

Fuji Electric's Semiconductors: Current Status and Future Outlook

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1. Introduction

At the July 2008 G8 summit in Toyako Hokkaido, the greatest challenge discussed was global warming. Dire circumstances require recognition of the seriousness of this issue.

In its own business-related activities, Fuji Electric addresses environmental issues by promoting built-in environmental management, aiming “to create efficiency without waste using few natural resources and with low energy consumption” to further advance core technologies cultivated over many years and to make continuous improvements⁽¹⁾.

Power electronics technology, which enables the efficient utilization of electrical power and energy, is positioned a major technology for protecting the global environment and reducing CO₂ emissions. In particular, power semiconductor devices, the key components that support power electronics technology, are expected to become increasingly important.

Environmental friendliness and ease of use are recently being requested of power semiconductors. Of course, components and materials having a deleterious effect on the environment should not be used. In addition to prior requests for lower cost and lower loss, “ease of use” is strongly requested, and technical efforts related to environmental protection, such as efforts to reduce noise, are also included among these requests.

This paper describes the current status and future outlook mainly for Fuji Electric's representative power semiconductor products, power modules, power discretes, power ICs and automotive-use MOSFETs (metal-oxide-semiconductor field-effect transistors).

2. Power Modules

Fuji Electric, an industry leader in IGBT (insulated gate bipolar transistor) technology, has begun selling the V-series of 6th generation IGBTs.

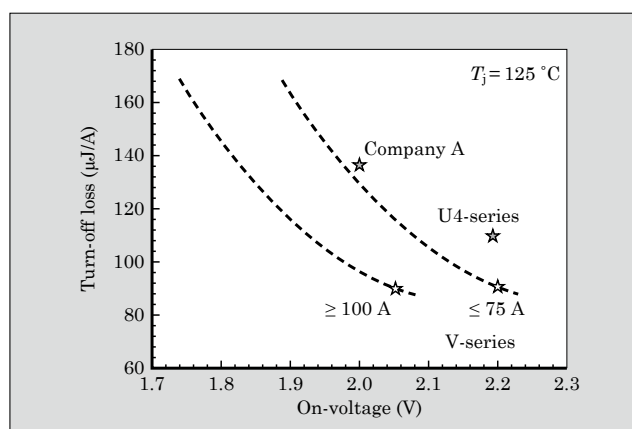
The V-series IGBT modules were designed in consideration of environmental issues, and all packages of this series are RoHS^{*1} compliant. The IGBT

chip structure uses an advanced form of the trench gate structure and field stop structure developed for Fuji Electric's U-series and also realizes lower loss and lower noise. Figure 1 compares the U-series and V-series chip characteristics. The package structure has also been optimized for heat management, and the package size for some current-rated products has been decreased by one rank. Additionally, in response to various customer needs, packages having a solder-free connection structure have also been prepared. Figure 2 shows Fuji Electric's lineup of V-series IGBT module products.

The development of high-power IGBT modules is also accelerating. High-power IGBT modules have begun to be deployed in high-voltage and high-power inverters for power conversion equipment used primarily for industrial infrastructure and in wind power generation systems. As shown in Fig. 3, the high-power modules are equipped with a 5th generation U4-series IGBT chip and are provided as 1,200 V/ 600 to 3,600 A and 1,700 V/ 600 to 3,600 A rated products. These high-power modules use silicon nitride as their substrate material to realize higher current ratings. Ad-

*1: RoHS is EU directive restricting the use of certain hazardous substances in electrical and electronic equipment.

Fig.1 Comparison of tradeoff for U-series and V-series IGBT chip characteristics



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Fig.2 V-series IGBT module product lineup




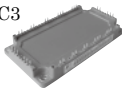
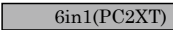









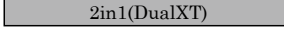
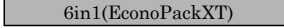
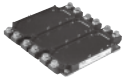


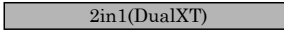

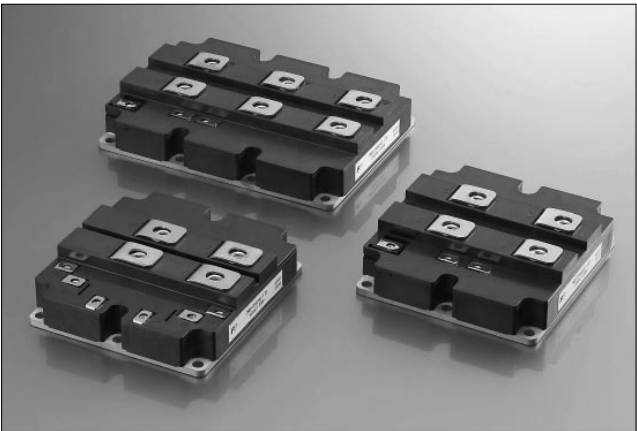
			Main terminal	10 (A)	15	25	35	50	75	100	150	200 225	300	400 450	600	900	1,200	
600 V	Solder	Pin		EP2/PC2										EP3/PC3				
																		
	Screw										Dual							
1,200 V	Solder	Pin													EP3/PC3			
																		
																		
	Screw										Dual							
Solder-free	Spring																	
																		

Fig.3 High-power IGBT modules



ditionally, these high-power modules also suppress the generation of noise, and with a 30% reduction in power loss compared to prior products, improved ease of use and enhanced conversion efficiency also contribute to energy savings.

In joint research with Professor Shimada of the Tokyo Institute of Technology, an IGBT module optimized for use in wind power generation was developed using a magnetic energy recovery switch (MERS). The IGBT used in the MERS operates at a switching frequency of several tens of Hz, which is lower than the conventional frequency (\leq several kHz). On the other hand, because the MERS is connected in series in a power conversion system, increased conduction loss becomes a problem. Thus, upon reconsideration of the tradeoff characteristics, we reduced the on-voltage to 1.54 V to

improve the overall efficiency of the conversion device.

As automotive power module products, a buck-boost converter IGBT IPM (intelligent power module) equipped with a present 5th generation U-series IGBT module and a plated chip mountable on both sides by soldering are being mass-produced and used in the Toyota CROWN*2 HYBRID, LEXUS*3 LS600h and LS600hL, and so on.

Next-generation automotive power modules equipped with a 6th V-series IGBT chip and realizing higher power density due to their smaller size and lower power loss can be miniaturized to 40% of the size of prior power module products. Targeting application to mild hybrid systems, next-generation automotive power modules are presently being developed.

IGBT characteristics are already approaching their theoretical limits with the 6th generation V-series IGBTs. For IGBT modules to become even easier to use, improvement in FWD (free wheeling diode⁽²⁾) characteristics and further package⁽³⁾ research and development are needed. With these comprehensive technologies, IGBT modules can be made to have lower noise, higher reliability and become easier to use.

3. Power Discretes

As high-voltage power MOSFETs, Fuji Electric

*2: CROWN is a registered trademark of Toyota Motor Corporation.

*3: LEXUS is a registered trademark of Toyota Motor Corporation.

has developed the “SuperFAP-E^{3S} low Q_g series” and the “SuperFAP-E³ 900 V series.” Recently, in the field of power supply devices that use high-voltage MOSFETs, and particularly as environmental measures, requests for energy savings in various electronic devices have intensified, and at the same time, regulations for higher power efficiency have been strengthened through the International ENERGY STAR program^{*4} standard, and requests for higher efficiency of switching-mode power supplies have also increased. Moreover, in order to satisfy various noise-related regulations, a product must simultaneously satisfy requests both for lower loss and for lower noise. In 2007, Fuji Electric developed and established product lines of its “SuperFAP-E³ 500 V series” and “SuperFAP-E³ 600 V series” of 6th generation high-voltage MOSFET products as power MOSFETs for realizing higher efficiency and lower noise in switching-mode power supplies. These product lines feature the industry’s lowest on-resistance for a planar structure. The newly developed SuperFAP-E^{3S} low Q_g series retains the low on-resistance characteristics, gate resistance controllability and low noise performance of the 500 V and 600 V series, while improving the switching performance. The gate charge characteristic Q_g of the new SuperFAP-E³ series is lower than that of the prior product series by approximately 20%, and lower switching loss is realized as a result.

Moreover, the SuperFAP-E³ 900 V series is a higher voltage version of the 500 V and 600 V series. The SuperFAP-E³ 900 V series suppresses operation in which avalanche current flows into parasitic bipolar transistors and eliminates non-uniform operation among cells during avalanche to realize a damage-resistant device having twice the resistance to avalanche current as the prior product series.

In the high-voltage power MOSFET field, lower cost, smaller size, lower loss and lower noise are strongly requested, and Fuji Electric is focusing on research and development to support these requests.

Looking ahead, research and development is also being advanced to realize both lower resistance and lower cost through the optimal design of super junction MOSFETs⁽⁴⁾.

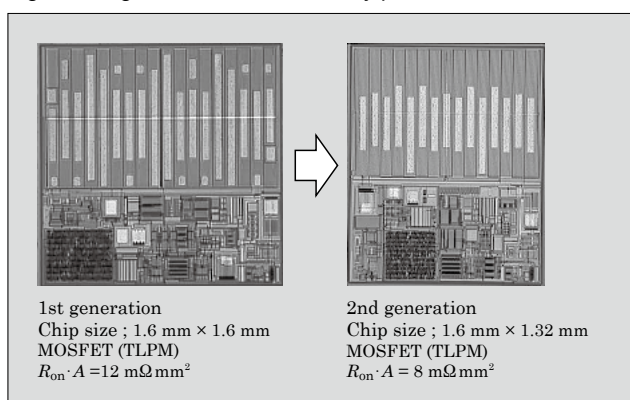
4. Power ICs

The following accomplishments have been realized for power ICs.

- (a) Lithium-ion battery protection IC
- (b) FA5560M combo-IC for critical conduction mode

^{*4}: International ENERGY STAR program is an international environmental labeling system for energy savings in OA equipment, and operates under mutual recognition by the Ministry of Economy, Trade and Industry in Japan and the US Environmental Protection Agency (EPA) in the United States.

Fig.4 2nd generation lithium battery protection IC



PFC current resonance

- (c) Low standby power quasi-resonant power supply controller IC “FA5571 series”
- (d) High efficiency buck converter IC “FA7743N”
- (e) Multi-channel switching DC-DC converter IC “FA7763R” for portable electronic equipment

Practical application of Fuji Electric’s proprietary low on-resistance three-dimensional power device technology enabled lithium-ion battery protection ICs to be mass-produced for the first time in the world. In response to market requests, and as a continuation of the 1st generation products which were mass-produced in 2007, the industry’s highest level of on-resistance of $R_{on} \cdot A = 8 \text{ m}\Omega \text{ mm}^2$, where the on-resistance is the resistance per unit area of the power MOSFET, has been achieved. A 2nd generation product has been realized with 17.5% smaller chip size than the 1st generation product. Figure 4 shows photographs of the chips.

To realize lower loss and smaller size in power ICs, the technology for realizing lower loss and smaller size in built-in power devices is critical. Fuji Electric continues to advance research and development for making lower loss and smaller size power devices that are incorporated into power ICs⁽⁵⁾.

5. Automotive Devices

- (1) Sophisticated single-chip igniter

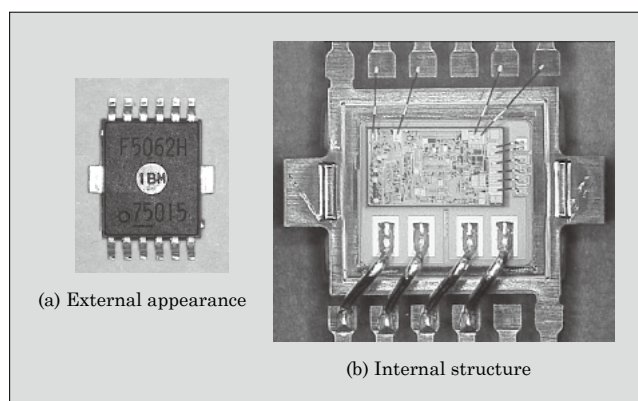
The transition from hybrid type igniters, configured from multiple components, to single-chip igniters is accelerating. In response, a single-chip IGBT incorporating all the relevant protection functions has been commercialized.

The expanded self-protection functionality is a key factor. Functions to prevent damage to the device itself, to prevent the coil from burning, to prevent abnormal ignition from causing engine damage and the like have been realized and the “TO220” single-chip small-size package has been commercialized.

- (2) IPS (intelligent power switch)

Automotive ECUs (engine control units) are installed in an environment that ranges from indoors to the engine compartment, and they are also incorpo-

Fig.5 External appearance and internal structure of COC package



rated into loading equipment and the like, and ECUs are requested to be small in size, have high functionality and be resistance to damage even in harsh environments. Respond to requests for smaller size, Fuji Electric has commercialized product lines of COC (chip on chip) and CSP (chip size package) devices, and also has commercialized a 2-channel product equipped with a status output. No other company provides a 2-channel chip with status output housed in a SOP-8 package.

With newly developed COC technology, the thermal stress behavior of film material for bonding an IC chip in a COC package was analyzed and higher reliability was realized. Figure 5 shows the external appearance and the internal structure of the COC package. As can be seen in the figure, an IC chip is bonded onto a MOSFET chip that has been soldered to the lead frame.

(3) Pressure sensor

A pressure sensor that uses a CMOS process-based digital trimming scheme has already been introduced to the market as a 5th generation pressure sensor. Applications are primarily for measuring pressure in suction/exhaust systems. Pressure sensors are also actively being developed for new applications, and one such type is the atmospheric pressure sensor, which is used for the purpose of optimizing the engine performance when traveling at a high elevation by providing high elevation compensation for the ECU. Other pressure sensors being developed for new applications

include high-pressure sensors for air conditioners, leakage sensors for fuel tanks, and so on.

Fuji Electric has leveraged the strength of its proprietary technology in response to customer needs for automotive devices. Fuji Electric intends to continue to emphasize cooperation with customers, and to respond to customer needs while aiming to achieve lower prices, smaller size and higher reliability

6. Postscript

Under the present circumstances in which environmental issues are beginning to become significant actual problems, corporations have a major role to play. Fuji Electric is moving ahead with efforts to help curb global warming and has positioned these efforts as a vital management task. In the field of power electronics technology, Fuji Electric is working on technical innovations for power semiconductors, the main components in this field, and is endeavoring to make these innovations responsive to the environmental issues.

This paper has described the present status and future outlook for the main products that use power semiconductors. Continuous innovation is needed for all products to achieve lower loss, lower noise, smaller size and higher reliability. Establishing "ease of use" as a product criterion from the customer's prospective, Fuji Electric intends to continue to advance technical development.

Reference

- (1) Fuji Electric Group Sustainability Report 2008.
- (2) Onozawa, Y. et al. Development of the 1200 V FZ-diode with soft recovery characteristics by the new local lifetime control technique. Proc. of ISPSD '08. p.80.
- (3) Ikeda, Y. et al. A study on the reliability of the chip surface solder joint. Proc. of ISPSD '08. p. 189.
- (4) Sugi, A. et al. Super Junction MOSFETs above 600V with Parallel Gate Structure Fabricated by Deep Trench Etching and Epitaxial Growth. Proc. of ISPSD '08. p. 165.
- (5) Sawada, M. et al. High side n-channel and bidirectional Trench Lateral Power MOSFETs on one chip for DCDC converter ICs. Proc. of ISPSD '08. p. 107.





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