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Power Devices

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ROHM SEMICONDUCTOR

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ROHM Semiconductor continues to increase its Portfolio of Power Devices. This Strategy has lead to Increased market share of High Voltage Products with SiC Devices.

Since its establishment in 1958, ROHM has consistently expanded its realm of business activity, and today has categorised power devices as priority development. In addition to semiconductor devices using the Si (silicon) which ROHM has developed for many years, they begin mass production of the semiconductor device SiC (silicon carbide) ahead of the industry. The result is an extremely wide variety of products, including designs with voltage of over 1000 V.

Power devices are a key business field for ROHM, alongside sensors and LEDs. The company has been accelerating its work in the field for several years now. ROHM currently offers products including discretes such as MOSFET(metal-oxide semiconductor field effect transistors), IGBT(insulated gate bipolar transistors), FRD(fast recovery diodes), and SBD(schottky barrier diodes), as well as gate driver ICs and other power devices. To meet changing user requirements, it is now further expanding the range of rated voltages and currents covered by standard products (Fig. 1). Si semiconductor devices are now available with rated voltages up to about 1500 V, and are the first devices in the industry to offer high voltage of over 600 V.

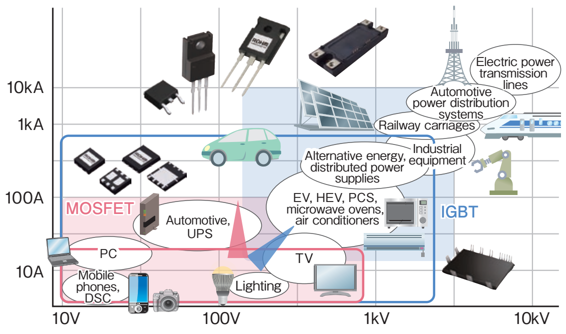

Fig. 1●Expanding range of application for power devices


Syoji Higashida
Group Manager
Power Device
Development Department
Discrete Production
Headquarters

Optimize characteristics for each application

"We specify exactly which applications our Si discrete semiconductors are optimized for, and provide them with the characteristics they need to achieve outstanding performance," explains Syoji Higashida,Group Manager,Power Device Development Department,Discrete Production Headquarters at ROHM. Devices with relatively low voltage—voltage ratings up through about 100 V—for example, target three key markets, namely smartphones, personal computers, industrial and automotive applications. "In smartphones," continues Higashida, the rated voltage is 10V to 20V, and miniaturization is a top priority." The firm's ECOMOS™, for example, offers a low ON resistance and a small mounting footprint of only 0.8 mm x 0.6 mm. "Its in the smallest class of 3-pin devices in the industry."

For personal computers, where rated voltage is 30V to 40V, and where rated current is about 20 A, ROHM continues to innovate process technology, supplying a variety of packages. "Personal computers have a considerable diversity, and we are working to expand our product line-up while improving development efficiency," says Higashida. The new HUML2020 MOSFET shipping in 2012 has a mounting footprint that measures only 2.0 mm square.

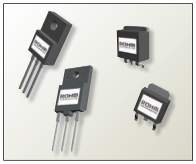

Fig. 2 ● PrestoMOS™ MOSFET with low ON resistance, high-speed switching and high voltage

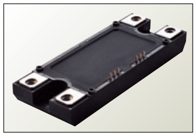

Fig. 3 ● Volume production of Full-SiC modules began in March 2012

ROHM is also expanding its line of products destined for use in automotive and industrial equipment, such as power tools, with rated voltages from about 40V to 100 V. "We began shipping samples of a new MOSFET with a 40-V rating, for 24-V input DC-DC converters, in April 2012. The device' s power conversion performance is outstanding in the industry," he reveals. This particular product covers a wide range of rated currents, from 9A to 100 A, available in six different packages for different applications. ROHM also plans to release a MOSFET covering the rated voltage range from 60V to 100 V.

Devices with high voltage, rated for several hundred V and currents up through 100 A, are intended for use in power conditioners, power supplies and similar products. "ROHM release mainly super junction structure MOSFET which has high voltage and low ON resistance." comments Higashida. One of the most exciting products in this selection of the PrestoMOS™ (Fig. 2) with a low ON resistance and fast reverse recovery time (trr). Most super-junction architecture devices have slow trr compared to planar MOSFETs, but unique manufacturing technology in the PrestoMOS™ cuts this to about 80% of ROHM's prior-technology products.

Pioneering the market for 1000-V voltage devices with SiC

In the field of the SiC semiconductor product that has more than 600V of rating voltage, ROHM accelerate product development to lead the industry. SiC power semiconductors are attracting attention in a wide range of sectors because they achieve lower losses than conventional Si materials. ROHM was the first Japanese semiconductor manufacturer to manufacture in volume a SiC SBD in April 2010. In December of the same year it was the first company in the world to begin mass production of SiC MOSFETs, and in March 2012 followed it up with the world's first volume produced Full-SiC module composed entirely of SiC devices (Fig. 3). "ROHM SiC power devices are already in widespread use in applications such as servers, air conditioners, industrial power supplies, power conditioners for photovoltaic power generation system and rapid chargers for electric vehicles," says Kazuhide Ino, General Manager, SiC Power Device Production Division, Discrete Production Headquarters at ROHM.

Kazuhide Ino
General Manager
SiC Power Device
Production Division
Discrete Production
Headquarters,
ROHM.

Already the company is rolling out its second-generation SiC power devices, delivering improved performance. In discretes, the new SBDs have forward voltage (Vf) of 0.1V to 0.15 V, significantly lower than first-generation designs. In addition to the SCT series of second-generation MOSFETs offering a voltage of 1200 V, ROHM has also begun volume production of the SCH series of MOSFETs, the first in the world to integrate SiC SBDs. "In the fall of 2012," continues Ino, "we sample-shipped an SiC-MOS module with a rated voltage of 1200 V and a rated current of 180 A, along with a Full-SiC module with a rated voltage of 1700 V."

ROHM is expanding product portfolio and business domain in the field of the power semiconductor. It may be said that ROHM is one of the most important companies for users who need a power semiconductor that has the superior characteristics.

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Power Devices

Power semiconductor devices such as metal-oxide semi-conductor field-effect transistors (MOSFET) and insulated gate bipolar transistors (IGBT) are attracting more attention that ever (Table 1), and semiconductor manufacturers around the world are investing massive amounts of capital into power device R&D and manufacture. In Japan, companies like Toshiba Corp., Fujitsu Microelectronics Ltd., Fuji Electric Co., Ltd., Panasonic Corp., Mitsubishi Electric Corp., Renesas Electronics Corp., and ROHM Co., Ltd. are struggling to dominate the market.

They are all so interested in power devices because of the rising sensitivity to environmental protection issues worldwide. Protecting the environment will require reducing energy consumption and CO_2 emissions, but few people want to impact their quality of life or convenience. Power semiconductors can satisfy these apparently contradictory requirements at once.

Take air conditioners, for example. Inverters using power devices can control operation with excellent precision, providing more comfortable heating and cooling than simple on/off designs while simultaneously slashing energy consumption by about 30%. The same applies to other appliances, like refrigerators and washing machines. With power devices it is possible to enjoy convenience and comfort while reducing energy consumption.

But power devices are important in more than just air conditioners and refrigerators: they are essential components in making hybrid and electric vehicles possible. In these vehicles electricity

Table 1 A comparison of power devices
A comparison of power MOSFET, SJ power MOSFET and IGBT devices. For reference, an SiC power MOSFET now under development is also shown.

	Power MOSFET	SJ power MOSFET		IGBT	SiC power MOSFET (reference)
Device type	Unipolar	Unipolar		Bipolar	Unipolar
Voltage resistance	About 12V to 500V	500V to 1kV		400V to about 12kV	600V to several kV
ON resistance	○	◎		○*1	◎
High-speed switching characteristics	○	○		△	◎
Cost	○	△		◎	×
Major manufacturers	Toshiba, Fuji Electric, Mitsubishi Electric, Renesas Electronics, Fairchild Semiconductor, Infineon Technologies, International Rectifier, Vishay Intertechnology	Toshiba, Renesas Electronics, ROHM, Infineon Technologies, STMicroelectronics		Toshiba, Fuji Electric, Mitsubishi Electric, Renesas Technologies, Infineon Technologies, Semikron, STMicroelectronics, Vishay Intertechnology	Toshiba, Mitsubishi Electric, ROHM, Infineon Technologies

*1 IGBTs are bipolar devices with no ON resistance, and so are evaluated by $V_{CE(sat)}$, (saturation voltage, ON voltage). That value is shown in the ON resistance here.

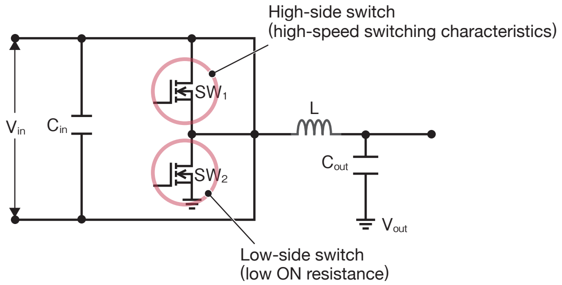


Fig. 1 Power device configuration in DC-DC converter
High-side switch and low-side switch are used in DC-DC converter circuits.

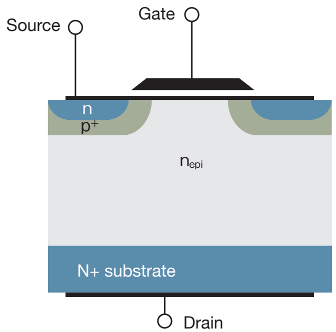
stored in rechargeable batteries is used to drive the motor. It is possible to utilize the power from the batteries to drive the motor directly, but efficiency would be poor. Higher efficiency can be attained by optimizing voltage and current (Fig.1), and this is implemented by power devices. The gate drivers that drive the power devices are also critical, key circuits that turn the power devices on and off. A single inverter in a hybrid or electric vehicle usually requires six gate drivers.

The term power device covers a lot of ground, with a wide range of characteristics and performance. Engineers must find the perfect device for the job, based on a solid understanding of these characteristics. Broadly speaking, the power devices used in power supply circuits can be categorized into three groups: power MOSFET, super-junction (SJ) power MOSFET, and IGBT.

Power MOSFET

The power MOSFET is a MOSFET device designed to handle large amounts of power, and most use the double-diffused MOSFET (DMOS) architecture. Most applications are between a little more than 10V up through about 500V. They combine a low ON resistance with high-speed switching characteristics, and because of their simple structure and high production volume, cost is quite low. They are, in short, the ideal power device, and hold an overwhelming share in application fields ranging from a little more than 10V up through about 500V.

They do have a drawback, however: it is difficult to boost voltage resistance any higher. Voltage resistance can be increased by making the device thicker, but that would also increase ON resistance. A device with a voltage resistance of 30V has an ON resistance of only a few mΩ, but in a 500V design the ON resistance rises to several Ω. While there are devices on the market with voltage resistance of 900V, power MOSFETs become significantly less competitive above 500V.



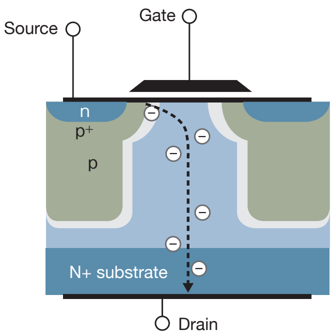
Representative power MOSFET structure
The diagram shows a standard structure, combining a low ON resistance with high-speed switching characteristics.

Super-Junction Power MOSFET

ON resistance rises sharply as voltage resistance exceeds 500V, and the super-junction (SJ) power MOSFET was developed to resolve this drawback. It is one of the newest MOSFET designs, commercialized in 1998. Many manufacturers have released products using the same basic architecture, and today it constitutes its own product class.

The structure of the SJ power MOSFET has a deep p-type epitaxial layer that assures a conductive path and facilitates electron travel in the perpendicular direction. This is another way of saying that ON resistance is reduced. The range of voltage resistance is from about 500V to about 1kV.

SJ power MOSFETs also have a drawback, however, which is price. The deep p-type epitaxial layer demands a relatively complex manufacturing process, which boosts cost.

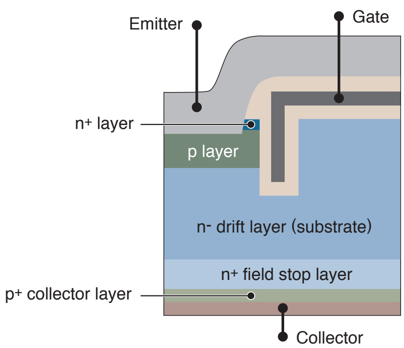


Super-Junction power MOSFET structure
Compared to the standard power MOSFET, the p layer is significantly deeper.

IGBT (Insulated Gate Bipolar Transistor)

IGBTs are the most common type of power device used when high voltage resistance is needed, from 400V to well over 10kV. The input section is MOS, and the output bipolar. This architecture means that while it is a bipolar device (using both electrons and holes as carriers), it has a low saturation voltage (equivalent to ON resistance in a power MOSFET). In spite of the low saturation voltage, it also has relatively fast switching characteristics.

The saturation voltage is now down to about 1.5V, and the switching characteristics up to about 50kHz. The simple structure of a bipolar design means that it is also quite inexpensive in comparison to a power MOSFET with the same voltage resistance. Even though switching characteristics have been improved, though, the IGBT is still inferior to power MOSFETs in this respect. With a power MOSFET, operation is possible at frequencies exceeding 100kHz.

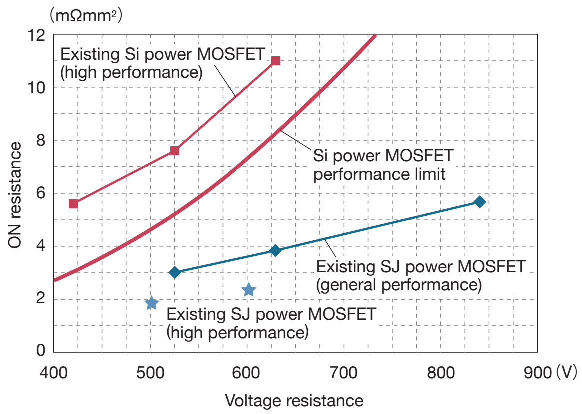


IGBT device structure
The input section is MOS, and the output bipolar.
(Courtesy Infineon Technologies)

Performance Limits of Silicon Devices

Development of next-generation power devices made with SiC and gallium nitride (GaN) is well under way, with some designs already available commercially. One of the reasons these next-gen power devices are bring developed so urgently is that conventional Si-based power devices are approaching their performance limits.

The power MOSFET ON resistance has a performance ceiling imposed by the properties of the Si material. The introduction of SJ structures has made it possible to break this performance limit, but there is very little room left for improvement even in SJ power MOSFET ON resistance. A new material capable of reaching higher levels of performance is needed.



Approaching the performance limits of Si power devices
The introduction of super-junction architecture has made it possible to exceed the performance limits of standard power MOSFETs, but it will be difficult to improve the ON resistance much more.
(Courtesy Infineon Technologies)

Next-Generation Power Device

Inverter power circuits are found in products such as air conditioners, refrigerators, and electric and hybrid vehicles. Next-generation semiconductor devices made with SiC and GaN technologies are expected to make it possible to slash energy loss in such power supplies.

Already commercial products are becoming available that leverage the outstanding properties of SiC and GaN. In August 2001 Infineon Technologies of Germany commercialized an SiC SBD, and both ROHM and Cree, Inc. of the US began volume production of SiC power MOSFETs from late 2010 through early 2011.

Now that the power MOSFETs (JFET) needed for inverters are available, all-SiC inverter designs are possible. Turning to GaN technology, International Rectifier Corp of the US announced a GaN power transistor in Feb. 2010, followed by another from Efficient Power Conversion Corp. of the US in March of the same year.

Halving power losses

Next-generation power devices have enormous potential. If used in inverters, for example, even though there are some differences in output power and circuit configuration, they are estimated to be able to cut power losses by at least half from those of conventional Si power semiconductors. Even better, they would offer smaller mounting footprints and lighter weight, all contributing to improved energy efficiency.

Next-generation power devices offer a variety of advantages over Si power devices. They can offer performance levels so much higher because of the basic properties of the SiC and GaN materials. Three of these properties are especially important (Table 1), namely breakdown voltage, saturated electron drift velocity and thermal conductivity.

Slashing ON resistance to 1/1000

The breakdown voltage of SiC and GaN is a power of ten higher than Si. For a given voltage resistance, then, a power device made with SiC or GaN technology can be made one-tenth the thickness of its Si counterpart. The thinner the device, the shorter the current paths (drift layer) inside the device, which in turn means that the ON resistance can be cut by 90%.

Compared to Si, SiC and GaN also have higher concentrations of dopants, which act as carriers, further lowering the ON resistance. Doping concentration can be increased proportionally to the square of breakdown voltage, so an SiC or GaN device with a breakdown voltage of 10x could handle a doping concentration increase of 100x. That would mean 100x carriers, cutting the ON resistance to 1/100.

ON resistance is reduced by improvement to both breakdown voltage and doping concentration, working together in a multiplicative relationship. In theory, SiC and GaN devices should be able to attain ON resistances of 1/1000 that of Si (Fig.1).

The second property, saturated electron drift velocity, is 2–3 times higher in SiC and GaN than in Si. The higher the velocity, the faster switching becomes. In other words, the higher the switching frequency.

A higher switching frequency means that smaller inductors, capacitors and other peripheral components can be used. In general, inductance and capacitance values in AC circuits are determined as functions of frequency, so for given inductance and capacitance

	Si (silicon)	SiC (silicon carbide)		GaN (gallium nitride)
Bandgap	1.12eV	3.26eV		3.4eV
Dielectric constant	11.9	9.7		9.5
Breakdown voltage	3.0×10^{5}V/cm	2.7×10^{6}V/cm		3.5×10^{6}V/cm
Saturated electron drift velocity	1.0×10^{7}cm/s	2.2×10^{7}cm/s		2.7×10^{7}cm/s
Electron mobility	1350cm^{2}/Vs	1000cm^{2}/Vs		900cm^{2}/Vs
Thermal conductivity	1.5W/cmK	4.9W/cmK		2W/cmK

Table 1 Basic material properties of SiC, GaN and Si
SiC and GaN are significantly superior to Si in breakdown voltage, saturated electron drift velocity and thermal conductivity, and these properties can be utilized to make high-performance power devices. Values shown for SiC are for 4H-SiC crystal.

a higher frequency would mean smaller inductors and capacitors.

The volume of inductors and capacitors are proportional to their value, so if inductance and capacitance can be cut by 90%, so can volume. At present, inductors and capacitors account for a considerable portion of total inverter volume, making higher-frequency operation a critical improvement.

The third crucial property is thermal conductivity. SiC has a thermal conductivity about 3x that of Si, and GaN about 1.4x. The higher the thermal conductivity is, the easier it becomes to transfer heat generated internally to the outside, which in turn means that heat sinks and other cooling components can be made smaller.

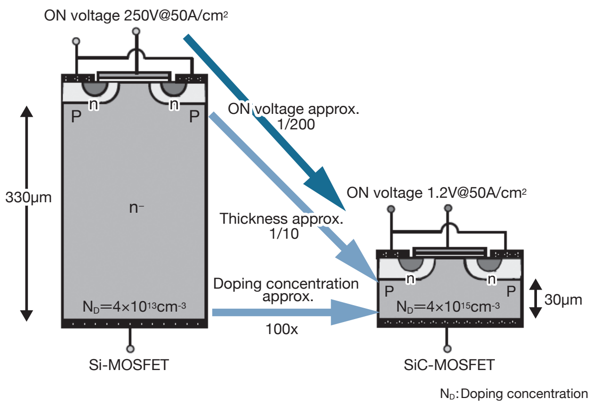


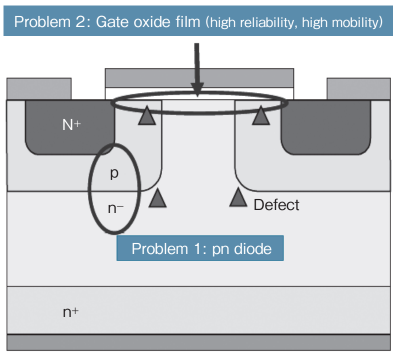
Fig. 1 Slashing ON resistance
Compared to Si power MOSFETs, SiC designs have a breakdown voltage about ten times higher, so device thickness can be cut to a tenth. Doping concentration is about 100x, which means ON resistance can theoretically be reduced to 1/1000 that of Si. AIST has successfully reduced ON resistance to 1/200.

SiC wafer

Next-generation power devices using SiC and GaN materials have made a strong start toward achieving widespread adoption in the market, but there are a number of issues that will have to be resolved before they can really replace Si. “The biggest remaining problem with both SiC and GaN is the wafers,” says Hajime Okumura of National Institute of Advanced Industrial Science and Technology (AIST) of Japan.

There are several issues involved here. In general, SiC power semiconductors use SiC monocrystal wafers, which suffer from two outstanding problems: wafer quality is still not high enough, and wafer diameter is too small.

Dislocation density is behind the wafer quality problem. Dislocation indicates that defects exist inside the wafer, and if the den-



Problems with the SiC power MOSFET
There are two major problems. The first is the pn diodes formed inside the devices, and the second gate oxide film quality. The gate oxide film problem is especially important, because it directly affects device reliability. The most effective solution would be to develop SiC monocrstal with a low dislocation density. (Courtesy AIST)

sity is too high it becomes difficult to pass high currents through the wafer, as well as impacting reliability.

According to Okumura, “SiC monocrystal dislocation density is about $10^4/cm^2$, which is sufficient to manufacture SBDs. It is not good enough for power MOSFETs, though. For power MOSFETs, we really need to improve that to about $200/cm^2$.”

Power MOSFETs require a low dislocation density because of the gate oxide layer, which is constantly charged with a high electric field. If the dislocation density is too high, the device itself will degrade.

Wafer diameter directly tied to cost

The other issue, wafer diameter, is directly related to manufacturing cost. The larger the diameter, the more devices can be diced from a single wafer, which naturally means a lower unit cost.

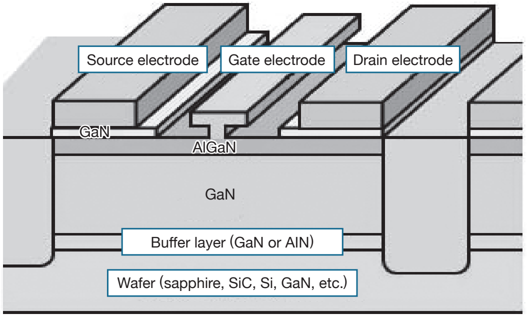
4-inch diameter SiC monocrystal wafers are relatively easy to get hold of, but as Okumura explains, “Four inches is still too small. It will be hard to meet cost demands with anything under six inches.”

An increase in diameter tends to result in an increase in dislocation density, however, and if the density rises too high then it will be impossible to ensure reliability. SiC monocrystal wafer manufacturing must find a way to boost wafer diameter while simultaneously slashing dislocation density.

GaN wafer

The first commercial GaN power semiconductors appeared in the winter of 2010, manufactured using hetero-expitaxial growth technology where the GaN thinfilm is grown on an Si wafer. In this technology the GaN is deposited on a substrate with a different crystalline lattice, making it difficult to manufacture high-quality crystal. “This wouldn’t have been a problem with LEDs, for example, but power devices have much stronger electric fields, and run higher currents. Assuring reliability is a key concern,” says Hajime Okumura, director of the Advanced Power Electronics Research Center at AIST. Voltage resistance was only between several dozen and about 200V, and drain current no more than 30A maximum. Clearly, this approach was not utilizing the outstanding operational characteristics of GaN.

The manufacturing method was changed to homo-epitaxial growth, where the same material is used for both. A GaN wafer is



GaN power device structure
GaN power devices use the high electronic mobility transistor (HEMT) horizontal structure, specifically to increase electron mobility. The switching frequency can be significantly increased, allowing the use of smaller power supply circuits. (Courtesy AIST)

used instead of one made of a different material such as Si or sapphire. GaN monocrystal wafers are already available commercially, but they are not quite good enough yet to use for GaN power devices.

They suffer from two outstanding problems. The first is the small diameter. The largest wafers available at present are two to four inches in diameter, while sapphire is available in 6-inch wafers, and Si in 8-inch and even larger sizes. The smaller the wafer, the fewer devices can be diced from it, naturally boosting the unit cost.

The second major problem is wafer quality. The dislocation density, which is the number of defects present in the interior of the wafer, is about $10^5/cm^2$. According to Okumura, "This level of dislocation density makes it difficult to volume-produce GaN power devices with high voltage resistances, capable of handling large currents. The density has to be reduced to between 10^2 and $10^3/cm^2$."

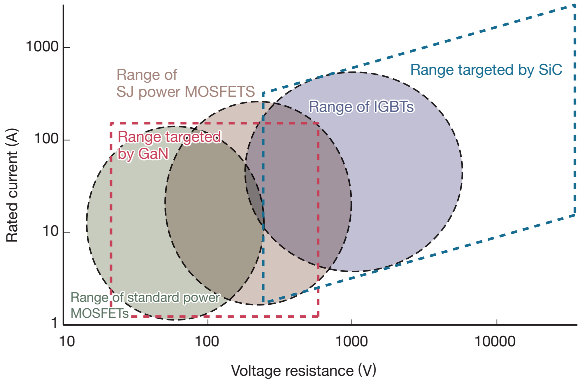
The development of such GaN monocrystal wafers is a priority today, and already there are firms announcing production plans for 6-inch GaN monocrystal, and installing new technologies to slice thinner wafers. Other developers are working on the application of technologies used to manufacture artificial quartz, in hopes of attaining larger wafer size and higher quality simultaneously.

If these wafer problems can be resolved in both SiC and GaN, a host of manufacturers will apply the new devices in a diverse range of applications.

SiC and GaN

The strategy adopted in SiC power devices is clear: they are aiming at the high voltage resistance region above about 600V, beyond what existing IGBT Si power devices can handle. While IGBTs offer relatively low ON resistances, they have low switching speed. An SiC power MOSFET, on the other hand, boasts better ON resistance and switching speed both.

Based on interviews with people in the industry, GaN power devices appear to be aiming at voltage resistance levels below that SiC targets. Concretely, between several dozen and about 600V. This market, however, is already supplied by an array of conventional and SJ power MOSFETs, with quite high-performance designs available at low cost The key to widespread adoption of GaN power devices will be to offer cost/performance well above that of Si power devices.



SiC aiming at voltage resistance above 600V
SiC power devices are being developed for the market of voltage resistance above 600V, while GaN power devices appear to be aiming below that level.

SiC SBD (Schottky Barrier Diode)

SiC Schottky barrier diodes (SBD) were first commercialized by Infineon Technologies of Germany in 2001, followed shortly thereafter by Italian-French joint venture STMicroelectronics, Cree of the US and others.

In Japan, ROHM was the first to begin volume production of the SCS110A series of SiC SBDs, with voltage resistance of 600V and output current of 10A, in April 2010, first resolving outstanding issues such as poor uniformity in the Schottky contact barrier and low-temperature formation of high-resistance guard ring layer. In October of the same year, Mitsubishi Electric mounted a SiC SBD developed in-house in its air conditioner compressor inverters. The manufacturer claims this was the first use of an SiC power device in a consumer product worldwide.

From 2010 a number of manufacturers entered the SiC SBD business: New Japan Radio Co., Ltd. in spring 2010, Shindengen Electric Manufacturing Co. Ltd in July 2010, and Renesas Electronics Corp. in March 2011 all shipped samples. Of those, Shindengen Electric had already begun SiC SBD volume production in Sept. 2006, but had been procuring chips externally. In 2010 they moved chip production in-house, bringing the entire manufacturing line under their direct control.

The increase in the number of SiC SBD manufacturers is due to the favorable change in the environment affecting SiC wafers, indispensible in power device manufacture. Lattice defects had dropped and quality improved overall, and wafer size was growing (Fig. 1) as the industry made the transition to 4-inch wafers. The first 6-inch wafer samples shipped in 2012, with volume production expected to start in 2013.

As the number of wafer manufacturers increased, price competition drove wafer prices down. More and more manufacturers began offering wafer with epitaxial layers already deposited, making it even easier for new players to enter the SiC SBD manufacturing arena.

With the upswing in the SiC wafer area there was also increased demand for SiC diodes. One engineer in the power device sector explains the interest was spurred by recognition that Si diode performance had little room for improvement beyond the level of Si transistors. “Si diodes are simple to manufacture,” he added, “but that structural simplicity also means the limits to performance improvement are approaching fast. Interest in moving to SiC will increase in the future.”

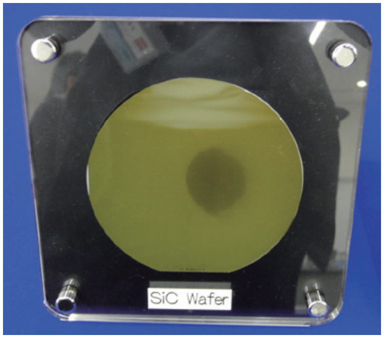


Fig.1 Large diameter SiC wafers
Larger SiC wafers and lower costs are driving business growth in SiC SBDs. Photo shows an SiC wafer manufactured by SiCrystal AG of Germany.

Next-generation products out in 2012

The next generation of products, with improved characteristics, is appearing in 2012.

Renesas Electronics announced the RJS6005TDPP SiC SBD in 2011, but in 2012 announced a package containing it along with a high-voltage resistance Si transistor (Fig. 2). A source at the firm commented “It can be pretty tough finding an existing device that works well with brand-new device like SiC SBDs. This composite device helps reduce that load quite a bit.” The composite device can be used with microcontrollers (MCU) or various control integrated circuits (IC) to easily configure control or inverter circuits, for example. The firm plans to offer a circuit evaluation board (development kit) for air conditioners and other specific applications.

ROHM, the domestic manufacturer that forged ahead of the pack in volume production, is responsible for the improved SiC SBD characteristics. The company developed the SCS210AG/AM SiC SBD with a low forward voltage of only 1.35V, beginning sample shipment in June 2012 (Fig. 3). Compared to their prior design, forward voltage has been reduced by 10%, making it “the lowest in the industry,” according to the firm.

In general, a reduction in forward voltage causes a corresponding increase in leakage current in the reverse direction. ROHM has not disclosed details, but apparently has managed to reduce forward voltage with no impact on leakage current through improvements in manufacturing technology and device structure. In particular, the forward rise voltage is low enough to provide efficiency improvements even in low-load usage states, which are quite common.

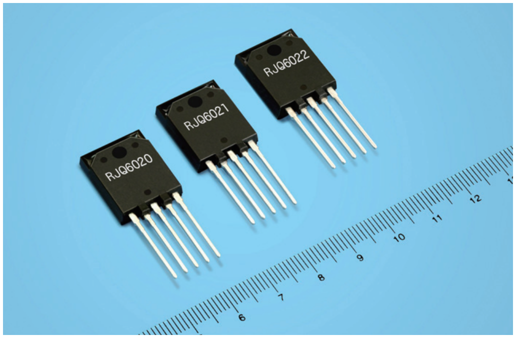


Fig. 2 SiC SBD and Si transistor in a single package
Renesas Electronics has commercialized a single package holding an SiC SBD and Si transistor. (Courtesy Renesas Electronics)

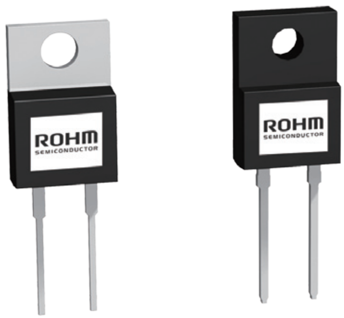


Fig. 3 Reverse direction voltage cut 10%
ROHM has developed an SiC SBD with forward voltage 10% lower than the firm’s prior design. (Courtesy ROHM)

SiC MOSFET

While SiC transistors are available on the merchandise market already, SiC diodes are few and far between, with only a few scattered applications. The manufacturing process for diodes is considerably more complicated than for transistors, cutting yield and boosting cost. And while the pace of Si transistor improvement has slowed somewhat, they are still evolving and remaining competitive. Compared to diodes, advises one engineer in the field, "They still have plenty of room to grow." At present, then, it is far easier to utilize cheap, high-performance Si transistors.

However, R&D is accelerating into slashing SiC transistor cost and fully utilizing the outstanding characteristics of SiC to achieve performance levels that Si cannot match. Many firms are working on MOSFETs, because of all the transistor types available they can easily offer the ideal "normally off" mode.

ROHM began shipping SiC MOSFETs as custom products in Dec. 2010, and in Jan. 2011 Cree announced a commercial design (Fig. 1). ROHM went on to improve reliability by developing its own electric field reduction architecture and screening method, as well as a way to minimize characteristic degradation due to the 1700°C process demanded by SiC, establishing the "world's first" volume production stance, according to the firm. Cree also claims to have offered the "first commercial device in the world."

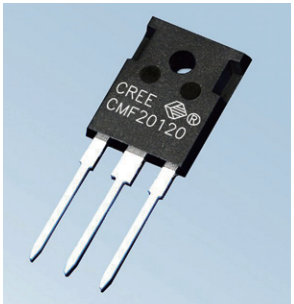


Fig. 1 Volume production SiC MOSFET
The volume-produced SiC MOSFET announced by Cree in Jan. 2011. (Courtesy Cree)

Reducing ON resistance

SiC MOSFETs normally have high loss when conducting, and R&D is working to find ways of reducing ON resistance to slash these losses. The goal is to cut ON resistance to less than 1/10 that of an Si power device.

One method of accomplishing this is the trench method: forming a trench directly under the gate. The SiC MOSFETs on the market now are planar. In planar designs, if a smaller cell is used in an effort to reduce channel resistance, it causes an increase in junction field effect transistor (JFET) resistance, creating a floor on ON resistance. With a trench, however, there is no JFET resistance, making it possible to reduce channel resistance and ON resistance both.

ROHM, for example, has already prototyped an SiC MOSFET design achieving an ON resistance 1/20 that of an Si MOSFET, and 1/7 that of the volume-produced SiC MOSFET (Fig. 2). As substrate resistance is also reduced, in addition to channel resistance, the prototype attains an ON resistance of 0.79mΩ/cm^2 for a voltage resistance of 600V, and 1.41mΩ/cm^2 at 1200V. Although the trench design offers lower ON resistance, the fact that the trench is directly below the gate makes volume production more difficult than planar. This design is not in volume production yet, but ROHM and other firms are expected to ship in 2013.

HOYA Corp. of Japan has prototyped an SiC MOSFET with a 3C crystalline structure. SiC power devices on the market now are 4H structures. The advantage of 3C is that the crystal can be grown directly on the Si wafer, reducing materials expenses and facilitating the shift to larger-diameter wafers, which are expected to cut total cost. Productivity is also likely to improve as the faster vapor-phase growth method can be used.

A 3C SiC MOSFET is likely to enjoy high channel mobility as well, because of the higher quality of the gate oxide film interface and the lower interface level which would otherwise capture electrons from the channel. The prototype MOSFET achieved peak channel mobility of 370cm^2/Vs at room temperature, or roughly 3 times better than the 4H design. The prototype retained a mobility of 178cm^2/Vs even when junction temperature reached 300°C.

HOYA is continuing R&D into 3C SiC MOSFETs, but has no plans to sell devices, only the 3C SiC wafers. They are investigating MOSFETs to demonstrate the utility of 3C SiC and boost wafer sales.

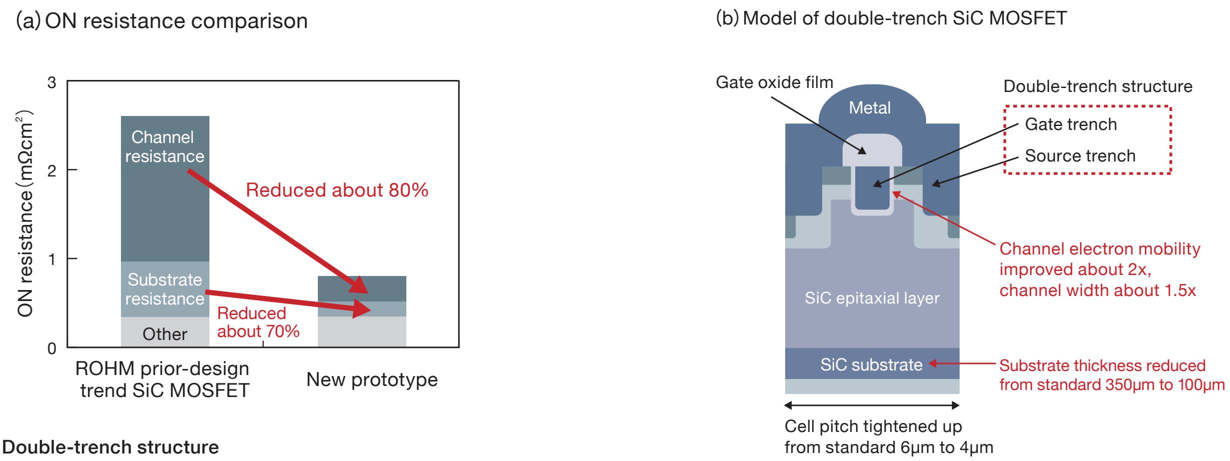


Fig. 2 Double-trench structure
ROHM has prototyped a trench-type SiC MOSFET with low ON resistance. In the double-trench design, both gate and source have trenches, helping minimize field concentration at the gate. (Based on material courtesy ROHM)

SiC BJT (Bipolar Junction Transistor)

A number of R&D papers have been published on improving the current amplification ratio in SiC bipolar junction transistors (BJT). The higher the ratio, the lower the current needed by the BJT for switching operation, and therefore the smaller the BJT control circuit. While the BJT does offer a low ON resistance, the fact that it requires current control means that the BJT control circuits are usually quite bulky. Honda R&D Co., Ltd. of Japan, which is working on high-current designs for automotive applications, has revealed the development of 50A and 100A devices collaboratively with Shindengen Electric. The 50A chip measures 0.54cm^2 in area, with an active region of 0.25cm^2. The current amplification ratio at room temperature is 145, or 50 at 250°C. The voltage resistance is 1100V, and ON resistance at room temperature 1.7mΩ/cm^2. The 100A device has a 0.79cm x 0.73cm footprint, with an active area of 0.5cm^2, a room-temperature current amplification ratio of 135, and 72 at 250°C. The voltage resistance is 1200V, and ON resistance 3.5mΩ/cm^2 at room temperature or 6.6mΩ/cm^2 at 250°C.

A research group at Kyoto University, meanwhile, has prototyped SiC BJTs with significantly higher current amplification ratios at room temperature: 257 and 335 (Fig. 1). With a ratio of over 200 at room temperature, the research group expects it will remain "over 100" even at elevated temperatures of 200°C. This would open up applications including photovoltaic power generation system power conditioners, motorized vehicle power control units and industrial inverters, among others.

Kyoto University reached 257 with three major improvements (Fig. 2), and by changing the crystal face used in BJT formation was able to boost it further to 335. The group is now working on improving voltage resistance and reliability while lowering cost.

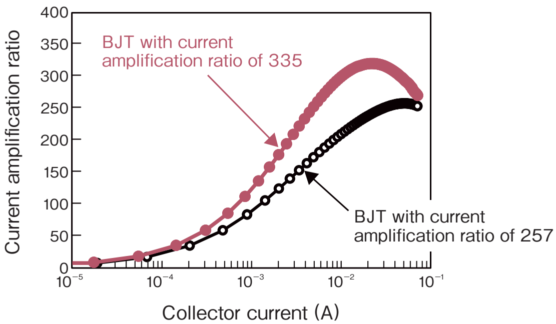


Fig. 1 Current amplification ratio over 200
Current amplification ratio for BJT prototyped by Kyoto University. (Based on material courtesy Kyoto University)

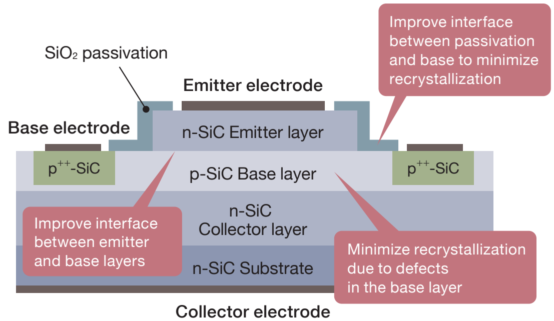


Fig. 2 Boosting current amplification ratio with three major improvements
The three key improvements were modifying the interface state between the passivation film and the base layer; suppressing impurities on the interface between emitter and base layers; and minimizing recrystallization due to defects in the base layer. (Based on material courtesy Kyoto University)

SiC module

Packaging technology is critical in realizing the full potential of next-generation power semiconductors. Key technical issues include encapsulation material, heat resistance of bond material, and cooling capacity. The first commercial SiC modules offering resolutions to these problems are appearing in 2012.

ROHM began volume production of “full SiC” power modules—made with SiC transistors and diodes—in March 2012. Modules using SiC diodes have been available for some time, but ROHM claims that this is the “first commercial module in the world” to use SiC transistors as well.

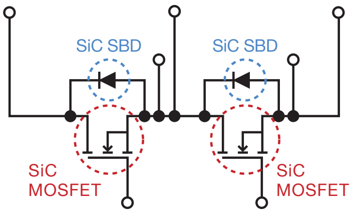
Compared to power modules using Si IGBTs, the full-SiC module has 85% lower switching loss, explains ROHM, and it is capable of high-speed switching at 100 kHz and above. This switching frequency is about ten times higher than what an Si IGBT module can offer.

The volume-production full-SiC module is currently only available in one specification: rated voltage 1200V, rated current 100A. Although the rated current is only 100A, high-speed switching and lower loss means it can be used to replace Si IGBT modules for 200A to 400A applications. If used to replace a 400A class Si IGBT, says ROHM, it would roughly halve needed volume.

Mitsubishi Electric began sample-shipping a range of SiC modules from July 2012. The firm has been using SiC power devices in its own air conditioners, power modules for rail use and other products, but says this is the first release of an SiC power module to the merchandise market. Of the five new products, three have voltage resistance of 600V for household appliances, and the remaining two 1200V for industrial use. The firm will release one full-SiC module in each category in the future.

(a) Full-SiC power module

(b) Power module schematic



(c) Power module outline

Rated voltage	1200V
Rated current	100A
Switching frequency	100kHz and higher
Dimensions	122mm × 46mm × 17mm (excluding pins)
Price	3x to 5x IGBT module price
Production scale	Unknown (Kyoto plant has production capacity of several thousand modules/month)

Full-SiC power modules enter volume production
Rated voltage is 1200V and rated current is 100A. The module is made with SiC transistors and diodes only.

GaN power device

Three major issues have prevented the commercialization of GaN power devices thus far, namely:

- Difficulty in reducing cost. The wafers needed for GaN devices have all been small-diameter, keeping prices high.
- Poor electrical characteristics. While GaN itself has outstanding material properties, when used in a power device electrical characteristics are inferior to even those of Si power devices.
- R&D into peripheral technologies needed to really utilize GaN power devices hadn't advanced far enough. For example, there were no dedicated gate driver ICs for GaN transistors, so drivers had to be made of discretes.

The situation has changed dramatically of late, though (Fig. 1). GaN power device costs are steadily dropping, and at last it appears they will drop to the level of Si power devices now that they can be manufacturing using cheap, large-diameter Si wafers. Si wafers, of course are available in 6-inch and larger sizes.

There has also been considerable improvement in electrical characteristics. Researchers have figured out how to remedy most of the characteristics that are inferior to those of Si power devices, such as controlling the "current collapse" phenomenon that causes ON resistance to jump at activation, or boosting voltage resistance. Powdec KK of Japan has suppressed current collapse by inserting undoped GaN and p-type GaN layers between gate and drain (Fig. 2), achieving a 1.1kV voltage resistance on sapphire and "essentially zero" ON resistance rise at activation. As a result, 600V voltage resistance devices appearing from the second half of 2011 through 2012 exhibit a rise in ON resistance to current collapse of only about 1.1x to 1.3x.

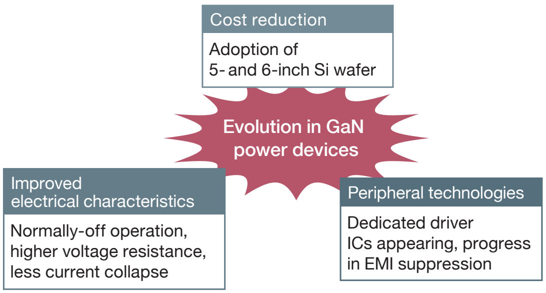


Fig. 1 Resolving GaN power device issues
The three key outstanding problems in GaN power devices are being resolved: Engineers have figured out how to drop costs and improve electrical characteristics, and peripheral technologies are making steady progress.

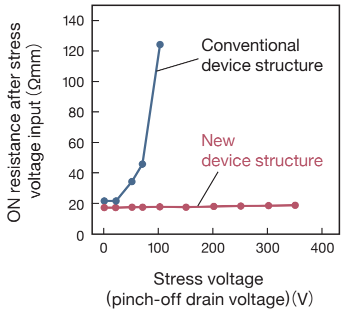


Fig. 2 Suppressing current collapse
Powdec has inserted undoped GaN and p–type GaN layers between gate and drain to allow higher voltage resistance while suppressing current collapse. This structure makes electric field concentration less likely, reducing leakage electrons and suppressing current collapse. (Based on material courtesy Powdec)

While commercial products only offer voltage resistance of up to 200V, researchers have achieved 1kV in the lab. The R&D Partnership for Future Power Electronics Technology (FUPET) has announced a GaN power device with a voltage resistance of 1.7kV (Fig.3). It was achieved by increasing epitaxial layer thickness to 7.3μm overall, thinning the undoped GaN layer to 50nm, and adding a C-doped GaN layer.

Panasonic Corp. of Japan has developed constituent technology capable of boosting voltage resistance to 2.2kV. A p-type layer is added near the Si wafer surface, suppressing leakage current from the inversion layer, generated at the interface between the Si wafer and the GaN, when +V is input to the drain (Fig. 4). This modification resulted in a voltage resistance of 2.2kV with a GaN epitaxial layer of 1.9μm, and researchers believe the same structure can be used to boost it to over 3kV.

Technological progress is also being made in areas surrounding the GaN power devices. Some of the normally-off GaN power devices available accept only very low input voltages. The 100V design from Efficient Power Conversion Corp (EPC) of the US, for example, has an input voltage range of –5V to +6V, considerably narrower than the ±20V of a MOSFET with the same voltage resistance, limiting the voltage to the gate. National Semiconductor Corp of the US, however, has developed a gate driver IC with protect function that prevents excessive voltage from being input to gates.

Research is also ongoing into high electron mobility transfer (HEMT) GaN semiconductors. In 2012, for example, ROHM began development of such a device for specific applications. By boosting the switching frequency and shrinking smoothing circuit capacitors and coils, it will be possible to make switching power supplies smaller. The firm also hopes to leverage high-speed switching characteristics to pioneer new applications such as wireless power supply systems.

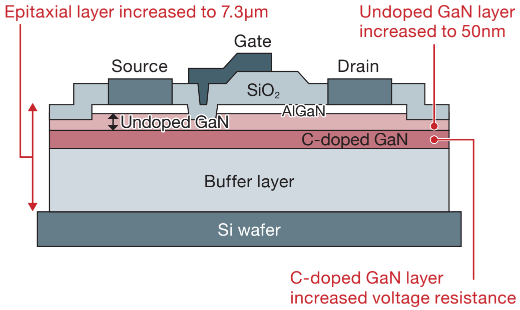


Fig. 3 Attaining a 1.7kV voltage resistance
FUPET has developed a normally-off GaN power device with a voltage resistance of 1.7kV.

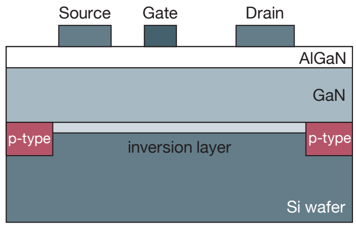


Fig. 4 Suppressing leakage current to boost voltage resistance
Panasonic added a p-type layer near the Si wafer surface to boost GaN power device voltage resistance. This reduces leakage current from the inversion layer, generated at the interface between Si wafer and GaN, when +V is to the drain. (Based on material courtesy Panasonic)

Gallium oxide

β-type Ga_20_3, one variety of gallium oxide, offers the potential for power semiconductors that can be made with higher voltage resistance and lower loss, for less money, than even the SiC and GaN materials being developed now for next-generation power devices.

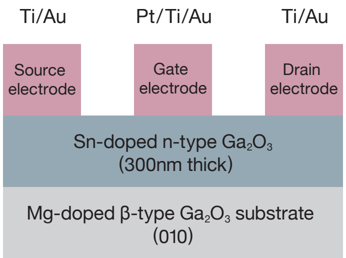
It all started with a β-type Ga_20_3 transistor prototyped jointly by the National Institute of Information and Communications Technology (NICT) of Japan, Tamura Corp. of Japan and Koha Co., Ltd. of Japan (Fig. 1). Under a research grant from the New Energy and Industrial Technology Development Organization (NEDO) of Japan for R&D into ultra-high voltage resistance gallium oxide power devices, as part of the Japanese governments project to develop new technology to reduce energy consumption, Tamura and Koha were in charge of substrate fabrication, Kyoto University and Tokyo Institute of Technology handled epitaxial growth, and NICT took care of process technology.

The finished transistor is a metal-semiconductor field effect transistor (MESFET), using a Schottky junction metal gate electrode. The simple structure does not have any passivation film, but still achieves a voltage resistance of 257V with a leakage current of 5µA/mm.

Surpassing SiC and GaN

The physical properties of the material are simply superior to those of SiC and GaN, making it possible to deliver higher voltage resistance with lower loss (Fig. 2). In particular, the bandgap and field breakdown values are high. The β-type is the most chemically stable of the Ga_20_3 varieties, offering a bandgap of 4.8eV to 4.9eV. This is about 4x that of Si, and still higher than the 3.3eV of SiC and the 3.4eV of GaN. The field breakdown is thought to be about 8MV/cm, roughly 20x that of Si and over 2x that of SiC and GaN.

(a) Model of prototyped device



(b) Electrical characteristics of prototype

Voltage	257V
Leakage current (drain off)	3µA (5µA/mm)
Drain current on/off ratio	10^4
Peak transconductance	1.4mS (2.3mS/mm)

Fig. 1 Prototype β-type Ga_20_3 transistor
A research team including NICT has prototyped a β-type Ga_20_3 transistor (a). The simple structure attained a high voltage resistance of 257V (b).

As a result, a unipolar power device with the same voltage resistance made with β-type Ga_20_3 will attain, theoretically, much lower ON resistance than with SiC or GaN. The lower ON resistance means lower power losses in the power supply circuit.

It is possible the material may also beat SiC when it comes to voltage resistance. With a passivation film and a field plate to alleviate electric field concentration at the gate, an engineer at NICT estimates a unipolar transistor should reach "3 to 4kV."

Ga_20_3 also offers an advantage in that it can utilize melt growth technologies such as floating zone (FZ) and edge-defined film-fed growth (EFG). These methods produce minimal lattice defects, facilitating low-cost volume production of large-diameter wafers.

The FZ and EFG methods are being used now in the manufacture of sapphire wafers for blue light-emitting diode (LED) chips. Sapphire substrate can be made at low ost with minimal lattice defects, in diameters of six or eight inches. Because SiC and GaN wafers are made with vapor-phase manufacturing technology, it is much harder to reduce defects and achieve larger wafer diameters.

The Ga_20_3 substrate used in the prototype transistor was made with the FZ method, and measures only 6mm x 4mm. NICT comments, however, "We believe it will be possible to manufacture 6-inch Ga_20_3 wafers for about 10,000 yen in the future. It seems unlikely that SiC wafers can be made that inexpensively."

While Ga_20_3 offers enormous potential, full-scale R&D has yet to begin. The prototyped transistor doesn't offer good enough performance for voltage resistance, output current or current on/off ratio, and has excessive leakage current. Worse, there are also unresolved issues like how to implement normally-off operation.

(a) Comparison of physical properties

Material	β-type Ga_2O_3	Si	SiC(4H type)	GaN	Diamond
Bandgap (eV)	4.8～4.9	1.1	3.3	3.4	5.5
Mobility (cm^2/Vs)	300(est.)	1400	1000	1200	2000
Field breakdown (MV/cm)	8 (est.)	0.3	2.5	3.3	10
Dielectric constant	10	11.8	9.7	9	5.5
BFOM ($\varepsilon\mu E_c^3$)	3444	1	340	870	24664

(b) Relationship between voltage resistance and ON resistance

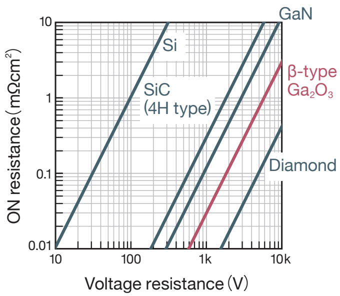


Fig. 2 Material properties superior to SiC, GaN
β-type Ga_20_3 has especially high values for bandgap and field breakdown, along with a high Baliga figure of merit (BFOM) indicating low loss (a). For a given voltage resistance, a chip made with β-type Ga_20_3 would have lower ON resistance than one made with GaN or SiC. (Based on material courtesy NICT)

Automotive

SiC power devices may make possible dramatic reductions in size and weight in various drive systems such as inverters and DC-DC converters, in hybrids, electric and fuel-cell vehicles. Automotive manufacturers are very, very interested in the technology.

Toyota Motor Corp. of Japan touched on its expectations for SiC at a recent conference presentation, listing smaller power modules as a major advantage of SiC power devices. For an intelligent power module (IPM), for example, they estimated SiC power devices would cut volume by between one-third and two-thirds compared to a module using conventional Si power devices.

If SiC power devices are used to boost the switching frequency, they suggest it will also be possible to reduce the volumes of capacitors, reactors and other components. Concretely, boosting the switching frequency to 8x, estimate the Toyota engineers, it should be possible to drop capacitors to 20 or 30%, and reactors to 25% of current volumes.

Flurry of new developments announced

In response to automotive manufacturer demand, a host of new inverters and other items are being developed. DENSO Corp. of Japan, for example, showed a demo and provided specs on its new inverter (Fig. 1) delivering an output power density of 60kW/L, at Automotive Engineering Exposition 2012 (May 23-25, 2012). It was based on collaborative R&D with Toyota Motor and the Toyota Central R&D Labs., Inc. of Japan.

The inverter uses SiC for the power semiconductors instead of the conventional Si, with a unique internal architecture that reduced internal resistance and power loss. Modifications to the power module internal wiring reduced overall module resistance, cutting heating by 68% from the standard design.

The inverter has a volume of 0.5L and output density of 60kW/L at 30kW output. The power device reaches 180°C in this state. In addition to the module with SiC power devices, the inverter also mounts the control circuitry needed by the devices, cooling fan, and capacitors.

Mitsubishi Electric has developed an electric vehicle motor system with 70kW class output, as an integrated unit mounting inverter and motor on a single shaft (Fig. 2). Compared the firm's prior system with separate inverter and motor, the new design cuts volume by half. The integrated approach also reduces wiring length between inverter and motor, making it possible to use a single water-cooling tube for both, reducing mass by about 10%.

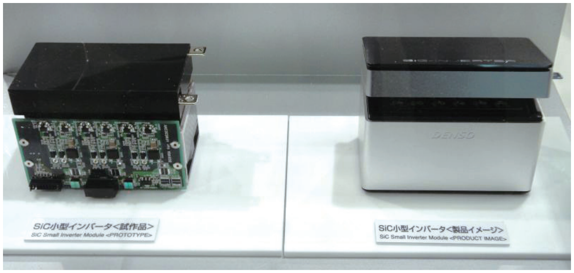


Fig. 1 DENSO inverter prototype
Prototype (left) and design for packaged product.

A source at the firm reveals “The biggest problem was how to cut down on the heat generated.” Motors and inverters are both big heat generators, so instead of boosting cooling performance engineers found ways to reduce heat output at the source. Concretely, they reviewed magnetic design of the motor, and switched to SiC power devices in the inverter. As a result, inverter power loss dropped to about half that of the prior design using Si power devices. Mitsubishi Electric plans to commercialize an electric vehicle motor system in 2014, first one using Si power devices with a separate motor.

ROHM and Yaskawa Electric Corp. of Japan have jointly prototyped a driving system for electric vehicles (Fig. 3), consisting of the propulsion motor and the motor drive. The drive uses ROHM SiC power devices, and has been integrated with the motor along with the winding selector, inverter, gate driver IC, microcontroller and peripheral components. The motor and driving system were separate in the design using Si power devices.

The prototyped system was based on the QMET driving system for electric vehicles already sold by Yaskawa Electric, but has been dubbed SiC-QMET for its use of SiC power devices, specifically the trench-type MOSFET and SBD products developed by ROHM.

Fig. 2 Mitsubishi Electric integral-inverter motor system
Volume is about half that of a system with separate inverter and motor.

Fig. 3 Driving system developed by ROHM and Yaskawa Electric
Motor integrated with winding selector, inverter, and controller (including gate driver IC and microcontroller).

Car audio system

Bewith Enterprise, Ltd. of Japan, specializing in high-grade car audio systems, offered a demonstration of its A-110S II power amplifier mounting SiC SBDs at the 42nd Tokyo Motor Show (Dec. 3-11, 2011). High-end vehicles like the Peugeot 308CC and Mercedes-Benz SLR McLaren Roadster mount several of these power amps, positioning audio quality as a key selling point (Figs. 1, 2). With their low noise and quick power-on response, says Bewith, "They can reproduce quiet, even intermittent music, beautifully. No matter what the genre, they are as close as you can get to the original sound source."

The SiC SBDs in the A-110S were jointly developed by Bewith and New Japan Radio Co., Ltd. of Japan. Two SiC SBDs, named the BD01, are used in the A-110S II amplification circuit power supply line, increasing power supply stability merely by being swapped in to replace prior Si SBDs. More stable amp circuit operation translates directly to improved audio quality.

According to New Japan Radio, there are two key reasons for the improved stability, the first of which is faster switching, possible because the SiC SBDs have a recovery time a third that of Si SBDs, at a quarter of current. The power supply now tracks load fluctuations due to audio output change much more accurately, the firm explains. The second reason is that SiC crystal has fewer defects, minimizing the leakage current they cause. When such leakage current occurs, it increases white noise in the power line.

Fig. 1 Power amplifier in Peugeot 308CC trunk
The SiC SBDs in the power amp were jointly developed by Bewith Enterprise and New Japan Radio.

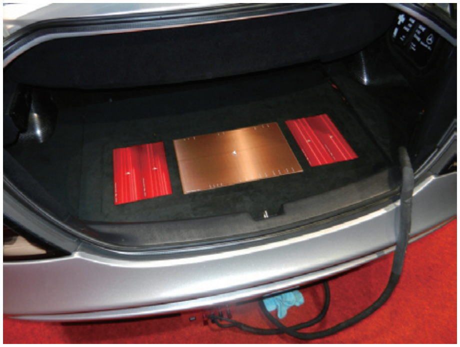


Fig. 2 Power amplifier in trunk of Mercedes-Benz SLR McLaren Roadster
The use of SiC SBDs stabilized power amp operation, thereby improving audio quality.

Railway

The development competition for SiC power semiconductors is intensifying in the railroading sector (Fig. 1). First on the scene was Mitsubishi Electric Corp. of Japan, which announced an inverter product line mounting SiC SBDs in Oct. 2011, for use in railway car motors. The inverters are used in some 01-series cars on the Tokyo Metropolitan Subway Ginza Line now.

Next was Toshiba Corp. of Japan, which announced its own SiC SBD-equipped inverters in Dec. 2011. Both companies use 1700V power modules, designed specifically to handle the DC600V/750V supplied from the aerial power lines. Hitachi Ltd. of Japan announced an inverter with a rated voltage of 3300V, for DC1500V aerial lines, in April 2012.

There are four major reasons for the adoption of SiC in railroading. First in that the technology may be able to reduce power loses in the railway carriage system. Estimates by Mitsubishi Electric, for example, suggest that overall carriage system power loss can be cut by about 30% from levels achieved with Si diodes. Second is smaller and lighter inverters, and because they generate less heat, cooling systems can also be made smaller. Mitsubishi Electric estimates that volume and mass both can be cut about 40% by switching to SiC SBDs. Third, there is not much room for improvement in Si diode performance, agree several engineers in the field, because diodes are structurally so much simpler than transistors. Switching to SiC significantly expands the potential for improvement.

Fourth and last is the adoption of a cost recovery model based on long-term utilization in the rail industry. SiC has been recognized for some time for its superior characteristics, but its high cost has limited it to only a few applications. In the rail industry, however, the reduction in operating cost over the long term makes widespread adoption possible.

Mitsubishi Electric

Toshiba

Hitachi

Power module performance	Mitsubishi Electric	Toshiba	Hitachi
Rated voltage	1700V	1700V	3300V
Rated current	1200V	1200V	1200V

Fig. 1 New SiC inverters
Mitsubishi Electric, Toshiba and Hitachi have all developed inverters using SiC diodes. The first two offer voltage ratings of 1700V, while the Hitachi inverter is rated at 3300V. (Center photo courtesy Toshiba, right courtesy Hitachi)

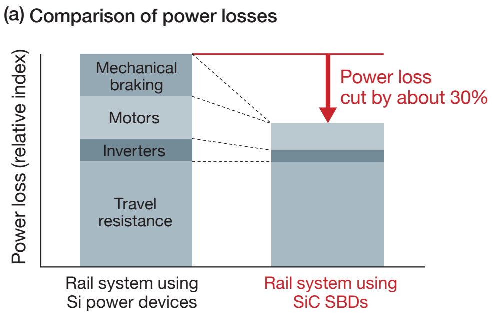
Reduced switching loss

Of these four, the one with the greatest impact is cutting power loss (Fig.2). In railroading, power losses would be cut for several reasons, specifically lower switching loss in the inverter, more energy recovered through regeneration, and lower motor losses.

Switching losses will be reduced by the adoption of SiC SBDs. They offer response significantly better than conventional Si diodes, making it possible to cut power loss by 55% with IGBT turn-on, and diode switching loss by 95%, according to estimates by Mitsubishi Electric.

Regenerative power gains are possible because of the wider range of carriage speeds that can be used to produce the needed braking force. The prior Mitsubishi Electric system for rail use combined mechanical braking with regenerative power at speeds above about 35km/h or 40km/h. Using regenerative braking alone caused higher Si power device losses, leading to excessive high junction temperatures that could exceed permissible ceilings. With SiC power devices, the higher permissible temperature means regenerative braking alone an be used up through 70km/h, producing roughly double the energy, explains a source at the firm.

The use of SiC power devices also helps reduce motor losses. With an induction motor, for example, the current waveform to the motor can be close to a sine wave, which (according to Mitsubishi Electric) can cut induction motor loss by about 40%.



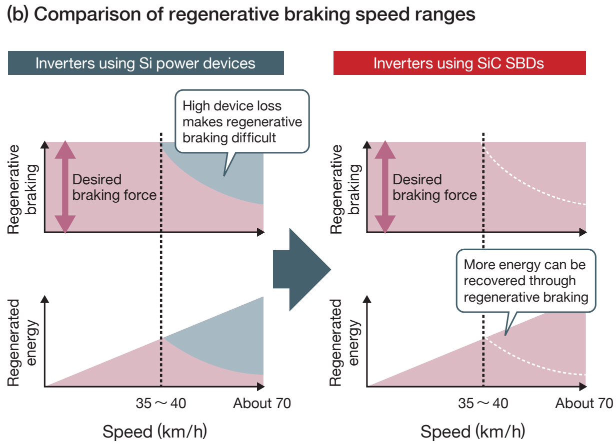


Fig. 2 Potential for lower power loss
Mitsubishi Electric estimates show that switching from Si power devices to SiC SBDs in the railroad carriage system could cut power losses by about 30%. In addition, the wider range of speeds at which regenerative braking could be used would provide more regenerative energy. (Based on material courtesy Mitsubishi Electric.)

Photovoltaic system

Mitsubishi Electric has prototyped a power condition for photovoltaic systems using SiC MOSFETs and SBDs (Fig. 1). Power conditioners convert the power generated by the photovoltaic system into power that can be effectively utilized.

The prototyped power conditioner replaces the Si power devices in the power module (with step-up circuit and inverter circuit) with SiC power devices. Conversion efficiency jumped 2%, to 98%, over the firm's mid-range PV-PN50G1 power conditioner using Si power devices and the same circuit configuration.

The improvement to 98% was not only due to the switch from Si to SiC, though: the firm also modified the materials used in the AC reactor and made other changes. The actual measurement showed 98.2% conversion efficiency, but the firm announced it as 98% to take possible measurement variation into account (Fig. 2).

The power conditioner with the highest power conversion efficiency offered by Mitsubishi Electric for use with photovoltaic systems is currently 97.5%. It used Si power semiconductors with an inverter technology called "gradational control." The full-SiC prototype does not use this control technology, but researchers are adapting the prototype to use it in the near future.

French-Italian joint venture STMicroelectronics has adopted the STPSC806G SiC SBD in its microinverter reference model to achieve a conversion efficiency of 95% or higher. Microinverters are used to implement power conditioner functions into individual photovoltaic modules.

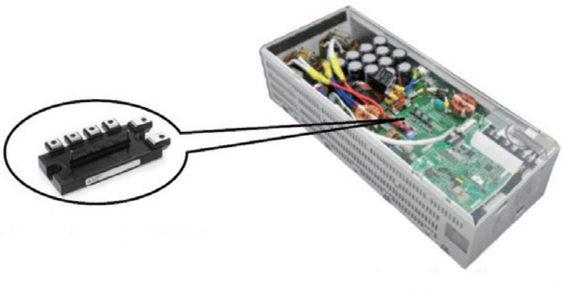


Fig. 1 Power conditioner for photovoltaic systems
Mitsubishi Electric has prototyped a power conditioner for photovoltaic systems using a full-SiC power module. (Courtesy Mitsubishi Electric.)

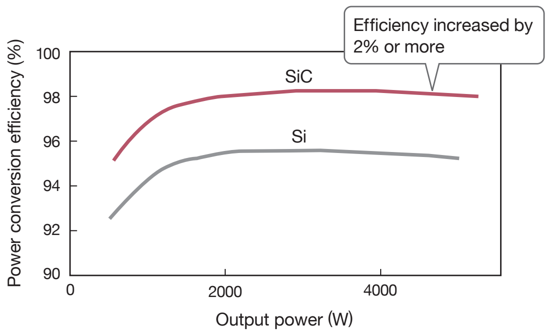


Fig. 2 98% conversion efficiency
Conversion efficiency was improved to 98%, up 2%, through the use of SiC power devices. (Based on material courtesy Mitsubishi Electric.)

Household appliance

Within the household appliance category, SiC SBDs have already been used in air conditioners. Mitsubishi Electric announced ten models in its Kirigamine MSZ-ZW Series in late October 2010, of which two (2.8kW and 3.6kW) used SiC SBDs in the compressor inverters (Fig. 1). The company has not disclosed the shipment volume for individual models, but total monthly production of 20,000 units was planned for the entire ZW series, ranging from 2.2kW to 7.1kW rated output. The firm explained that it absorbed the increased cost due to the SiC SBDs, without reflecting it in product pricing.

The reduced energy consumption gained from just SiC SBDs, though, was limited. "The switch to SiC SBDs cut inverter power consumption by about 15%, and total air conditioner power consumption by about 2%," says a source at the company. Greater energy savings and smaller power modules demanded the wholesale adoption of SiC power semiconductors throughout (Fig. 2), and Mitsubishi Electric had no choice but to wait until IGBTs could be replaced by SiC MOSFETs.

It appears that the company didn't make the decision to adopt SiC SBDs in the air conditioner to save energy, but rather to stimulate the SiC industry and boost competitiveness over the competition. The company explains "At present, SiC wafers are pretty much monopolized by Cree, and that means wafer prices remain high. By leading the way in SiC adoption, we hoped to stimulate other SiC wafer manufacturers, so that competition would bring prices down."

Wireless power supply system prototyped

A second example of adoption of SiC power semiconductors in the household appliance sector is the wireless power supply system prototyped by ROHM in 2011. Utilizing magnetic field cou-

Fig. 1 Air conditioner with SiC SBDs
One of the models in the Kirigamine MSZ-ZW Series of air conditioners from Mitsubishi Electric, equipped with SiC SBDs.

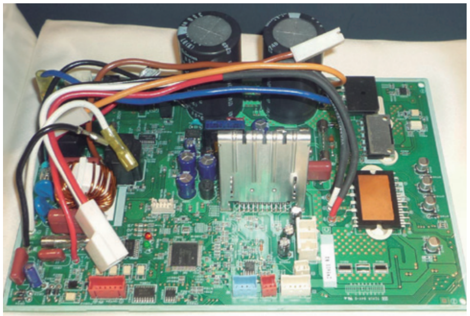


Fig. 2 Inverter module
The air conditioner inverter board. The red dashed circle is the inverter module, with SiC SBDs mounted.

pling, the transmitter side is equipped with SiC trench-type MOSFETs (Fig. 3). This design allows the inverter to attain a conversion efficiency of 95% at a switching frequency of 6.78MHz.

The prototyped system can pump up to 50W, according to the developer, which has demonstrated the system running wall-mount OLED lighting and desktop light, and recharging smartphone internal rechargeable batteries.

The prototype is merely a technology platform designed to demonstrate the outstanding characteristics of SiC power devices, and ROHM has no plans to develop an actual wireless power supply system. ROHM has not disclosed the name of the firm which did develop the system for it.

Fig. 3 Wireless power supply system inverter
The transmitter inverter circuit uses SiC trench-type MOSFETs.

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