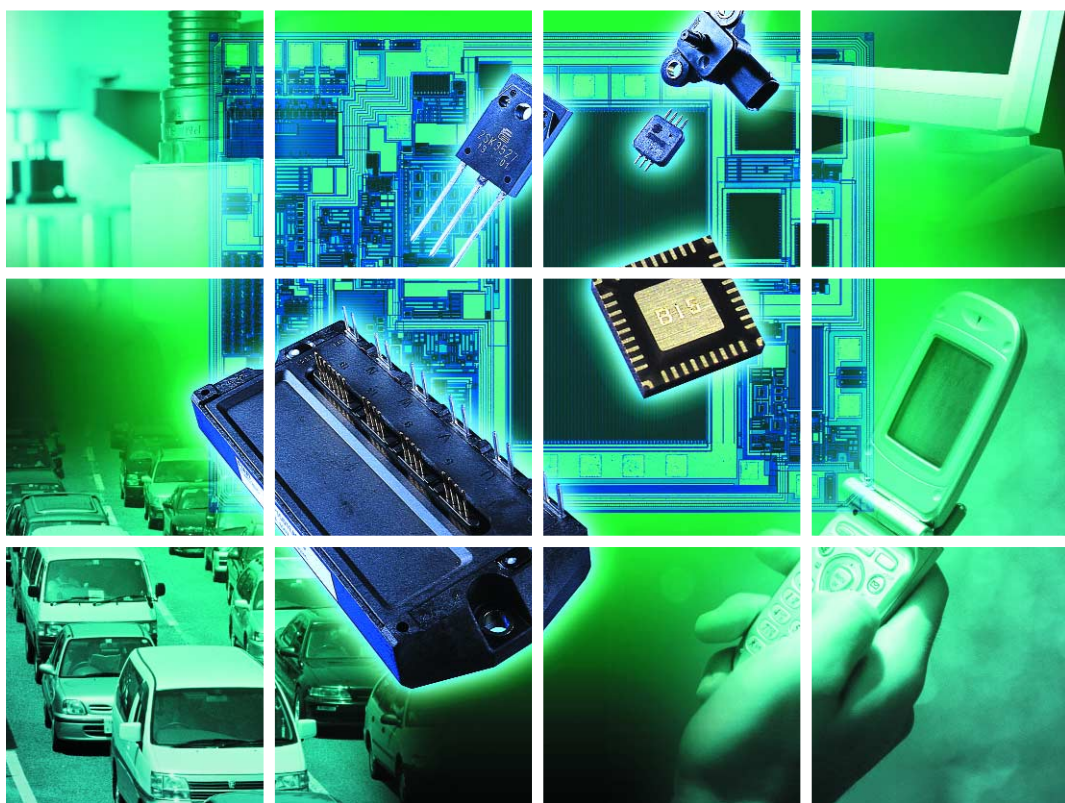


FUJI ELECTRIC REVIEW

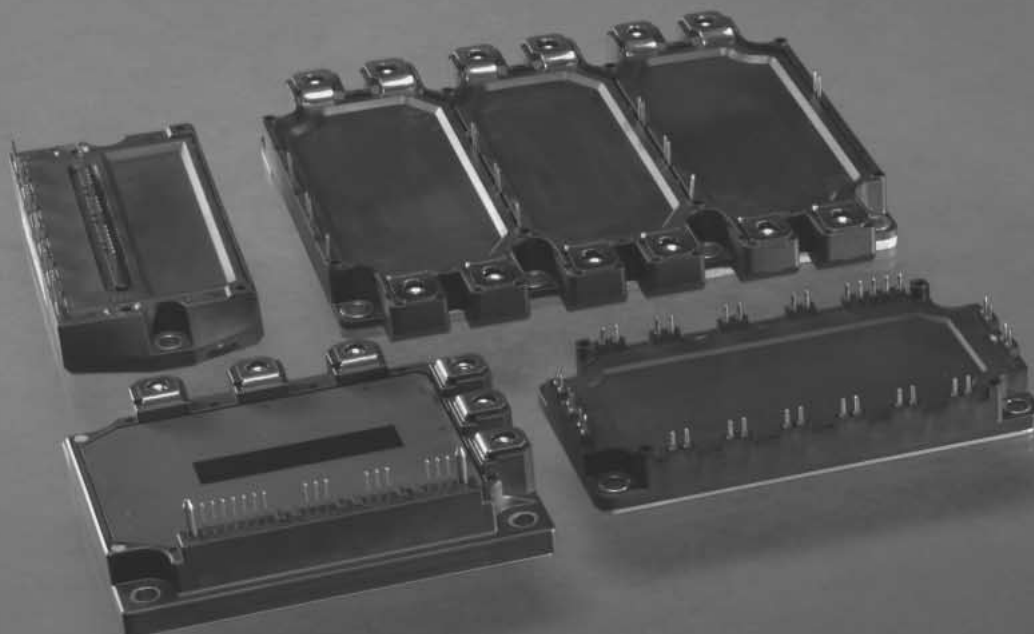
Semiconductors

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2005 VOL.51

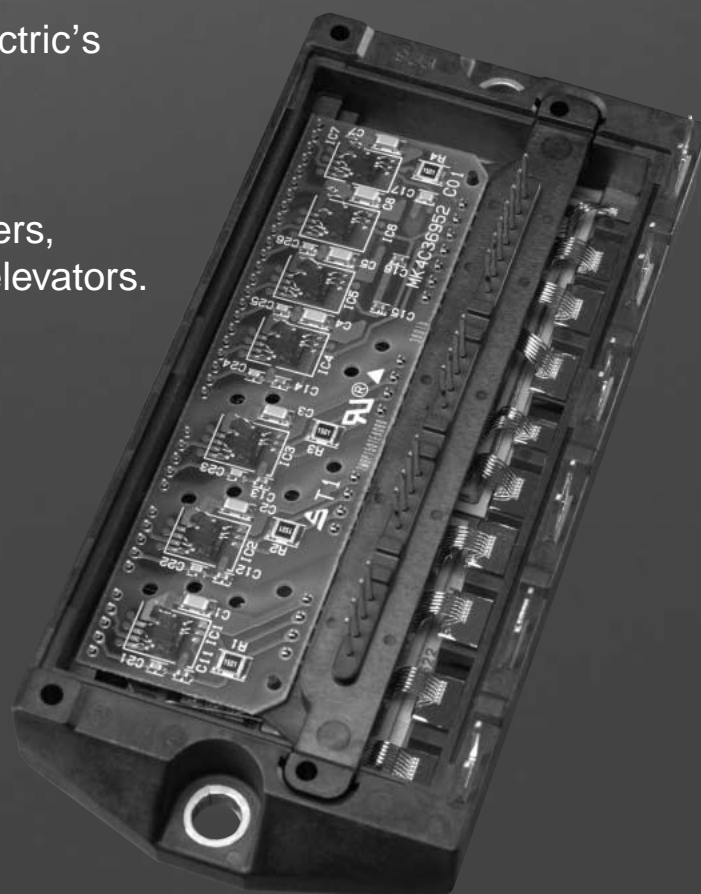


Fuji Electric Group



The key technology to power electronics, Fuji Electric's power devices.

The innovative technologies of Fuji Electric's power devices lead to market needs. Our power devices will contribute to the miniaturization and lower power consumption of such devices as inverters, industrial robots, air conditioners and elevators.



FUJI ELECTRIC REVIEW

Semiconductors

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Cover photo:

Accompanying the developments of the times, the attributes of lower power consumption, compact size and higher functionality are increasingly being required of electronic devices, electrical machinery, automobiles and the like. Semiconductor technology is essential to the evolution of these products and it is not an overstatement to say that semiconductors are the "bread of industry."

Fuji Electric is concentrating its energies on semiconductors for industrial, automotive, IT and power supply fields, and is involved at all stages, from research and development to production and marketing, in the power semiconductors and power ICs that support the power electronics industry.

The cover photo shows images of an IGBT module, power MOSFET and power IC, superimposed upon a background depicting the industrial, automotive, IT, and consumer electronic appliance fields in which these devices are applied.

Fuji Electric's Semiconductors: Current Status and Future Outlook

Hirokazu Kaneda
Akinori Matsuda

1. Introduction

The development of broadband networks and ubiquitous computing are major trends of the 21st century and the technologies for supplying and controlling energy are important technologies for supporting this cause. Power electronics will certainly be an important technology for supporting the society of the future.

Fuji Electric's semiconductor business has defined its business domain and market segment focus based on this power electronics technology, and has been developing proprietary semiconductor technology and supplying commercial products to expand this business. In order to support various applications, Fuji Electric is expanding its product line of power electronics semiconductor devices, which include insulated gate bipolar transistors (IGBTs), metal oxide semiconductor field effect transistors (MOSFETs), diodes, control integrated circuits (control ICs) and the like, with a wide range of voltage and power capabilities, from low-voltage, low-power devices suitable for battery power sources to high-voltage, high-power devices capable of handling more than several thousand volts and several hundred amps.

This paper describes Fuji Electric's semiconductor products and summarizes the technical trends of each major application.

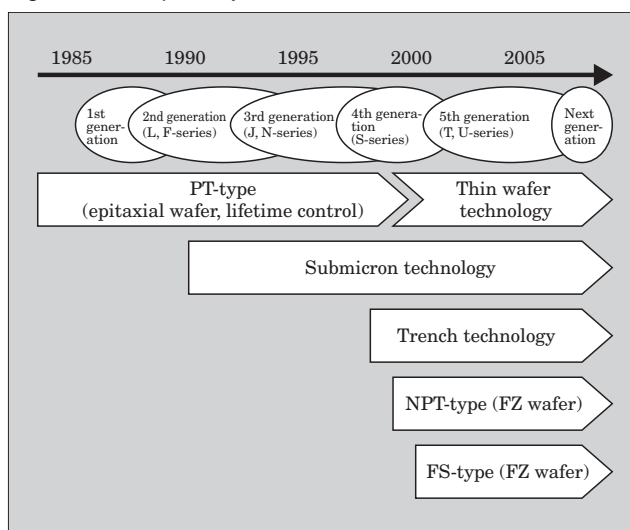
2. Industrial-use Semiconductors

2.1 Fuji Electric's IGBTs

IGBT devices can be said to support the foundation of power electronics in industrial applications, which are typically inverters. Since the latter half of the 1980s, IGBTs have increasingly been used as power electronics devices due to their high-speed switching capability and higher voltage and current capacity than a conventional bipolar transistor.

Fuji Electric began commercial production of IGBTs in 1988 and since then has continued to develop proprietary leading-edge technology and to supply products to the market that realize low loss and high-speed switching performance. Figure 1 shows the IGBT product history and main device technologies for

Fig.1 Roadmap of Fuji Electric's IGBTs



1st generation through 5th generation IGBTs. The 1st through 3rd generation IGBTs used epitaxial wafers, and their performance was enhanced through optimized injection efficiency and lifetime control and the adoption of submicron processing technology. Beginning with 4th generation IGBTs, a major advance in the design concept was implemented to realize a dramatic reduction in loss by employing a non-punch through (NPT) structure that achieves higher transport efficiency without lifetime control, instead of the conventional punch through (PT) structure that had been utilized thus far, and by implementing innovative processing technology that uses a thin floating zone (FZ) wafer having a lower thickness of nearly 100 μm .

Additionally, the recent 5th generation IGBT realizes both lower loss and higher speed switching capability by employing a field stop (FS) structure and a trench-gate structure to achieve a large increase in surface cell density.⁽¹⁾ Figures 2 and 3 show the changes in device structures for Fuji Electric's 600 V and 1,200 V IGBTs.

2.2 Increased performance from IGBTs

IGBTs are expected to continue to evolve as the main power devices used in industrial applications. In

response to requests for increased performance from IGBTs, Fuji Electric is vigorously pursuing technical development from the following three approaches. The first approach involves the application of leading-edge process technology. Fine surface structures, such as a trench gate structure, enable a dramatic improvement to be realized in the tradeoff relation between on-voltage and turn-off loss. Device characteristics will be improved by promoting the integration of technology acquired from IC-related research and the adoption of submicron processing technology. The second approach is to find breakthrough solutions to the problem of decreased resistance to short circuit loads caused by the application of submicron processing technology and to the problem of noise that becomes more prominent at higher switching speeds. To realize solutions, rather than focusing solely on the chip itself, comprehensive technology that involves the materials, wiring structure and cooling structure of the IGBT module is needed.^{(2), (3)} With the ultimate goal of providing noise-

Fig.2 Changes in the 600 V IGBT chip cross-sectional structure

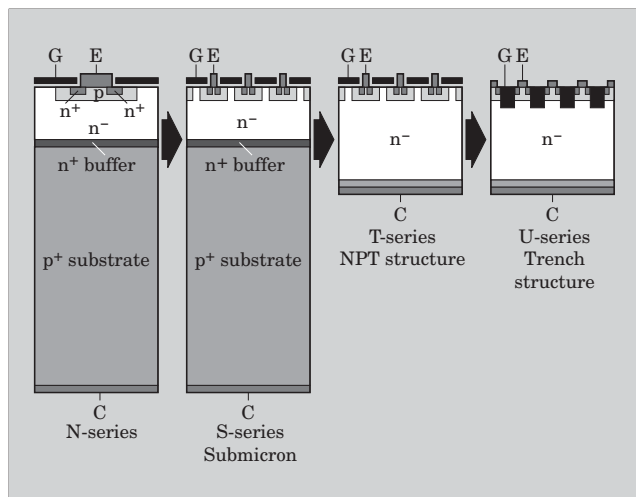
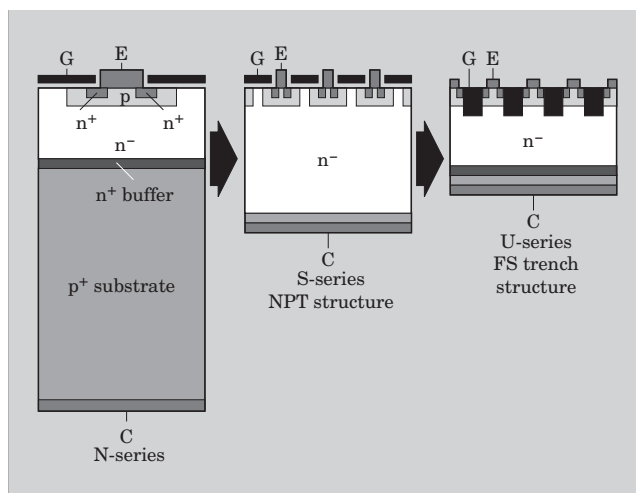


Fig.3 Changes in the 1,200 V IGBT chip cross-sectional structure



free operation without any failures, Fuji Electric aims to develop easy-to-use devices and supply them to its customers. The third approach is the creation of power devices based on a new concept that will help revolutionize the next generation of power electronics technology. For example, Fuji Electric is actively promoting the research and development of a reverse-blocking IGBT which has the potential to revolutionize power conversion methods.

In this manner, Fuji Electric intends to continue to supply devices that realize advanced power electronics capabilities.

3. Automotive Semiconductors

3.1 Fuji Electric's automotive semiconductors

The use of electronics in automobiles is rapidly increasing in order to achieve such goals as higher energy efficiency, lower emissions and improved safety and comfort, and consequently, the number of semiconductors installed in automobiles is steadily increasing. Because automotive semiconductors are used in a severe operating environment, and for safety reasons, high reliability is required. Additionally, the attributes of small size, lightweight, a small footprint and low cost are also strongly requested.

Fuji Electric supplies a variety of application-specific automotive semiconductor products. For engine system applications, Fuji Electric is commercializing pressure sensors for manifold air pressure measurement and atmospheric pressure compensation, smart IGBTs and hybrid ICs for use in igniter circuits, and high-voltage diodes to prevent premature ignition. For applications involving the chassis system, Fuji provides MOSFETs, smart MOSFETs and diodes for transmission control, traction control, brake control, suspension control, power steering, etc. In applications involving the body system, Fuji Electric's MOSFETs and diodes are used for power window, power lock, automatic mirror and windshield wiper control circuits.

3.2 Intelligent functions of automotive semiconductors

The performance of automotive MOSFETs has been improved through innovations in the device structure and advances in submicron processing technology. Figure 4 shows the roadmap of Fuji Electric's automotive MOSFETs. The application of a trench gate structure and submicron processing technology to the low-voltage class of products, which are used in many applications such as power steering and air conditioning circuits, and for which use is likely to increase in the future, enables the realization of a low on-resistance per unit area of 0.8 mΩ, which is approximately 40 % of the on-resistance of conventional products. Moreover, the development of a quasi-planar junction structure enables the high-voltage class of products, used in the DC-DC converters and electronic

Fig.4 Roadmap of Fuji Electric's automotive MOSFETs

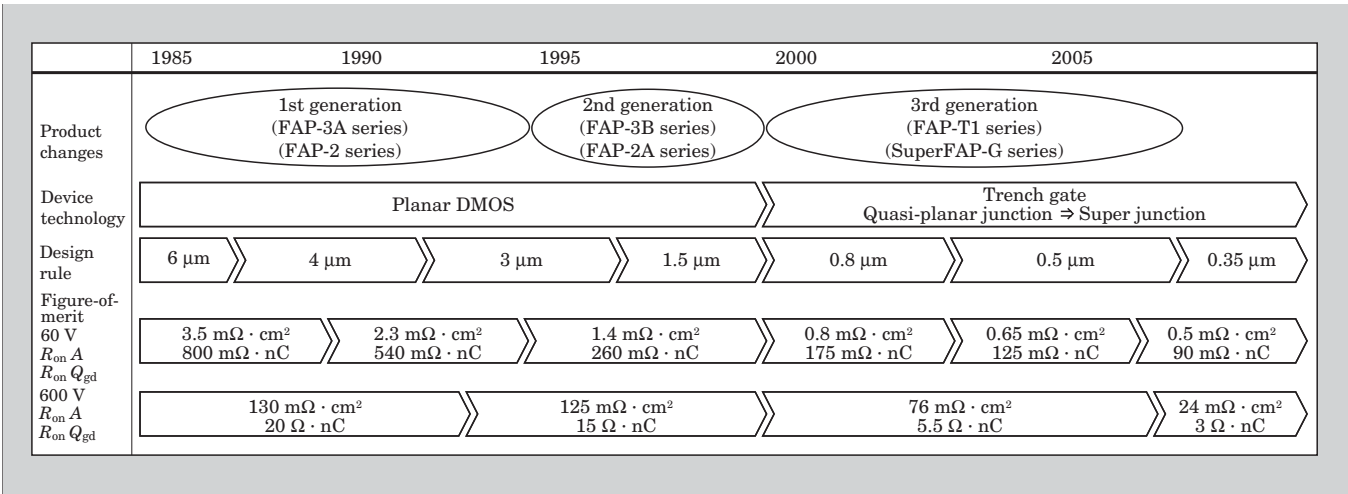


Fig.5 Cross-sectional structure of self-isolation power ICs (control circuit)

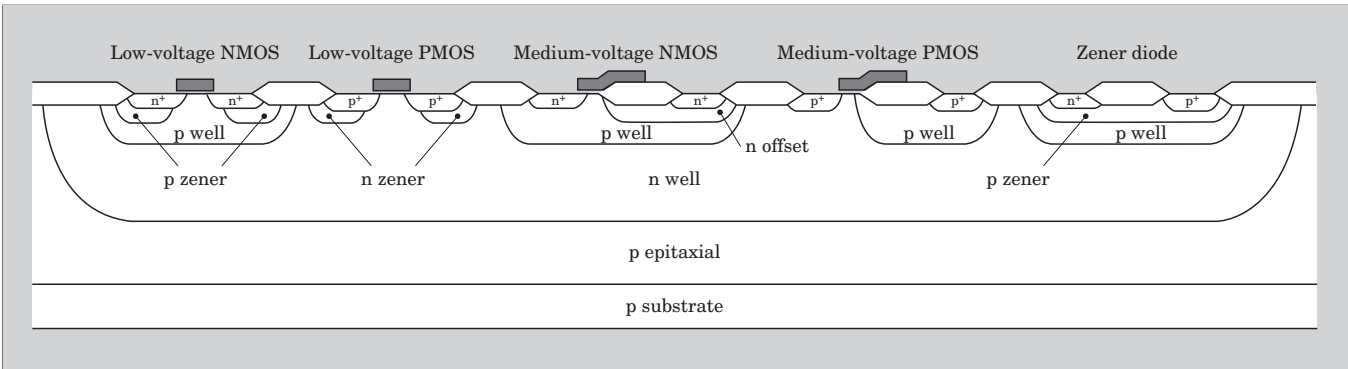
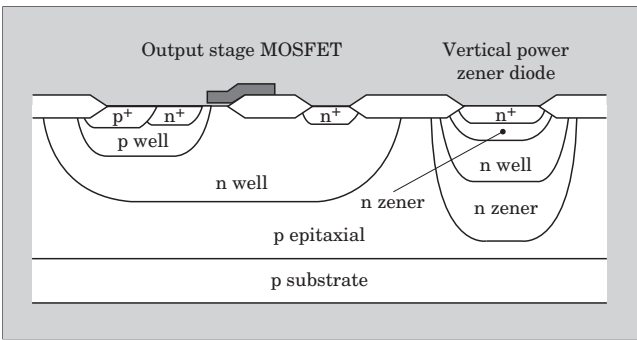


Fig.6 Cross-sectional structure of self-isolation power ICs (power MOSFET)



ballasts of hybrid automobiles, to realize an on-resistance per unit area and switching time that are both less than one-half the corresponding values of a conventional device.

Meanwhile, semiconductor devices are increasingly being requested to provide higher reliability due to the increasing scope and complexity of the electronic control unit in response to requests for even higher-level electronic control, and also due to the year-after-year increase in temperature of the operating environment resulting from installation space constraints. In response to this request for higher reliability, Fuji

Electric has developed smart MOS technology that integrates a conventional MOSFET and a protection circuit, a status monitoring and output circuit, and a drive circuit all onto a single chip, and has provided the device with intelligent functionality.

In an intelligent device that includes an integrated vertical power MOSFET and control circuit, the isolation structure is very important. As technology capable of realizing stable isolation at minimal cost, Fuji Electric has developed and is applying its proprietary self-isolation complementary MOS/double-diffused MOS (CDMOS) technology. Figures 5 and 6 show typical examples of this self-isolation structure. With the self-isolation structure, the output-stage power MOSFET is isolated from other devices integrated on the same silicon substrate, such as a low/high voltage MOSFET or a protection zener diode, by the pn junction of each device. Compared to the dielectric isolation or junction isolation structures, this self-isolation structure is advantageous because it enables the easy integration of peripheral circuitry with an existing MOSFET, at a dramatically lower cost.

Automotive semiconductors are expected to evolve into even smaller sizes in the future. Fuji Electric intends to respond such market requests by actively developing unified IC technology capable of realizing

multi-channel integration with lateral MOSFETs, chip-on-chip technology capable of reducing the required installation area, and chip size package (CSP) technology. Environmental responsiveness is increasing in importance and Fuji Electric intends to give priority to the elimination of lead in these semiconductor products.

4. Semiconductors for Information Devices and Power Supply Systems

4.1 Fuji Electric's semiconductors for information devices and power supply systems

With advances in information technology, the popularity of PCs, digital household appliances and portable information devices is spreading rapidly. In order to conserve natural resources and energy, lower power consumption is becoming increasingly important, and the power supply systems in which these devices are installed are strongly requested to provide high efficiency and low loss, as well as have a small footprint, low height and light weight. As semiconductors for power supply system applications, Fuji Electric has supplied a product series of AC-AC and DC-DC power supply control ICs, MOSFETs, Schottky barrier diodes (SBDs), and low-loss fast recovery diodes (LLDs).

Fuji Electric's ICs feature mixed analog-digital power technology that combines high-voltage power technology, high precision complementary metal oxide semiconductor (CMOS) analog technology and CMOS digital technology into a single chip. For relatively low capacity AC-DC conversion applications, Fuji Electric supplies a power IC containing an integrated 700V power MOSFET, and this product can be used to configure a small-size AC adapter with a minimum number of parts. Moreover, for larger capacity AC-DC conversion applications, Fuji supplies all the semiconductor devices, including CMOS control ICs capable of voltage mode and current mode control, MOSFETs and

SBDs, required to configure a power supply system.

For DC-DC conversion, there is a trend towards using customized ICs for each portable device application. These devices often require different power supply voltages for each system block, and multi-channel ICs that integrate multiple outputs on a single chip are commonly used.

For information device applications, Fuji Electric supplies LCD backlight control ICs and plasma display panel (PDP) driver ICs for flat panel display applications. Future growth is anticipated for these flat panel display applications.

4.2 Power IC technology

Portable information devices use batteries as their power source. These devices are also equipped with image displays and high-speed microprocessors, and their required supply voltage differs according to their internal circuitry. Accordingly, it is important for the power supply of a portable information device to be capable of supplying different voltages at high efficiency, while realizing a small footprint and small volume.

Fuji Electric responded to this need early on by developing a proprietary lateral CDMOS structure that realizes mixed analog-digital power technology that enables multiple power MOSFETs and CMOS circuits to be integrated in a single chip, and has supplied various such products. Figure 7 shows Fuji Electric's roadmap for power IC technology. Fuji Electric has supported the trends towards multi-channel, higher functionality devices by applying sub-micron technology and a proprietary lateral DMOS structure to reduce the MOSFET on-resistance and enable large-scale control circuits to be integrated within a power IC chip.

As device technology that aims to realize even lower on-resistance and higher switching performance of power MOSFETs, Fuji Electric is researching and developing technology for fabricating three-dimensional devices on a silicon substrate and for achieving

Fig.7 Roadmap of Fuji Electric's power IC technology

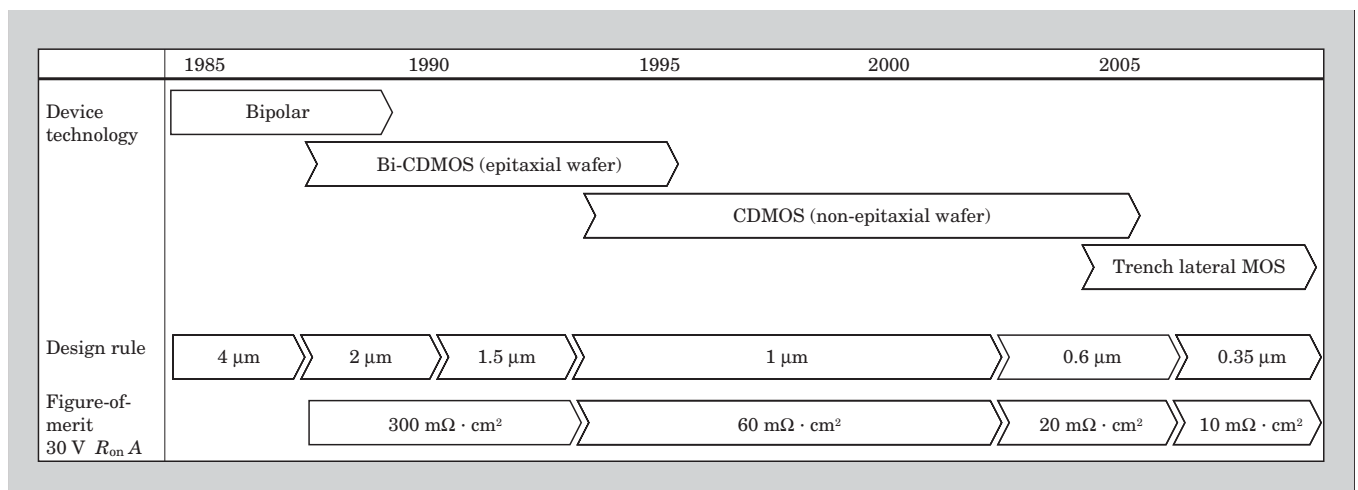
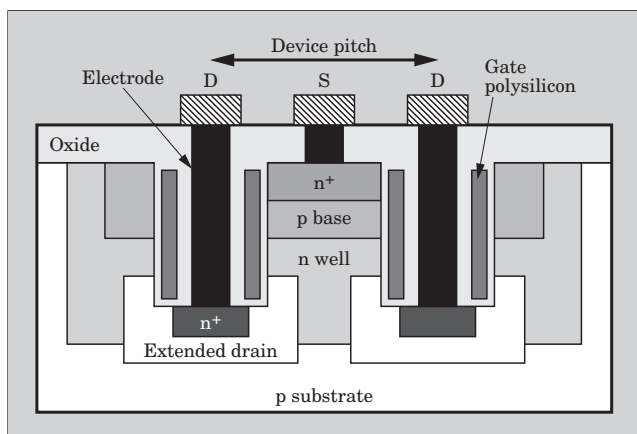


Fig.8 Cross-sectional structure of trench lateral power MOSFETs in power ICs



dramatically smaller DC-DC converters that integrate passive devices with a control IC (see Fig. 8). Fuji Electric plans to develop commercial products in the near future.^{(6), (7)}

4.3 Reduction of the MOSFET loss

In a switching power supply for performing AC-DC conversion, the turn-off loss and on-resistance loss of the power MOSFET account for the majority of the total loss. Therefore, in order for the switching power supply to realize higher efficiency and lower loss, the turn-off loss and the on-resistance loss of the power MOSFET must both be reduced simultaneously. Moreover, in order to increase the switching frequency in response to requests for smaller size of the switching power supply, the reduction of switching loss, as typified by turn-off loss, is expected to become even more important in the future.

In response to these needs, Fuji Electric has developed and commercialized its propriety low-loss, high-speed power MOSFET technology as the SuperFAP-G series. The SuperFAP-G series uses quasi-planar junction technology to achieve a lower on-resistance that is within 10 % of the silicon limit.⁽⁵⁾

The SuperFAP-G series realizes high-voltage power MOSFET performance that approaches the theoretical performance limit, but Fuji Electric's super junction MOSFET (SJ-MOSFET) technology is attracting attention as a breakthrough technology that, despite using silicon, achieves performance beyond the silicon limit. Fuji Electric is vigorously pursuing development of this SJ-MOSFET technology and plans to commercial-

ize this technology in the near future.

5. Conclusion

Fuji Electric is developing proprietary power device and IC technology for power electronics applications and is developing and supplying smart and intelligent products that provide solutions matched to the customer. This paper has summarized Fuji Electric's efforts involving semiconductors and has presented an overview of each application field. For additional details of the various relevant technologies and products, please refer to the other papers in this special issue.

In the society of the future, robotics and broadband technology will be even more pervasive in our daily lives and accordingly, the importance of power electronics will increase. Fuji Electric intends to continue to develop advanced, proprietary semiconductor technology and to commercialize semiconductor devices that support power electronics. Additionally, based upon our corporate motto of "*Quality is our message*," Fuji Electric intends to continue to supply reliable quality products to its customers.

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U-series IGBT Modules

Shuji Miyashita

1. Introduction

Power conversion equipment such as general-purpose inverters and uninterruptible power supplies (UPSs) is continuously challenged by demands for higher efficiency, smaller size, lower cost and lower noise. Accordingly, the power-converting elements used in inverter circuits are also required to have high performance, low cost and high reliability. At present, insulated gate bipolar transistors (IGBTs) are widely used as the main type of power converting elements because they exhibit low loss and enable the easy implementation of drive circuitry. After commercializing the IGBT in 1988, Fuji Electric has made efforts to improve the IGBT further in pursuit of lower loss and higher reliability.

This paper introduces the technology and product line-up of Fuji Electric's fifth generation IGBT modules (U-series), which feature a large improvement in electrical characteristics compared to the fourth generation IGBTs (S-series).

2. Features of the New IGBTs

2.1 Trench gate IGBT

Fuji Electric is producing trench-gate type power metal oxide semiconductor field effect transistors (MOSFETs), to which design and process technologies have been applied in order to ensure sufficient reliability. The trench IGBT is the result of applying these technologies to IGBTs.

Figure 1 shows a comparison of the planer and trench IGBT cell structures. The trench IGBT achieves a drastic increase in cell density, enabling the voltage drop at the channel part to be suppressed to a minimum. Since the distinctive JFET region, sandwiched between channels of the planer type device, does not exist in the trench IGBT, the voltage drop across this region can be completely eliminated. On the other hand, the high channel density of the trench IGBT causes the problem of low capability to withstand a short-circuit condition. However, the trench gate structure developed by Fuji Electric optimizes the total channel length of the MOS device to realize high

short-circuit withstand capability without sacrificing the saturation voltage.

2.2 NPT-IGBT

The unit cell structures of a non-punch through (NPT) IGBT and a punch through (PT) IGBT are

Fig.1 Comparison of planer and trench IGBT cell structures

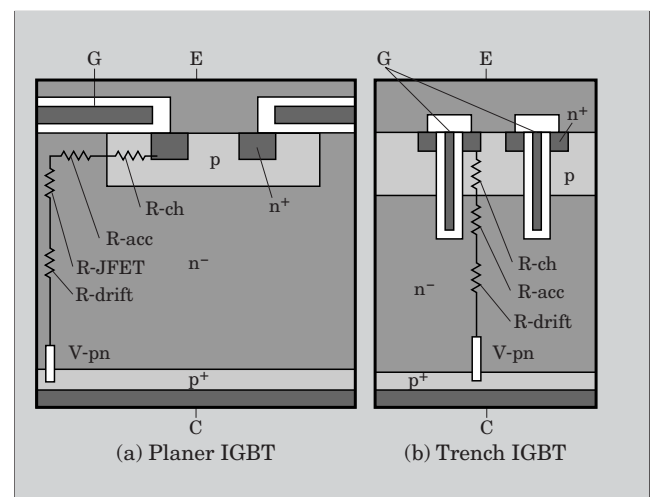
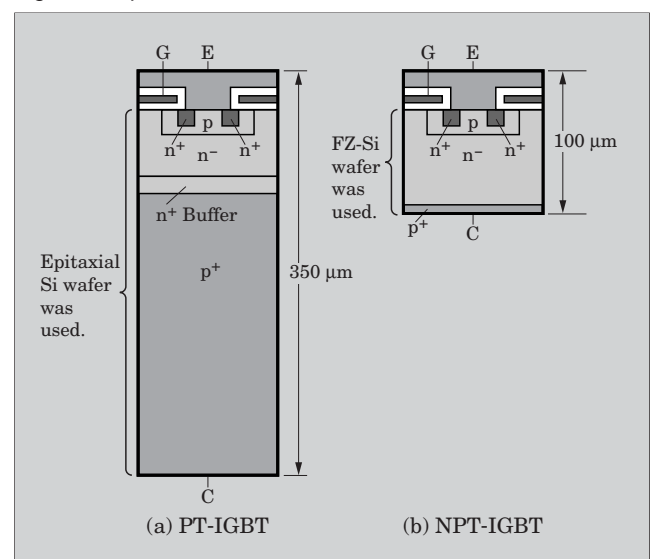


Fig.2 Comparison of PT and NPT-IGBT cell structures



shown in Fig. 2. Features of the NPT-IGBT are as follows.

- (1) Since injection from the collector-side can be suppressed, lifetime control is unnecessary and the switching loss does not increase even at high temperatures.
- (2) Because the temperature dependence of output characteristics is positive (the saturation voltage increases at higher temperature), these devices are well suited for parallel applications.
- (3) Withstand capability, including the load short-circuit withstand capacity, is higher than that of a PT-IGBT.
- (4) Use of a floating zone (FZ) wafer achieves better cost performance and higher reliability owing to its low rate of crystal defects.

Also, it is important for NPT-IGBTs to suppress saturation voltage while maintaining the collector-emitter (C-E) blocking voltage. The saturation voltage will be lower when thinner wafers are used, however, the thickness of the depletion layer end must be maintained sufficiently thick so there will be no punch through even when the maximum rated C-E blocking voltage is applied, and this sufficient thickness is the minimum value. Therefore, the optimal thickness is thinner for devices having lower C-E blocking voltage, making their manufacture even more difficult. For 600 V NPT-IGBTs, Fuji Electric has established mass production technology to handle the optimal wafer

thickness by carefully choosing the optimal wafer specification and improving the precision of back-grinding process technology so that the reduction of saturation voltage could be achieved.

Thinner wafers also feature a reduction in turn-off switching loss. Figure 3 shows a comparison of turn-off waveforms. In the PT-IGBT, which has more carriers injected from the collector side, lifetime control is implemented to promote the recombination of carriers at the time of turn-off. However, this effect decreases as the temperature increases, and therefore the turn-off switching loss tends to increase due to an increase in fall time. For the NPT-IGBT, on the other hand, lifetime control is not implemented and therefore this temperature dependence does not exist and there is no change in the turn-off waveform and no increase in turn-off switching loss. Accordingly, the trade-off relationship between saturation voltage and turn-off switching loss has been improved, and both can be reduced simultaneously with the use of an NPT-IGBT.

When the load is short-circuited, the NPT-IGBT, having a thick n^- drift layer, can support the voltage with its wide n^- drift layer, thereby suppressing the temperature rise which causes breakdown and achieving high short-circuit withstand capability. Even a thin-wafer 600 V NPT-IGBT can achieve a short-circuit withstand capability of 22 μ s.

2.3 Field stop (FS) structure

Figure 4 compares the cross sections of NPT-IGBT and FS-IGBT unit cells. The NPT-IGBT requires a thick drift layer so that the depletion layer does not contact the collector side during turn-off. The FS-IGBT does not, however, require as thick a drift layer as the NPT type because it is provided with a field stop layer to block the depletion layer, and accordingly, saturation voltage can be lowered for the FS-IGBT. Furthermore, the FS-IGBT has fewer excess carriers because of its thinner drift layer. Moreover, the FS-IGBT can achieve reduced turn-off switching loss because the remaining width of its neutral region is

Fig.3 Comparison of turn-off waveforms

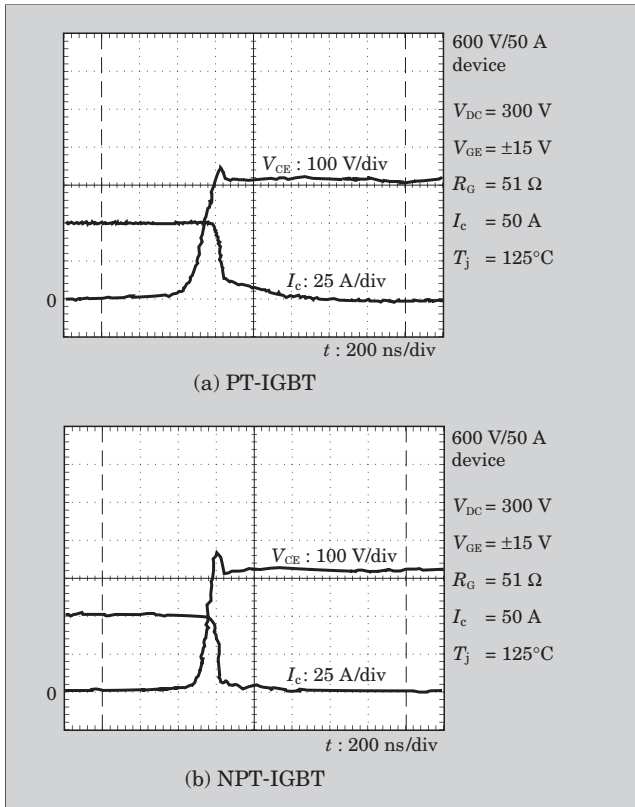


Fig.4 Comparison of NPT and FS-IGBT cell structures

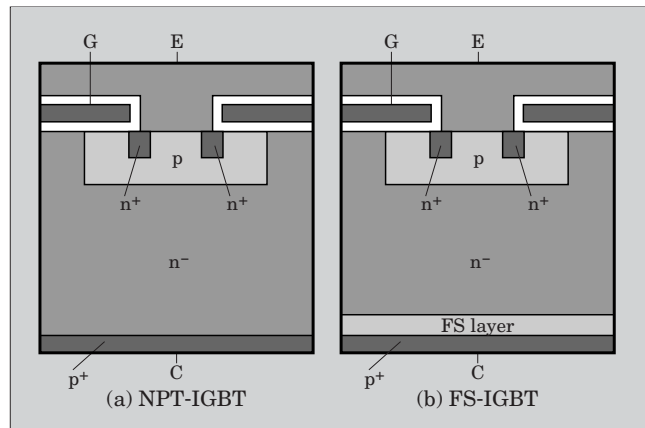


Fig.5 Comparison of conventional and new FWD cell structures

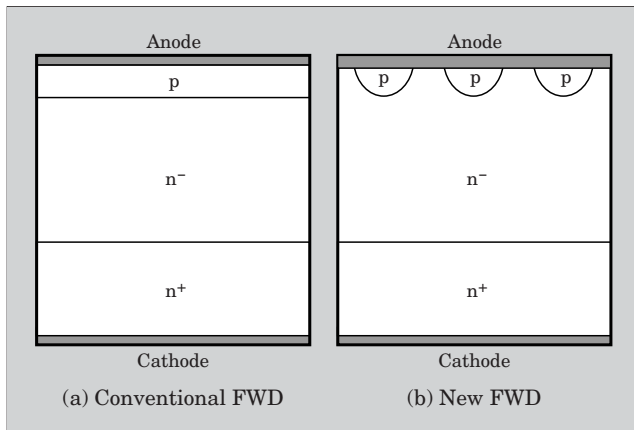
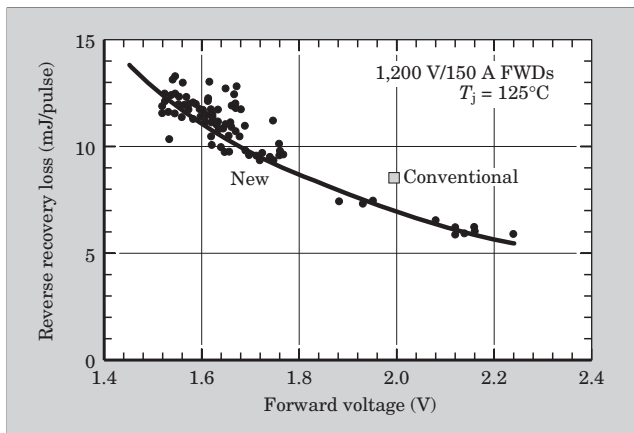


Fig.6 Trade-off between forward voltage and reverse recovery loss



small when its depletion layer is completely extended. Thus, by applying the FS structure to 1,200 V and 1,700 V devices, their trade-off relationship between saturation voltage and turn-off switching loss has been improved, and both can be reduced simultaneously.

3. Features of Fuji's New FWD

As IGBTs are improved, free wheeling diodes (FWDs), which are packaged together with IGBTs into IGBT modules are then installed in inverter circuits, are also subject to improvement. The FWDs are required to have lower conduction loss, which is caused by forward voltage, and lower reverse recovery loss. Also, soft reverse recovery of FWDs, which correlates to the faster turn-on switching of IGBTs, is an especially important characteristic in order to suppress a rise in surge voltage, protect the IGBT from damage, and to suppress malfunction of peripheral circuitry. By optimizing the wafer specifications, applying injection control from the anode at the chip's front structure and implementing optimal lifetime control, Fuji Electric has developed a new FWD having superior soft

Fig.7 Trade-off relationship for 1,200 V devices

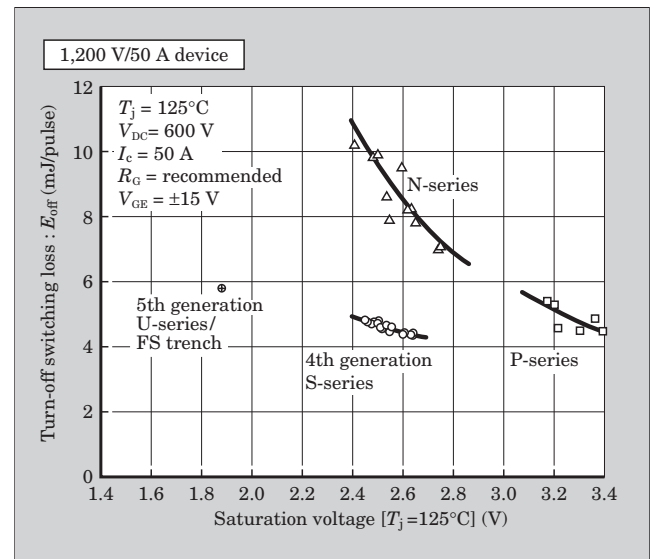
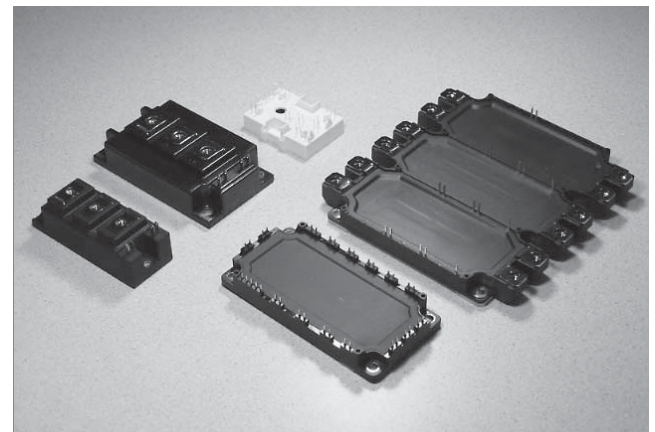


Fig.8 Examples of packages for U-series IGBT modules



reverse recovery characteristics.

Figure 5 compares the cross sectional structures of a conventional and a new FWD. The new FWD has a structure that is able to suppress carrier injection. Peak current during reverse recovery is reduced, and the new FWD achieves not only a softer reverse recovery characteristic but also less reverse recovery loss. Figure 6 shows an example of the trade-off relationship between forward voltage and reverse recovery loss. The new FWD shows the better result of improved reverse recovery loss compared to that of the conventional FWD. On the other hand, the forward voltage was designed to be approximately 1.6 V at a higher temperature ($T_j = 125^\circ\text{C}$). Therefore, the conduction loss in an inverter circuit application would be lower due to the lower forward voltage of the new FWD. Furthermore, since the output characteristic of the new FWD has a positive temperature coefficient, similar to the U-series IGBT, the current imbalance among parallel-connected devices will be smaller. Therefore, in a parallel connection application, for

Table 1 U-series IGBT modules line-up

V_{CES} rating	Package	I_C rating (Inverter rating)	10 A	15 A	20 A	30 A	50 A (5.5 kW)	75 A	100 A (11 kW)	150 A	200 A (22 kW)	300 A	400 A (40 kW)	600 A	800 A	1,200 A	1,600 A	2,400 A	3,600 A			
600 V	Small		PIM				6 in 1															
	PIM						EP2		EP3													
	6 in 1								NewPC2		NewPC3											
	2 in 1										M232		M233		M247							
V_{CES} rating	Package	I_C rating (Inverter rating)	10 A	15 A	25 A (5.5 kW)	35 A	50 A (11 kW)	75 A	100 A (22 kW)	150 A	200 A (40 kW)	300 A	400 A (75 kW)	600 A	800 A	1,200 A	1,600 A	2,400 A	3,600 A			
1,200 V	Small		PIM		6 in 1																	
	PIM				EP2																	
					EP3																	
	6 in 1						NewPC2															
							NewPC3															
									EconoPack-Plus* (6 in 1)													
	2 in 1/ 1in1						M232		M233		M247		M138		M142		M143					
1,700 V	PIM/ 6 in 1		For vector control				NewPC3 (with Shunt R)															
	6 in 1 2 in 1 1 in 1										EconoPack-Plus (6 in 1)		M248		M142		M143					
			General purpose Inverter								High performance Inverter											
*EconoPack-Plus : A registered trademark of Eupec GmbH, Warstein																						

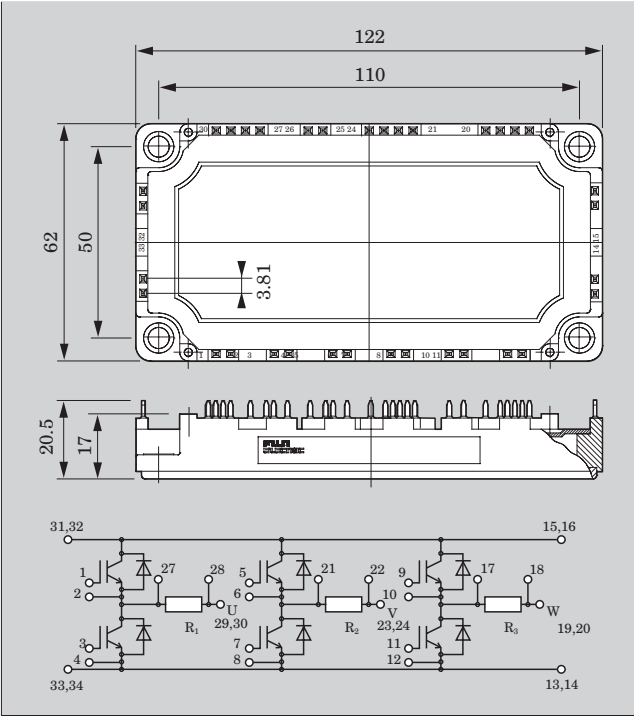
*EconoPack-Plus : A registered trademark of Eupec GmbH, Warstein

example, high power inverter circuits will be easier to use.

4. Introduction of Fuji Electric’s Product Line-up

Fuji Electric has combined the above IGBT and FWD technology while continuously employing the same packaging technology as used in fourth generation IGBT modules which have higher power cycling capability, and has finally completed the development and product line-up of U-series IGBT modules that exhibit much improved characteristics in comparison to fourth generation S-series IGBT modules. Figure 7 shows an example of the trade-off relationship for a 1,200 V device. Both the saturation voltage and the turn-off switching loss are simultaneously reduced. It can be seen that the trade-off relationship is dramatically improved in comparison to that of fourth generation IGBT modules, and that almost 20 % less power dissipation loss can be expected in the case of an inverter circuit application. Figure 8 shows examples of packages for these U-series IGBT modules, Table 1 lists Fuji Electric’s line-up of U-series IGBT modules. Three blocking voltage ratings of 600 V, 1,200 V and 1,700 V, a wide current range from 10 A up to 3,600 A, and many package variations have been prepared to enable application to various types of power conversion equipment. Also, new module packages with shunt-resistors have been developed as an addition to the U-

Fig.9 Module package (6 in 1) with shunt-resistors



series product line-up. A schematic drawing of the package and its equivalent circuit are shown in Fig. 9. The modules are designed for vector control inverters,

and the shunt resisters and their voltage drop detection terminals are installed at the AC output terminals of a three-phase inverter bridge. In contrast to the conventional current detection method that uses an external current detector, a voltage detection method that uses these modules will be able to control the motor output current, thereby enabling inverter equipment to be made simpler and smaller.

5. Conclusion

IGBT and FWD technology of Fuji Electric's U-series IGBT modules, its features and product line-up have been presented. Through using the latest semiconductor technology and packaging technology,

these products achieve superior low loss characteristics, and we believe they will make important contributions to the realization of smaller size and lower loss inverter circuit equipment.

Fuji Electric intends to continue working to improve this technology further, with the goals of realizing higher performance and higher reliability devices, and to contribute to the development of power electronics.

References

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U-series of IGBT-IPMs (600 V)

Kiyoshi Sekigawa
Hiroshi Endo
Hiroki Wakimoto

1. Introduction

Intelligent power modules (IPMs) are intelligent power devices that incorporate drive circuits, protection circuits or other functionality into a modular configuration. IPMs are widely used in motor driving (general purpose inverter, servo, air conditioning, elevator, etc.) and power supply (UPS, PV, etc.) applications.

The equipment that uses these IPMs are required to have small size, high efficiency, low noise, long service life and high reliability.

In response to these requirements, in 1997, Fuji Electric developed the industry's first internal over-heat protection function for insulated gate bipolar transistors (IGBTs) and developed an R-IPM series that achieved high reliability by employing an all-silicon construction that enabled a reduction in the number of components used.

Then in 2002, Fuji Electric changed the structure of its IGBT chips from the punch through (PT) structure, which had been in use previously, to a non-punch through (NPT) structure, for which lifetime control is unnecessary, in order to realize lower turn-off loss at high temperature, and also established finer planar gate

and thin wafer processing technology to develop an R-IPM3 series that realizes low conduction loss.

With the goal of reducing loss even further, Fuji Electric has developed an IGBT device that employs a trench NPT structure to realize lower conduction loss and has developed a new free wheeling diode (FWD) structure to improve the tradeoff between switching noise and loss. Both of these technologies are incorporated into Fuji Electric's newly developed U-series IGBT-IPM (U-IPM) which is introduced below.

2. U-IPM Development Concepts and Product Line-up

The concepts behind the development of the U-IPM are listed below.

(1) Realization of lower loss

Lower loss can be realized by developing new power elements and optimizing the drive performance. Increasing the carrier frequency of the equipment contributes to improved control performance. Also, larger output can be obtained from the equipment during the operation at the same carrier frequency.

(2) Continued use of the same package as prior products

Table 1 Product line-up, characteristics and internal functions of the U-IPM series

No. of elements	Model	V _{DC} (V)	V _{CES} (V)	Inverter part		Brake part		Internal function								Package type
				I _C (A)	P _C (W)	I _C (A)	P _C (W)	Both upper and lower arms			Upper arm		Lower arm		TcOH	
								Dr	UV	TjOH	OC	ALM	OC	ALM		
6 in 1	6MBP 20RUA060	450	600	20	84	—	—	Yes	Yes	Yes	None	None	Yes	Yes	None	P619
	6MBP 50RUA060			50	176	—	—	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	6MBP 80RUA060			80	283	—	—	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	6MBP100RUA060			100	360	—	—	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
	6MBP160RUA060			160	431	—	—	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
7 in 1	7MBP 50RUA060	450	600	50	176	30	120	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	7MBP 80RUA060			80	283	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	7MBP100RUA060			100	360	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
	7MBP160RUA060			160	431	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611

Dr: IGBT driving circuit, UV : Under voltage lockout for control circuit, TjOH: Device overheat protection, OC: Over-current protection, ALM: Alarm output, TcOH: Case temperature over-heat protection

*6MBP20RUA060 uses a shunt resistance-based over-current detection method at the N line.

Fig.1 External view of U-IPM packages

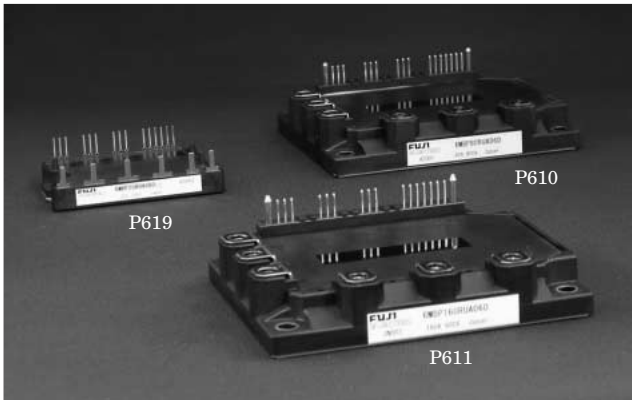
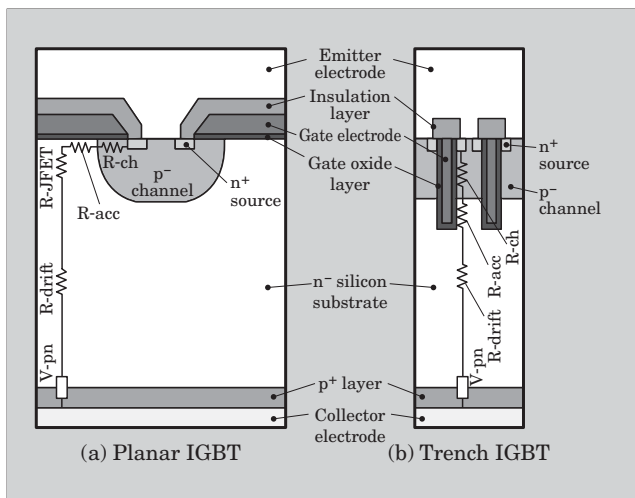


Fig.2 Comparison of planar IGBT and trench IGBT chip cross sections



The continued use of the same package as with prior products makes it possible to improve equipment performance by replacing the IPM without having to modify the design of the equipment.

Table 1 lists the product line-up, characteristics and internal functions of Fuji Electric's 600 V U-IPM series. The U-IPM series maintains internal functions and a package size that are interchangeable with the R-IPM series; its rated current is 20 to 160 A for the "6 in 1" pack and 50 to 160 A for the "7 in 1" pack (containing an internal IGBT for braking use). Figure 1 shows an external view of the packages.

3. Characteristics of the Power Devices

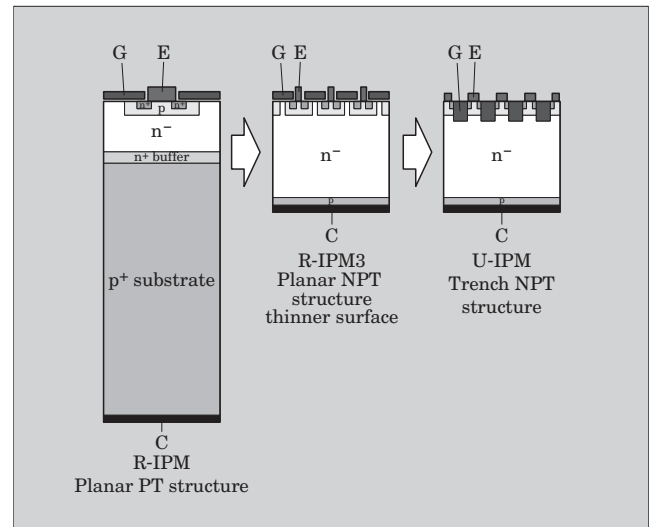
A fifth-generation U-series IGBT (U-IGBT) is used as the power device. This U-IGBT combines trench gate technology with a basic design comprising Fuji Electric's floating zone (FZ) wafer technology, thin wafer processing technology, carrier injection control technology, and transportation factor improving technology.

Figure 2 compares the structures of the conventional planar IGBT and the trench IGBT. The adoption of

Table 2 Changes in IGBT technology

IGBT technology	R-IPM	R-IPM3	U-IPM
	N-IGBT	T-IGBT	U-IGBT
Wafer	Epitaxial		FZ
Wafer thickness	350 μm		100 μm
Structure	PT		NPT
Gate structure	Planar		Trench
Lifetime control	Yes		None
Carrier injection	High		Low
Transportation factor	Low		High

Fig.3 Change in cross-sectional structure of 600 V IGBT chip



a trench gate structure results in a smaller voltage drop at the channel (R-ch) due to increased surface cell density and results in a lower saturation voltage due to the smaller voltage drop resulting from the elimination of the planar device's characteristic J_{FET} region (R-JFET). Moreover, short circuit immunity capability is realized through optimization of the design of the surface structure. Figure 3 illustrates the changes that have occurred in the cross-sectional IGBT structure in the transition from the conventional IGBT to the U-IGBT, and Table 2 compares their applied technologies.

The FWD, in accordance with the U-IGBT, incorporates a new design featuring optimized wafer specification, control of anode-side injection and optimal lifetime control technology to realize the characteristics of low peak current during reverse recovery operation, low generated loss, and soft recovery.

4. U-IPM Loss

4.1 Comparison of total loss

The marketplace requires that new IPM products achieve lower levels of loss. (1) Increased carrier frequency to enhance controllability and (2) larger output current at the same carrier frequency are necessary for the achievement of the goal. The loss

Fig.4 Comparison of total loss (at same current) for the U-IPM, R-IPM3 and R-IPM series

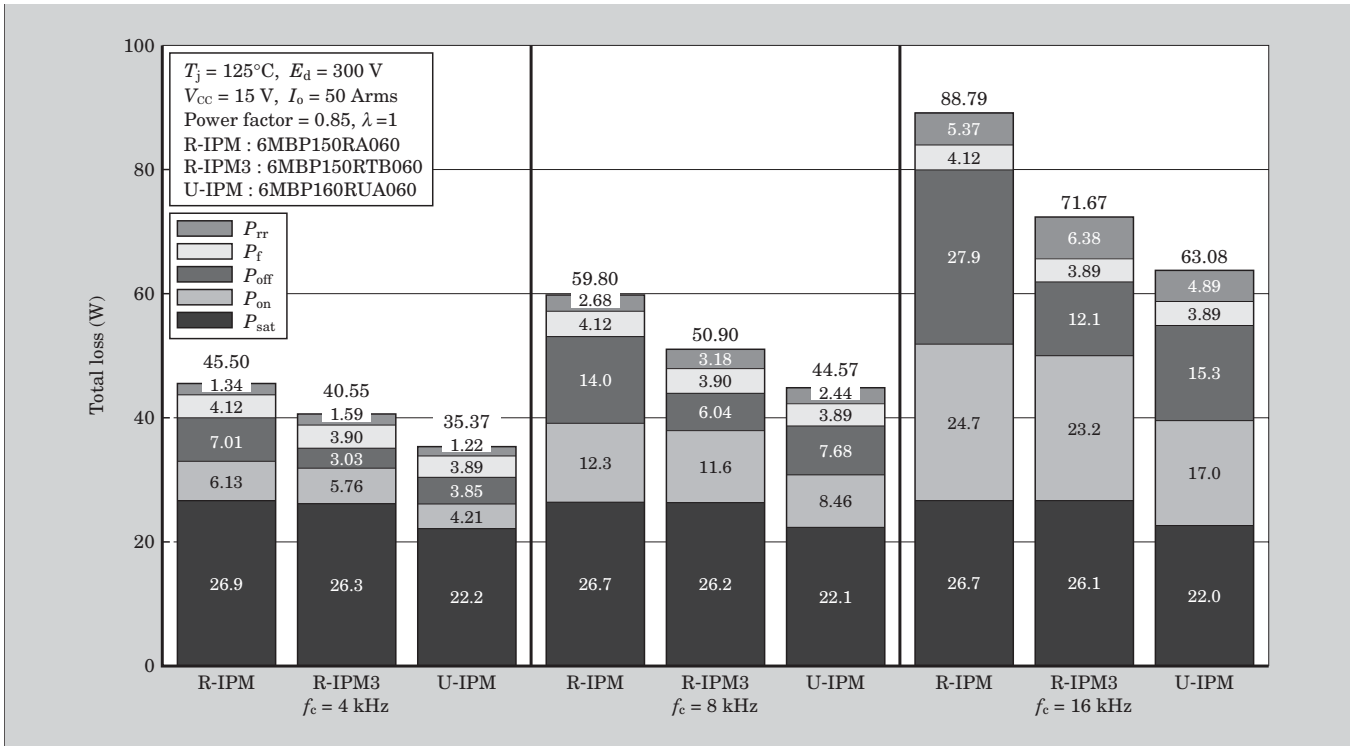
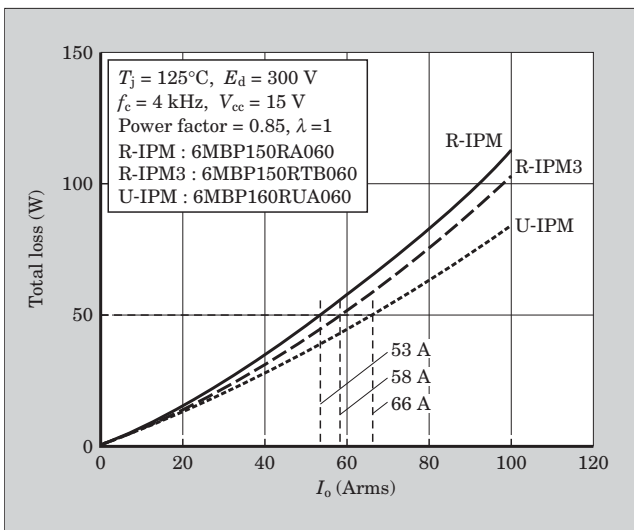


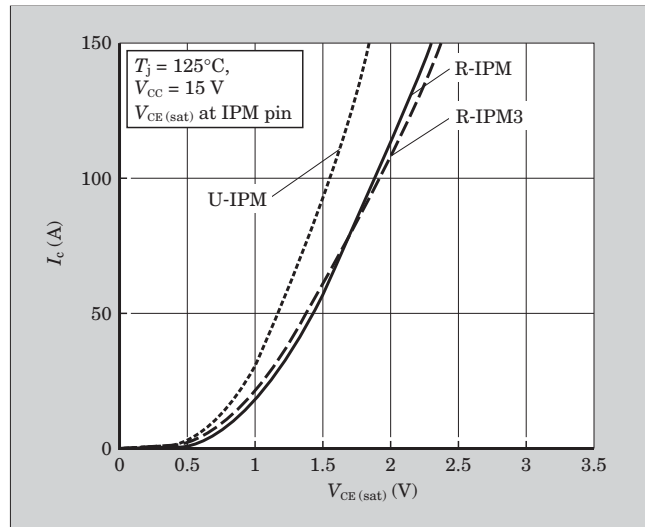
Fig.5 Current vs. total loss (at same frequency) for U-IPM, R-IPM3 and R-IPM



generated by existing models and by the U-IPM is described below.

Figure 4 compares the loss of the U-IPM and the existing R-IPM and R-IPM3 devices in the case of operation at carrier frequencies of 4, 8 and 16 kHz, and a current of 50 Arms (1/3 of the rated current). As can be seen in the figure, the newly developed U-IPM realizes a total loss that is approximately 22 to 28 % lower than that of the R-IPM and approximately 11 to 12 % lower than that of the R-IPM3. In particular, it can be seen that the loss generated when using the U-IPM at a carrier frequency of 8 kHz is less than the

Fig.6 I_c - V_{CE} characteristics for U-IPM, R-IPM3 and R-IPM



loss generated by a R-IPM operating at a carrier frequency of 4 kHz, and therefore, the carrier frequency can be increased from 4 kHz to 8 kHz by replacing a R-IPM with a U-IPM of the same size package. Moreover, according to Fig. 5 which shows the relationship between current and total loss at $f_c = 4\text{ kHz}$, to generate the same amount of loss (50 W) as the R-IPM, the output current of the U-IPM can be increased by 24.5 % compared to that of the R-IPM, or increased by 13.7 % compared to that of the R-IPM3.

These techniques for reducing loss were focused on reducing the conduction loss, which accounts for more than 50 % of the total loss, and on reducing the turn-on

Fig.7 Characteristics of turn-on waveform and emission noise

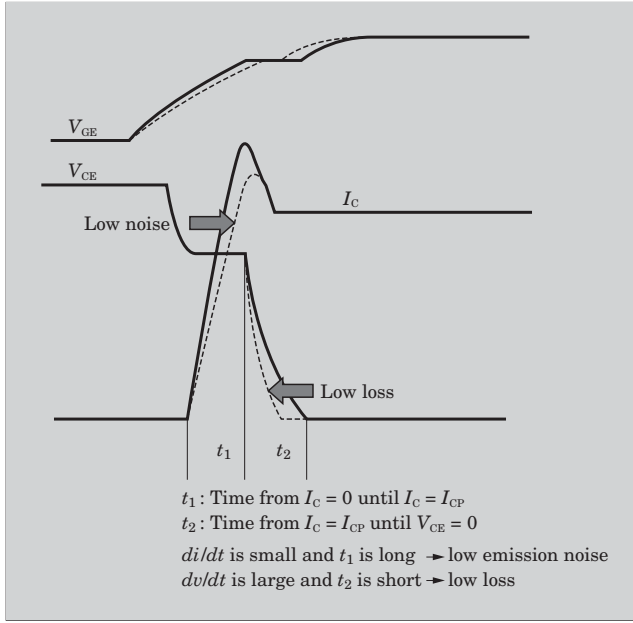


Table 3 Characteristics of gate resistance and turn-on waveform

		Turn-on di/dt	Turn-on dv/dt	Loss	Emission noise
Gate resistance R_G	High	Low	Low	Increases	Decreases
	Low	High	High	Decreases	Increases

loss, which accounts for a large percentage of the switching loss of the R-IPM3. Each type of loss reduction is described below.

4.2 Reduction of conduction loss

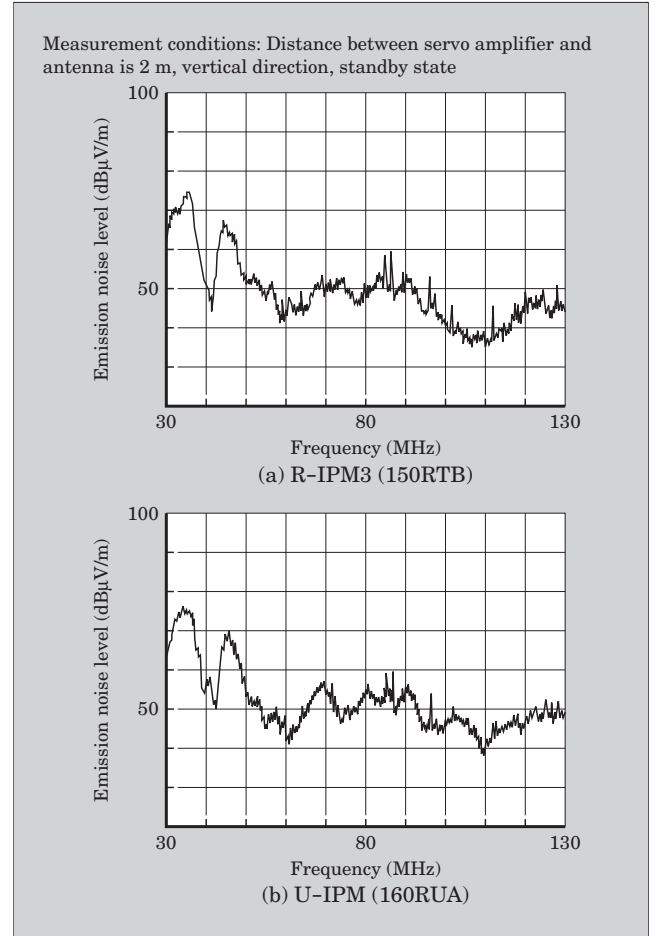
Figure 6 shows I_C - $V_{CE(sat)}$ characteristics for U-IPM, R-IPM3 and R-IPM devices. It can be seen that when $I_C = 150$ A, the $V_{CE(sat)}$ of the U-IPM is 0.45 V less than that of the R-IPM and 0.55 V less than that of the I-RPM3. This is the $V_{CE(sat)}$ reduction effect due to the trench IGBT described in chapter 3.

4.3 Turn-on loss and emission noise

Figure 7 shows a schematic drawing of the current (I_C) and voltage (V_{CE}) at the time when the device is turned on. As can be seen in the figure, typically, loss can be reduced by making dv/dt larger and emission noise can be reduced by making di/dt smaller. However, in the case where turn-on operation is controlled by the typical method of gate resistance only, there is a tradeoff relation as shown in Table 3, and it is difficult to establish both high dv/dt and low di/dt simultaneously.

In the newly developed U-IPM, the following two techniques suppress the emission noise that usually increases when gate resistance is decreased and di/dt is increased, thereby enabling di/dt to be increased and turn-on loss to be decreased without any increase in

Fig.8 Emission noise



the emission noise.

- (1) Application of the new soft recovery FWD suppresses dv/dt .
- (2) The capacitance between the gate and emitter is optimized in order to reduce di/dt , which increased as a result of the lower gate resistance, without reducing dv/dt

Through application of the above techniques, even if currents of all sizes are controlled with the same gate resistance, emission noise will be maintained at the same level as that of the R-IPM3 as shown in Fig. 8, and lower loss can be realized. Accordingly, the total loss generated in all these products is linearly proportional to the current, and the total loss and temperature rise that occur during actual use can easily be estimated.

5. Conclusion

Fuji Electric's 600 V U-IPM that uses a U-series IGBT chip having a trench NPT structure has been described above. This U-IPM provides suitable performance to satisfy the marketplace in which lower loss is required. In the future, Fuji Electric intends to continue to develop new IPMs that will satisfy market requirements.

Development of a Next-generation IGBT Module using a New Insulating Substrate

Yoshitaka Nishimura
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Yoshikazu Takahashi

1. Introduction

In response to the recent demand for energy-efficient electronic appliances, insulated gate bipolar transistor (IGBT) modules are being utilized in a wider scope of applications, ranging from conventional industrial applications to home-use electronic appliance applications and the like. There is strong demand for low-capacity IGBT modules, which are used mainly for these home-use electric appliances, to be low cost, lightweight and have a compact size.

In response to this demand, Fuji Electric has developed and has begun producing its “Small Pack” series of IGBT modules. This series utilizes a heat-dissipating base-free structure (which does not contain a heat-dissipating metal base) in order to realize low-cost and lightweight IGBT modules.

This paper introduces a heat-dissipating base-free structure that utilizes a new insulating substrate to achieve an additional 30 % decrease in thermal resistance.

2. Design Concept ^{(1), (2)}

Heat-dissipating base-free structures, which typically have larger thermal resistance than heat-dissipating metal-base-equipped structures, have been difficult to use in industrial applications and other such applications where the usage conditions are severe. Heat-dissipating base-free structures are presently used only in low power applications and, unless a new technological approach is employed, their application to medium and large capacity applications is seen as

unlikely.

Figure 1 shows a cross-sectional view of typical IGBTs. In the heat-dissipating metal-base-equipped structure of Fig. 1(a), the DCB substrate (substrate with ceramic insulation) is soldered to a heat-dissipating metal base, and a cooling fin is attached to the base. In the heat-dissipating base-free structure of Fig. 1(b), a cooling fin is attached directly to the DCB substrate.

In order to transfer the heat efficiently to a cooling fin, a thin thermal compound must be used to fill any gaps between the fin and module. In actuality, it is important that a screw be tightened in order to maintain the pressure between the fin and module surfaces, and in order to prevent damage to the module while the screw is tightened, the module must maintain its mechanical strength. In the conventional heat-dissipating base-free structure, the alumina ceramic portion of the DCB substrate is made thicker in order to maintain the mechanical strength. As a result, however, the thermal resistance becomes larger than in the case of a heat-dissipating metal-base-equipped structure, and this is a factor which limits applications for heat-dissipating base-free structures.

Figure 2 shows Fuji Electric’s “6 in 1” IGBT module. In terms of the power per unit area of an IGBT module, the heat-dissipating metal-base-equipped structure of Fig. 2(a) has a capacity of 4.7 W (max)/

Fig.1 Cross section of an IGBT module

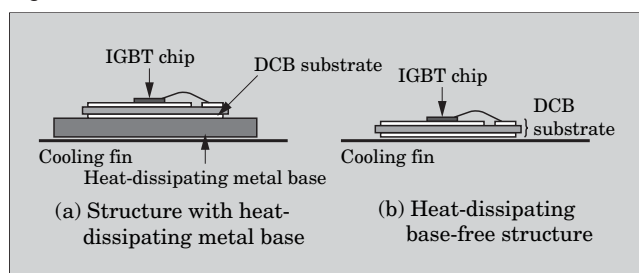
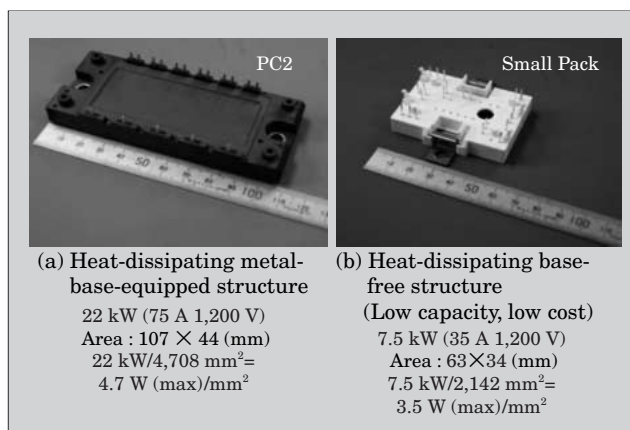


Fig.2 Fuji's 6-pack module



mm², while the heat-dissipating base-free structure of Fig. 2(b) has a capacity of 3.5 W (max)/mm².

Given these circumstances, we investigated and then developed a DCB substrate having low thermal resistance and high strength in order to increase the usable power per unit area of an IGBT module while realizing lighter weight, smaller size and lower cost.

3. Design of a New Alumina Insulating Substrate

3.1 A comparison of characteristics according to IGBT module structure

Table 1 lists the characteristics of the conventional heat-dissipating base-free structure and of the heat-dissipating metal-base-equipped structure. The heat-dissipating base-free structure uses a 0.635 mm-thick alumina ceramic layer in order to maintain mechanical strength of the IGBT module. On the other hand, the heat-dissipating metal-base-equipped structure has sufficient mechanical strength and the thickness of its alumina ceramic layer can be reduced to 0.32 mm.

Due to this difference, the thermal resistance of the heat-dissipating base-free structure is 1.6 times that of the heat-dissipating metal-base-equipped structure.

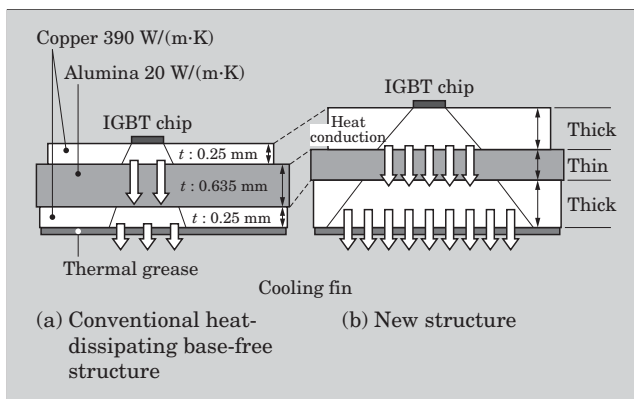
3.2 Factors that inhibit thermal conduction and measures for improvement

Figure 3 shows cross sections of IGBT modules

Table 1 Comparison between the metal-base free structure and the structure having a metal base

		Conventional heat-dissipating base-free structure	Heat-dissipating metal-base-equipped structure
DCB substrate characteristics	Alumina thickness	0.635 mm	0.32 mm
	Bending strength	108 N	53 N
Thickness of metal base		—	3.0 mm
Thermal resistance $R_{th(j-c)}$		100	62

Fig.3 Cross-section of DCB structures and thermal characteristics



having a heat-dissipating base-free structure. Heat generated at the junction in an IGBT chip passes through the DCB substrate and is transferred to a heat-dissipating fin. Because the thermal conductivity of the alumina ceramic of the insulated portion of the DCB substrate is 20 W/(m·K) and the thermal conductivity of the copper used for the electronic circuitry is 390 W/(m·K), the alumina ceramic layer of the DCB substrate acts as a thermal resistance layer through which heat generated from the IGBT chip has difficulty in passing through.

In order to make it easier for heat to pass through this layer, it is efficient to make the thermal resistance layer smaller and to decrease the heat flow (heat density) per unit area. Specifically, the following two countermeasures are proposed.

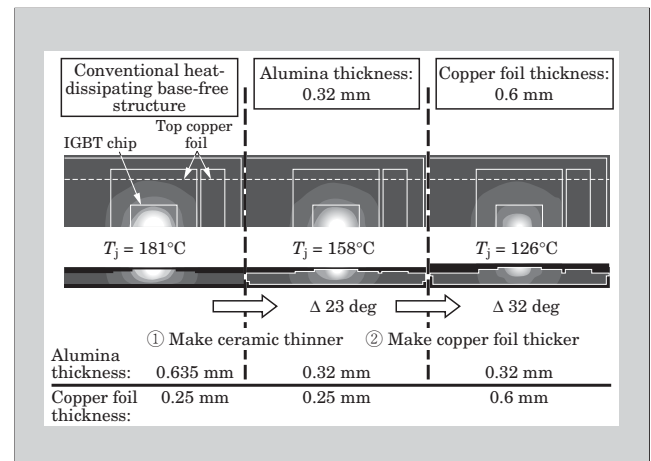
- (1) Decrease the thickness of the alumina ceramic layer
- (2) Increase the thickness of copper foil in order to disperse the heat and decrease the heat flow per unit area of the alumina ceramic layer

Accordingly, reducing the thermal resistance of the DCB substrate is an efficient way to lower the temperature of the IGBT chip. Moreover, by increasing the thickness of the copper foil, an improvement in the mechanical strength of the DCB substrate itself can be expected.

3.3 FEM analysis results

Next, as a first step to verify the effectiveness of the above, we performed a steady-state thermal analysis using the finite element method (FEM). The analysis was performed under the conditions of a DC 80 A current applied to a 3-dimensional half-scale model of a 9.25 mm-square IGBT chip, a 33 × 30 (mm) DCB ceramic substrate, and a 25 × 17 (mm) copper foil on top of the DCB surface. In the steady-state analysis, we varied the thickness of the alumina ceramic layer and the thickness of the copper foil to analyze their effect on IGBT chip temperature. The

Fig.4 Thermal simulation results for each structure (DC 80 A steady state condition)



results are shown in Fig. 4.

From the results of this analysis, it can be seen that by reducing the thickness of the aluminum ceramic layer from 0.635 mm to 0.32 mm, the IGBT chip temperature decreases by 23°C. Moreover, while maintaining the thickness of the alumina ceramic layer at 0.32 mm and increasing the thickness of the copper foil from 0.25 mm to 0.6 mm, it can be seen that the chip temperature decreases by an additional 32°C.

Next, we performed a steady-state heat analysis in which the IGBT chip temperature was fixed at 126°C, and we analyzed the relationship between copper foil thickness and heat conduction. Those results are shown in Fig. 5.

Compared to the DCB substrate copper foil thickness of 0.25 mm, a copper foil thickness of 0.6 mm exhibited greater conduction of heat. From this result, it can be understood that increasing the thickness of the copper foil decreases the density of heat flow through the alumina ceramic layer.

Additionally, we performed a steady-state heat analysis to investigate the correlation between copper foil thickness and chip temperature for the two alumina ceramic layer thicknesses of 0.32 mm and 0.635 mm. Those results are shown in Fig. 6.

It can be seen that decreasing the alumina ceramic

Fig.5 Relationship between copper foil thickness and heat conduction area

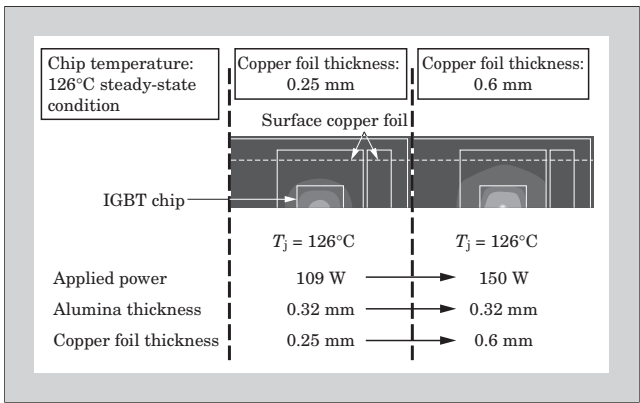
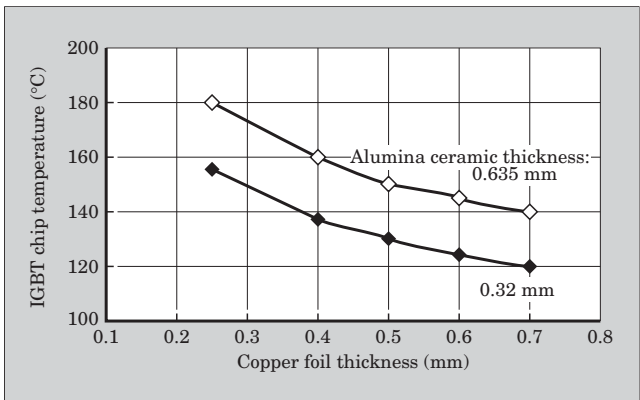


Fig.6 Relationship between copper foil thickness and chip junction temperature



layer thickness and increasing the copper foil thickness are effective measures for lowering the IGBT chip temperature. Moreover, in a steady-state heat analysis under the same conditions, the IGBT chip temperature was 125°C in the case of a heat-dissipating metal-base-equipped structure. To realize an IGBT chip temperature of 125°C with a heat-dissipating base-free structure, the same thermal resistance was obtained by selecting an alumina ceramic layer thickness of 0.32 mm and a copper foil thickness of 0.6 mm.

4. Results of Testing and Verification with Actual Machines

In order to verify the above analysis results, we measured the transient thermal resistance and steady-state thermal resistance of a DCB test piece and measured the mechanical characteristics of a DCB substrate.

4.1 Transient thermal resistance

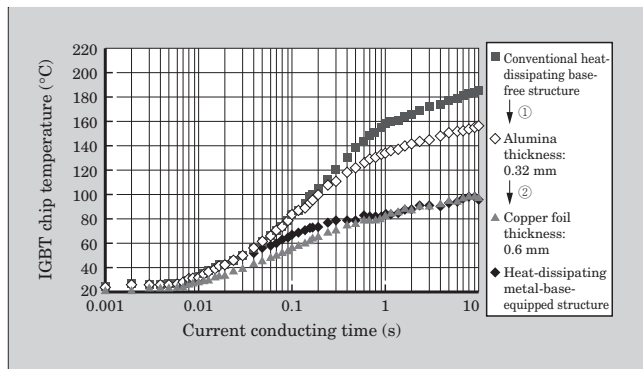
We input a DC 80 A current to the IGBT chip and investigated the relationship between current conduction time and IGBT chip temperature for three different types of DCB substrates (using the same conditions as the FEM simulation of Fig. 4).

Figure 7 shows the relationship between the current conduction time and chip temperature.

First of all, one second after the start of current conduction, it can be seen that the conventional heat-dissipating base-free structure (alumina ceramic thickness of 0.635 mm, copper foil thickness of 0.2 mm) had an IGBT chip temperature which was 85°C higher than that of the heat-dissipating metal-base-equipped structure (DCB: alumina ceramic layer thickness of 0.32 mm, copper foil thickness of 0.2 mm, and base thickness of 3 mm).

Secondly, while maintaining the heat-dissipating base-free structure but reducing the thickness of the alumina ceramic layer in the DCB substrate from 0.635 mm to 0.32 mm, it can be seen that the IGBT chip temperature decreases by approximately 20°C. (See ① of Fig. 7.)

Fig.7 Time dependent temperature rise of three different types of substrates



Thirdly, by reducing the thickness of the alumina ceramic layer in the DCB substrate to 0.32 mm and increasing the copper foil thickness to 0.6 mm, it can be seen that the IGBT chip temperature decreases by 66°C compared to the case where the copper foil thickness is 0.25 mm (see ② of Fig. 7).

Fourthly, by reducing the thickness of the alumina ceramic layer to 0.32 mm and increasing the copper foil thickness to 0.6 mm, it can be seen that the IGBT chip temperature decreases by 86°C compared to the conventional heat-dissipating base-free structure.

This value is nearly the same as the IGBT chip temperature of the heat-dissipating metal-base-equipped structure. Accordingly, the above results verify that decreasing the thickness of the alumina ceramic layer in the DCB substrate and increasing the copper foil thickness are extremely effective measures for improving the transient thermal resistance characteristic.

4.2 Steady-state thermal resistance

We measured the steady-state thermal resistance under the same conditions as used in the measurement of transient thermal resistance. Figure 8 shows thermo-photographs of the IGBT chip in a steady-state condition. With a new heat-dissipating base-free structure using an alumina ceramic layer thickness of 0.32 mm and a copper foil thickness of 0.6 mm, the IGBT chip temperature decreased by 62°C compared to the conventional heat-dissipating base-free structure, and this IGBT chip temperature is approximately the same as that of the heat-dissipating metal-base-equipped structure. From these experimental results, it was verified that the use of a thinner alumina layer in the DCB substrate and a thicker copper foil are effective measures for improving the steady-state thermal resistance.

4.3 Mechanical characteristics of the DCB substrate

Figure 9 shows cross-sectional photographs of DCB substrates. In the figure, (a) shows a DCB substrate that uses the conventional heat-dissipating base-free structure, and (b) shows the newly-developed thick copper foil DCB substrate.

When a copper foil of thickness 0.4 mm or greater is directly bonded to a alumina ceramic layer having a

typical purity of 96 %, differences in the coefficients of thermal expansion between the alumina ceramic material and the copper cause cracking to occur in the alumina ceramic layer near the bonded junction. The bending strength of 96 % pure alumina ceramic material is approximately 400 MPa, and as a DCB substrate, this strength is insufficient for bonding to a thick copper foil.

Therefore, by adding zirconia to the alumina ceramic material to increase its mechanical strength and increase its bending strength to 700 MPa, we succeeded in bonding a 0.6 mm-thick copper foil to this alumina ceramic (Table 2). Compared to the conventional heat-dissipating base-free structure, a structure that uses this new DCB substrate achieves an approximate 30 % total improvement in mechanical strength due to the increased thickness of the copper foil, despite the thin alumina ceramic layer.

By making the copper foil thicker and by using a thin zirconia-doped alumina ceramic layer, a new heat-dissipating base-free structure is possible, realizing greater mechanical strength and lower thermal resistance of the module compared to the conventional heat-dissipating base-free structure.

4.4 Evaluation and results of reliability testing

There were concerns that the increase in thickness of the copper foil would lead to an increase in the coefficient of thermal expansion of the copper circuitry, deterioration of the solder at the bottom of the silicon

Fig.9 Cross-sectional photographs of DCB substrates

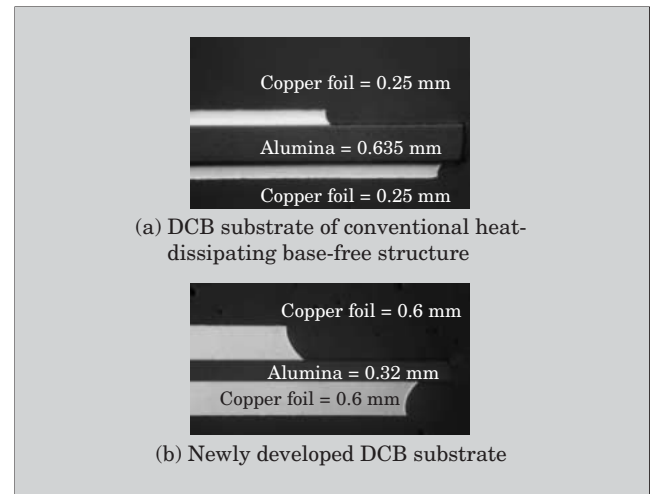


Fig.8 Thermo-photographs (at steady-state condition)

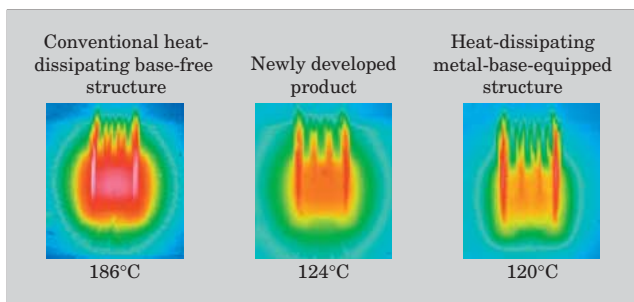


Table 2 Fabrication limits for DCB

	Copper foil thickness (mm)				
	0.3	0.4	0.5	0.6	0.7
Alumina	○	×	—	—	—
Zirconia-doped alumina ceramic	○	○	○	○	×

Ceramic thickness: 0.32 mm

○ : Possible × : Not possible

Table 3 Evaluation results of Fuji Electric's new product that uses the new DCR structure


	Conventional heat-dissipating base-free structure	New structure
Thermal resistance $R_{th(j-f)}$	100	71

Fig.10 Characteristics of Fuji Electric's IGBT chips

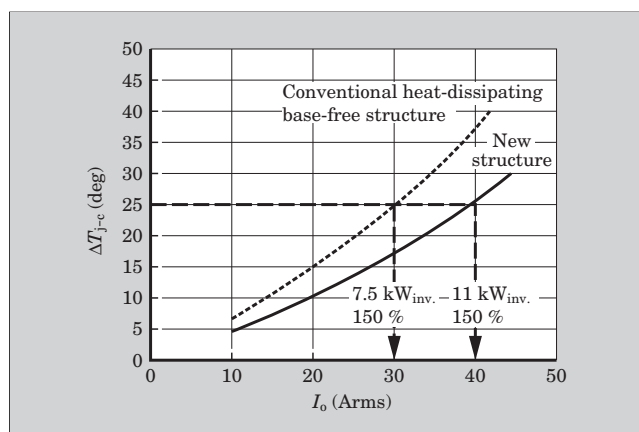
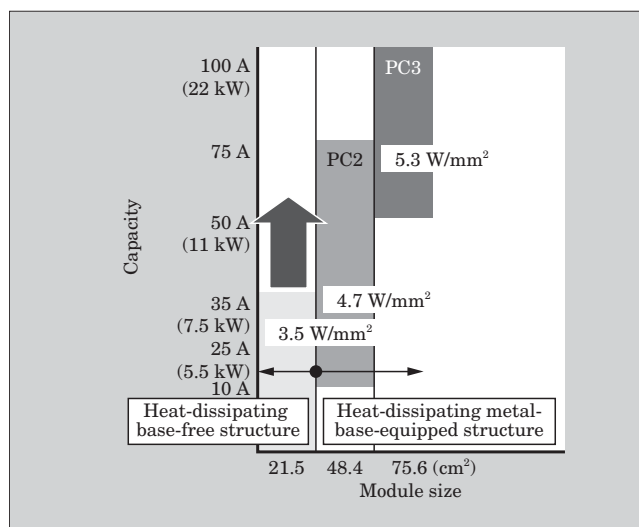


Fig.11 Fuji Electric's 1,200 V IGBT module line-up



chip, cracking of the alumina ceramic layer, and so on. Therefore, we performed heat cycle tests and power cycle tests to investigate the reliability of a heat-dissipating base-free structure that uses this new DCB substrate.

A heat cycle test was performed for 500 cycles under test conditions of -40 to $+125^{\circ}\text{C}$, and it was verified that there was no degradation of the solder at the bottom of the IGBT chip, no change in thermal resistance due to solder deterioration, and no cracking of the alumina ceramic layer.

A power cycle (intermittent operation) test was also performed under the test condition of $\Delta T_{j-c} = 75$

deg. No changes in thermal resistance or electrical characteristics have been observed through 350 k cycles of the test. The above results demonstrate that an IGBT module using the new DCB substrate achieves the same reliability characteristics as a conventional IGBT module.

5. Product Evaluation Results

Table 3 shows the results of an evaluation of Fuji Electric's Small Pack which uses the new heat-dissipating base-free structure.

The use of the new heat-dissipating base-free structure achieves 30 % lower thermal resistance than the conventional Small Pack. The new heat-dissipating base-free structure also achieves sufficient module mechanical strength and reliability.

Figure 10 shows the characteristics (ΔT_{j-c} and output) of Fuji Electric's latest IGBT chip used in the Small Pack. A Small Pack that employs the conventional heat-dissipating base-free structure can be used in inverter systems of up to 7.5 kW maximum. However, a Small Pack that employs this new DCB substrate can be used in inverter systems of up to 11 kW maximum.

Figure 11 shows Fuji Electric's 1,200 V IGBT module line-up. The application of a new heat-dissipating base-free structure enables the power applied per unit area to be increased from 3.5 W/mm^2 to 5.1 W/mm^2 .

6. Conclusion

By adding zirconia to a DCB substrate of alumina ceramic material, decreasing the thickness of the alumina ceramic layer and increasing the thickness of the copper foil, a lightweight, compact and low cost IGBT module that uses a low thermal resistance heat-dissipating base-free structure has been developed.

Fuji Electric efforts in developing this new IGBT module structure have been described above. Fuji Electric intends to continue to expand the range of applications for this technology and to develop IGBT modules that satisfy increasingly severe customer needs and new demand.

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Low I_R Schottky Barrier Diode Series

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Masaki Ichinose

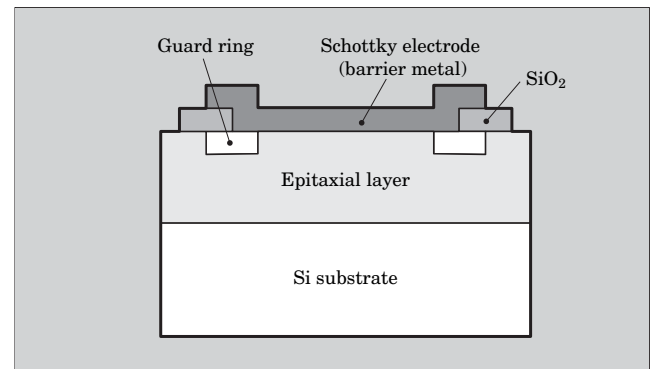
1. Introduction

Representative of the recent trends towards smaller size and higher functionality of portable devices and towards higher speed CPUs for computers, electronic devices are rapidly becoming smaller in size, lighter in weight and are achieving higher performance, and it is essential that their circuit boards and switching power supplies be made to consume less power, are more efficient, generate less noise and support higher density packaging. Moreover, in order to suppress the surge voltage that is applied across a diode during switching and the noise generated by a steep dv/dt characteristic, snubber circuits, beads and the like are used, but as a result the number of components increases, leading to greater cost. In order to achieve better portability, AC adapters for notebook computers are being miniaturized; however, the trend toward higher power consumption results in higher internal temperatures, increasing the severity of the environment in which these semiconductor devices are used. Consequently, semiconductor devices are strongly required to provide the characteristics of lower loss, improved suppression of thermal runaway, higher maximum operating temperature and lower noise. In particular, an improvement in the characteristics of the secondary source output rectifying diode, which accounts for nearly 50 % of the loss in a switching power supply, is strongly desired.

2. Overview

Schottky barrier diodes (SBDs) exhibit the properties of low forward voltage (V_F), soft recovery and low noise, and are widely used in the secondary source rectifying circuits of switching power supplies. Fuji Electric has previously developed a product line of conventional 20 to 100 V SBDs (low V_F type) and 120 to 250 V SBDs [low reverse current (I_R) type] as a diode series available in a variety of packages and supporting various output voltages and current capacities in order to be applicable to a wide range of power supply applications. However, when the conventional low V_F type SBD operates at high temperatures, its I_R

Fig.1 Cross-sectional structure of SBD chip



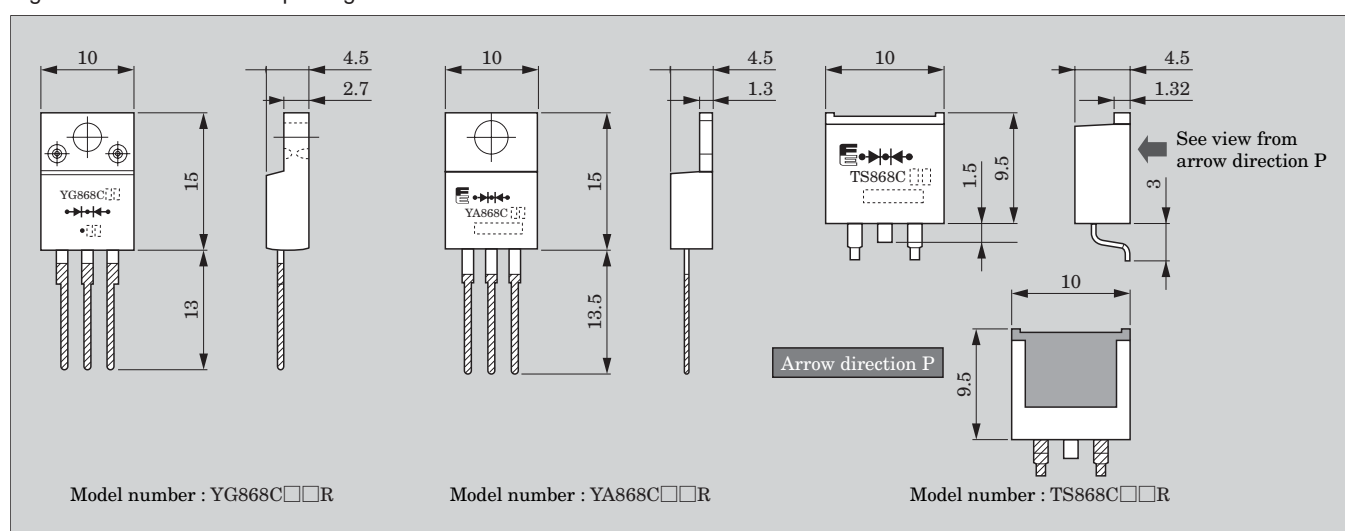
becomes large, and as a result reverse loss increases, efficiency decreases and thermal runaway may occur, making it difficult to use this low V_F SBD in a small power supply packages such as an AC adapter.

The newly developed low I_R -SBD is considered to be the ideal diode for secondary source rectification in a switching power supply, and is especially well suited for rectification in a high temperature environment. Figure 1 shows the cross-sectional structure of the SBD chip. The chip design incorporates a guard ring to prevent premature breakdown, and the doping density, specific resistance and thickness of the epitaxial layer (n^- layer), diffusion depth, and barrier metal that have been optimized to develop a low I_R -SBD series that provides not only low I_R , but also breakdown voltages of 40, 60 and 100 V, comparable to the conventional V_F . Compared to a conventional SBD having the same breakdown voltage, this product achieves an approximate single-digit decrease in I_R , a large decrease in reverse loss, a higher temperature at which thermal runaway occurs, and a higher maximum operating temperature. Moreover, this new series has a high avalanche breakdown voltage and is expected to be capable of withstanding the large surge voltage that occurs when a power supply is turned on. The new series is also expected to enable the design of switching power supply circuits that realize increased efficiency, smaller size and greater flexibility. Table 1 lists the absolute maximum ratings and electrical characteristics of this low I_R -SBD series and Fig. 2 shows external

Table 1 Absolute maximum ratings and electrical characteristics of low I_R SBD

Model number	Package	Absolute maximum ratings					Electrical characteristics		
		V_{RRM} (V)	V_{RSM} (V)	I_O (A)	I_{FSM} (A)	P_{RM} (W)	V_{FM} (V) $I_F = 0.5 \times I_O$ ($T_j = 25^\circ\text{C}$)	I_{RRM} (μA) $V_R = V_{RRM}$	$R_{th(j-c)}$ ($^\circ\text{C/W}$)
YG862C04R	TO-220F	45	45	10	125	330	0.61	150	3.50
YA862C04R	TO-220	45	45	10	125	330	0.61	150	2.00
TS862C04R	T-Pack	45	45	10	125	330	0.61	150	2.00
YG862C06R	TO-220F	60	60	10	125	330	0.68	150	3.50
YA862C06R	TO-220	60	60	10	125	330	0.68	150	2.00
TS862C06R	T-Pack	60	60	10	125	330	0.68	150	2.00
YG862C10R	TO-220F	100	100	10	125	330	0.86	150	3.50
YA862C10R	TO-220	100	100	10	125	330	0.86	150	2.00
TS862C10R	T-Pack	100	100	10	125	330	0.86	150	2.00
YG865C04R	TO-220F	45	45	20	145	330	0.63	175	2.50
YA865C04R	TO-220	45	45	20	145	330	0.63	175	1.75
TS865C04R	T-Pack	45	45	20	145	330	0.63	175	1.75
YG865C06R	TO-220F	60	60	20	145	660	0.74	175	2.50
YA865C06R	TO-220	60	60	20	145	660	0.74	175	1.75
TS865C06R	T-Pack	60	60	20	145	660	0.74	175	1.75
YG865C10R	TO-220F	100	100	20	145	660	0.86	175	2.50
YA865C10R	TO-220	100	100	20	145	660	0.86	175	1.75
TS865C10R	T-Pack	100	100	20	145	660	0.86	175	1.75
YG868C04R	TO-220F	45	45	30	160	1,000	0.63	200	2.00
YA868C04R	TO-220	45	45	30	160	1,000	0.63	200	1.25
TS868C04R	T-Pack	45	45	30	160	1,000	0.63	200	1.25
YG868C06R	TO-220F	60	60	30	160	750	0.74	200	2.00
YA868C06R	TO-220	60	60	30	160	750	0.74	200	1.25
TS868C06R	T-Pack	60	60	30	160	750	0.74	200	1.25
YG868C10R	TO-220F	100	100	30	160	750	0.86	200	2.00
YA868C10R	TO-220	100	100	30	160	750	0.86	200	1.25
TS868C10R	T-Pack	100	100	30	160	750	0.86	200	1.25

Fig.2 External view of the packages



views of the packages. The current ratings are 10 A, 20 A and 30 A and the product packages are available as the TO-220, the TO-220F full-mold type, and the T-

Pack (S) surface mount type.

The newly developed low I_R -SBD is described below.

Fig.3 Comparison of forward characteristics

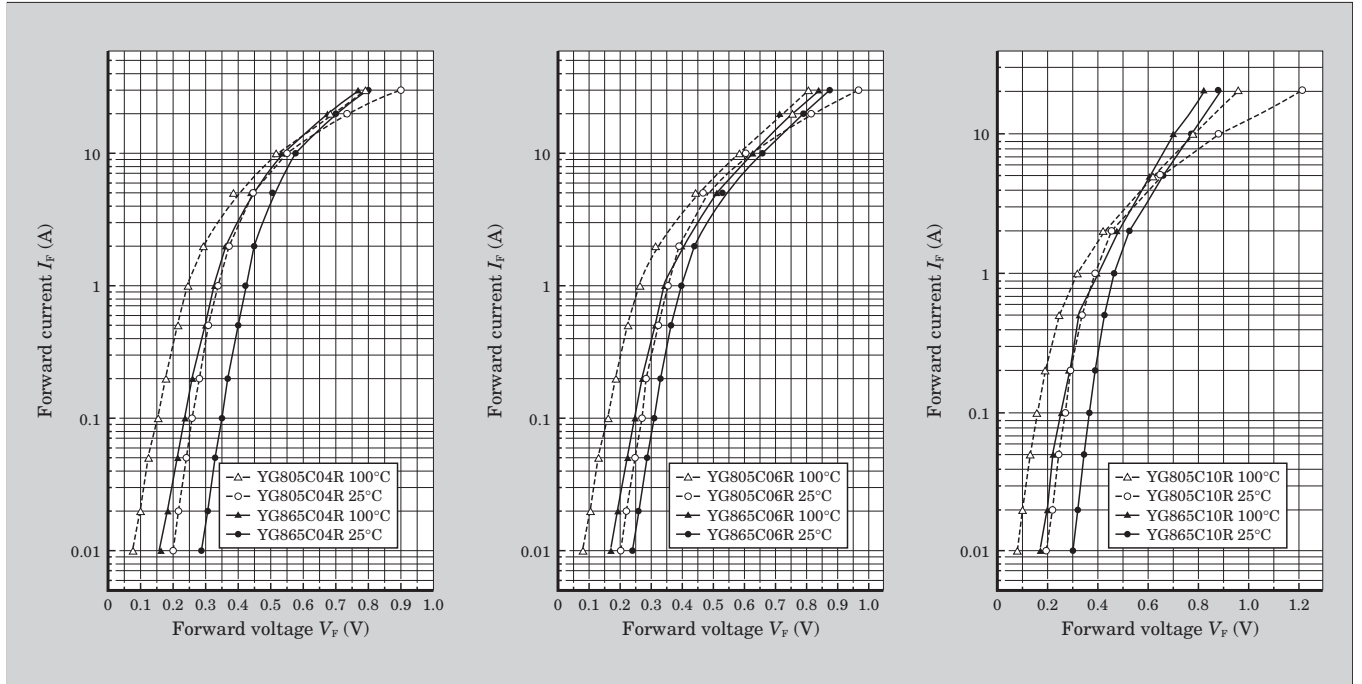
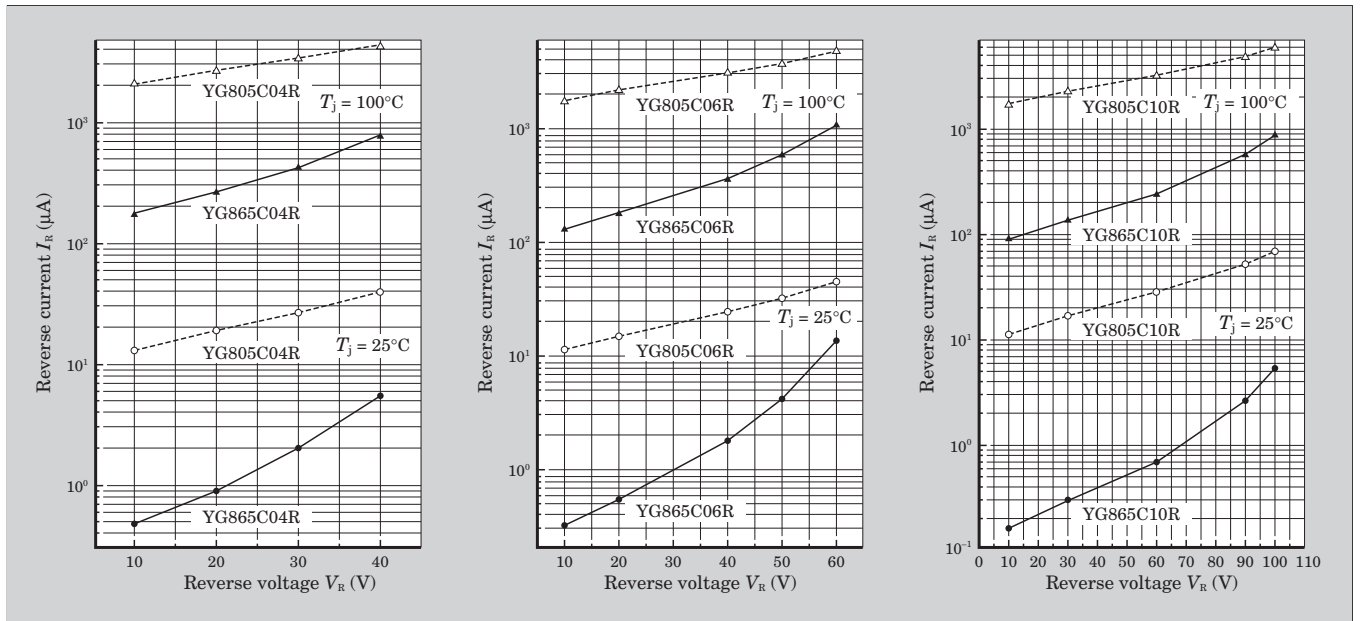


Fig.4 Comparison of reverse characteristics



3. Device Characteristics

Figure 3 compares the forward characteristics of the low I_R -SBD with those of conventional products, and Fig. 4 compares their reverse characteristics. The SBD loss is the sum of the forward and reverse losses, and it is desirable that this loss be reduced within the actual operating temperature range. In particular, the reverse loss caused by increased I_R at higher temperatures must be considered. A tradeoff relation exists between V_F and I_R , however, and V_F typically increases

when I_R is reduced. The newly developed 40 to 100 V SBD achieves a dramatic decrease in loss at high temperatures through the use of a new barrier metal as described in chapter 2 and optimized crystal specifications in order to achieve an approximate 10 % increase in V_F at rated current compared to a conventional product, and an I_R that is reduced to approximately 1/10th that of the conventional product.

4. Consideration of the Generated Loss

A simulation was performed to calculate the loss

Fig.5 Junction temperature vs. estimated loss (60 V/20 A)

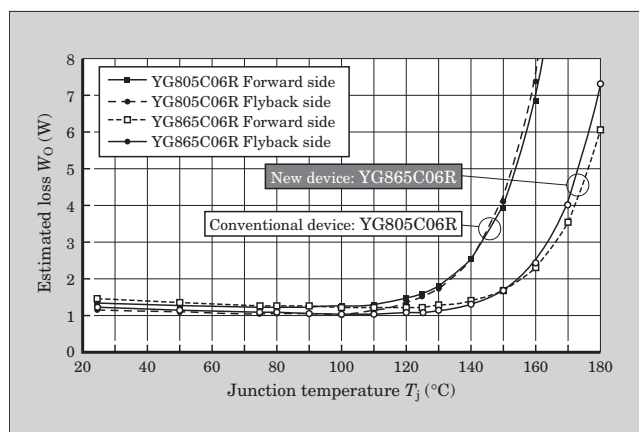
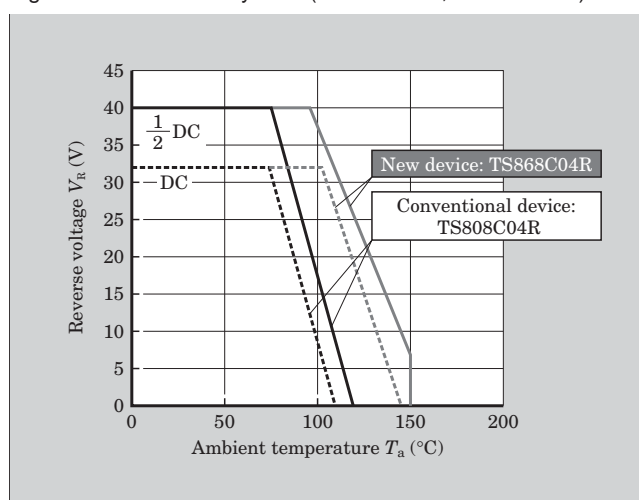


Fig.6 Thermal runaway data (TS868C04R, TS808C04R)



generated in the case of a 24 V power supply ($V_{dc} = 380$ V, $I = 5$ A) for a liquid crystal display (LCD) TV. Figure 5 shows the relationship between junction temperature (T_j) and estimated loss (W_o) for a 60 V/20 A product. For the sake of comparison, a conventional SBD is also shown. In the region of low T_j , the conventional product has less loss, but because I_R has a large effect on loss at high temperatures, the low I_R device achieves less loss than the conventional device at high temperatures, and at $T_j = 150^\circ\text{C}$, the low I_R product achieves approximately 76 % less loss than the conventional product, and its application to higher efficiency power supplies is anticipated.

5. Consideration of the Thermal Runaway Temperature

The temperature of an element rises as its loss

Table 2 Ambient temperature when beginning thermal runaway at LCD-TV 24 V output power supply

Condition : installation cooling fin (30°C/W)

Model number	23-inch LCD-TV power supply (+24 Vout/3.5 A)		30-inch LCD-TV power supply (+24 Vout/5.0 A)	
	Forward	Flyback	Forward	Flyback
Conventional device : YG805C06R	Approx. 74°C	Approx. 84°C	Approx. 72°C	Approx. 77°C
New device : YG865C06R	Approx. 98°C	Approx. 108°C	Approx. 97°C	Approx. 100°C

increases, and I_R becomes more noticeable as it increases at higher temperatures. As a result, a vicious cycle ensues in which the increase in I_R leads to an increase in loss, which generates heat in the element, leading to an increase in I_R , etc. In some cases, this phenomenon ultimately leads to thermal damage (thermal runaway) of the element. Figure 6 shows thermal runaway data of the ambient temperature vs. reverse voltage for a 40 V/30 A product. For the sake of comparison, a conventional SBD is also shown. Compared to the conventional product, it can be seen that the allowable operating temperature range has been expanded due to the lower I_R . Table 2 shows the estimate thermal runaway temperatures for a 60 V/20 A product in 24 V output power supplies ($V_{dc} = 380$ V, $I = 3.5$ A or 5 A) for 23-inch and 30-inch LCD TVs, which approximate actually installation conditions. Compared to the conventional product, the thermal runaway ambient temperature is estimated to be 32 % higher (98°C) at the forward side and 28 % higher at the flyback side (108°C) in the case of the 23-inch LCD, and 34 % higher (97°C) at the forward side and 29 % higher at the flyback side (100°C) in the case of the 30-inch LCD. With a high maximum allowable operating temperature, these new devices are well suited for high temperature applications.

6. Conclusion

An overview of the low I_R -SBD and its application to secondary source rectification applications in switching power supplies have been presented.

In response to the anticipated future requests for power supplies that are smaller in size, generate less loss and have higher efficiency, Fuji Electric intends to further improve SBD characteristics and to develop a product line of small package products. Fuji will continue to make additional improvements in order to develop high quality products and enrich this product series.

Medium-voltage MOSFETs for PDP-use

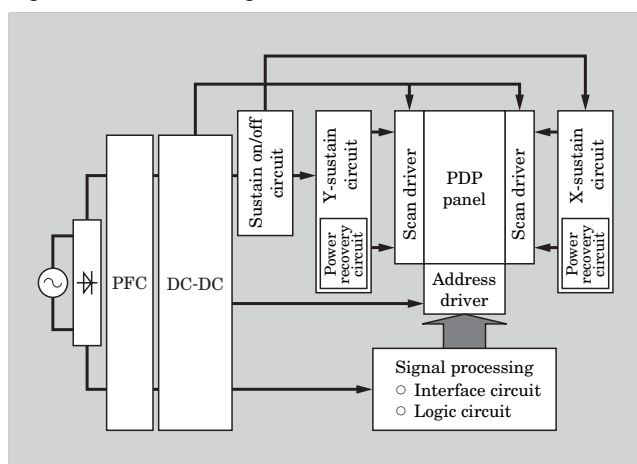
Yukihito Hara
Masanori Inoue

1. Introduction

Flat-screen televisions are a digital consumer appliance of modern convenience, and plasma display panel (PDP) flat-screen televisions are capable of displaying high definition images on a large screen. With the evolution in PDP technology towards higher quality images, larger screen size and lower cost, and with the partial start-up of digital terrestrial television broadcasting in Japan, the popularity of PDPs is increasing at a rapid rate.

PDP technology is trending toward lower power consumption, higher brightness, quieter (fan-less) operation, and thinner panel sizes. Similarly, the attributes of higher efficiency and smaller and thinner size are required of the sustain circuit that controls the plasma light emission. Figure 1 shows the basic circuit configuration of a PDP. The sustain circuit consists of an on/off circuit, a main circuit (X/Y sustain circuits) and a power recovery circuit, and also utilizes several dozens of power MOSFETs (metal oxide semiconductor field effect transistors). Because a large current flow occurs instantaneously, it is important for this sustain circuit to have low on-resistance. In addition, the attributes of small size (reduced number of parallel elements) and thinner profile (surface mounting) are also required.

Fig.1 PDP circuit configuration



In response to these requirements concerning PDP sustain circuits, Fuji Electric has used its existing high-voltage SuperFAP-G series technology to develop a new SuperFAP-G series, ranging from 150 to 300 V, for use in PDP sustain circuits. Additionally, in response to requests for even smaller size and higher efficiency, Fuji Electric is developing trench MOSFETs capable of realizing even lower resistance. It is anticipated that the application of these products will enable small mounting area and more efficient mounting due to the reduced number of MOSFET elements in the sustain circuit and also small cooling elements (heat sinks) and higher operating efficiency due to the lower loss.

The product line and characteristics of the Super FAP-G series and the trench MOSFETs are described below.

2. Characteristics of PDP Power MOSFETs

It is important that the power MOSFETs used in PDP sustain circuits have low on-resistance. Characteristics of the SuperFAP-G series and the trench MOSFETs are described below.

2.1 Characteristics of the SuperFAP-G series

Compared to the conventional MOSFET, the SuperFAP-G series features an improved gate-drain charge (Q_{gd}) tradeoff relation, the charging time constant determined by the on-resistance (R_{on}) and turn-off loss, also a dramatic improvement in the $R_{on} \cdot Q_{gd}$ MOSFET figure-of-merit. The following technology was adopted to realize these characteristics.

(1) QPJ technology

Resistivity of the epitaxial layer is the predominant component of on-resistance in a MOSFET and simply lowering this resistivity causes the drain-source breakdown voltage to decrease. A conventional MOSFET has a 3-dimensional cellular structure, and high electric fields exist locally in portions of the structure. As an improvement to the conventional structure, the quasi-plane junction (QPJ) shown in Fig. 2 was developed. The QPJ features a bonded planar cellular structure realized by fabricating a dense arrangement

of low concentration shallow p⁻ wells instead of the deep p⁺ wells used conventionally. Accordingly, the electrical fields in the cellular structure are reduced, enabling the use of an epitaxial resistive layer having lower resistivity than that of the epitaxial resistive layer in a conventional MOSFET.

By employing the QPJ structure, the width of the n⁻ silicon region (current path) becomes narrower and shorter, and Q_{gd} can be decreased. On the other hand,

Fig.2 Comparison of SuperFAP-G chip structure (QPJ structure) and conventional MOSFET

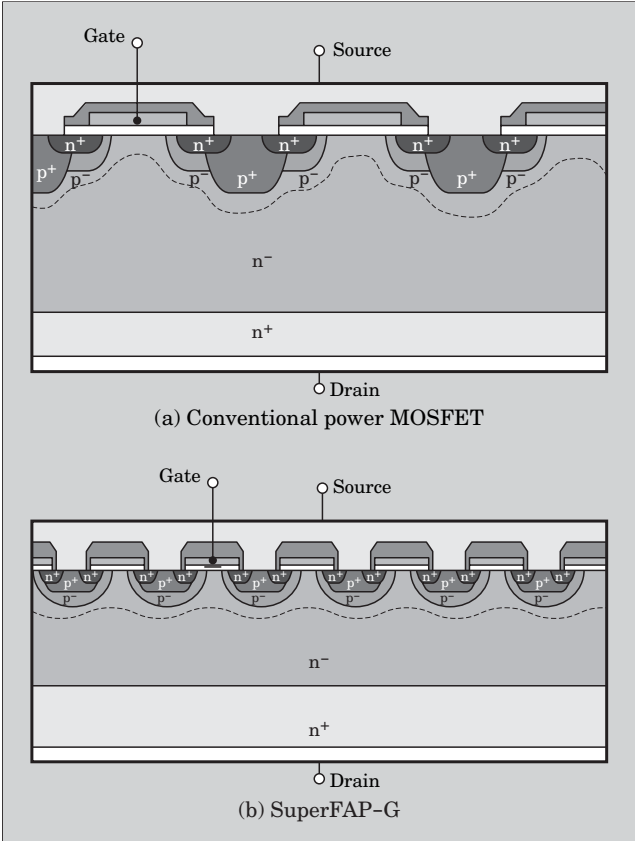
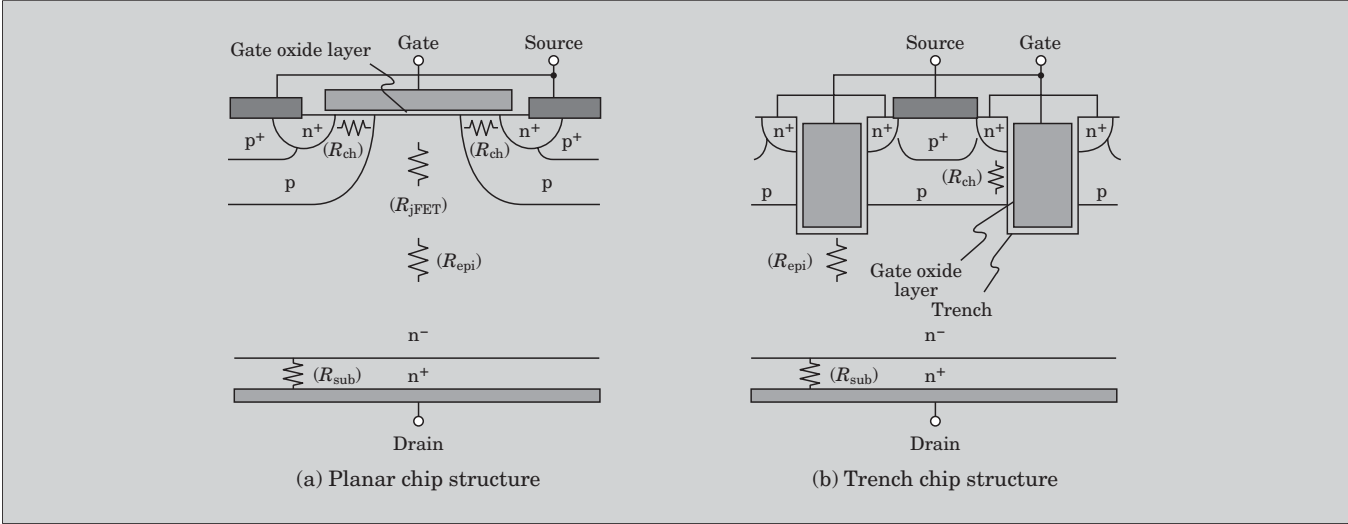


Fig.3 Planar chip structure and trench chip structure



the narrowing of the n⁻ silicon region is correlated to an increase in on-resistance, and a tradeoff relation exists between the width of this region and Q_{gd} . The increase in on-resistance is caused by narrowing of the current path in the n⁻ silicon region due to an expanding depletion layer. In order to limit this expansion of the depletion layer, the concentration of impurities in the n⁻ silicon region was optimized and the tradeoff relation improved. By applying these enhancements, $R_{on} \cdot Q_{gd}$ was decreased by approximately 60 % compared to Fuji Electric's conventional MOSFET. Table 1 lists characteristics of a SuperFAP-G and a conventional product.

(2) Guard ring

By employing a design that uses the QPJ structure, the device will achieve a reduced cellular electric field and it will be possible to use a low-resistance epitaxial layer. However, by continuing to use the conventionally designed breakdown structure, a problem occurs in that the electrical field of the breakdown structure becomes greater than that of the cellular structure, and the breakdown voltage cannot be ensured. It is essential for the electric field of the

Table 1 Comparison of characteristics of SuperFAP-G and conventional product

Parameter	Series	Conventional product
	2SK3535	2SK2254
V_{DS}	250 V	250 V
I_D	±25 A	±18 A
P_D	270 W	80 W
$V_{GS(th)}$	3 to 5 V	2.5 to 3.5 V
$R_{DS(on)(typ)}$	75 mΩ	130 mΩ
Q_g	50 nC	52 nC
Q_{gd}	16 nC	16 nC
$R_{on} \cdot Q_{gd}$ figure-of-merit	1.20 Ω · nC	2.08 Ω · nC

breakdown structure to be lower than that of the cellular structure, and the development of a breakdown structure capable of reducing the electric field was necessary. While using an epitaxial layer of low resistance, an irregularly-pitched optimized guard ring (OGR) was applied in order to reduce the electric field of the breakdown structure. The electric field was simulated in order to determine the optimal pitch and number of guard rings for a design which realizes a

Fig.4 Comparison of the ON-resistance components of a 200 V conventional planar chip and a trench chip

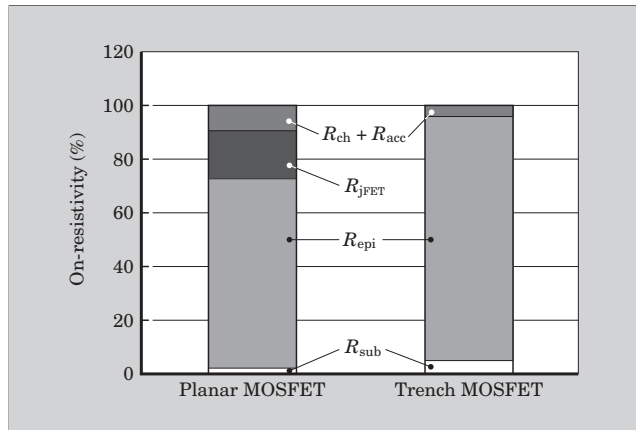


Table 2 Comparison of ON-resistance of conventional MOSFET and trench MOSFET

Drain-source breakdown voltage	On-resistance R_{on} (mΩ)		R_{on} reduction rate
	Conventional MOSFET	Trench MOSFET	
200 V	66	50.6	23.3 %
250 V	100	84	16 %

lower electric field in the breakdown structure than in the cellular structure. Moreover, in order to insure reliability, the design was made resistant to any influence from charge accumulation.

2.2 Characteristics of trench MOSFETs

Fuji Electric has previously promoted its Super-FAP-G series that realizes low on-resistance. However, in response to requests from the PDP field for even lower on-resistance, Fuji Electric is concentrating on

Fig.5 Internal structure of MOSFET (surface mount type)

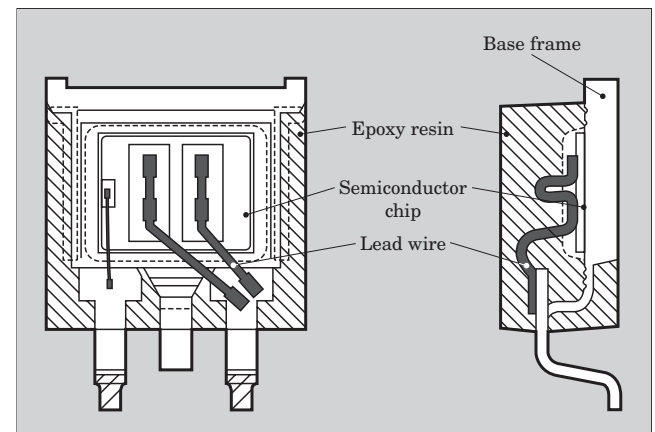


Table 3 Sheet resistance (calculated value: TO-220 series)

	$\phi = 400 \mu\text{m} \times 2$ wires	$\phi = 400 \mu\text{m} \times 2$ wires Stitch bonding
Sheet resistance calculated value	0.4 mΩ	0.2 mΩ

Table 4 Fuji Electric's product line of power MOSFETs for PDP-use

Breakdown BV_{DSS}	Rated current I_D	ON-resistance $R_{DS(on)}$	Package					
			TO-220	TO-220F	T-Pack (D2-Pack)	TFP	TO-247	TO-3PF
150 V	57 A	41 mΩ	2SK3590	2SK3591	2SK3592	2SK3593	—	—
	65 A	28.5 mΩ	*FMP65N15T2	*FMA65N15T2	*FMB65N15T2	—	—	—
	92 A	26 mΩ	—	—	—	—	2SK3788	2SK3789
	100 A	16 mΩ	—	—	—	—	2SK3882	—
200V	45 A	66 mΩ	2SK3594	2SK3595	2SK3596	2SK3597	—	—
	49 A	50.6 mΩ	*FMP49N20T2	*FMA49N20T2	*FMB49N20T2	—	—	—
	73 A	36 mΩ	—	—	—	—	2SK3780	2SK3781
	100 A	20 mΩ	—	—	—	—	2SK3883	—
250V	37 A	100 mΩ	2SK3554	2SK3555	2SK3556	2SK3535	—	—
	38 A	84 mΩ	*FMP38N25T2	*FMA38N25T2	*FMB38N25T2	—	—	—
	59 A	53 mΩ	—	—	—	—	2SK3778	2SK3779
	100 A	30 mΩ	—	—	—	—	2SK3884	—
300V	32 A	130 mΩ	2SK3772	2SK3773	2SK3774	2SK3775	—	—
	53 A	72 mΩ	—	—	—	—	2SK3776	2SK3777
	86 A	40 mΩ	—	—	—	—	2SK3885	—

* on development

developing next generation products and, based on Fuji's track record of success with the trench gate structure technology (60 V and 75 V devices for automotive use), is optimizing the trench depth and wafer specifications in order to achieve higher performance.

Figure 3 shows a cross-sectional comparison of the planar chip and trench chip structures. In the trench chip structure, a gate is formed on a groove (trench) that passes through the channel, and this enables the cell to be made smaller and the channel resistance (R_{ch}) component and JFET resistance (R_{jFET}) component to be reduced, which had been difficult to implement with the planar chip structure shown in Fig. 4. Table 2 compares the on-resistance of the conventional MOSFET with that of the trench MOSFET. As can be seen, adoption of the trench gate structure achieves a large decrease in on-resistance.

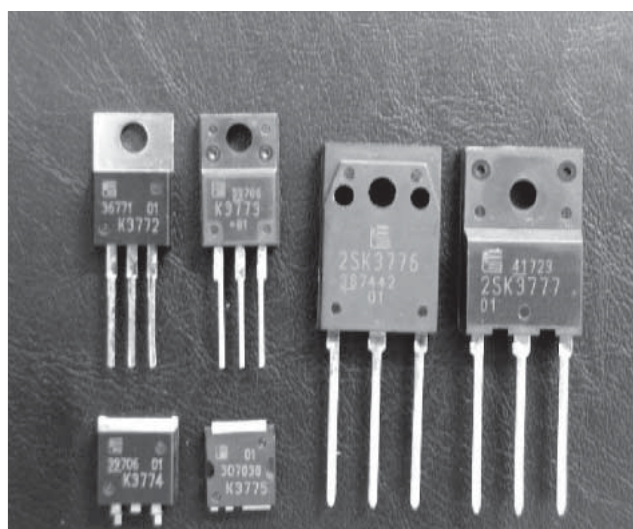
2.3 Reduction of the internal wiring resistance

Because the MOSFETs used in PDPs must have low on-resistance, it is important to reduce the on-resistance of the MOSFET chips and the resistance of wiring inside the package. For low on-resistance chips of the 150 V drain-source voltage class, the sheet resistance of the source aluminum electrode on the chip's surface increases as a percentage of the total on-resistance of the product. Figure 5 shows the internal structure of a T-Pack package. A reduction in sheet resistance is achieved by bonding the source aluminum wire to the chip's source electrode in several locations. Table 3 shows the effectiveness of reducing the sheet resistance.

3. Product Line and External Appearance

Table 4 lists a summary of Fuji Electric's power MOSFET series for PDP-use. Figure 6 shows the external appearance of these packages. The product line contains drain-source voltages ranging from 100 to

Fig.6 External view of packages



300 V and a series of TO-220, TO-3PF and TO-247 packages. A series of T-Pack (D2-Pack) and TFP surface-mount products are also available and are anticipated to contribute to the production of thinner sustain circuits.

4. Conclusion

This paper has described features of Fuji Electric's SuperFAP-G series for PDP-use and Fuji's medium-voltage trench MOSFETs, which are still under development. In the future, Fuji Electric intends to continue to develop products optimized for PDPs and to contribute to the development of the PDP industry.

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PDP Scan Driver IC

Hideto Kobayashi
Gen Tada
Hitoshi Sumida

1. Introduction

A shift in consumer electronics from analog to digital technology is underway, and the television industry is transitioning from CRT to flat panel display (FPD) technology. With the increasing popularity of FPDs, the market for plasma display panels (PDPs) has also grown rapidly. The FPD market is divided according to screen size: sizes of 30 inches and smaller use liquid crystal display (LCD) technology, sizes from 40 to 50 inches use PDP technology, and larger sizes use projector technology. However, competition among the different FPD technologies is intensifying and the market division according to screen size is becoming less prevalent. Within this context, PDP technology is being required to provide such performance improvements as lower power consumption and higher luminous efficient, as well as lower cost.

There are two types of PDP driver ICs, a scan driver IC that selects scan lines and an address driver (or data driver IC) that selects data lines. The characteristics of the driver ICs affect the quality of the image display, and because many IC devices are used in a single panel, these driver ICs are required to provide high performance at a low cost.

Fuji Electric develops both scan driver ICs and address driver ICs and this paper describes the technology used in Fuji Electric's FD3284F PDP scan driver IC which features high current and low on-state resistance.

2. Features of the PDP Scan Driver IC

Figure 1 shows the drive circuit of a PDP module. The scan driver IC has 64-bit output lines, and 12 of these scan driver ICs are used in an extended graphics array (XGA) panel. The basic operation of the scan driver IC is shown in Fig. 2.

(1) Scan period

During the scan period, the scan driver IC selects a scan line, and according to signal from an address driver IC, outputs a 100 V address discharge to the cell to be displayed.

(2) Sustain period

Fig.1 PDP module drive circuit

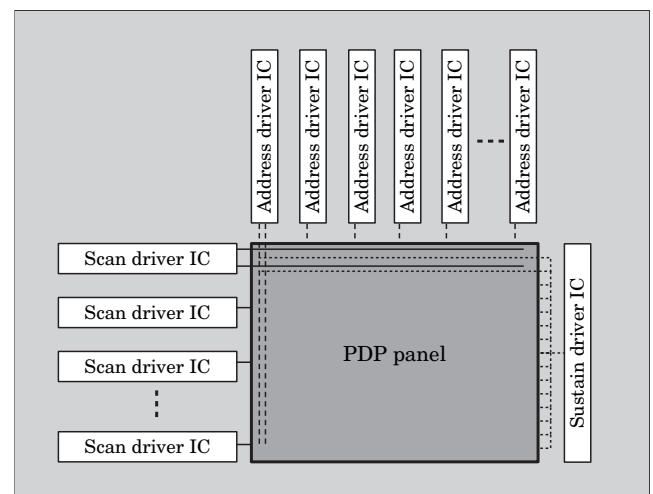
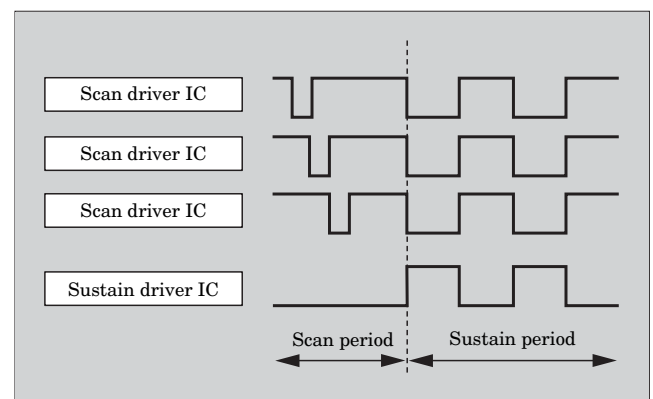


Fig.2 Scan driver IC operation



During the scan period, the scan driver IC alternates operation with the sustain driver IC, and outputs a 160 V sustain discharge to the cell that received an address discharge during the scan period.

This sustain discharge operation is repeated to implement a grayscale display.

The scan driver IC must be able to supply a large current at a high voltage during address and sustain discharges.

3. PDP Scan Driver IC Technology

3.1 Process and device technology

Fuji Electric has been using a silicon-on-insulator (SOI) method of dielectric isolation technology. Although the SOI process has the disadvantage of an expensive wafer cost, it features small device isolated areas and latch-up free operation, and therefore SOI process technology is well suited for scan driver ICs that require high voltage and high current.

The output device uses insulated gate bipolar transistors (IGBTs) connected in a totem pole configuration. The output circuit of a scan driver IC occupies 60 % of the IC area and therefore the output device size has a large impact on cost. The IGBT, which is able to output a large current from a small area, is optimally suited as an output device for a scan driver IC. As shown in Fig. 3 and Table 1, the newly developed third-generation SOI-IGBT device is smaller and achieves greater drive capability than a conventional IGBT.

Fig.3 IGBT device comparison

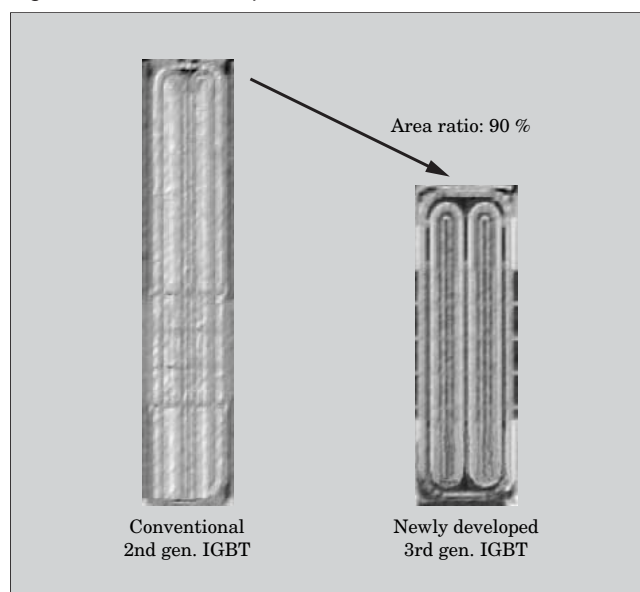


Table 1 FD3284F characteristics

Parameter	Conventional IGBT	FD3284F
Absolute maximum voltage (logic circuit)	7.0 V	7.0 V
Absolute maximum voltage (output circuit)	165 V	165 V
Operating voltage (logic)	5.0 V	5.0 V
Operating voltage (output)	30 to 130 V	30 to 130 V
High output source or sink current	- 200 mA/ +1,000 mA	- 200 mA/ +1,500 mA
High output diode current	- 1,000 mA/ +1,000 mA	- 1,200 mA/ +1,500 mA

3.2 Circuit technology

Figure 4 shows the output stage circuit of a scan driver IC. N-channel IGBTs are connected in a totem pole output configuration. The high-side IGBT (N2 in the figure) is controlled by a level shifter, and because the IGBT gate is driven at 5.5 V, a 5.5 V zener diode is inserted between the gate and source for protection.

The operation of the output stage circuit is summarized below.

(1) Scan period

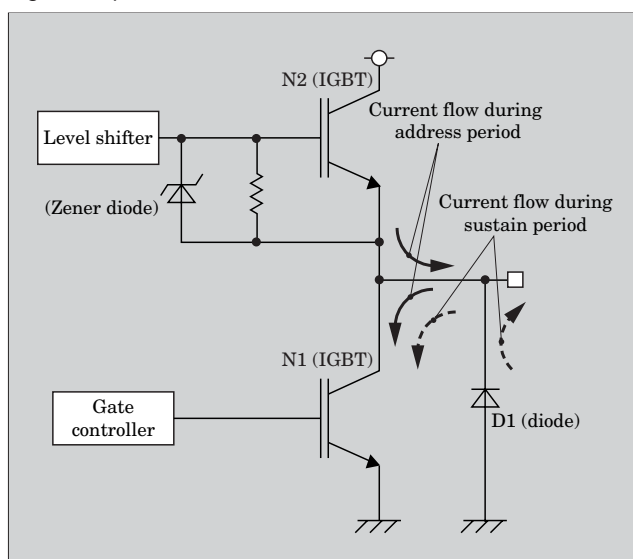
IGBTs N1 and N2 operate to output selected waveforms and unselected waveforms. During an address discharge, the N1 IGBT supplies a large current.

(2) Sustain period

The N1 IGBT and the D1 diode operate to provide a sustain discharge current supplied from both the N1 and D1 devices.

As the size of the display panel increases, a larger discharge current is required for address discharge and sustain discharge, and the on-state resistance of the device becomes an issue. If the device has a large on-state resistance, it will emit a large quantity of heat and the resulting temperature rise will lead to degradation of the device characteristics and a corresponding degradation of display quality. Comparing the on-state resistance of the N1 IGBT and the D1 diode reveals that when the on-state resistance of the D1 diode is 1.4 V/400 mA, the N1 IGBT will have a large on-state resistance of 6.0 V/400 mA. Because the N1 IGBT operates during both the scan period and the sustain period, its on-state resistance has a dominant effect on the amount of heat generated. Accordingly, the key to the development of a successful scan driver IC is to provide an N1 IGBT device with high drive capability.

Fig.4 Output circuit



3.3 IGBT gate control technology

If the current density of an IGBT device is increased so that large current can be obtained in a small area, the safe operating area (SOA) will become smaller and if an unusual discharge occurs during address or sustain discharge operations and causes an overload or short-circuit state, the device will exceed its SOA and be damaged.

Similarly, if waste metal adheres between the output terminals and the device unexpectedly enters an overload state, the device will exceed its SOA and become damaged.

On the other hand, in an attempt to expand the SOA, if the current density is decreased, the device area will increase due to the tradeoff relation that exists between current density and cost will also increase. In order to resolve this tradeoff between current density and SOA, Fuji Electric has developed technology for controlling the gate voltage of the N1 IGBT in accordance with the output timing. This operation is shown in Fig. 5.

During the scan period, in the case of a 5 V supply voltage VDL, so as to supply sufficient current for the output to drop, a voltage of approximately 4.5 V is applied to the gate of the N1 IGBT, causing the output voltage to drop from 100 V to 0 V and a scan line to be selected.

Fig.5 Address discharge operation

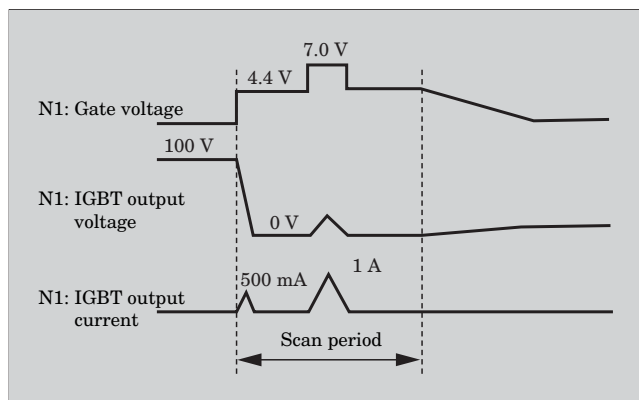
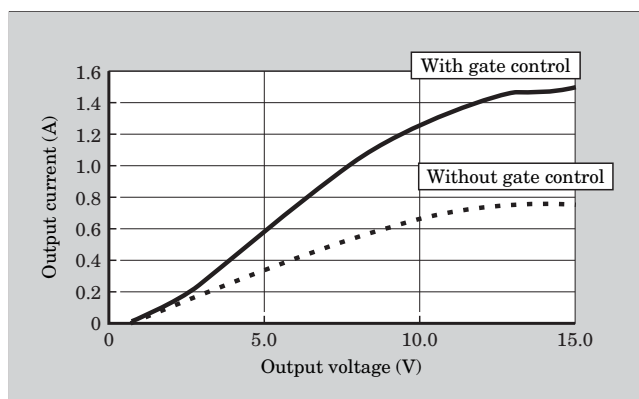


Fig.6 FD3284F's low-level R_{ON} (N1)



The address discharge begins, and when a larger current is required, the gate voltage of the N1 IGBT is increased to 7 V to boost the current drive capability of the N1 IGBT.

After the address discharge, the gate voltage is again lowered to 4.5 V to reduce the drive capability. Then, 1.5 μ s after the scan period, the voltage of the N1 IGBT gate is gradually decreased until the IGBT turns off. This control prevents the N1 IGBT from operating outside its normal operating period, thereby prevent possible damage due to an unexpected overload condition caused by an unusual discharge, short circuit or the like.

Figure 6 shows the characteristics of an N1 IGBT that incorporates this gate control technology. Even if the device area is 10 % smaller than a conventional IGBT, implementation of this gate control enables twice the output current capacity compared to the case without gate control.

4. Application to a PDP Scan Driver IC

Fuji Electric's FD3284F PDP scan driver IC, which uses this newly developed third-generation SOI-IGBT device and gate control circuit technology, is described below.

4.1 Features

- (1) 64-bit bidirectional shift register (15 MHz, with CLR function)
- (2) Absolute maximum voltage: 165 V (output circuit), 7 V (logic circuit)
- (3) Output operating voltage: 32 to 130 V
- (4) Logic operating voltage: 5 V
- (5) High output current: -0.2 A/+1.5 A (source/sink)
- (6) High output diode current: -1.2 A/+1.5 A (source/

Fig.7 FD3284F block diagram

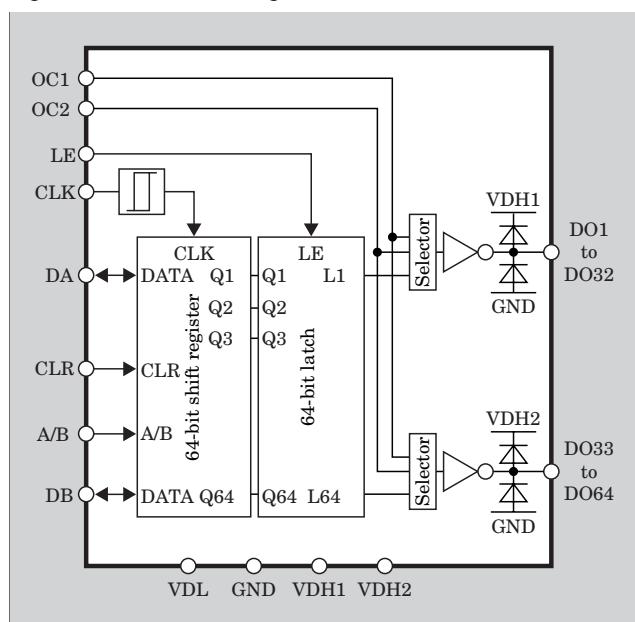
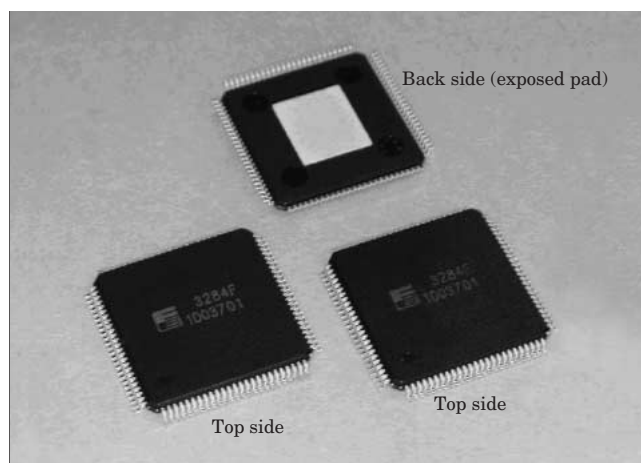


Fig.8 FD3284F package



sink)

(7) Package: TQFP 100-pin (exposed pad)

4.2 Circuit configuration

Figure 7 shows a block diagram of the circuit configuration. The circuit is configured from a 64-bit bidirectional shift register, a 64-bit latch, data selector circuits, and a totem pole output drive circuit.

4.3 Characteristics compared to those of a conventional IC

Table 1 lists the main differences in characteristics between the conventional scan driver IC and the FD3284F. The FD3284F, which has been designed to be capable of driving large PDP panels, features dramatically improved driver output current and diode output current capabilities. Figure 8 shows external views of the FD3284F which uses a heat-radiating exposed pad TQFP 100-pin package.

5. Conclusion

This paper has described characteristics of PDP scan driver IC technology and of Fuji Electric's FD3284F PDP scan driver IC. Competition among FPD technologies will intensify in the future and Fuji Electric plans to continue to advance device, circuit and process technologies in order to satisfy market requirements for higher performance and lower cost PDPs.

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