On the Road to Higher Efficiency

After the Silicon Carbide User Forums organised by ECPE in 2006 and 2007, the time had come to continue the exchange between experts involved in converter and device development. The third User Forum (September 11-12, Barcelona, Spain) also considered other wide bandgap devices for the first time, in particular Gallium Nitride (GaN). Again, it has focused on typical power electronic systems. The use of wide bandgap is highly promising for electric drives, converters in transportation and power supplies. Additionally, an insight in recent material and device technology, which is the base for future system development, has been given.

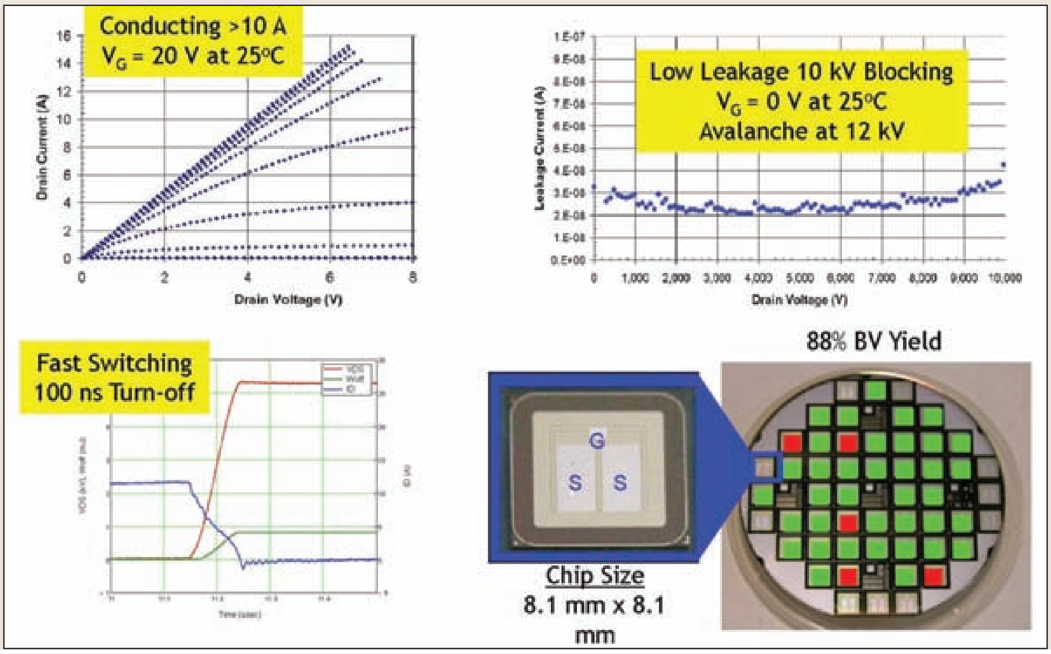
Starting at the beginning of the supply chain, the SiC material situation is no longer a concern: while cost has decreased over the course of time, wafer quality has increased, permitting devices to be produced with an area of some 25mm² at 75/100mm diameter wafers with appropriate yield. This is suitable for a nominal power in the Kilowatt range and can be extended by parallel connection of devices.

According to Cree's Marketing Manager Gregory Mills, a significant downward cost trend on unit area basis can be observed, i.e. current Schottky-like EPI wafers cost $15/cm². Three years ago, pricing was $25/cm² and eight years, ago 40/cm², a 60% decrease. And this trend will continue with the introduction of 150mm wafers in the year 2011 at $5/cm². SiC epitaxial capability will be developed simultaneously. Regarding defect density, yield on wafer level improves continously and reaches 98% for 2mm² chips such as diodes. Larger chips of 8.1 x 8.1mm for a 10kV/10A SiC MOSFET have a 88% yield. Nevertheless, SiC starting material is around ten times more expensive than Silicon.

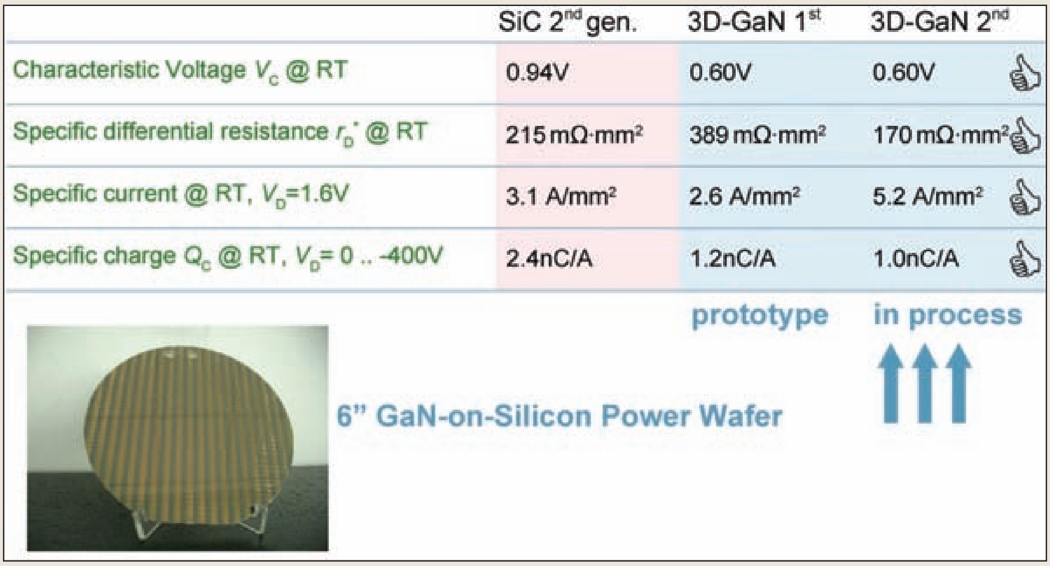
Schottky diodes with voltage ratings of typically 600 and 1200V are commercially available from various vendors such as Cree, Infineon/SiCED, or ST Microelectronics, and are used in different kinds of converters, often together with Silicon transistors; this combination permits significant reduction of switching losses, thus to downsize the transistors or to increase efficiency. SiCED's Peter Friedrichs pointed out that the solderless method with optimised leadframe, higher current density and multichip mounting option, efficiently utilises the high thermal conductivity of SiC in Infineon's 3rd generation of SiC diodes (see also PEE 3/2009, pages 24-27). SiCED is also working on 6.5kV SiC switches, but for the near future, a displacement of Silicon in power electronics is not yet visible today and thus, smart Si/SiC combinations will be promoted first.

SiC transistors are currently sampled as JFETs, MOSFETs or BJTs, typically with voltage ratings of 1200V or above: JFETs are quite mature unipolar devices; normally-on JFETs, however, require some measure – like a cascode circuit – to avoid short-circuit during power-up in voltage source converters. Alternatively, MOSFETs can be used as unipolar SiC switches, also providing a significantly lower on-state resistance than comparable high-voltage Silicon devices; conduction of bipolar body diode can be deactivated connecting a SiC Schottky diode antiparallel. Although channel mobility and oxide stability still lead to some concern, SiC MOSFETs have already proven to pass at least most reliability tests.

Bipolar junction transistors can serve as an alternative, requiring current-source instead of voltage-source drivers. Devices for higher voltage ratings – including bipolar pin-diodes for blocking voltages above 4500V – have been built and tested in special applications, proving their feasability. However, obviously the high-power segment suffers from a kind of chicken and egg



Characteristics of 10kV/10A SiC MOSFET
Source: Cree



	SiC 2nd gen.	3D-GaN 1st	3D-GaN 2nd
Characteristic Voltage V_C @ RT	0.94V	0.60V	0.60V 👍
Specific differential resistance r_D^* @ RT	215 mΩ·mm²	389 mΩ·mm²	170 mΩ·mm² 👍
Specific current @ RT, V_D=1.6V	3.1 A/mm²	2.6 A/mm²	5.2 A/mm² 👍
Specific charge Q_C @ RT, V_D= 0 .. -400V	2.4nC/A	1.2nC/A	1.0nC/A 👍
		prototype	in process

Characteristics of 600V GaN Schottky Barrier Diode Source: MicroGaN

problem: system manufacturers would need to calculate the bill of materials of a novel system with SiC converter; however extrapolation of high-voltage device cost today will still end up with quite inaccurate numbers. It is obviously easier to take evolutionary steps, gradually increasing device voltage and current capability.

GaN devices will always be of lateral type which facilitates integration. According to Azzuro's Armin Dagda, GaN is a competitor to SiC and can be much cheaper in the end. A 100mm GaN on Sapphire wafer costs $500 compared to $800 for a 100mm SiC wafer. Limitations are the lateral structures allowing 3μm deep trenches only. Conventional and cost-effective processing is e.g. possible on Silicon wafers. The first power devices – such as 600V diodes – have been introduced already by Ulm-based (Germany) MicroGaN.

The aforementioned components and samples are still packaged in a conventional way, i.e., as modules, transfer moulded discretes or, in some cases, with hermetic packages. Research aims at progress regarding parasitics – of particular importance with respect to fast switching of unipolar devices – and also reliability when elevated temperature is applied.

Japan is obviously at the forefront with research and industrial activities, from crystal growth and wafer processing up to system design, as illustrated by Hajime Okumura from the National Institute of Advanced Industrial Science and technology (AIST). Within AIST, around 50 research units are working on wide bandgap electronics. SiC wafer companies such as Nippon Steel and Showa Denko offer up to 4in wafers, whereas Rohm is one of the first to offer trench SiC MOSFETs and a SiC-SBD/MOSFET and a SiC inverter circuit 280kW (1200V/230A). Mitsubishi has also introduced a SiC inverter circuit.

Generally speaking, the availability of wide bandgap devices has not set an end to the art of circuit design – still, the philosophy of circuit designers may be to follow different approaches: The most simple solution can be preferred, but also a technically more complex circuit eventually reducing cost. The former, in many cases, happens when SiC Schottky diodes replace bipolar Silicon diodes such as in power supplies with high switching frequency; however – as an example for the latter – some snubber circuit together with a reduced switching frequency may be a workaround too. Obviously, well-established Silicon- competes with emerging SiC- and, in the future, GaN-technology. In the case that the functions of active and passive switch can be decoupled, often a coexistence will be the optimum, combining a Silicon transistor – such as a charge-compensated MOSFET – with a wide bandgap – i.e., SiC – diode.

While this is already cost-effective for many applications, special requirements enable more comprehensive use of wide bandgap devices: SiC devices permit an up to now unrivalled efficiency of more than 99% to be achieved for photovoltaic inverters; increased device cost will pay back rather soon through the compensation for electricity fed into the grid. For this reason, converters for renewable energy can be expected to contribute to the continuous introduction of wide bandgap devices in power electronics. Other application areas – possibly also related to high voltage or high temperature – may follow in the future.

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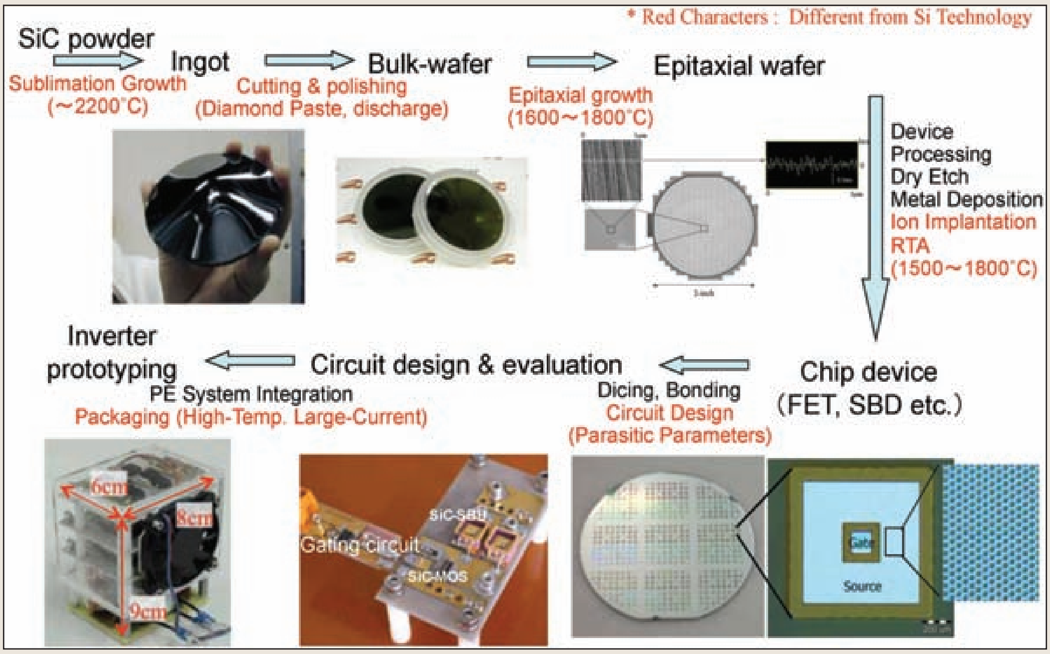

Research activities in Japan from crystal growth to power converter design Source: AIST