MicroGaN takes nitride transistors into the third dimension

Purchasers of power electronics want transistors and diodes that deliver SiC performance at silicon prices. Next year they should get their wish when MicroGaN launches a range of 600 V, GaN-on-silicon devices. **Richard Stevenson investigates.**

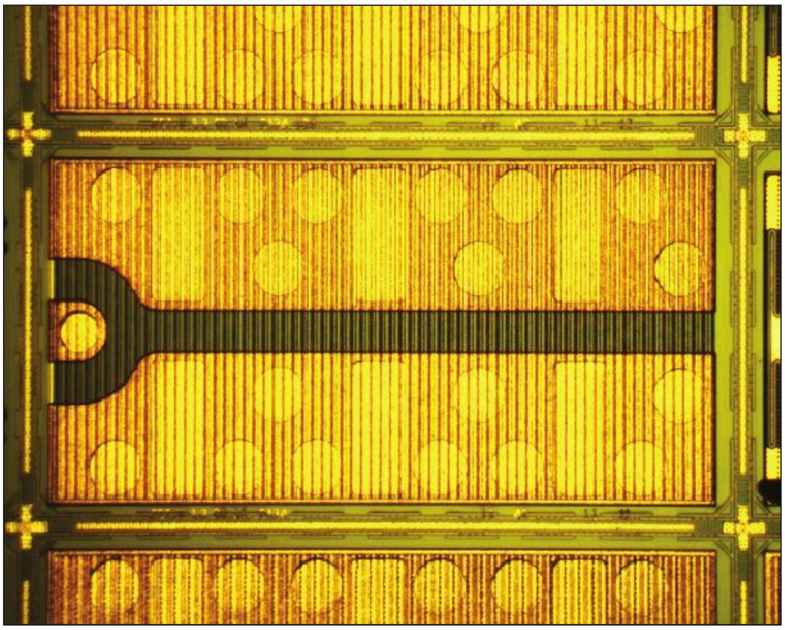
Interest in energy efficiency continues to rise. This is evident in the values for the power consumption of electrical goods that are no longer tucked away in the small print of the owner manuals – now they displayed along with the item for sale, and considered to be an important consideration for every potential customer.

Heightened interest in the energy efficiency of electrical products by individuals and corporations is partly behind increasing sales in the multi-billion dollar power electronics market. Silicon dominates this arena, with ten or so firms taking the lion's share of this market that provides electronic components for various products, including switch mode power supplies used in PCs, solar invertors and the power electronics in hybrid electric vehicles. However, these multi-million dollar chipmakers are facing ever stiffer competition from wide-bandgap semiconductors.

Leading this charge are SiC diode and transistor manufacturers such as Cree, Infineon and SemiSouth. In terms of efficiency, their products outperform those made from silicon by a significant margin. However, high costs hamper sales, with customers having to pay, for example, around $90 for a 1200 V SiC MOSFET from Cree.

Fortunately, there is another promising option: GaN-on-silicon. "We promise SiC performance for the price of silicon," claims Ertuğrul Sönmez, business development manager at the German GaN-on-silicon start-up MicroGaN, which is a spin-off of the University of Ulm.

According to him, the pairing of silicon and GaN also has the potential to deliver of high levels of integration, because it can accommodate several power devices, including power diodes and switches, on a single chip.

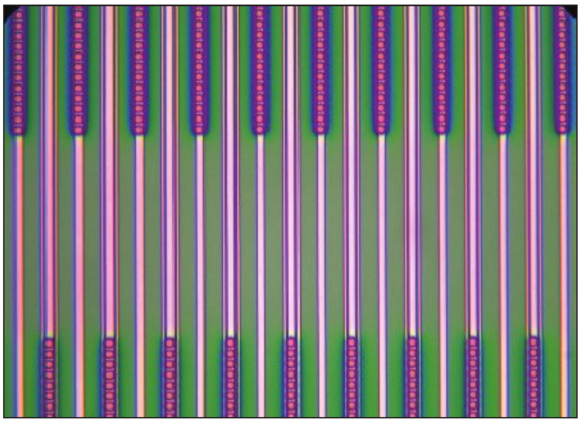


MicroGaN die are fabricated from GaN-on-silicon epiwafers

Strength in numbers

MicroGaN, which is currently sampling 600 V diodes and transistors, is not alone in pioneering power electronics with this class of material: International Rectifier is shipping 30V/12A modules, EPC is selling normally off transistors with voltages ranging from 40 V to 200 V, and a handful of other firms dotted around the globe are developing similar products.

Such competition, especially from industry heavyweights, could alarm many a small start-up. Sönmez, however, offers a completely different take on the situation: "If you have a new materials system, it needs to be convincing to application engineers. They



A partially processed die produced by MicroGaN, a spin-off of the University of Ulm

will use one that is efficient, known and trusted, and competition helps greatly to increase that trust." He hopes that all players in the GaN-on-silicon power electronics sector will work together to extol the virtues of this platform, and believes that there will be a place for many of them in this market.

Within the GaN-on-silicon fraternity, MicroGaN is the sole developer of 600 V devices featuring a three-dimensional chip architecture, which delivers benefits in terms of cost and performance. The Ulm start-up applies its three-dimensional technology to the surface-state transistor, which is a simple, robust technology with the strengths of no doping or implantation steps.

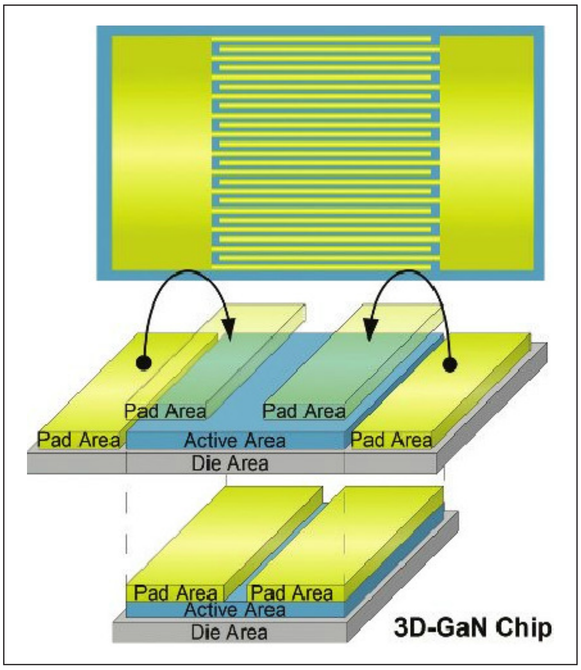


Figure 1. By adopting a three-dimensional architecture, MicroGaN is able to build more compact diodes and transistors that have lower manufacturing costs and reduced parasitics

Epitaxial growth of GaN and AlGaN on silicon forms a two-dimensional electron gas thanks to the internal electric fields in these materials, and depositing metallic ohmic contact layers tens of microns apart from one another forms devices. Contact widths of typically 100 mm enable the realisation of devices with sufficiently low resistance. The practical way to do this is to employ a 'folded-down topology' incorporating many, many fingers (see Figure 1).

Although such devices could be fabricated with a planar technology, it is far better to adopt a three-dimensional architecture. "It's really the only way for large area, power integrated circuit solutions," argues Sönmez. He points out that in addition to the obvious cost benefit stemming from a reduction in device dimensions, the three-dimensional architecture paves the way to a lower specific on-resistance.

For devices with a metallic contact strip width of 100 mm, on-resistance is just 170 mΩ, and additional improvements in the quality of the epitaxial material could substantially reduce this figure further.

One of the strengths of MicroGaN's approach is its common platform. By altering the contact architecture and working with both GaN and silicon devices it is possible to build diodes and normally on and normally off transistors (see "Utilizing a common approach" for details).

A strong GaN-on-silicon pedigree

MicroGaN developed the three-dimensional architecture that lies at the heart of this common platform in-house. These efforts were driven by its founders, Mike Kunze and Ingo Daumiller, who started the company in 2002 after carrying out doctoral research that included the growth of III-V materials. This pair focused on GaN-on-silicon technology from the very beginning.

Funding to found the company and enable it to form its initial business plan came from the German investment bank KfW. This backer provided additional financing with a series A round at the end 2005, along with MAZ Level One and Technostart ventures, and in 2009 the Ulm spin-off had a further cash injection from KfW and Technostart. A location for the start-up has been provided by the University of Ulm, which is a strong supporter of spin-offs and has played a major role in the success of VCSEL manufacturer Ulm Photonics.

Initially the university provided offices to MicroGaN, and also granted its employees access to a 1000 m^2, fully equipped cleanroom. But as the company grew it needed more space of its own, so in 2009 it moved into the basement of this building, assembling a fab just for itself. "We just share the central supply systems, like gases and clean water," explains Sönmez.

Additional milestones for MicroGaN include the demonstration of 1000 V devices in 2007 and the establishment of intellectual property for three-dimensional devices the following year. "In 2009 we set up our 6-inch capability and in 2010 the initial prototypes of our switches went to customers," adds Sönmez. "2011 will be the year of our fully featured prototype."

Spreading the load

Despite having tremendous expertise in hetero-epitaxial deposition of nitride films, the founders of MicroGaN decided to outsource epi-growth. "You cannot do everything at the same time – our decision was to make close partnerships and jointly develop epi with our partners," says Sönmez.

The only significant change to MicroGaN's strategy over the years has been to switch its focus from RF devices to power devices. Sönmez reveals that the reason behind this move was an increase in the electrical field strength of GaN, which at one point was insufficient for making power devices. "Our RF technology was transferred to high-voltage technology after having the first high-voltage results from the epi."

Today the firm is making products on 4-inch wafers. "In parallel, we are taking a close look at 6-inch, but for 600 V applications the critical field strength and homogeneity are tough requirements," explains Sönmez. Device development is almost complete, and it will not be long before MicroGaN starts to demonstrate its products, both in-house and with lead customers.

The German outfit is already discussing the results of its prototype diodes and switches. Its 600 V Schottky barrier diode, which it claims to be 'best in class', turns on at 0.3 V and delivers 4 A at 1.2 V. This compares to a turn-on voltage for SiC diodes of over 0.9 V, a difference that accounts for the lower DC loss of the GaN-on-silicon product.

Meanwhile, the company's 600 V, normally off switch has an on-resistance of 320 mΩ – and at a gate-source voltage of 0 V, it has a drain current below 1 mA at a drain-source voltage of 600 V. Fix the drain-source voltage to 0.7 V, and drain current exceeds 2 A when the gate-source voltage hits just 3 V.

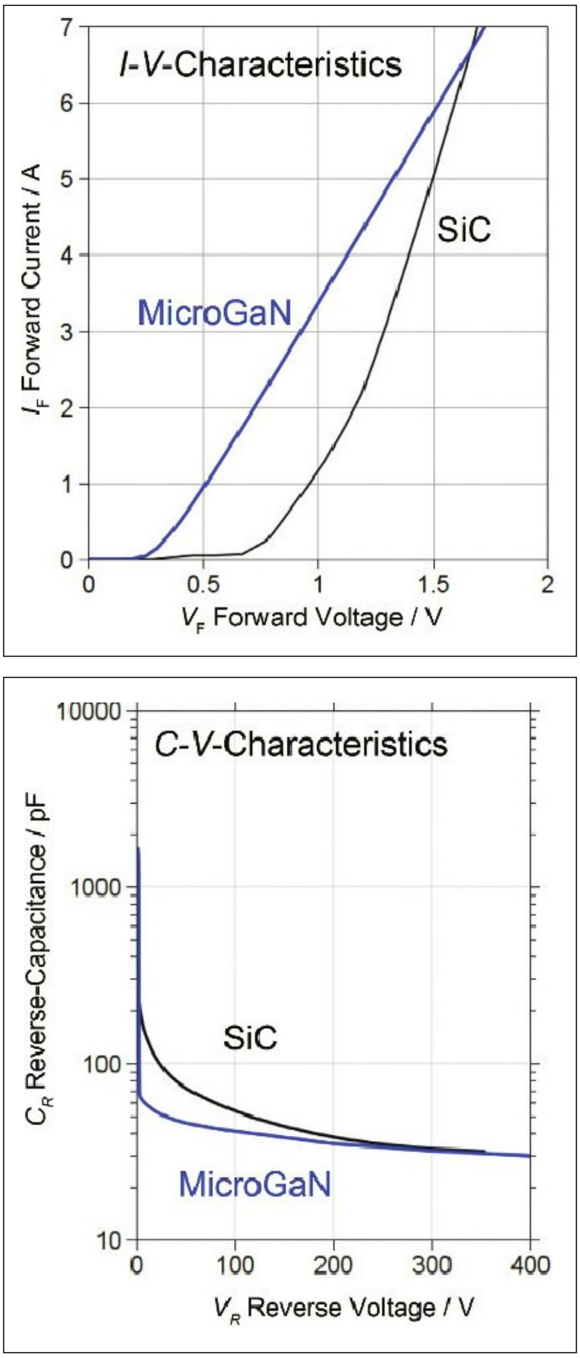
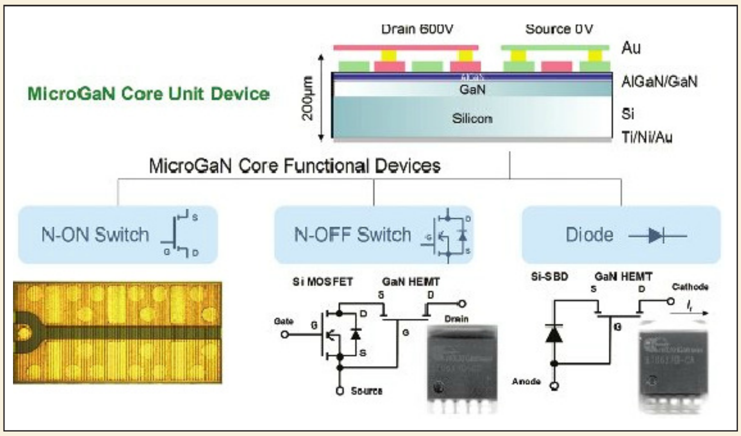


Figure 2. The combination of a GaN HEMT and a silicon Schottky diode allows the exceptional low-voltage characteristics of this diode to be transferred to higher voltages

Utilizing a common approach

MicroGaN has a common platform for forming three different types of device: a 600 V diode and normally off and normally on transistors operating at the same voltage.

The normally on transistor has the simplest construction – it's just a GaN HEMT with a source, drain and gate. But this class of device is unlikely to be a big seller because in many applications concerns over safety lead to the requirement for a normally off transistor.



The architecture for the diode is more complex, combining a GaN HEMT with a silicon Schottky barrier diode. "Silicon's low-voltage diode properties, which are fantastic at low voltages, are transferred to 600 V," enthuses Sönmez.

He explains that it's a similar story for the normally off transistor, which pairs a GaN HEMT with a MOSFET in a cascode configuration. "The advantage then is that you don't need a free-wheeling diode," explains Sönmez, who adds that the MOSFET that is used is of very high quality and features a low-voltage barrier diode.

According to him, silicon MOSFETs perform poorly at high voltages due to high levels of stored charge. "But you don't have this problem for silicon MOSFETs at low voltages – they are incredible." So, just like the diode, this approach allows the strengths of silicon to be translated to high voltages.

That's not the only advantage of this approach, though, says Sönmez: "If you want to make an AlGaN/GaN system operate normally off, you have to destroy the nature of the two-dimensional gas at the location of the gate." By sidestepping that issue, MicroGaN can produce devices that excel in a key figure of merit – the on-resistance, multiplied by the area of the device.

Great performance is of little benefit in the commercial arena if manufacturing costs are high. This is certainly not the case, according to Sönmez, who claims that the cost of making these normally off GaN-on-silicon switches is lower than that for manufacturing sophisticated silicon products. "Our processing complexity is very low – lower than sophisticated silicon, such as coolMOS, and far lower than SiC transistors that might have trenches or other technological steps to ensure normally off operation."

He admits that the costs for epitaxy are higher than those for silicon, but points out that this can be offset by resistance figures up to ten times lower. "You end up with a really competitive cost structure even to silicon."

Initially, MicroGaN's products will probably be used as drop-in replacements for those made from SiC and silicon. Employed in that way, circuits don't have to be re-designed, making it relatively easy to displace SiC free-wheeling and boost diodes that are used in boost stages of power factor correction units, and in H-bridge circuits that are used to control the current flow in solar applications and motor drives.

Further inroads into the power electronics market require a re-design of the H-bridge circuit Currently, these circuits require four separate silicon IGBTs and additional free-wheeling diodes. To begin with, MicroGaN's transistors could replace the IGBTs and eliminate the need for diodes. But further down the road the changes could be far more radical: "I can see a fully integrated power conversion technology that can be made on one chip and will, for the first time, facilitate today's three-dimensional technology advantages," says Sönmez.

Over the next few months MicroGaN will be preparing its technology for its initial sampling phase with selected customers that is planned for the first quarter of 2012. Mass production will follow as the Ulm start-up establishes manufacturing partners.

"Our process has been developed from the beginning to be transferable," explains Sönmez. This allows the company to not just outsource epitaxy, but the entire production process, a move that the company is preparing to make. "This will start using 4-inch, using its maturity at 600 V. But we are tracking 6-inch in parallel, and as soon as the electrical properties fulfil our needs - in terms of yield, homogeneity, breakdown voltage, leakage current, and so on – we will switch." If the company can make these transitions smoothly, it should to be a major force in the power device market.