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POWER SEMICONDUCTOR DEVICES

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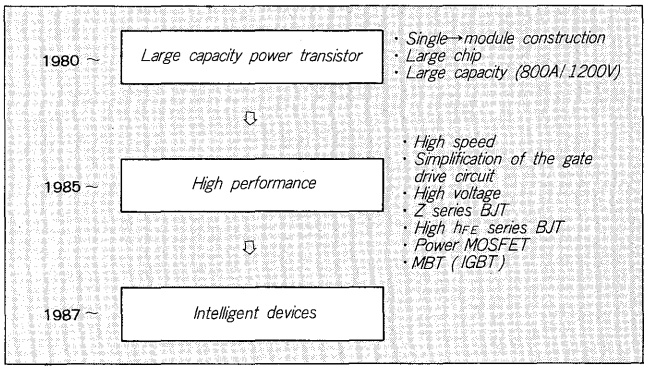
1. INTRODUCTION

Power semiconductor devices played an important role in the technological revolution in the industrial, information, consumer products, automotive, and may other fields. Compared to VLSI technology, there are few opportunities for taking up power semiconductor devices in journalism and they are often considered to belong to a mature technological field. However, with the strong desire of application engineers for a technological revolution and the rapid advance of semiconductor technology as the background, semiconductor engineers are pouring their efforts into the development of new products and new technology. Power semiconductor technology is advancing at a fairly rapid pace.

There are the following three trends in power semiconductor devices. The first of these trends is higher power transistor capacity. The history of development of Fuji switching devices is shown in *Fig. 1*. Modular products containing multiple silicon chips were developed from 1980. The capacity of power transistor modules increased together with the enlargement of the transistor chip (current maximum size: approx. 500mm^2). Today, units with capacities up to 400A/1,200V are manufactured and sample shipment of maximum 800A/1,200V modules has commenced. By using these hybrid modules, higher performance and higher efficiency are possible and smaller size and lighter weight can be realized even with power switching equipment of several hundred kVA. Device having a high power capacity over this are thyristors. Development of higher performance GTO (Gate Turn Off) thyristors, in particular, is being advanced actively. The second trend is development of new types of power semiconductor devices and improvement of the characteristics of existing types of devices through the application of LSI technology. MOS technology, poly-crystalline silicon technology, photolithography technology, isolation technology, etc. are being applied positively. Power MOSFET and IGBT and other MOS gate type devices have appeared through the application of LSI technology. Even bipolar junction transistors (BJT) with substantially improved characteristics, such as the Fuji Z Series module (see Chapter [2]) have been developed. The third trend is intelligent power semiconductor devices. Intelligent power devices with various sensing, self-protection, diagnosis, and other functions are not far from becoming the center of development of these.

Fig. 1 Development of switching power devices



This paper describes the most recent results and future trends of development of high performance and intelligent power semiconductor devices and high power semiconductor devices by Fuji Electric to meet the technological trends described above.

2. HIGH PERFORMANCE

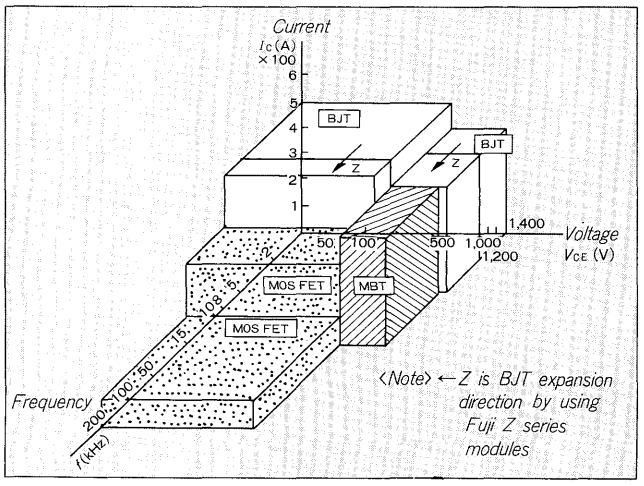
A noticeable trend has been evident in power semiconductor devices since 1985. This is the development of new types of devices with improved performance to cope with the (1) higher switching speed, (2) simiplification of the gate drive circuit, and (3) higher resistance to load shorts and other accidents demanded by the market described next. To increase the speed and withstand capacity of BJT, Fuji Electric already offers the Z Series module with a revolutionary chip construction which integrates several thousand poly-crystal silicon emitter resistors. Following this, a high h_{FE} silicon module was developed to substantially simplify the gate drive circuit. Since this module has a much higher h_{FE} than conventional devices, all classes, from 30A to 150A ($h_{FE} > 1{,}500$), can be driven by a base current of 0.1A. In other words, a gate drive circuit of the same design is used in all modules, from 30A to 150A.

From the standpoint of simplification of the drive circuit, device with an MOS type gate construction are the most beneficial. A high switching speed is also possible with MOS gate devices. Fuji Electric is advancing serialization of power MOSFET and offers a standard series (F-I series), low-loss series (F-II series), and logic level series (F-III series) in the 50V to 900V voltage range and 3A to 45A current range and counts approximately 70 types in its catalog alone. In addition to these the F-V series power MOSFET has been developed for inverter applications. This series device has a high speed integral diode. This series realizes a higher speed and greater breakdown capacity than conventional internal reverse diodes and is perfect for motor control and other inverter applications.

Because of their principle, power MOSFET are not suited for high voltage and large current capacity applications. The MBT (IGBT) is expected to quickly become popular as an MOS gate device with the same high power processing ability as the BJT. In connection with this, the MBT (Mos-gate Bipolar Transistor) is the original name of Fuji Electric for IGBT. Serialization of one pack, two pack, and six pack 600V and 1,200V MBT modules from 8A to a maximum 400A (one pack) is advancing. These MBT modules are gaining attention as devices for low acoustic noise inverters and for precision NC machines. Fuji Electric has completed an MBT module application data book and offers it to customers.

Fuji Electric increased the performance and series of its switching power devices such as the above. Fuji Electric wishes to exchange opinions with users regarding the positioning of each device. For example, in application to PWM control inverters, the trend is toward the use of the BJT, MBT, and power MOS FET in the under 10kHz, 10 to 20kHz, and over 20kHz carrier frequency ranges, respectively. *Fig. 2* shows the application range of each type of switching device currently forecast by us. This range will probably expand and change with the future technological revolution of each device. In any case, these three kinds of devices are expected to coexist through their use in field suitable for each.

Fig. 2 Application region of various switching power devices



2.2 High speed diode

A large number of switching power supplies tend to be widely used in various fields. Fuji Electric offers 40V series SBD (Schottky Barrier Diode) and 200V series LLFRD (Low Loss Fast Recovery Diode) as high speed diodes for secondary rectification. Recently, the demand for high speed diodes of higher voltages has risen because of expansion of the allowable input voltage range and simplification of the circuit for cost-reduction of switching power supplies. To meet this market demand, Fuji Electric has developed the 60V series SBD and 300V series LLFRD. The biggest objective of this development was higher voltage and maintenance of the tradeoff characteristics. The high voltage diode made by stacking of several to several 10 high speed diodes was developed, for color TV high voltage rectification and is used widely as a important color TV part. The microwave oven is the next important market of the high voltage diode after TV. Recently, however, the use of inverter control to improve its functions and reduce its weight and size has advanced. A function which switches a comparatively large current at high speed is demanded of the high voltage diodes used and development based on a design policy different from that of the high voltage diode for TV use is necessary. To meet this demand, Fuji Electric has developed new products with excellent large current rectification capacity without a drop of RF drive performance even in high temperature environments.

3. INTELLIGENT DEVICES

The necessary direction of power devices with higher capacity and performance advanced as shown in *Fig. 1* is considered to be intelligent devices. The need for intelligent devices is due to the many advantages of expected by device makers and users. The advantages expected at listed in *Table 1.*

Making power devices intelligent is considered to be advanced through a number of steps. Currently, the concept of the devices which should also be called the first generation is in the outline solidification stage. The concept of the first generation can be represented by power

Table 1 Advantages expected by making power semiconductor devices intelligent

User side	Device side
• Black boxing of important parts • Shortening of design time • Elimination of shortage of engineers experienced in device usage methods • Full automatic assembly (reduction of assembly processes) • Reduction of management cost • Full use of devices • Total cost reduction of equipment	• Matching with development intent of engineer • Increase of additional value of product • Reduction of claims by mismatching of device and circuit • Lightening of technical assistance to customers • Improvement of reliability by building in of protection functions • Full use of chips • Reduction of assembly processes and package cost

devices with self-protection functions and self-diagnosis functions for abnormal operation of equipment and with gate (base) drive circuits. Currently, first generation intelligent devices are being advanced along two parallel approaches. The first is a "smart power" construction which monolithically integrates the power device and control circuit on one chip. Mainly, devices of 500V class or less and 10A class or less are being developed. The IPS (Intelligent Power Switch) for automobile control which has the control circuit integrated with a power MOSFET is typical of these. The other approach has 500V, 10A class and higher devices as the objective and is an "intelligent module" with multiple power chips and control circuits integrated in a module. At present, this device is being developed for application to inverters. The main direction of its development is toward high current capacity. Fuji Electric is promoting the two approaches described above.

4. HIGH POWER SEMICONDUCTOR DEVICES

High power semiconductor devices which have a withstand voltage of several kV and rectify or switch large currents of several kA have advanced from the first diode to the thyristor and then to the GTO thyristor. GTO thyristor are important devices that cover high power applications not reached by the power transistor. Recently, their economy has also improved and they have become truly popular. Backed up by our original device simulation etc., we have advanced development of GTO thyristors with excellent turn-off performance. Three series of asymmetrical type, reverse blocking type, and reverse conducting type devices are being serialized for a wide range of applications. A 4.5kV, 3kA rating, the highest class in the world, asymmetrical type and reverse blocking type have been completed.

The reverse conducting type uses a construction in which a free-wheeling diode is integrated on the same wafer as the GTO thyristor. In the past, 2.5kV, 2kA rating reverse conducting type devices were serialized. Now, development of a high voltage, high current 4.5kV, 3kA rating device for AC motor drive has been completed.

Inverter control, which promotes miniaturization of equipment, is suitable for a wide range of fields and its application to spot welder, etc. has started. An SBD with high current and high speed switching characteristics has been developed for such applications. The SBD is superior to the pn junction diode in many ways, such as high speed characteristics, low loss characteristic, etc. However, existing devices had a comparatively low current capacity. The new SBD has a 300A (60V) rating and a capacity higher than that possible in the past and is a unique product with a 56mm diameter silicon wafer housed in a flat case.

Besides the power semiconductor devices described above, Fuji Electric is, of course, developing general purpose diodes and thyristors and light-triggered thyristors etc. To cope with larger diameter or more complex construction of silicon wafers, efforts are also being put into the revolution of ion injection technology and photolithography technology and other process technology.

5. CONCLUSION

As described above, the performance of power devices is being increased steadily through the proposal of new device constructions, application of new process technology, etc. However, the focus of future development will probably gradually shift to making the devices intelligent. Devices with a power device and IC intergrated on the same chip by using insulation technology are expected to welcome in their age of popularity in the near future. It will be necessary for power device technology development engineers to pay more attention to the trend of LSI technology than in the past and to plan its fusion with power device inherent technology for some time.

One important topic in the power semiconductor device field is the speeding up of the GTO thyristor. Current GTO thyristors are difficult to operate at 1kHz or higher and their speed is inferior to that of the power transistor. Currently, a current capacity of about 1kA is the boundary region between the power transistor and GTO thyristor. Ideally, smooth continuation in the frequency characteristic is desired at the boundary. For this reason, efforts must be put into both speeding up the GTO thyristor and raising the capacity of the power transistor.

Fuji Electric is collecting and analyzing future market needs and promoting the development of new products which offer easy-to-use and reliable power semiconductor devices to the market. We welcome the guidance and cooperation of users.