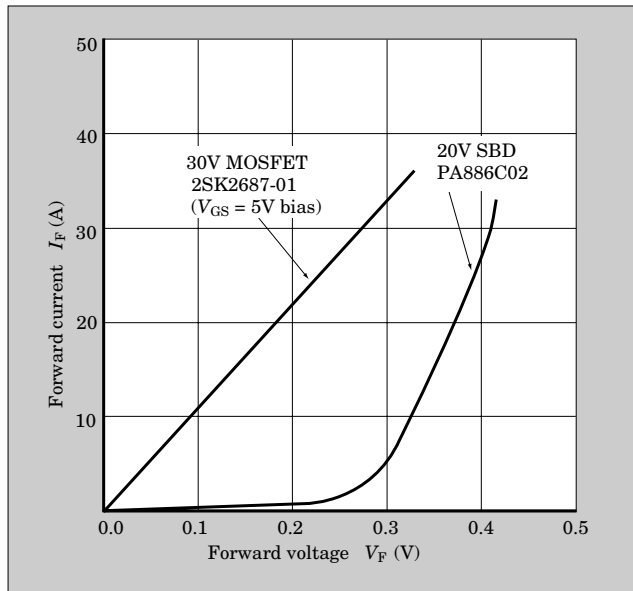
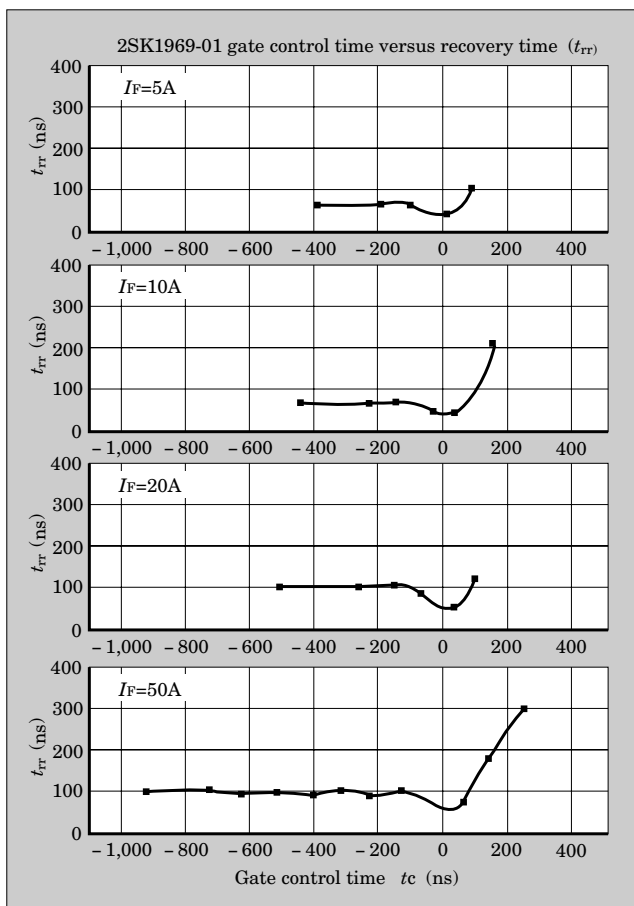


Fig.4 Control time versus recovery time



efficiency. It is important to lessen the amount of this decrease in efficiency. For this reason, the use of power MOSFETs in a synchronous rectifying system has been increasing. The synchronous rectifier circuit is shown in Fig. 2. Compared to typical rectifying system with Schottky diodes, the synchronous rectifier circuit can reduce the threshold voltage loss of the diode. Figure 3 compares forward voltage characteristics for the Schottky diode and power MOSFET. Since loss in the synchronous rectifier circuit can increase in certain situations when the timing of the input excites the switching and rectifying power MOSFET, dead time for the signal must be set reasonably. Figure 4 shows gate control time versus reverse recovery time for the switching power MOSFET when the input is in the ON-state and the rectifying power MOSFET when the input is in the OFF-state.

3. SOP-8 Power MOSFET

The ratings and characteristics and an overview of the SOP-8 Power MOSFET, developed in consideration of the requirements for Li-ion batteries and DC-DC converters as described above, are shown in Table 1 and Fig. 5, respectively.

Table 1 Ratings and characteristics of SOP-8 power MOSFET

Item	Model	F8006N	F7007N
V_{DS}		20V	30V
I_D		$\pm 5A$	$\pm 7A$
I_{Dpulse}		$\pm 60A$	$\pm 84A$
P_D		2W	2W
$V_{GS(th)}$		0.5 to 1.5V	1.0 to 2.0V
$R_{DS(on)}$		48m Ω at $V_{GS}=4V$	25m Ω at $V_{GS}=10V$
Package		2 devices SOP-8	1 device SOP-8

Note 1) I_D and I_{Dpulse} are the rated values for 1 device.

Note 2) P_D is the rated value when mounted on a 1,000mm² FR-4 type glass epoxy substrate.

Note 3) The P_D of F8006N is for 2 devices operating in parallel. When 1 device is operating, the P_D is guaranteed to be 1.7W.

Fig.5 External view of SOP-8 power MOSFETs

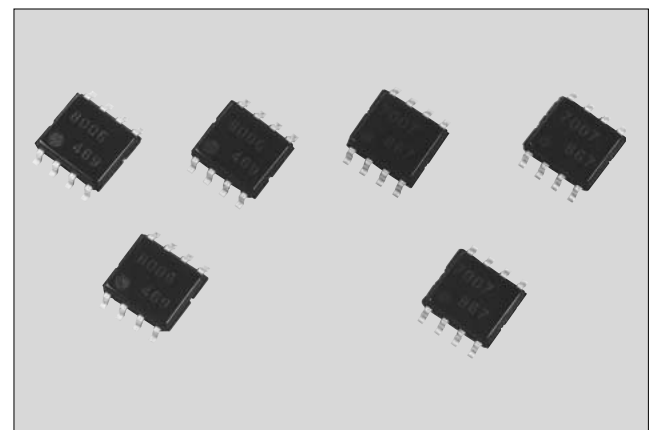
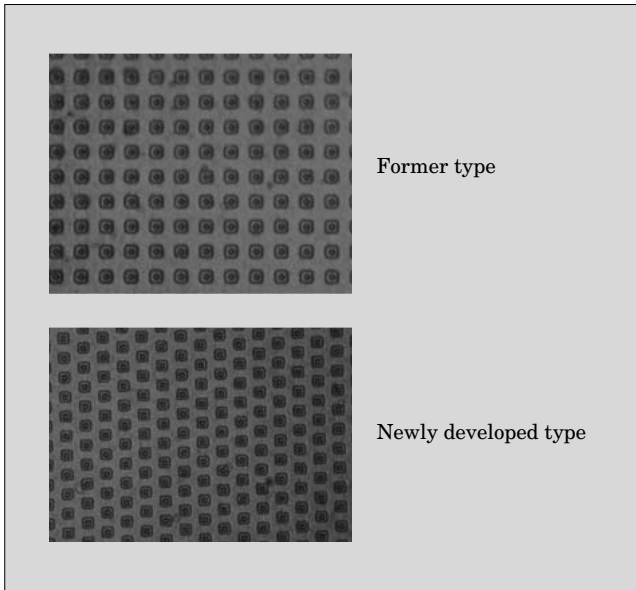


Fig.6 Cell photographs



3.1 Chip development

(1) Lower RDS (on)

There are many requests for low voltage power MOSFET with lower RDS (on). Manufacturing technologies for lower RDS (on) in the newly developed power MOSFET are listed below.

- (a) Arsnide doped Si substrate, which has approximately 30% lower resistivity than Antimon doping
- (b) 60% reduction in cell size compared to conventional devices (cell photos of conventional and newly developed power MOSFETs are shown in Fig. 6)
- (c) Lower resistivity and optimized depth of epitaxial layer
- (d) Lower metal layer resistivity

By using above the technologies, RDS (on) was reduced by approximately 50% compared to conventional devices.

(2) Zener diode inserted between gate and source (G-S)

Since the DC-DC converter for Li-ion batteries and portable devices generates a low voltage, the power MOSFET must be able to operate at a low voltage. However, driving a lower gate voltage causes a problem of reduced gate blocking capability. For this reason, a twin type zener diode is inserted between the gate and source of an SOP-8 power MOSFET to increase gate block capability.

3.2 Package development

(1) Improved heat radiation

Because of the importance of heat radiation, the design criteria of a power device such as the power MOSFET is different than that of ICs. To improve the heat radiation, an SOP-8 package has been designed

Table 2 Items for improved thermal characteristics

Item	IC	Power MOSFET
Lead frame	Isolated frame	Die-pad integrated frame
Die bonding	Silver paste	Solder
Mold resin	Low stress	Low stress Higher heat conduction

Fig.7 Comparison of frame structure

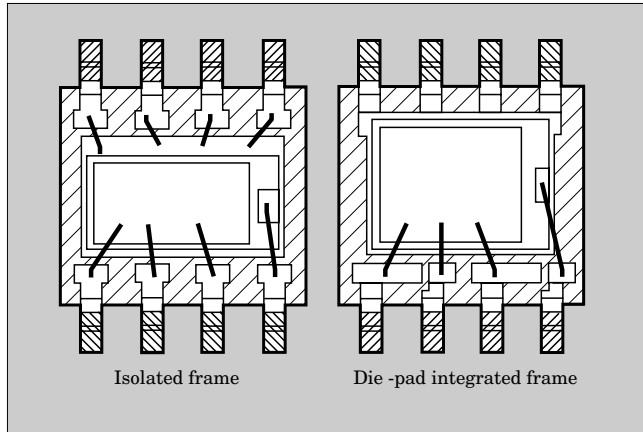
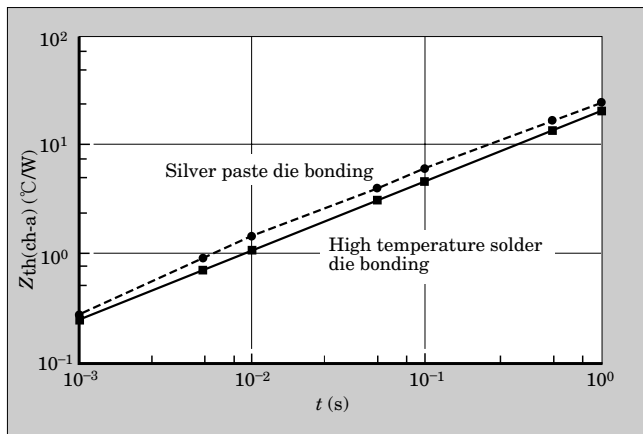


Fig.8 Thermal resistance of SOP-8 power MOSFET



and applied in a way as shown in Table 2. (Figure 7 shows the frame structure)

Measured thermal resistance of the SOP-8 power MOSFET is shown in Fig. 8.

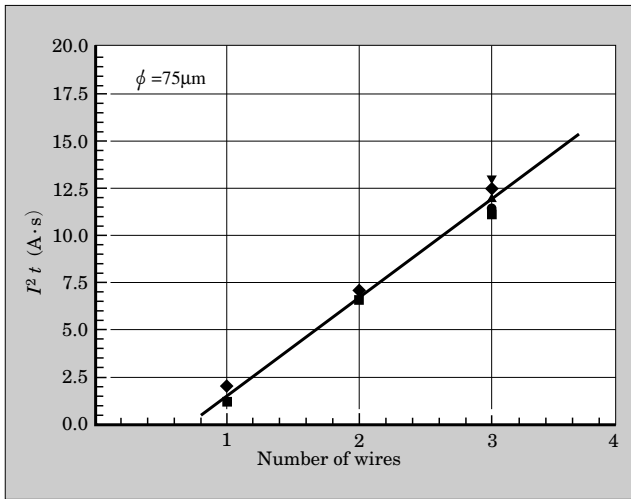
(2) Improved blocking capability

When using Li-ion batteries, the inrush current causes an over-current to flow through the power MOSFET. Bonding wire for the power MOSFET must be designed to withstand the over-current and not melt down. Blocking capability of the wire has been strengthened by using larger diameter (greater than 75μm in diameter) and multi-lined wire (3 lines). Measured wire melt down in shown in Fig. 9.

(3) Decreased wire touch

The wire loop height is limited by the frame, chip and wire widths in a SOP-8 package covered by 1.6mm thick resin. When the die pad and thermal electrode are connected on the same step, it is difficult to avoid

Fig.9 Wire meltdown characteristics



contact between the wire and chip edge without increasing the wire loop height. In order to solve the contact problem, the frame has been constructed by using different steps with a lower plane for the die pad and an upper plane for the terminal electrode.

3.3 Reliability

Surface mount packages such as the SOP-8 are soldered onto a printed substrate with flow or reflow solder. When designing for reliability, the effect of package cracks caused by thermal stress generated during the soldering process must be examined. The following pretreatments are being implemented to ensure reliability of the SOP-8 power MOSFET.

- (1) Humidity 85°C, 65%, subject to 168h
- (2) Thermal (solder dipping) 250°C, 5s

Reliability test items and results are listed in Table

3.

Table 3 Reliability test items and results

Item	Standard value and condition	Result
High temperature storage	$T_a=150^{\circ}\text{C}$ 1,000h	No faults detected in 22 samples of each item
Low temperature storage	$T_a=-55^{\circ}\text{C}$ 1,000h	
Moisture resistance (steady state)	$T_a=85^{\circ}\text{C}$, 85%RH 1,000h	
Thermal humidity bias	$T_a=85^{\circ}\text{C}$, 85%RH $V_{DS}=0.8 \times V_{DSmax}$ 1,000h	
Pressure cooker	$T_a=130^{\circ}\text{C}$, 85%RH 48h	
Temperature cycle	-55 to RT to $+150^{\circ}\text{C}$ 30min. 5min. 30min. 100 cycles	
Temperature moisture resistance cycle	$T_a=-10$ to 65°C 80 to 95%RH 10 cycles	
Intermittent operation	$\Delta T_c=90^{\circ}\text{C}$ 5,000 cycles	
High temperature reverse bias	$T_a=150^{\circ}\text{C}$, $V_{DS}=V_{DSmax}$ 1,000h	
High temperature gate bias	$T_a=150^{\circ}\text{C}$, $V_{GS}=V_{GSmax}$ 1,000h	

4. Conclusion

This paper has presented an outline of the SOP-8 power MOSFET developed for Li-ion batteries and DC-DC converters in portable devices.

Fuji Electric intends to meet the challenge of developing a p-channel SOP-8 power MOSFET and a TSSOP (Thin Shrink SOP) with lower height and narrower terminal pitch, as well as new devices to satisfy the diversifying market's need for portable devices.

Intelligent Power MOSFETs

Shin Kiuchi
Motoi Kudoh
Naoki Yaezawa

1. Introduction

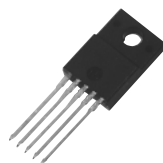
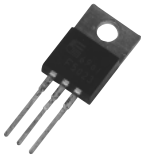
The development of automotive electronics is accelerating year after year. Currently, the percentage of cars equipped with anti-skid brake systems (ABS) and air bags, which were very highly priced several years ago, is rising at an increasing rate. Manufacturers' and users' concern for safe and environment-friendly automobiles has grown so high that the inclusion and superiority of these electronics systems is regarded as adding value to automobiles, and has become a sales point.

At present, technical developments in advanced vehicle control technology to ensure safety and ad-

vanced combustion technology to reduce exhaust gas and improve fuel consumption are progressing year by year. It is expected that in the future, as promoted by the Ministry of Transportation, the technical trends represented by advanced safety vehicles (ASV: advanced safety vehicles integrally controlled by electronics technologies for safety prevention and accident avoidance during normal driving and safety in case of collision) and "automated travel" to minimize manual operation will create a greater incentive to develop and increase the scale of car control electronics, and automobile manufacturers will desire to reduce the size and cost of these increasing systems.

Intelligent power MOSFETs (metal-oxide-semicon-

Table 1 List of intelligent power MOSFET series

Type		High-side					Low-side											
		IPS					Intelligent power MOSFET											
Model		F5001H	F5016H	F5017H	F5021H	F5015L	F5020	F5022	F5018	F5019	F5023	F5027	F5029	F5030	F5031	F5032	F5028	F5033
Package		TO-220F-5					K-pack			T-pack	TO-220	T-pack	TO-220	T-pack	K-pack		T-pack	SOP-8
		TO-220F-5					K-pack			T-pack		TO-220			SOP-8			
																		
Rated voltage *1		60V	60V	60V	50V	45V	40V	60V	40V	40V	40V	40V	40V	40V	40V	40V	40V	40V
Rated current *2		3A	3A	6A	3A	10A	3A	3A	8A	12A	52A	18A	14A	6A	28A	1A		
ON-state resistance (max.)		0.16Ω	0.16Ω	0.16Ω	0.16Ω	0.07Ω	0.4Ω	0.5Ω	0.14Ω	0.14Ω	0.02Ω	0.07Ω	0.07Ω	0.2Ω	0.04Ω	0.6Ω		
Functions	Overcurrent protection	◁○▷					◁○▷											
	Overtemperature protection	◁○▷					◁○▷											
	Overvoltage protection	◁○▷					◁×▷											
	Open load detection	◁○▷					◁×▷											
	Status output	◁○▷					◁×▷											
	Induced voltage clamping	◁○▷ (Reference - 11V)			◁○▷ (Reference - 42V)		◁○▷ Drain-gate zener diode ▷											

*1: Limited by drain-gate zener diode, *2: Limited by overcurrent and short-circuit protection

ductor field-effect transistors), which integrate control, protection, self-diagnosis circuits and a power device on a chip, can be used to integrate electronic parts at a lower price than that of conventional automobile manufacturers. MOSFETs are becoming regarded as devices capable of constructing highly reliable systems.

To meet the above requirements for automotive electronics, Fuji Electric has developed two lines of intelligent power MOSFETs, an IPS (intelligent power switch) series and an intelligent power MOSFET series that is described below.

2. Overview of the Products

2.1 Overview of the product series

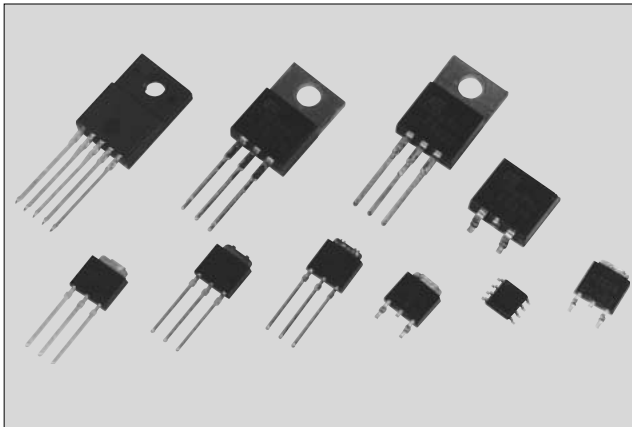
Table 1 shows a list of Fuji Electric's intelligent power MOSFET series.

The IPS series incorporates a power device, drive and protection circuits, and a function to communicate with the CPU on a single chip and is enclosed in a TO-220F-5 (5 terminals) package.

A new device among this series, the F5021H, retains the basic performance of the former series that performed well in solenoid valve, lamp, and motor drive applications, while expanding the range of use and reducing the chip size by lowering the on-state resistance of the output stage MOSFET. The F5021H has the following special features.

- (1) Low on-state resistance achieved by shrinking the power MOSFET to half the former size.
- (2) Improved induced voltage clamping capacity for high-speed switching of inductive loads (lowering clamping voltage from ref. -11V to ref. -42V achieves times higher speed than the former devices)
- (3) Reduced EMI (electro-magnetic interference) noise by reducing control circuit standby current (to half the former value, when IPS is on)
- (4) Improved current conducting capacity at high temperatures by making the over current detection value dependent on lower temperature (half the former value)

Fig.1 Appearance of intelligent power MOSFETs



Although the intelligent power MOSFET series incorporates a power device and an overvoltage protective function similar to the IPS series, it has a discrete 3-terminal package construction similar to unit MOSFETs and bipolar transistors. The intelligent power MOSFET series is easy to handle and enables the configuration of reliable systems. This series is well suited for automated mounting as surface-mount type packages are widely available. Figure 1 shows the external appearance of packages in this series.

This intelligent power MOSFET series is described below.

2.2 Main characteristics

The F5020 device is selected as a typical device from among the low-side intelligent power MOSFET series. Tables 2 and 3 list its main characteristics, and Figs. 2 and 3 show the block diagram and chip appearance, respectively. Main features are listed below.

- (1) Short-circuit protection with built-in short-circuit and overtemperature detection functions
- (2) Over voltage protection and high-speed switching for inductive loads with a built-in dynamic clamping circuit
- (3) Can withstand a high ESD (electro-static discharge) voltage (withstands 25kV between drain and source, and 10kV between gate and source at

Table 2 F5020 absolute maximum ratings (at $T_c = 25^\circ\text{C}$)

Item	Symbol	Rating	Unit
Drain-source voltage	V_{DSS}	40	V
Gate-source voltage	V_{GSS}	-0.3 to +7.0 DC	V
Drain current	I_D	3	A
Max. power dissipation	P_D	10	W
Operating junction temperature	T_j	150	$^\circ\text{C}$
Storage temperature	T_{stg}	-55 to +150	$^\circ\text{C}$

Table 3 F5020 electrical characteristics (at $T_c = 25^\circ\text{C}$)

Item	Symbol	Condition	Standard		Unit
			Min.	Max.	
Drain-source voltage	V_{DSS}	$I_D=1\text{mA}$ $V_{GS}=0\text{V}$	40	60	V
Gate-source threshold voltage	$V_{GS(th)}$	$I_D=1\text{mA}$ $V_{DS}=13\text{V}$	1.0	2.8	V
Gate-source leakage current	$I_{GSS(n)}$ $I_{GSS(un)}$	$V_{GS}=5\text{V}$		500	μA
				800	
Drain-source ON-state resistance	$R_{DS(on)}$	$I_D=1\text{A}$ $V_{GS}=5\text{V}$		0.4	Ω
Overtemperature protection	T_{trip}	$V_{GS}=5\text{V}$	150		$^\circ\text{C}$
Overcurrent detection	I_{OC}	$V_{GS}=5\text{V}$	5		A
Dynamic clamping energy dissipation	E_{CL}	$T_j=150^\circ\text{C}$	50		mJ
Thermal resistance	$R_{th(j-c)}$			12.5	$^\circ\text{C/W}$

*1: during normal operation, *2: when protection is activated

Fig.2 F5020 block diagram

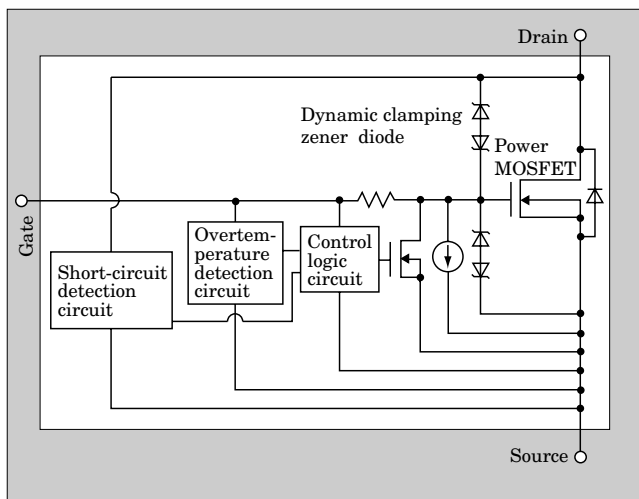
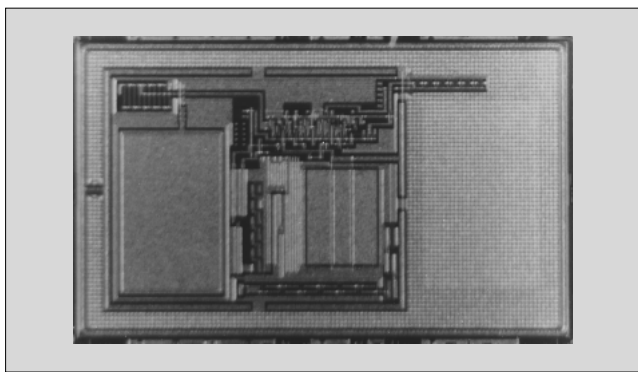


Fig.3 F5020 chip



150pF, 150Ω)

- (4) Can directly drive a microcomputer possible with 5V gate drive
- (5) Built-in function turns off output when the gate terminal is open to fail-safe the system as a whole
- (6) Control unit and power MOSFET unit integrated on a single chip
- (7) Low price achieved by utilizing self-isolation ND (N-channel diffusion)-MOS process
- (8) Smaller size and automated mounting by utilizing SMD (surface mounted device) packages

3. Intelligent Power MOSFET Series Product Line

As shown in Table 1, this intelligent power MOSFET series is for current ratings of 1 to 50A.

The 1A device is being developed for the control of the many types of 1.4W class warning lamps mounted in instrument panels, or for the lower-than-1A class of solenoid valves used for fuel injection control. Utilizing an SOP-8 package for this sort of intelligent device, the chips are packaged together in two channels to make the system small and flat.

The 50A device is used for solid-state relays in automotive electronic systems or for the control of body

Fig.4 F5020 waveforms from short-circuiting to current limiting

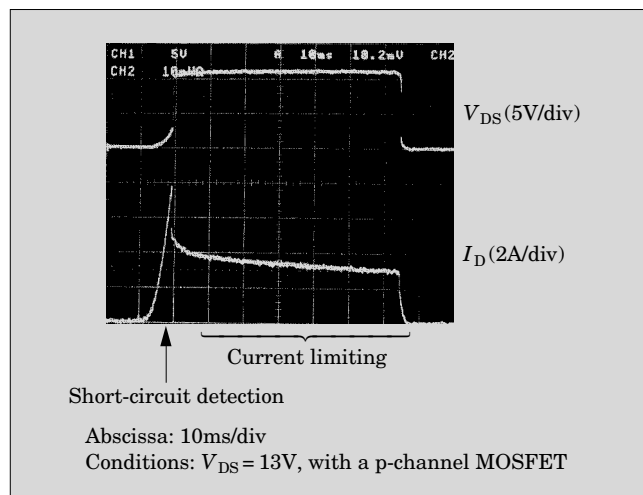
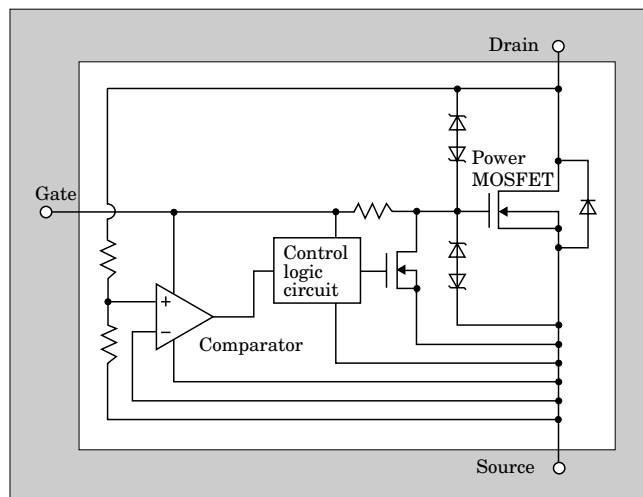


Fig.5 F5020 short circuit detection circuit



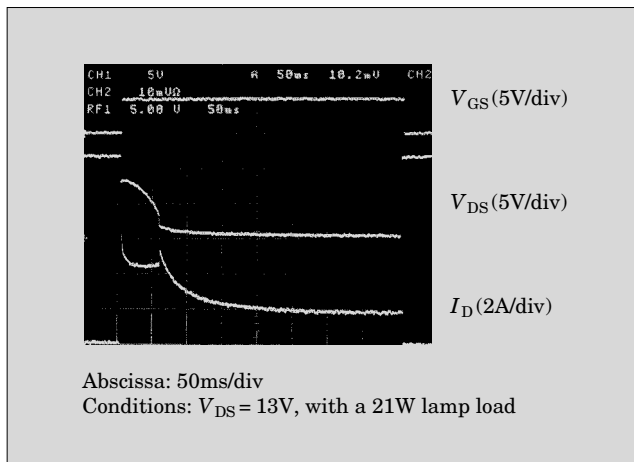
systems, large capacity motors and lamps.

4. Characteristics

4.1 Short-circuit protection

The intelligent power MOSFET incorporates a short-circuit detection circuit to protect the system, load, and device itself even when a drop in load impedance causes an excessive current. As an example, Fig. 4 shows the waveforms of F5020 operation from short-circuiting to current limiting. To obtain the waveforms, using a test circuit with a p-channel MOSFET as the load, the drain current was gradually increased from 0A, and F5020 operation from short-circuit detection to current limiting was observed. Figure 5 shows the short-circuit detection circuit. The circuit monitors the ON-state voltage of the MOSFET output stage, and the comparator for monitoring drain-source voltage detects drain currents exceeding the short-circuit detection value and lowers the gate voltage of the MOSFET output stage to a fixed value to limit output current and prevent the device from short-

Fig.6 Waveforms of F5020 driving a lamp load



circuit breakdown. This detection circuit does not use a conventional current detection system that requires a large-scale circuit configuration such as a current sensing device and an operational amplifier, but instead uses an ON-state voltage monitoring system to reduce the size of the current detection circuit.

The intelligent power MOSFET uses this current-limiting system for short-circuit protection for the following reasons.

Figure 6 shows the F5020 waveform (40V/3A/0.4Ω) driving a lamp load (21W/12V). Since the load is 21W, a rush current of approximately 20A flows when started in cold temperature. When selecting a device to drive a lamp with such a rating, a device rated at 10A or more is generally selected in consideration of the above-mentioned rush current. The F5020 rated at 3A is judged to have insufficient current capacity. However, in the region where the applied lamp load causes a rush current to flow, even when the current is more than the rated current, the F5020 does not completely shut down output current, but actively maintains the ON state by limiting the output current at a given value. With this short-circuit protection system that limits output current, the F5020 is able to perform basic switching of the 21W lamp without concern over the rush current. Therefore, if this intelligent power MOSFET is selected for a system design that requires lamp load drive, devices can be selected based not on rush current but on steady current, thereby enabling systems to be designed with devices rated at about half the conventional current.

Further, the current-limiting system is a short-circuit protection system suitable not only for lamp loads but also for systems such as ABS that requires a constant current supply even when an excessive current flows due to a drop in load impedance.

The problem with applying latch type systems, completely shutting down the output current upon detecting a short circuit to the short-circuit protection system, is that self-reset by the device itself is impossible. This means that the output current will be

Fig.7 Different time required for protection due to different temperature sensor positions

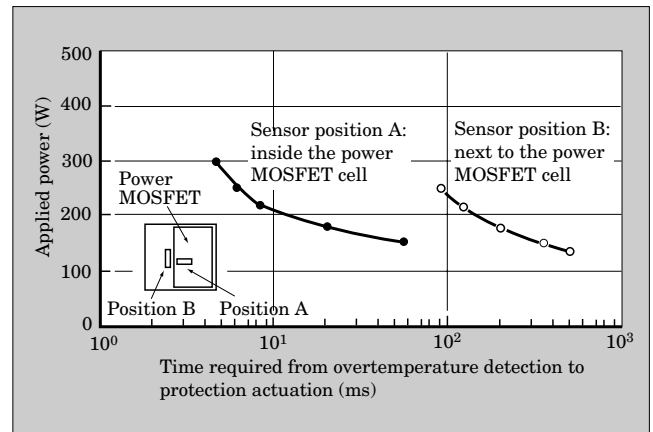
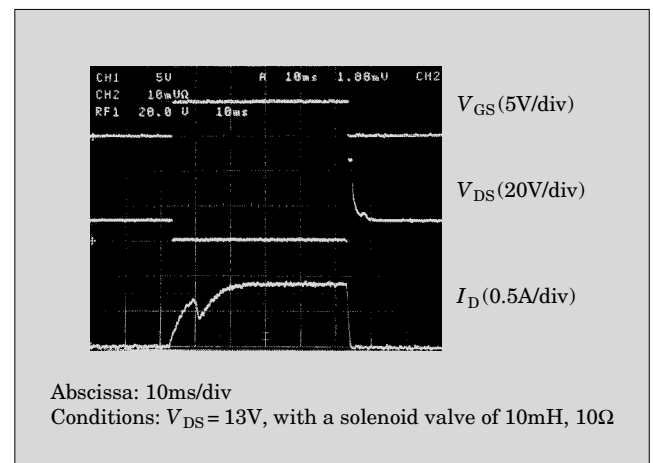


Fig.8 Waveforms of F5020 operating a solenoid valve



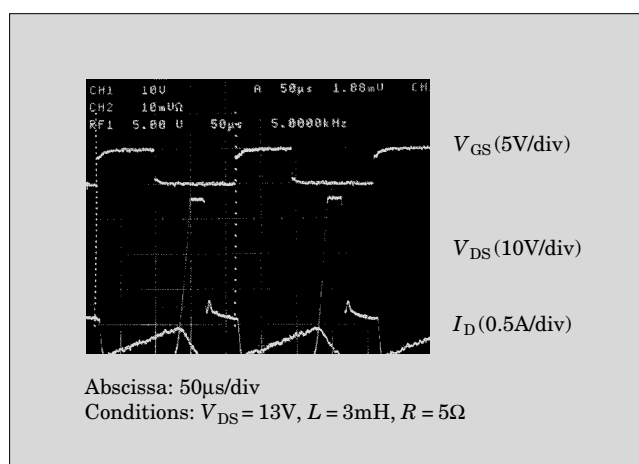
completely shut down even by an instantaneous short circuit such as loose short-circuiting. A means for reset is necessary in order to restart the device. This complication is disadvantageous to the system design.

The intelligent power MOSFET, which incorporates a built-in short-circuit protection circuit based on the above design concept, does not require short-circuit protection circuit components formerly added by the system side to protect the power device from external DC short-circuiting. This enables smaller size and lower cost systems.

4.2 Overtemperature protection

If the above-mentioned current-limiting operation continues after a short circuit is detected due to an external DC short circuit, excessive heat will be generated in the intelligent power MOSFET. The response time of a circuit is critical to avoid damage due to overheating of a protection circuit. To reduce the response time when overheating is detected, the intelligent power MOSFET has a temperature sensor on the power MOSFET cell as shown in Figs. 7 and 3. The response time is approximately ten times quicker than that of the case of where a temperature sensor is

Fig.9 Waveforms of F5020 performing PWM on an inductive load



located next to the power MOSFET cell. The result is highly coordinated protection.

4.3 Dynamic clamping function

In devices used in automobile systems where there are many inductive loads such as solenoid valves, there is a problem of dealing with the $LI^2/2$ energy accumulated in the inductive load.

The intelligent power MOSFET incorporates a dynamic clamping circuit which clamps at approximately 50V the surge voltage generated by turning off the inductive load and absorbs energy accumulated in the inductive load by the power MOSFET itself. Additional external components, such as a snubber circuit, are not necessary. Figure 8 shows actual waveforms of the F5020 operating a solenoid valve. It can be clearly seen that the F5020 rapidly processes energy accumulated in the inductive load when the dynamic clamping voltage is set to a value near the power MOSFET withstand voltage of 60V. Figure 9 shows waveforms of the F5020 performing PWM (pulse width modulation) on an inductive load. It can be seen that at a frequency of approximately 5kHz, the F5020

is able to perform adequate PWM control without adding components to the system.

4.4 Electrostatic breakdown withstand voltage

The intelligent power MOSFET has been designed with careful consideration to withstand surge voltages in the severe surge environment of automobiles. In the intelligent power MOSFET, low-voltage devices for control circuits and a vertical power MOSFET for output are integrated into a single chip using a self-isolation process that requires less steps than junction or dielectric isolation. It is said the self-isolation process is superior in cost performance, but inferior in surge withstand voltage to the dielectric isolation process because of the greater number of parasitic devices. However, in the intelligent power MOSFET, the construction of the zener diode for surge suppression and the layout of the control circuit's internal resistance have been optimized such that the electrostatic breakdown voltage of the F5020 (for example) (at 150pF, 150Ω) is greater than 25kV between the drain and source, and more than 10kV between the gate and source. Moreover, its AC latch-up voltage (at 150pF, 150Ω, $V_{DS} = 13V$, $V_{DS} = 0V$ and 5V) is greater than 25kV between both the drain and source and between the gate and source.

5. Conclusion

This paper has presented an overview and described characteristics of the line of intelligent power MOSFETs, focusing on the low-side intelligent power MOSFET series. Products have been introduced on the assumption that they will be used in the automotive electronics field, however the intelligent power MOSFET series can be used in various applications because of its high versatility.

In the future, Fuji Electric will expand the line of intelligent power MOSFETs to meet the needs of diversified applications and establish technologies to further improve performance.

IGBT Modules

Shuji Miyashita
Hiromu Takubo
Shin'ichi Yoshiwatari

1. Introduction

Power electronics, in which power control and conversion are the main technologies has rapidly progressed in recent year. Application examples include general purpose inverters, uninterruptible power supplies (UPS) and numerical control (NC) machines. Market needs for these power converting systems always require small size and light weight, higher efficiency and lower noise. Therefore, technical innovations of power semiconductor devices (power devices), such as higher performance, advanced function and more power, are required from the market.

In these circumstances, the IGBT (insulated gate bipolar transistor) attracts attention because of its low loss, ease of driving circuit design, high blocking voltage, and development of high power devices. In 1993, Fuji Electric released the third generation IGBT (J series), leading all other companies. We then developed new third generation IGBTs (the N series and G series) which aim at lower price, improved usability and higher reliability. These IGBTs have been adopted in various fields.

In this paper, we will introduce the semiconductor device technology now developing, together with the

present state of the newest IGBT modules.

2. The Present IGBT Module Series

2.1 Configuration of the inverter's main circuit and module

The configuration of the inverter's main circuit is shown in Fig. 1. This circuit is comprised of a converter circuit that converts (rectifies) alternating current (AC) to direct current (DC), an electrolytic smoothing capacitor to remove ripple voltage and an inverter circuit to get an AC output from a DC input. Furthermore, in the case of the motor control inverter, a dynamic brake (DB) circuit is necessary to suppress a rise of the smoothing capacitor voltage by regenerative operation.

Except the smoothing capacitor and a resistance of the DB circuit, all components in this configuration are power devices. Module products of this insulation type are widely used as power devices because of their ease of mounting.

2.2 The present IGBT module series

The above mentioned IGBT modules include various products such as a 6-in-1 (6 elements in one module), 2-in-1 or 1-in-1 for the inverter circuits, 7-in-1 for the DB + inverter circuit and a power integrated module for the converter + DB + inverter. Fuji Electric has mass-produced and brought these products to the market as the line-up for the new third generation IGBTs. This broad line-up is shown in Table 1, and the products are compatible with past company products as well as products of the other companies.

3. Present Problems and Subjects

We believe that the new third generation IGBTs (N and G series) comply with the market's needs by balancing low loss, soft switching characteristics, high withstand capability and an abundant product line-up. However, technological innovation for higher performances, advanced function and larger capacity is always necessary to comply with the ever-changing market needs, described previously. Using the exam-

Fig.1 Main configuration of the inverter circuit

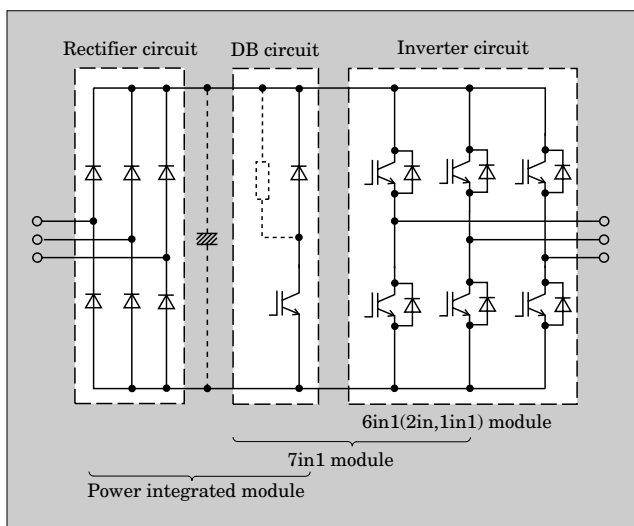
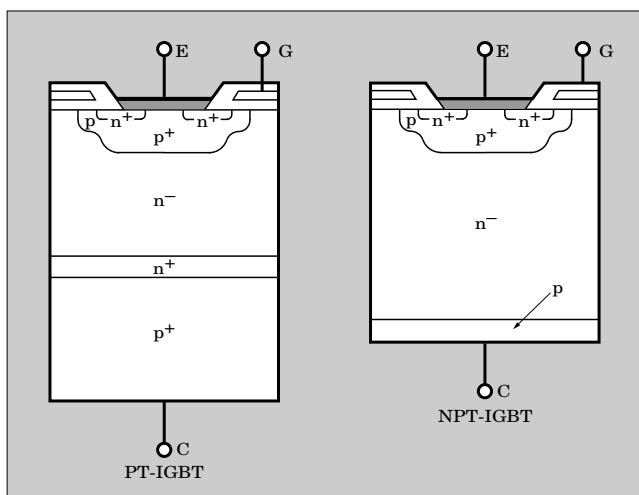


Table 1 The new third generation IGBT line-up

I_c rating	600V	1,200V
10A	6MBI10GS-060	7MBR10NE120 7MBR10NF120
15A	6MBI15GS-060	7MBR15NE120 7MBR15NF120
20A	6MBI20GS-060	
25A		7MBR25NE120 7MBR25NF120
30A	7MBR30NE060 7MBR30NF060	
40A		7MBI40N-120
50A	7MBR50NE060 7MBR50NF060 2MBI50N-060	7MBI50N-120 2MBI50N-120
75A	7MBR75GE060 7MBI75N-060 2MBI75N-060	2MBI75N-120
100A	7MBI100N-060 2MBI100N-060	2MBI100N-120 2MBI100NB-120 2MBI100NC-120 2MBI100NE-120
150A	2MBI150N-060 2MBI150NC-060	2MBI150N-120 2MBI150NB-120 2MBI150NC-120 2MBI150NE-120
200A	2MBI200N-060	2MBI200N-120 2MBI200NB-120 2MBI200NE-120 1MBI200N-120 1MBI200NB-120
300A	2MBI300N-060 2MBI300NB-060	2MBI300N-120 1MBI300N-120 1MBI300NB-120 1MBI300NP-120 1MBI300NN-120
400A	2MBI400N-060	1MBI400N-120 1MBI400NB-120 1MBI400NP-120 1MBI400NN-120
600A	2MBI600NT-060 1MBI600NP-060 1MBI600NN-060	

Fig.2 Cross section of the NPT and PT chips



ple of general purpose inverters, the following must be considered:

- (1) A blocking voltage of 1,400V for North America
- (2) A wider reverse bias safe operating area (RBSOA) to simplify the snubber design.
- (3) Soft switching characteristics to comply with EMI (electromagnetic interference)
- (4) Specification of parallel connection or high blocking voltage and large current to increase inverter capacity

Furthermore, for power supply equipment in DC electric cars for subway and suburban trains, isolated type of IGBTs are considered an alternative to the present GTO (gate turn-off) thyristors from the viewpoints of ease of maintenance, high-speed switching and drive ease, and required high blocking voltage.

At present, Fuji Electric is investigating and developing the basic technology for these requirements. We will present some examples on the above subjects in and after the next section.

4. Results of New Technology

4.1 Technology and characteristics of the NPT-IGBT chip

4.1.1 NPT structure and features

The NPT (non punch-through)-IGBT has a structure designed for optimum thickness of the n^- layer so as not to elongate the depletion layer to the p layer. It is shown in Fig. 2 compared with the conventional structure (PT: punch-through).

The NPT-IGBT has attracted attention in recent years due to the following three items:

- (1) A high blocking voltage IGBT can be designed by setting the thickness of the n^- layer.
- (2) As shown in Fig. 3 (a), collector-emitter saturation voltage $V_{CE(sat)}$ increases as the temperature rises. Therefore, when chips or modules are connected in parallel, current imbalance is smaller and it is easy to increase inverter capacity using them in parallel.
- (3) Cost/performance is high because FZ (floating zone) silicon wafers can be used.

Fig.3 I_C - V_{CE} characteristics of the NPT-IGBT

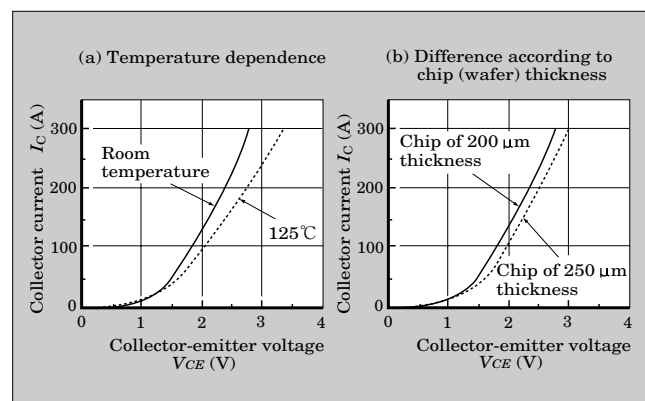


Fig.4 Reducing E_{off} by a thinner chip of 20 μ m thickness

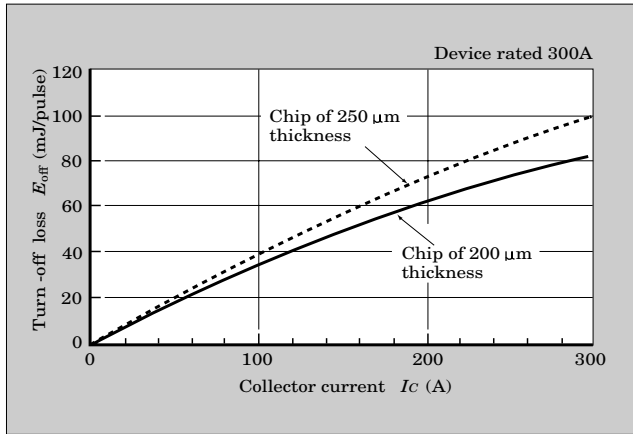


Fig.5 Reducing short-circuit current with a chip of higher $V_{GE(th)}$ (for a 100A device)

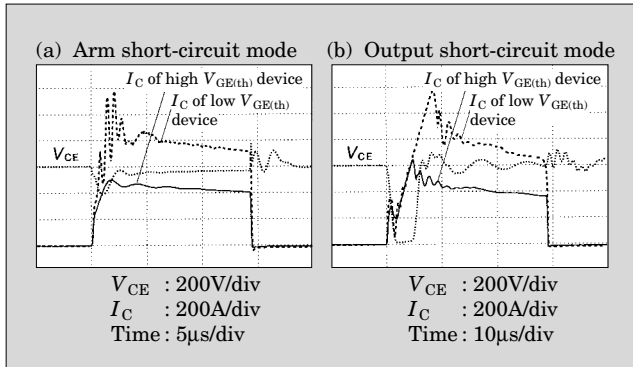
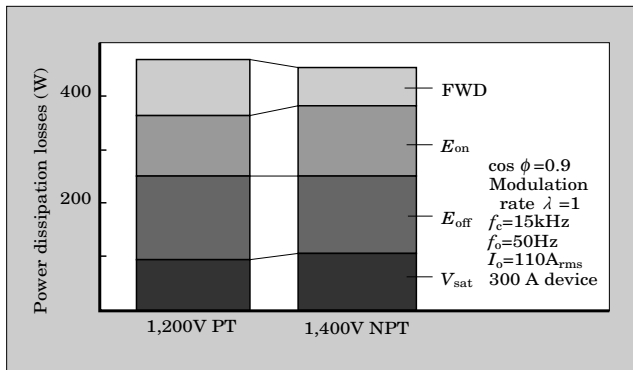


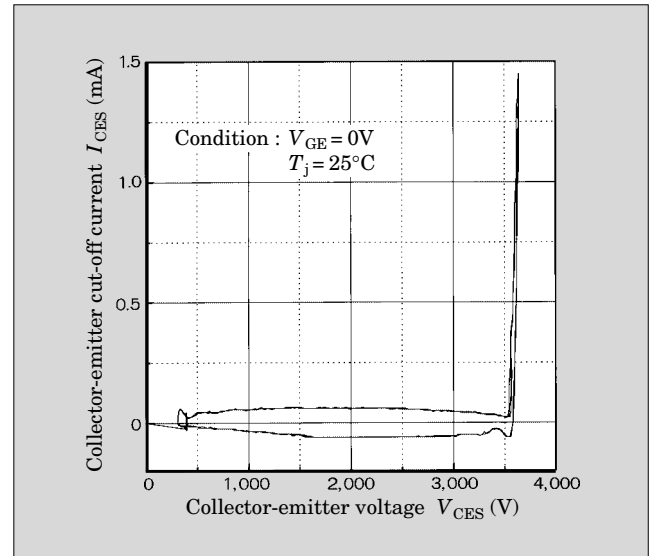
Fig.6 Comparison of power dissipation losses between PT and NPT



4.1.2 Features of Fuji Electric's NPT-IGBT

When using the IGBT as main switching device in an inverter equipment, dissipation loss is an important item to be evaluated. Dissipation loss is generally classified into conduction loss and switching loss. These losses have a close relationship with $V_{CE(sat)}$ and turn-off characteristics respectively. The thinner the n^- layer is, the smaller the $V_{CE(sat)}$ and tail current at turn-off become. It is necessary to then optimize the thickness of the n^- layer, taking into consideration the trade-off with the device's blocking voltage. On the other hand, when the inverter has

Fig.7 Blocking voltage of the 3,300V prototype



short-circuit trouble, the devices are specifically required to have a short-circuit withstand capability to tolerate a certain minimum short-circuit period by reduction of short-circuit current.

Fuji Electric has optimized the NPT-IGBT to make the chip's thickness thin while securing the device's blocking voltage and establishing the manufacturing technology. As a result, reducing $V_{CE(sat)}$ (as shown in Fig. 3) and reducing E_{off} (as shown in Fig. 4) became possible. Furthermore, the short-circuit current is reduced by setting $V_{GE(th)}$ somewhat higher and the short-circuit oscillation is suppressed by adopting a terrace-gate structure. The comparison of waveforms is shown in Fig. 5.

A comparison of inverter losses using the newly developed IGBT and the conventional IGBT is shown in Fig. 6. Surprisingly the 1,400V NPT-IGBT shows an equivalent total power dissipation loss as the 1,200V PT-IGBT. Furthermore the NPT-IGBT can have short-circuit withstand capability of about twice or more that of the PT-IGBT.

4.2 Technology and characteristics of the high blocking voltage chip

As described in section 3, higher performance of semiconductor devices is indispensable for the power supply equipment of DC electric cars used by subway and suburban trains. Especially in recent years, semiconductor devices with an insulated module structure are positively investigated because of their ease in handling and maintenance. They are also widely noted as an alternative to GTO thyristors from the viewpoints of high-speed switching and driving ease. Fuji Electric plans to introduce high blocking voltage IGBTs, thus enlarging the product series.

We have developed an IGBT with a high blocking voltage applicable to 2-level inverter for overhead traction wire with voltages of 750V or 1,500V. We will

Fig.8 Output characteristics of the 3,300V prototype

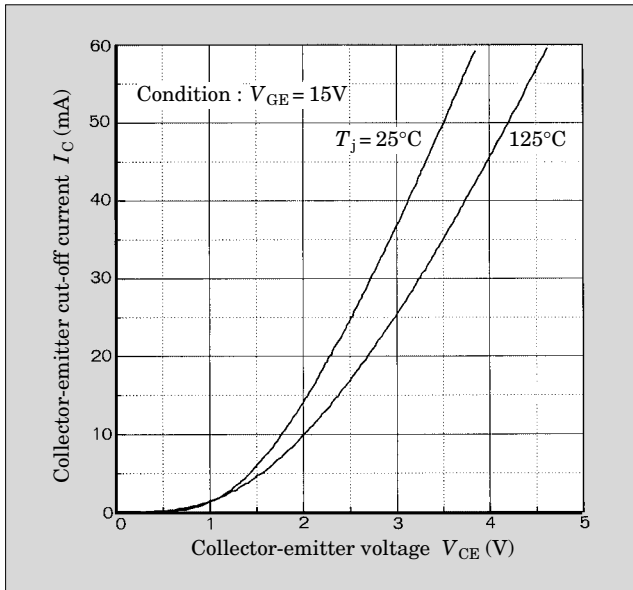
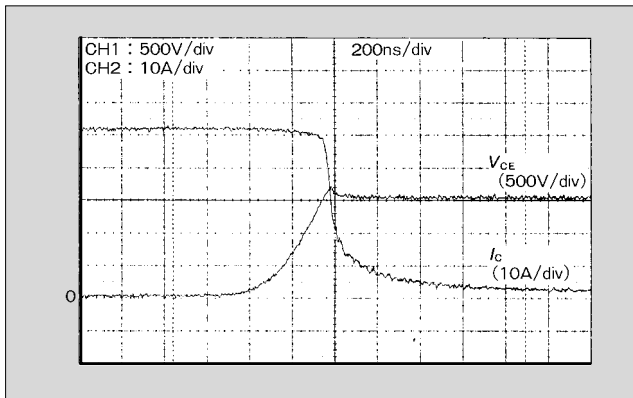


Fig.9 Turn-off waveform of the 3,300V/50A prototype



explain the features and characteristics of this IGBT.

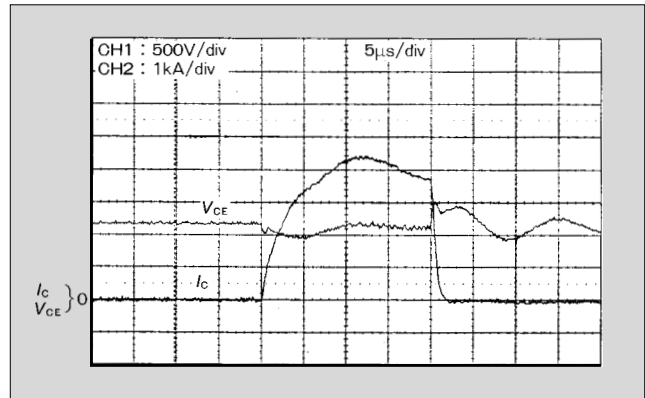
4.2.1 High blocking voltage

Setting the thickness of the n^- layer and specific resistance and design of the blocking voltage structure are important for high blocking voltage in the NPT structure. Recently, prototypes developed and produced were chips of 3,300V based on the design of 2,500V flat type IGBTs. By optimizing the structure and number of guard rings and length of the field-plate, blocking voltage of a 3,300V/50A prototype are achieved stably and its characteristic is shown in Fig. 7. The avalanche voltage is nearly 3,600V.

4.2.2 Saturation voltage characteristics

Since the module for traction cars is required to be 400 to 1,200A per module, chips of about 50 to 100A should be connected in parallel in a module. Therefore, NPT-IGBT chips having a positive temperature coefficient of saturation voltage characteristics are optimum in securing a good current sharing between the chips inside the module and between them. The output characteristics of this chip are shown in Fig. 8. The characteristics show about 3.5V at the rated

Fig.10 Short-circuit waveform of 1MBI800PN-180



current of 50A by improving the trade-off between blocking voltage, switching characteristic and the short-circuit withstand capacity and by optimizing the process conditions.

4.2.3 Turn-off characteristics

The turn-off waveform is shown in Fig. 9. This waveform shows turn-off of rated current at 1,500V and demonstrates useful characteristics that surge voltage is smaller by suppressing the $-di/dt$.

4.3 Packaging technology and its reliability

When applying IGBT to inverter equipment, long-term reliability is required for traction cars in particular. In this section, we will explain package technology focusing mainly on securing reliability.

4.3.1 Securing isolation voltage

The required isolation voltage in electric railways is 4,500V AC or more in an overhead traction wire of 1,500V DC. The IGBT module satisfies this requirement by optimizing the material and thickness of the isolation substrate and the design of the edge part.

4.3.2 High current module

The reliability of semiconductor devices depends on their heat dissipation, which decreases as the temperature increases. Therefore, the current sharing of the chips should be equalized to suppress temperature imbalance when structuring a module with a high current rating with plural chips connected in parallel. It was found that the current sharing largely depends on the geometrical form of the current path in the module. Then, it becomes possible to equalize the current sharing by equalizing the arrangement of the chips and designing the wiring layout symmetrically inside the module.

On the other hand, to reduce surge voltage in the module, the inductance or current value between the terminals inside the module should be greatly reduced. It is then required to reduce the inductance for making the current high. This is attainable by utilizing mutual induction of parallel conductors and putting the collector and emitter electrodes close together to reduce the inductance. We have acquired the patent to reducing inductance by utilizing the mutual induction

of parallel conductors (Japan Patent No. 2046854).

4.3.3 Reducing loss and securing reliability

Reducing loss and the short-circuit withstand

Fig.11 Cross section of wire bonding after 800,000 power-cycles

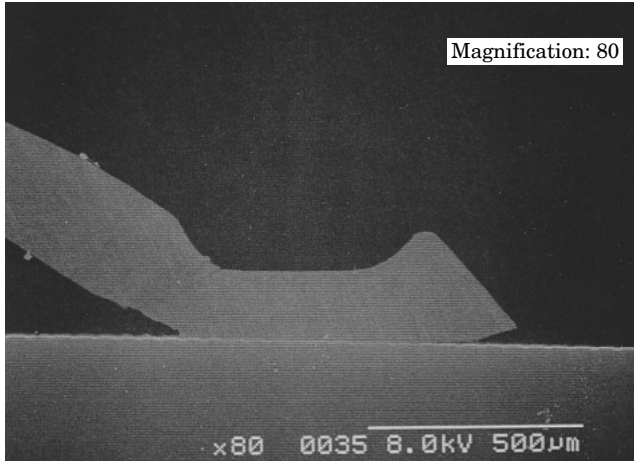


Fig.12 Change of transient thermal resistance during heat cycle (ΔT_j) test

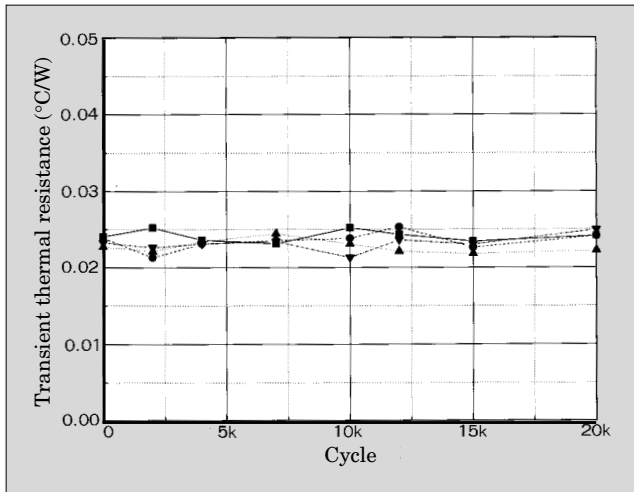
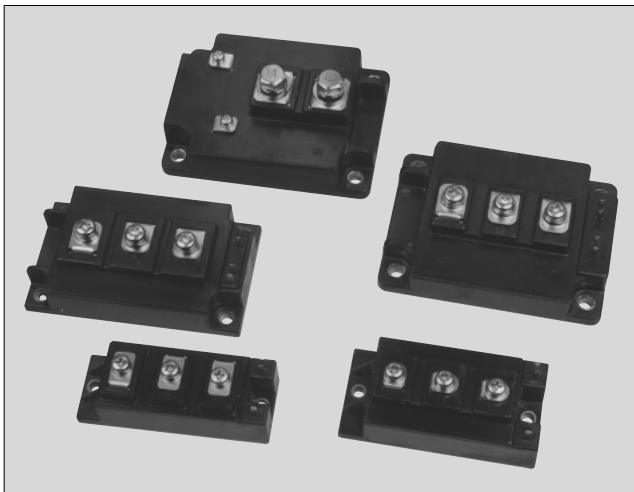


Fig.13 View of Fuji Electric's NPT-IBPT



capability have a trade off relationship. The short-circuit withstand capability is reduced when the saturation voltage and switching loss are improved. We have secured the short-circuit withstand capability

Table 2 Fuji Electric's NPT-IGBT series

Model	No. of elements	V_{CES}	$I_{C(DC)}$	$V_{GE(th)}$ (typ.)	$V_{CE(sat)}$ (typ.)	V_F (typ.)
2MBI50P-140	2	1,400V	50A	8.0V	2.8V	2.4V
2MBI75P-140	2	1,400V	75A	8.0V	2.8V	2.4V
2MBI100PC-140	2	1,400V	100A	8.0V	2.8V	2.4V
2MBI150PC-140	2	1,400V	150A	8.0V	2.8V	2.4V
2MBI200PB-140	2	1,400V	200A	8.0V	2.8V	2.4V
2MBI300P-140	2	1,400V	300A	8.0V	2.8V	2.4V
1MBI600PX-120	1	1,200V	600A	8.0V	2.9V	2.5V

Table 3 Ratings and characteristics of 1MBI800PN-180

(a) Absolute maximum rating ($T_j = T_c = 25^\circ\text{C}$)

Item	Symbol	Maximum rating	Unit
Collector-emitter voltage	V_{CES}	1,800	V
Collector current (DC)	I_C	800	A
Isolation voltage	V_{iso}	5,400 AC (1 minute)	V
Junction temperature	T_j	150	$^\circ\text{C}$
Storage temperature	t_{stg}	- 40 to +125	$^\circ\text{C}$

(b) Electrical characteristics ($T_j = 25^\circ\text{C}$)

Item	Symbol	Conditions	Characteristics	Unit
Collector-emitter cut-off current	I_{CES}	$V_{CE}=1,800\text{V}$ $V_{GE}=0\text{V}$	Max. 1.0	mA
Gate-emitter threshold voltage	$V_{GE(th)}$	$V_{CE}=20\text{V}$ $I_C=800\text{mA}$	Typ. 6.0	V
Collector-emitter saturation voltage	$V_{CE(sat)}$	$V_{GE}=15\text{V}$ $I_C=800\text{A}$	Typ. 3.7	V
Diode forward voltage	V_F	$V_{GE}=0\text{V}$ $I_F=800\text{A}$	Typ. 3.7	V
Thermal resistance	IGBT part	$R_{th(j-c)}$	Max. 0.03	$^\circ\text{C/W}$
	FWD part	$R_{th(j-c)}$	Max. 0.075	$^\circ\text{C/W}$
	Case-heat sink	$R_{th(c-f)}$	Typ. 0.01	$^\circ\text{C/W}$

Fig.14 View of 1MBI800PN-180



without increasing dissipation loss by performing optimum design for vertical profile and process of the chip to improve this trade-off. The waveform of a 1,800V/800A device in a short-circuit test is shown in Fig. 10. The peak current became less than 4,500A when 1,200V DC was applied at $T_j = 25^\circ\text{C}$, and a pulse width of 20 μs or more was secured.

Furthermore, if the dissipation loss of the device is large, the lifetime will be shorter by the increase in temperature rise and temperature change. The lifetime of the semiconductor device required for traction cars is required to be as long as 20 to 30 years. For securing high reliability, it is important to execute the power-cycle (ΔT_j) test for the lifetime of conducting operation and the heat cycle (ΔT_c) test for the lifetime of environmental temperature change.

To improve the power cycle withstand capability, securing the strength of the wire-bonding part is important. The strength is dependent on the bonding conditions. By optimum design of the wire material and bonding part, wire bonding was confirmed not to be abnormal after 800,000 cycles of the power cycle test (acceleration test at $\Delta T_j = 100^\circ\text{C}$). The cross section of the wire bonding part after the test is shown in Fig. 11.

On the other hand, the generation of thermal stresses to the solder layer joint between the chip and isolation substrate and between the isolation substrate and copper base is problematic for the heat cycle. When excess thermal stress is applied to the solder layer, a problem of deteriorated thermal resistance occurs by cracks in the solder layer. As counter-measures against this stress, an analysis of the thermal stress is executed using the finite element method to reduce the stress and extend the life time. The characteristics were confirmed not to deteriorate until 20,000 cycles of acceleration test at $\Delta T_c = 70^\circ\text{C}$ (equivalent to a lifetime of 30 years mounted on a vehicle). The results of the heat cycle (ΔT_c) test are shown in Fig. 12.

5. New Product Series

As described in section 4.1, the 1,400V NPT-IGBT

realized equal or better characteristics as the existing 1,200V series. Their appearances and series contents are shown in Fig. 13 and Table 2. In the near future, Fuji Electric intends to develop a 6-in-1 module and a PIM and to expand the series to inverter applications.

As for the high voltage IGBT, a 1,800V/800A IGBT module (1MBI800PN-180) is in production. This is expected to be applied to the large capacity inverter and 2-level inverter for the 750V overhead traction wire or 3-level inverter for the 1,500V overhead traction wire in electric railways. Table 3 shows its rating and characteristics and Fig. 14 shows its appearance. An IGBT module having a blocking voltage of 3,300V is planned for development in 2-level inverters for 1,500V overhead traction wire.

6. Future Prospects

The NPT-IGBT demonstrates features for blocking voltage of 1,200V or more, but it is difficult to realize lower blocking voltage such as 600V because of difficulty to handle very thin wafers. Improvement of the present PT technology is more promising rather than that of the NPT. Expected candidates for this may be fine patterned cell structure and trench-gate IGBTs. Both are effective in reducing on-state voltage and are being investigated as elemental technologies. We are also considering other devices with new structures and new operation principles.

7. Conclusion

We have introduced a series of IGBT modules and new technology under investigation and development. We believe that these IGBTs and large capacity modules will penetrate into not only existing application fields but also new fields. They will certainly contribute to improvement of equipment performance and ease of design.

Fuji Electric will contribute to the development of power electronics by further striving to improve performance, function and reliability of power devices and to develop the products in response to diversifying market needs.



New Intelligent Power Modules (R Series)

Atsushi Yamaguchi
Hiroaki Ichikawa

1. Introduction

The equipment of power electronics application is comprised of general use inverters, numeric control (NC) machine tools, and industrial robots. Recently, the requirements of lower noise, higher efficiency, advanced functions, lower price, and downsizing for these items have been growing.

The power devices used as the equipment of power electronics applications are progressing toward lower loss and higher frequency, and the IGBT (insulated gate bipolar transistor) rather than the bipolar transistor is gaining popularity.

On the other hand, together with lowered loss for the IGBT, intelligence is achieved by locating the peripheral circuits such as the driving circuit and various protective circuits inside the module. It then becomes possible to shorten the design time at the power circuit and contributes to downsizing and advanced equipment function.

In keeping step with the trends of making the power devices intelligent, Fuji Electric announced the bipolar transistor type of intelligent power modules

(BJT-IPM) in 1989. In 1992, the J series of IGBT-IPM (J-IPM) that pursued lower loss was developed and in 1995 the N series of IGBT-IPM (N-IPM) aimed at lower price and lower noise was developed and produced. This time, the R series of IGBT-IPM (R-IPM) pursues higher cost performance, higher reliability and advanced functions.

The line-up and features of Fuji Electric's IGBT-IPMs and the R-IPM are introduced in the following.

2. Fuji Electric's Conventional IGBT-IPM Line-Up and Problems

The line-up, performances and features of both the J-IPM and N-IPM are shown in Table 1. The J-IPM was developed with particular attention to low loss. The N-IPM realized low noise (soft switching) and low loss in order to respond to the market needs of EMC (electro magnetic compatibility) regulations and to match the CE mark. Furthermore, the N-IPM is an IPM with a lower price and higher reliability made possible by the adoption of new construction and new materials. The integrated functions are shown in

Table 1 The J-IPM and the N-IPM

Series	Type	Inverter			Dynamic brake			Features
		V_{CES} (V)	I_C (A)	P_C (W)	V_{CES} (V)	I_C (A)	P_C (W)	
J-IPM	6MBP15JB060	600	15	40	—	—	—	Low loss High speed switching
	6MBP20JB060	600	20	50	—	—	—	
	6MBP100JA060	600	100	240	—	—	—	
	6MPB150JA060	600	150	450	—	—	—	
	6MBP200JA060	600	200	600	—	—	—	
	6MBP100JA120	1,200	100	600	—	—	—	
	7MBP50JB060	600	50	150	600	30	80	
	7MBP75JB060	600	75	195	600	30	80	
	7MBP50JA120	1,200	50	240	1,200	15	80	
N-IPM	6MBP50NA060	600	50	198	—	—	—	Low loss Soft switching High reliability
	6MPB75NA060	600	75	320	—	—	—	
	6MPB100NA060	600	100	400	—	—	—	
	7MBP50NA060	600	50	198	600	30	120	
	7MBP75NA060	600	75	320	600	50	198	
	7MBP100NA060	600	100	400	600	50	198	

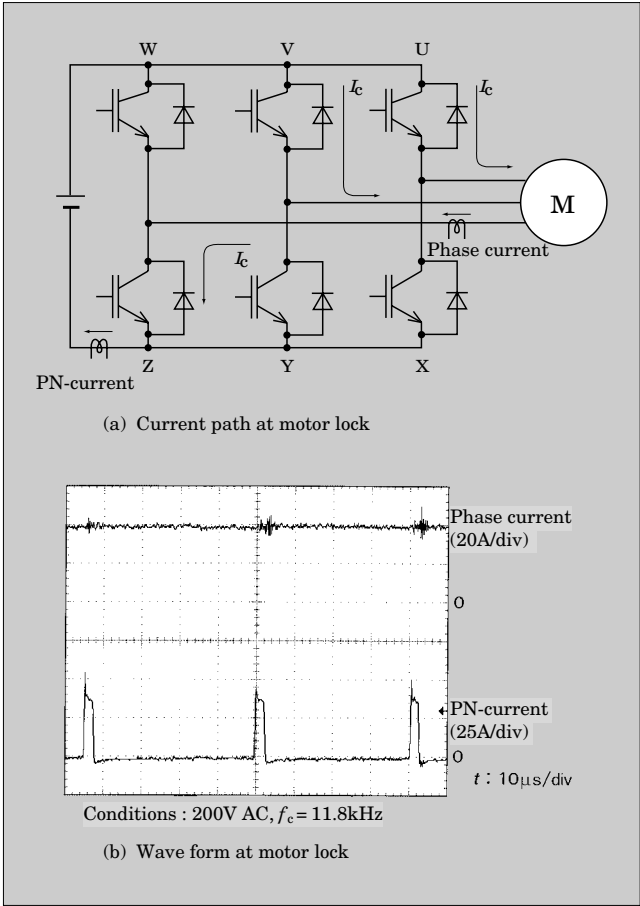
Table 2. The functions of the J-IPM and N-IPM are identical, and the protection functions against short circuit, overcurrent, drive power supply under-voltage and overheating are integrated.

However, since both the J-IPM and the N-IPM are constructed of many types of electronics parts, there are of course some limits to downsizing and low price. To protect against overheating the temperature of the insulation substrate mounted with the IGBT chips was detected by thermistors. But it became problematic in applications where the current was concentrated into a few chips like motor lock mode, as shown in Fig. 1.

Table 2 Protective functions of the IPM

Function	Description
Overcurrent protection	Monitor collector current of every IGBT, and protect against overcurrent by cutting off the current
Short circuit protection	Protects against short circuit current by cutting off the current by the same means as overcurrent protection
Drive power supply under-voltage protection	Detects drive power supply voltage, and protect in order to avoid destruction caused by under-voltage in case of lowering of voltage
Overheat protection	Stores precise thermistor as temperature sensor and protects against abnormal temperature rise by rejection of output

Fig.1 Current path and waveform at motor lock



When the current was concentrated to the chip which was located on the far side from the sensor on the substrate, the sensor could not follow the rapid temperature risings and could not protect it. In order to solve these problems and to realize higher performance as well as higher cost performance, the R-IPM was developed.

3. The R-IPM

The line-up, characteristics and integrated functions are shown in Table 3. The R-IPM has been applied the 3rd generation IGBT chip, which $V_{CE(sat)}$ is 2.3V typically, thereby achieving lower loss. Furthermore, they are comprised of the T_j detecting overheat protection function in addition to the former IPM's functions. Outlines, external view and internal equivalent circuit are shown in Figs. 2, 3 and 4 respectively.

Because it is composed of a wide range including the ratings of 600V/50 to 300A and 1,200V/25 to 150A

Fig.2 Package outline drawing of the R-series IPM

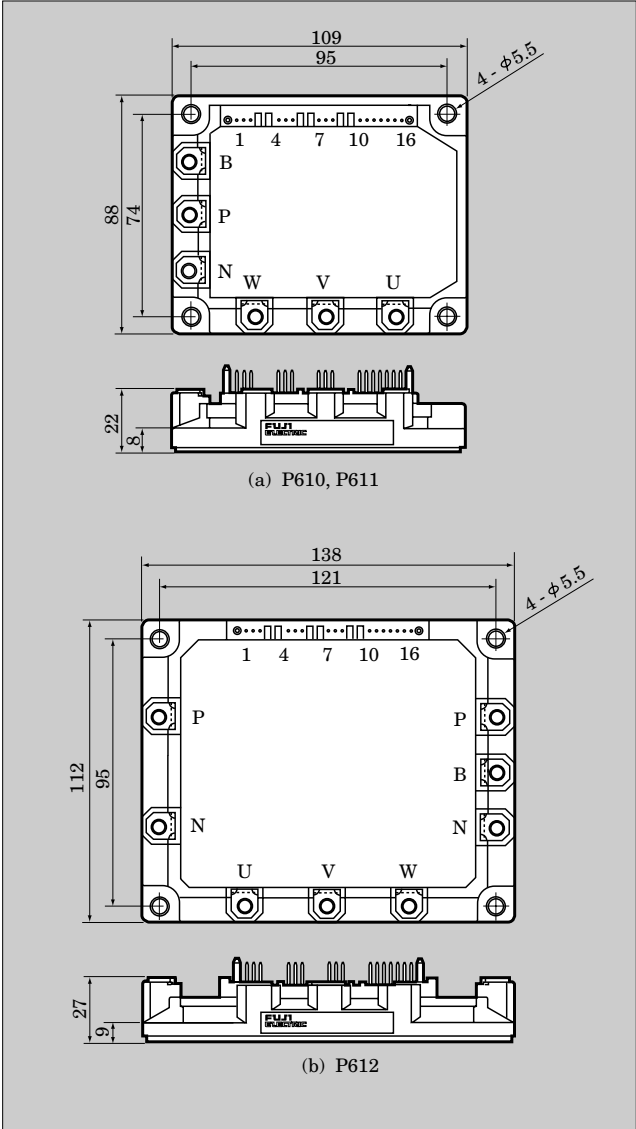


Table 3 Line-up and integrated functions of the R-IPM

(a) 600V series

Type	Inverter					Dynamic brake				Integrated functions						Package
	V_{DC} (V)	V_{CES} (V)	I_C (A)	P_C (W)	$V_{CE(sat)}$ Typical (V)	V_{CES} (V)	I_C (A)	P_C (W)	Diode I_F (A)	Dr	UVT	OCT	SCT	T _c -OHT	T _j -OHT	
6MBP50RA060	450	600	50	198	2.3	—	—	—	—	○	○	○	○	○	○	P610
6MBP75RA060	450	600	75	320	2.3	—	—	—	—	○	○	○	○	○	○	P610
6MBP100RA060	450	600	100	400	2.3	—	—	—	—	○	○	○	○	○	○	P611
6MPB150RA060	450	600	150	600	2.3	—	—	—	—	○	○	○	○	○	○	P611
7MBP50RA060	450	600	50	198	2.3	600	30	120	30	○	○	○	○	○	○	P610
7MBP75RA060	450	600	75	320	2.3	600	50	198	50	○	○	○	○	○	○	P610
7MBP100RA060	450	600	100	400	2.3	600	50	198	50	○	○	○	○	○	○	P611
7MBP150RA060	450	600	150	600	2.3	600	50	198	50	○	○	○	○	○	○	P611
6MBP200RA060 *	450	600	200	735	2.3	—	—	—	—	○	○	○	○	○	○	P612
6MBP300RA060 *	450	600	300	1,040	2.3	—	—	—	—	○	○	○	○	○	○	P612
7MBP300RA060 *	450	600	300	1,040	2.3	600	100	400	100	○	○	○	○	○	○	P612
7MBP200RA060 *	450	600	200	735	2.3	600	75	320	75	○	○	○	○	○	○	P612

(b) 1,200V series

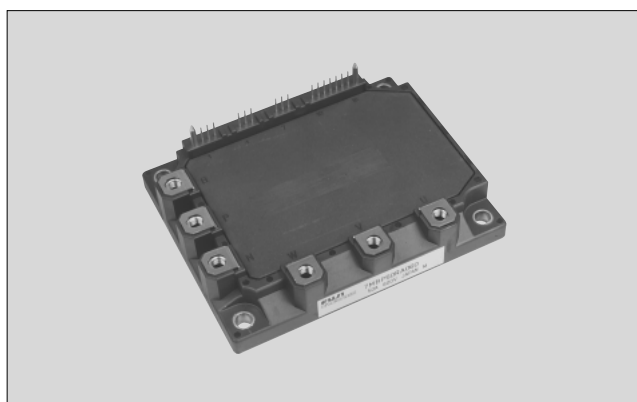
Type	Inverter					Dynamic brake				Integrated functions						Package
	V_{DC} (V)	V_{CES} (V)	I_C (A)	P_C (W)	$V_{CE(sat)}$ Typical (V)	V_{CES} (V)	I_C (A)	P_C (W)	Diode I_F (A)	Dr	UVT	OCT	SCT	T _c -OHT	T _j -OHT	
6MBP25RA120 *	900	1,200	25	198	2.3	—	—	—	—	○	○	○	○	○	○	P610
6MBP50RA120 *	900	1,200	50	400	2.3	—	—	—	—	○	○	○	○	○	○	P611
6MBP75RA120 *	900	1,200	75	595	2.3	—	—	—	—	○	○	○	○	○	○	P611
7MPB25RA120 *	900	1,200	25	198	2.3	1,200	15	120	15	○	○	○	○	○	○	P610
7MBP50RA120 *	900	1,200	50	400	2.3	1,200	25	198	25	○	○	○	○	○	○	P611
7MBP75RA120 *	900	1,200	75	595	2.3	1,200	25	198	25	○	○	○	○	○	○	P611
6MBP100RA120 *	900	1,200	100	735	2.3	—	—	—	—	○	○	○	○	○	○	P612
6MBP150RA120 *	900	1,200	150	1,040	2.3	—	—	—	—	○	○	○	○	○	○	P612
7MBP100RA120 *	900	1,200	100	735	2.3	1,200	50	400	50	○	○	○	○	○	○	P612
7MBP150RA120 *	900	1,200	150	1,040	2.3	1,200	50	400	50	○	○	○	○	○	○	P612

*: Under development

Dr: Drive circuit. UVT: Control power supply under voltage protection, OCT: Overcurrent protection, SCT: Short circuit protection

T_c-OHT: Case overheat protection, T_j-OHT: Device overheat protection

Fig.3 External view of the R-IPM



as well as 6-pack and 7-pack (including a dynamic brake circuit), this series is able to respond to the various market needs.

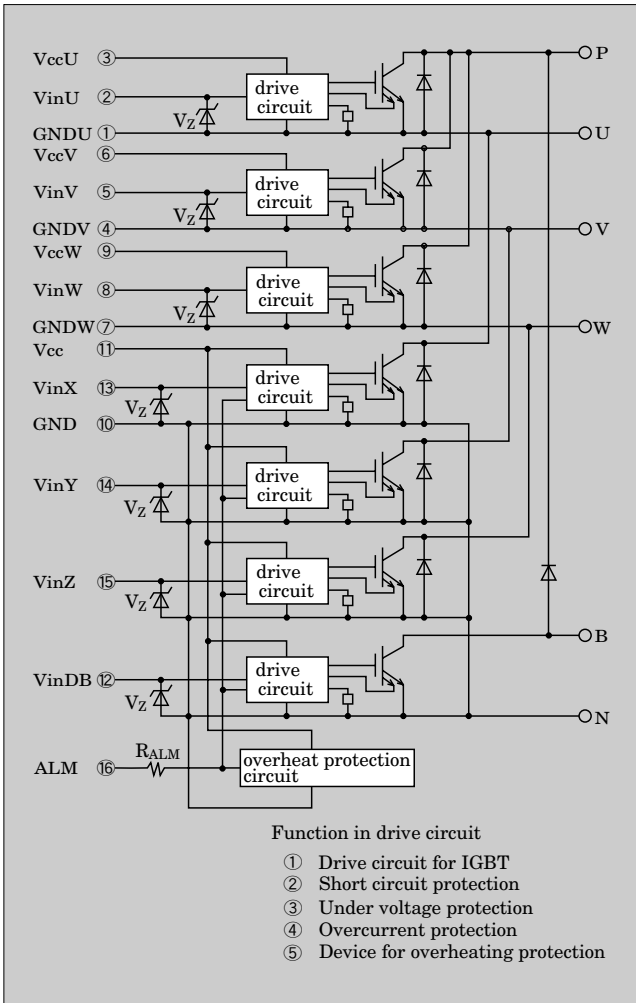
4. Features of the R-IPM

The features of the R-IPM can be summarized as follows:

- (1) Low loss and soft switching by using the third generation IGBT chips
- (2) Realization of high reliability, pursuing higher performance of the IGBT by means of the protection by directly detecting the IGBT chips temperature
- (3) Realization of high reliability and high cost performance by means of integrating all control circuits into the IC chips
- (4) A wide line-up together with the adoption of a compatible package (P610, P611) with Fuji's conventional IPM
- (5) Accomplishment of good noise immunity against malfunction due to switching noise

The key technical points concerning the develop-

Fig.4 Internal equivalent circuit of the R-IPM (a 7 set example)



ment are introduced below.

4.1 Improvement in performance of overheat protection function

In addition to the conventional case overheat protection, the device overheat protection function is integrated in the R-IPM.

The conventional case overheat protection function is indispensable. It was certainly effective against relatively slow temperature risings when overload occurred or a fan broke down.

However, since protection is insufficient against the phenomenon of rapid temperature rise of the IGBT chips, like the motor lock mode mentioned in section 2, the T_j detecting overheat protection function is applied in the R-IPM.

In an experiment simulation a motor lock mode, the junction temperature of the IGBT chip which located on the farthest position from the sensor and temperature of the sensor were measured when the IGBT chip was applied power loss and heated using a conventional IPM. The results are shown in Fig. 5. Since the temperature of the IGBT chip exceeded 150°C before the temperature sensor reached the

Fig.5 Temperature rise of the IGBT chip and the temperature sensor

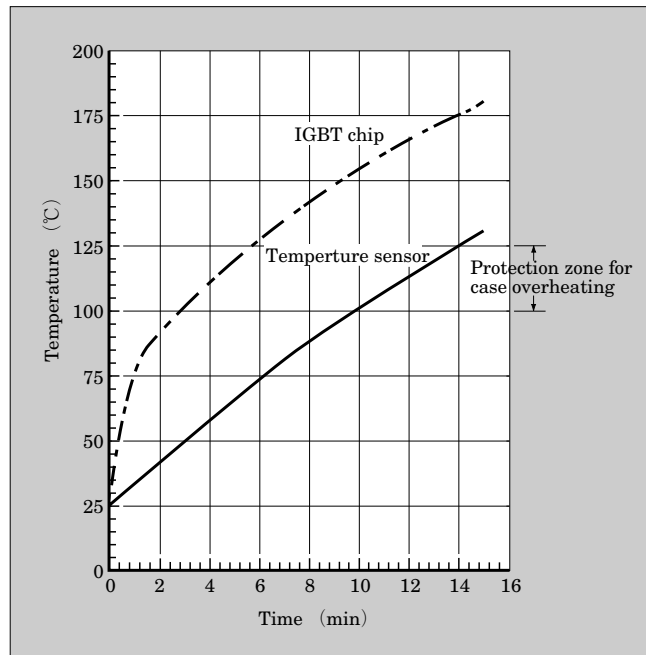
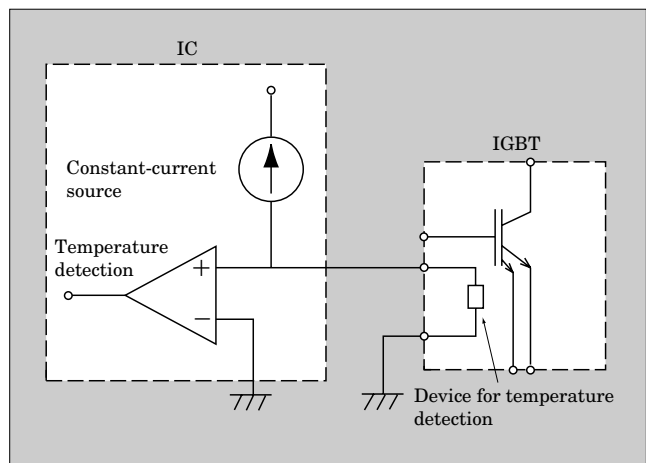


Fig.6 Overheating protection device



temperature for case protection, there is the possibility that the IGBT chips may be destroyed if this operating condition continues. It is clear that the device overheat protection function is indispensable.

The device overheat protection function differs from the case overheat protection of conventional IPMs. It protects against thermal destruction of the IGBT chips by directly detecting the junction temperature of the IGBT chips in which the temperature sensor is embedded.

In order to achieve this function, the temperature detection device is made on the IGBT chip as shown in Fig. 6. Detection of the IGBT chips temperature is performed utilizing the dependance of this device on temperature.

This device is embedded by using poly-silicon on insulator technology to prevent the influence of the

Fig.7 Timing chart of protection function

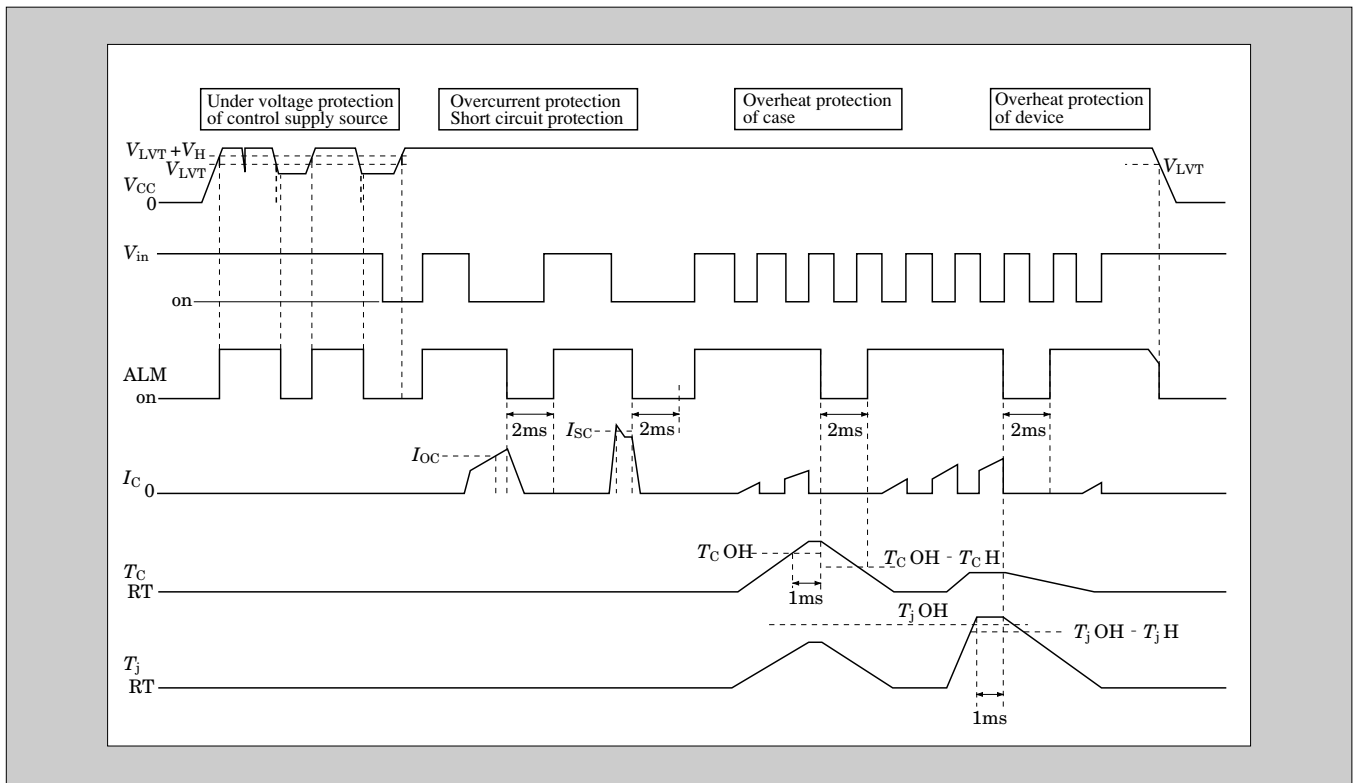


Fig.8 Switching waveforms of the R-IPM and the J-IPM

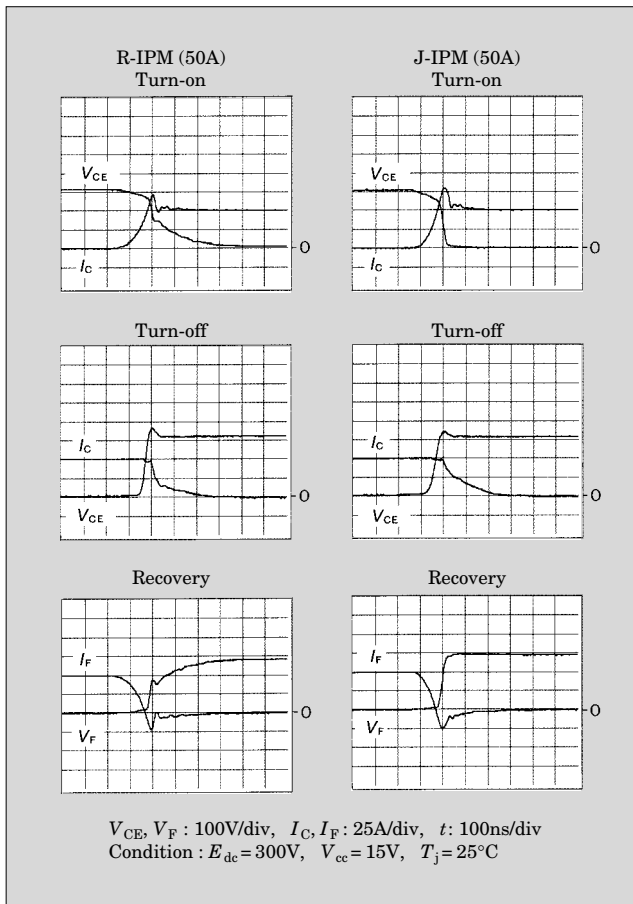
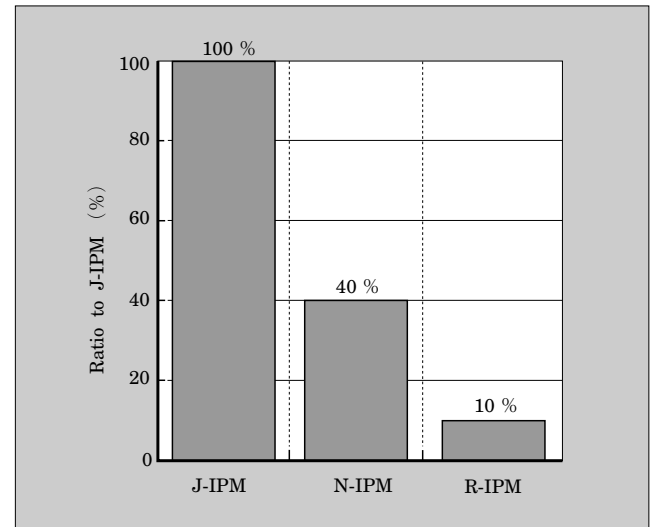


Fig.9 Ratio of electronic parts (IC inclusive)



switching noise of the IGBT chips. A dead time of 1ms is provided when detecting the IC side so that false detection by noise is prevented.

The timing chart of the protection functions are shown in Fig. 7. Overheat protection goes into effect and softly shut down the current when a certain condition continues for 1ms. This condition entails that overheat protection of both the case and the device reach the detection level. At the same time, the alarm's output and the protection state are engaged. The alarm output and protection state are reset when

the input signal is off state and the temperature reaches reset level.

4.2 Integration of the control circuit to the IC

The control circuit of IPMs were designed and evaluated, combining with IGBT chips after ICs were designed. Therefore, it had to adjust a drive ability of an IGBT and various protection functions and accomplish good noise immunity by using additional parts other than ICs. It is impossible to achieve a single chip IC which is not adjustable and has adopted a hybrid construction combined with various electronics parts. Consequently, the further downsizing or lowering of costs is deviously limited. However, the R-IPM solves these problems through experiments cultivated by the development of the conventional IPM and the technologies to be described below.

Integration of the IPM control circuit with the IC involves an adjusting method with the IGBT and measures against noise. With the following technologies, the integration of the control circuit to the IC is successful.

- (1) Through simulation technology conducted by a combination of IGBT characteristics and IC characteristics, the most suitable design is determined by theoretical study and review of such factors as the necessary capabilities required for the IC.
- (2) The noise immunity is improved by insertion of a filter on the reference power supply of each circuit block, and by incorporating a filter into the IC, formerly provided externally, which results in less noise on the circuit pattern.
- (3) Malfunction are prevented by reducing noise inflow. This is achieved by separating the noise sensitive IGBT ground from the sensing and protection circuit grounds.
- (4) The noise immunity increased remarkably by the reduction of wiring volume of the control circuit compared with the conventional IPM through the integration of the control circuit within the IC.
- (5) Low loss and soft switching are realized through the prevention of influence from outside noise by locating the IGBT and the IC as close as possible and through the optimization of the IC so that it

can efficiently drive the IGBT.

The switching waveforms of the J-IPM and the R-IPM are shown in Fig 8. In particular, the R-IPM restricts di/dt , dv/dt at the time of turn-on and recovery, and realizes soft switching.

Through the measures mentioned above, the number of electronics parts have been reduced to 1/10 that of the J-IPM, as shown in Fig. 9.

4.3 Package construction

Facilitated use is taken into consideration for the newly designed package, maintaining compatibility.

The features are as follows.

- (1) Preservation of compatibility of the mounting, main terminal and control terminal position (P610, P611 package)
- (2) Preservation of endurance against bending fracture through the adoption of metallic guide pins for the control terminals
- (3) Dissolution of a terminal deformation through the shortening of control terminals
- (4) Realization of a thin shape and light weight through optimization of the internal construction

5. Conclusion

Fuji Electric's IPMs and the series and features of the recently developed the R-IPM have been introduced. The R-IPM is the first product to comprise the IPM utilizing only silicon semiconductors. In addition, the function which directly detects the temperature of the IGBT chips has been newly built-in. We firmly believe that application of the R-IPM contributes to the downsizing and high reliability of the equipment by a considerable degree.

Furthermore, making the power devices intelligent will be promoted more often in the future, together with the progress of IC technology, corresponding to the needs for reduced total system costs, downsizing and high reliability of application products. We resolve to strive for the development and production of such products so that we are able to fully respond to the market's needs.



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AMERICA

■ FUJI ELECTRIC CORP. OF AMERICA

● Head Office

Park 80 West Plaza II, Saddle Brook, NJ07663, U.S.A.
TEL : (201) 712-0555 FAX : (201) 368-8258

■ FUJI ELECTRIC DO BRASIL INDUSTRIA E COMERCIO LTDA.

Rua Guajajaras, 1707, Barro Preto,
CEP 30180-101 Belo Horizonte, M. G., BRASIL
TEL : (031) 291-5161 FAX : (031) 291-8185

EU

■ FUJI ELECTRIC CO., LTD.

Erlangen Representative Office, Sieboldstr. 3, D-91052
Erlangen, F.R. GERMANY
TEL : (09131) 729613, 729630 FAX : (09131) 28831

■ FUJI ELECTRIC GmbH

Lyoner Str. 26,
D-60528 Frankfurt am Main, F.R. GERMANY
TEL : (069) 6690290 FAX : (069) 6661020

■ FUJI ELECTRIC CO., LTD.

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Bangkok Representative Office, Room No.1202, 12th Fl.
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142 Sukhumvit Rd. Bangkok 10110, THAILAND
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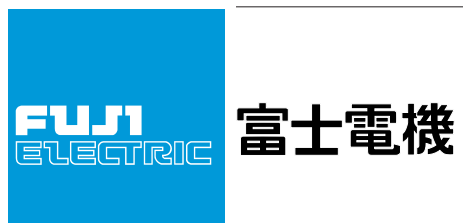
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Nicolaou Pentadromos Centre, Office 908,
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