

Fuji Electric's Semiconductors: Current Status and Future Outlook

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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.

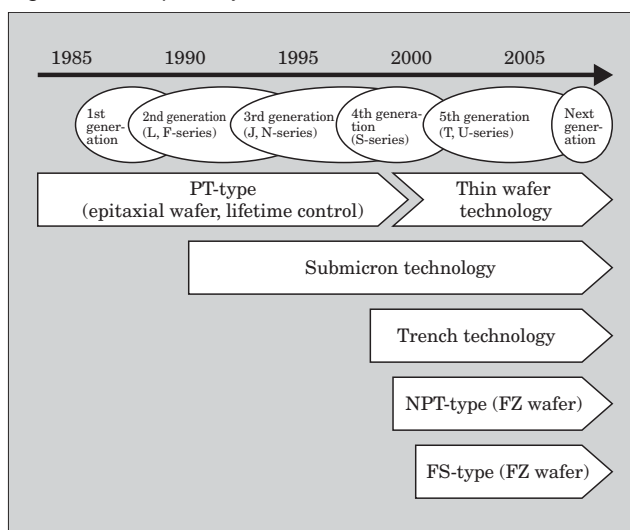
2. Industrial-use Semiconductors

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

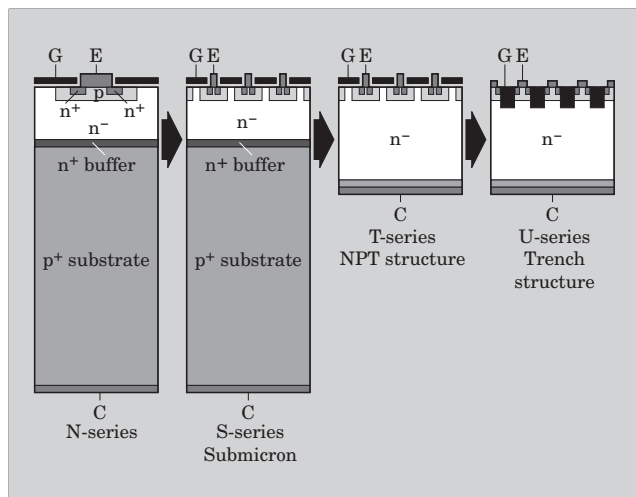
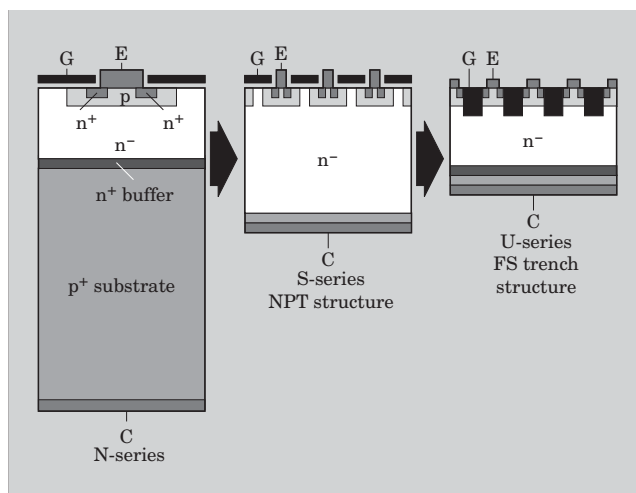


Fig.3 Changes in the 1,200 V IGBT chip cross-sectional structure



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

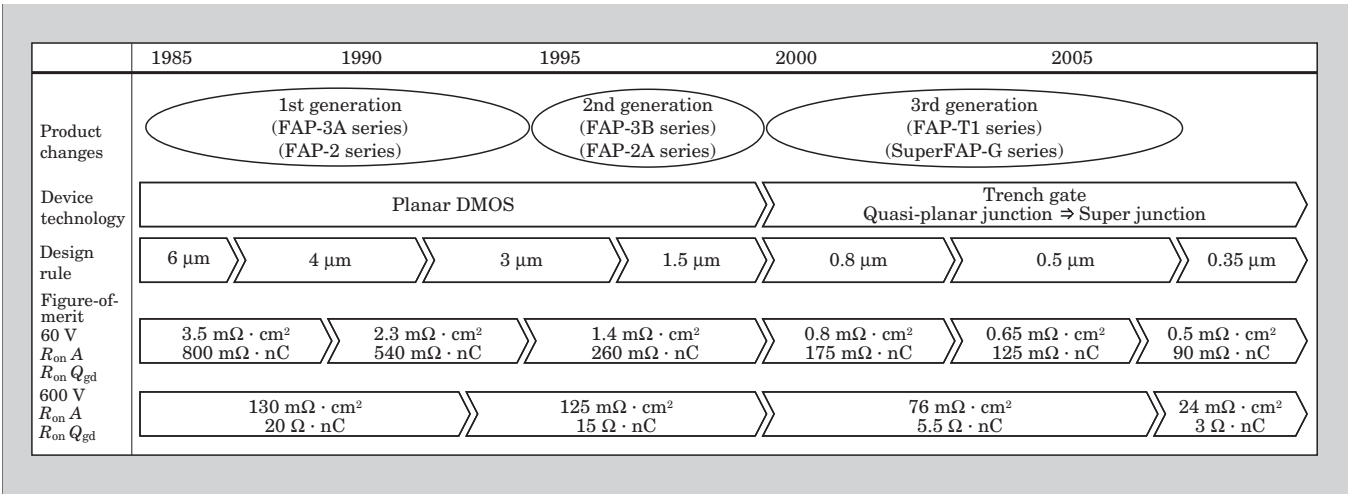


Fig.5 Cross-sectional structure of self-isolation power ICs (control circuit)

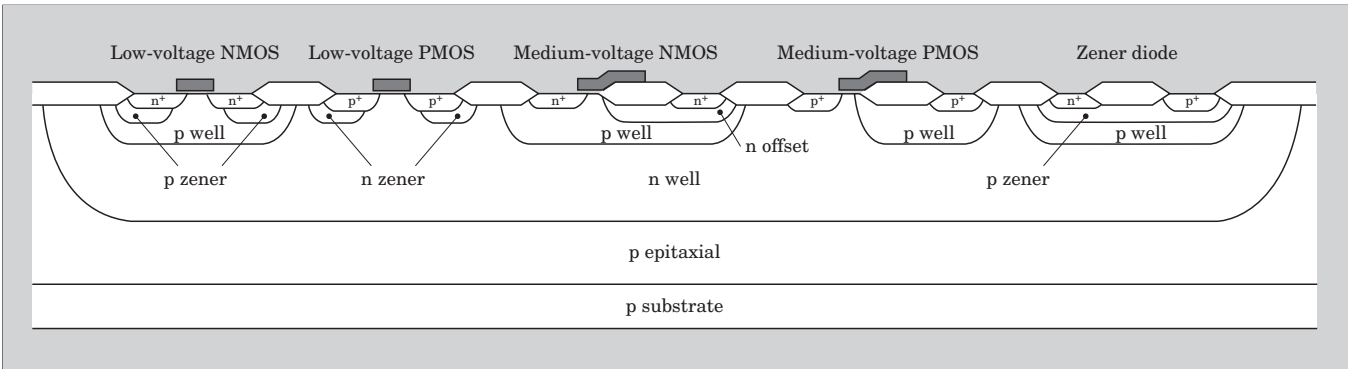
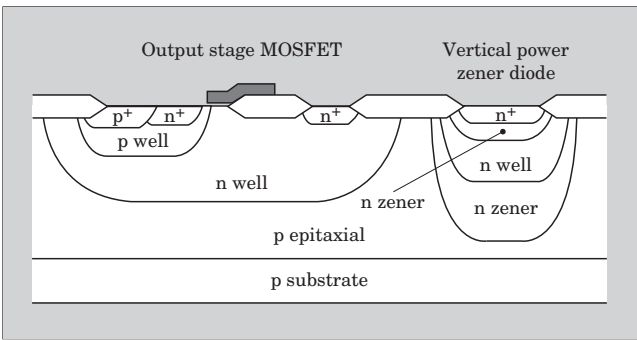


Fig.6 Cross-sectional structure of self-isolation power ICs (power MOSFET)



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

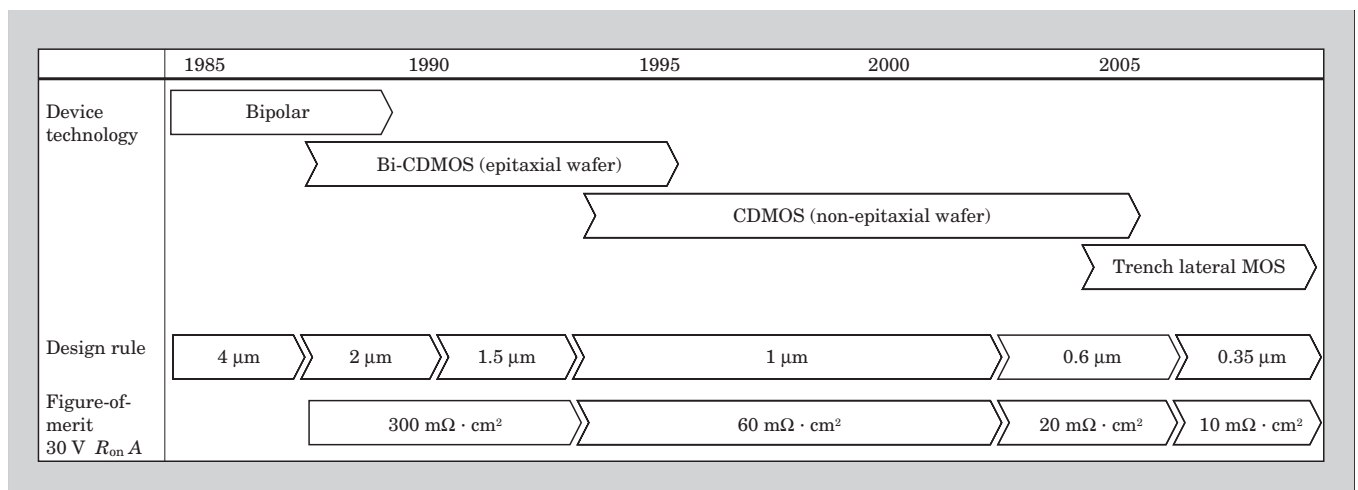
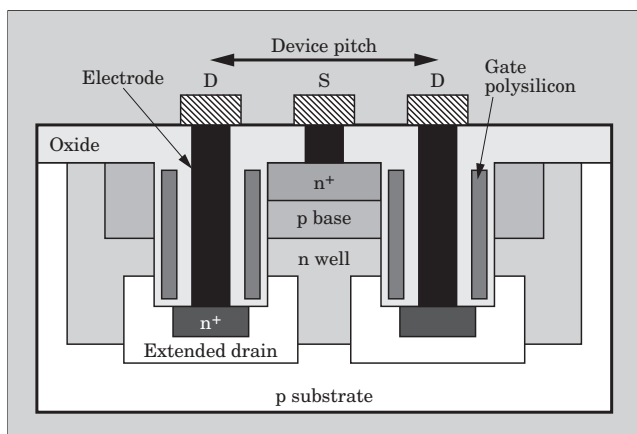


Fig.8 Cross-sectional structure of trench lateral power MOSFETs in power ICs



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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