SiC and GaN power devices jostle to grow their role

Efficient Power Conversion Corporation (EPC), Fairchild Semiconductor, GeneSiC Semiconductor, ROHM Semiconductor, and Transphorm tell Andy Extance and Power Dev’ how they’re turning module and system makers towards wide bandgap devices.

Displacement technologies are ‘a very difficult game’, according to Alex Lidow, Chief Executive Officer of El Segundo, California’s Efficient Power Conversion Corporation (EPC). He’s referring to EPC’s eGaN GaN-on-silicon FETs, which he believes can broadly displace silicon MOSFETs in power electronics. But he’s also drawing on his experience in developing and pushing those MOSFETs to displace previous technologies earlier in his career, across El Segundo, at International Rectifier. “It is brutally painful when you come to a customer and say ‘I’ve got a better technology for you’,” Lidow said. “That’s the last thing they want. Give them the same old technology at lower cost, and they’d be happy.”

Beyond EPC, that’s what all devices made from wide-bandgap materials SiC and GaN must do to establish themselves in the power electronics market. Device producers must prove their products’ reliability, reach competitive costs, and educate industry on how to best exploit their advantages. But is there enough room in power electronics for two similar materials to do all this simultaneously?

Kazuhide Ino, General Manager of SiC Power Device Production Division at Kyoto, Japan’s ROHM Semiconductor, stressed that SiC and GaN device architectures give them diverging strengths. “For SiC devices, current flows vertically from the chip backside to its surface, the same as in silicon power devices,” he said. “By contrast, in GaN devices current flows horizontally, so it is difficult to manage the relatively larger current. GaN devices have the characteristics of HEMT structures, therefore their switching speed reaches the MHz range, which is a unique characteristic compared to silicon and SiC devices.”

As such, ROHM is more concerned that its SiC products displace silicon. “SiC devices mostly do not compete with GaN devices,” Ino said. He underlined that ROHM is already producing highly reliable SiC MOSFET and diode power devices and modules that are available for industrial and automotive applications. “The reliability of ROHM’s SiC has been revealed to be the same level as that of silicon power devices,” Ino said.

GaN and SiC’s properties don’t overlap much, EPC’s Lidow agreed. “GaN’s 2-dimensional electron gas dynamics make it the obvious choice at 600V and under,” he said. “SiC is the obvious choice 600V and up. 600V is disputed territory, but if I were to bet, I’d bet on GaN today.” EPC already supplies 200V eGaN FETs commercially, and started sampling
600V FETs in 2011, though those devices remain in the sampling phase. "600V is a materials challenge," Lidow explained. "Can we harness the GaN heterostructure to create reliable higher voltage devices? I think so. But we’re balancing many growth dynamics to create stable 600V devices. We only find out if we’ve met that challenge at the very end of the line, after thousands of hours of testing. It’s a very long learning cycle."

Mats Reimark, senior director of Fairchild Semiconductor’s Stockholm, Sweden, based SiC operations, also thinks that SiC and GaN do potentially compete at 600V. “But generally I think we should see them as complementary rather than competing," he added. "Wide-bandgap devices are going to be a very small portion of the total market, so there won’t really be head-to-head competition.”

His company is currently sampling four 1,200V BJTs. It offers the same two devices, rated at 20A and 6A at 250°C, in both high temperature packaging and in lower-temperature TO-247 format. "We are looking upwards and downwards in voltage," Reimark said. "For the immediate future we will go up, where there are interesting high-power module markets. There SiC will give our customers faster switching and better conduction. But we are also looking to go down in voltage, and face an interesting decision in where SiC makes sense and GaN does not, and vice versa.”

Platforms established

Dulles, Virginia’s GeneSiC Semiconductor deliberately chose to develop its SiC “Super” Junction Transistors (SJTs) and Schottky rectifiers that don’t enter the range GaN might reach. "Our product portfolio mostly starts from 1,200V," explained Ranbir Singh, the company’s chief executive officer. "We don’t go into 650V unless devices are specifically targeted for high temperatures. I believe GaN will have some challenges going to those areas. GeneSiC has developed unique 8,000V and 10,000V diodes which we are selling openly, and internally we have developed 10,000V Junction Transistors and Thyristors through US government projects. The advantage that SiC offers compared to traditional silicon solutions in this area is extremely significant. For example, one customer told us that using our 8,000V and 10,000V Schottky and PIN diodes their circuit efficiency went from 43% to 94% in a voltage multiplier application.”

Singh pointed out that GeneSiC also has an interest in GaN devices, having recently won a project from the US government to work on them. GeneSiC also intends to expand the marketplace it addresses by increasing current ratings. "By the third quarter of this year, we should be releasing 50A/1200V transistors, to match the 50A rectifiers we are presently selling," Singh said. "From those building blocks we’re going to be able to deliver 100A modules in the 1,200V range in the 2013 financial year.”

In March, following highly accelerated stress tests recommended by the semiconductor trade organization JEDEC, Goleta, California’s Transphorm qualified 600V GaN-on-silicon HEMTs and diodes from its California facility. "This is a major milestone for GaN power electronics, enabling mass adoption price points for devices providing dramatically improved power efficiency,” said Primit Parikh, the company’s president. It also validates their manufacturability and meant the devices could be released for production, which was Transphorm’s target after gaining qualification for GaN-on-SiC devices in September 2012. "Transphorm’s qualification of GaN-on-SiC proved the device design could pass all the JEDEC accelerated tests,” explained Parikh. "That accomplishment made the GaN-on-silicon qualification predictable. Transphorm’s EZ GaN 600V products are now in production with customer deliveries already occurring.”

Passing qualification was tough, Parikh underlined, but finding package and circuit level solutions that maximize GaN’s benefits while making it easy to use was equally important. And having solved these problems, Transphorm now wants to expand the applications using its products. Parikh believes that GaN could even enter market areas that SiC producers consider their own.

"In future GaN will also move to the higher voltages, offering a complete solution from a few hundred volts to as high as 1,700 volts,” he said.

**SiC & GaN**

**Expected improvements in power conversion efficiency**

(Source: SiC 2013 report, Yole Développement, May 2013)

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<thead>
<tr>
<th>Power conversion efficiency - Expected improvements</th>
<th>Expected improvement compared with Silicon</th>
<th>Efficiency value improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-DC (POL, boost…)</td>
<td>+5 points</td>
<td>90% → 95%*</td>
</tr>
<tr>
<td>AC-DC (PFC, UPS…)</td>
<td>+1.5 points**</td>
<td>88% → 90%</td>
</tr>
<tr>
<td>DC-AC (Motor, PV…)</td>
<td>+2 to +3 points</td>
<td>90% → 95%*</td>
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(1): International Rectifier 2012. Comparison 300Vin-30Vout SJ MOSFET vs. GaN DC-DC @ full-load
(2): SemiSouth + Delta Elektronika 2012. full SiC.
(3): Fraunhofer Institute 2011. Full-SiC PV inverter
ROHM’s Kazuhide Ino said that his company is also looking beyond device design alone to make the highest performance SiC power devices. “ROHM is conducting total optimization from substrate to the final packages,” he said. “We also have specific cost reduction programs through innovative device, process and production system development across all SiC substrate, epi, device and module manufacturing processes.”

In December 2012, ROHM announced a 1,200V module using its second generation SiC MOSFETs. These modules have already been shipped to many customers for final evaluation, Ino said. “Some customers have already started mass-production,” he added. In 2013, the company aims to release its third generation SiC Schottky barrier diode, third generation planar MOSFET and first generation trench MOSFET. It will also increase its standard SiC power modules’ current rating to 300A. Together, these will help meet the trends that ROHM is seeing trends towards lower device cost and higher performance–particularly on-resistance. “Both are aggressively and instantaneously developing,” Ino said.

Meanwhile, GeneSiC is comfortable addressing the higher-voltage sector using its fab-lite strategy. The company is even expanding its in-house manufacturing infrastructure, and intends to complete the expansion in two quarters. Nevertheless, getting products designed into customer projects remains perhaps its hardest task. “We’re still in many design cycles or product introductions especially in SJTs and 1,200V commercial rectifiers,” Ranbir Singh said.

Gaining purchase

For example, GeneSiC’s SJTs are targeted as almost direct replacements for silicon IGBTs, and can be used with the same industry-standard IGBT drivers. And though the SJTs were only released in the last six months, they are gaining momentum. “We believe we are one of only two companies that can offer SiC switches in the open market,” Singh said. “Though we are shipping to three or four OEM customers, we are not yet shipping large quantities, so that’s an issue of how to manage growth.”

Fairchild’s Reimark says that while BJTs are the most efficient SiC devices today, they too are not yet accessible to electronics designers unused to current drive. “Our solution is to make drivers and design-in solutions available to the public,” he said. “We are going to supply both discrete drivers and integrated drivers with our components to make it easier to design in, and also supply guidelines. That’s one of the advantages of being a part of Fairchild, which is a whole solution company.”

And though mindsets might be slow to change, Reimark expects 1,200V SiC devices ultimately to emulate MOSFETs’ success at 600V today. “There is inertia in designing in fast switching solutions into the 1,200V area, which is predominantly IGBT slow switching solutions today,” he said. “There are a lot of areas where IGBTs are still used at 600V, but today fast switching designs dominate. In the future, we will see a similar situation in 1,200V and above.”

To aid design-in Transphorm provides evaluation boards and application notes to help its customers fully exploit GaN’s value. 600V wide-bandgap devices can meet needs for energy efficient and power dense AC power conversion in power supplies, solar inverters and motor drives, Primit Parikh said. “These trends are leading to natural convection cooling, without a fan, for some applications which greatly reduces the operating cost of cooling the electronics,” he said.

GaN already can enable a superior system performance/cost value to silicon today, Parikh added. “One of our customer partners demonstrated a GaN PV inverter with significantly lower loss and smaller size, enabling a cost-effective end system,” he said. Transphorm targets competitiveness at device level too, through smaller devices and its soon-to-be-delivered 8-inch wafer capacity MOCVD reactor for GaN deposition. “GaN die are smaller than equivalent silicon devices even today, and will shrink further,” Parikh said. “Together small die size and large wafer diameter make GaN cost competitive with 600V silicon devices.”

Careful choices: Using silicon IGBTs and SiC diodes in this rectifier GeneSiC Semiconductor provides a combination of cost, size, weight and volume that it says neither silicon nor a pure SiC module can offer. (Courtesy of GeneSiC Semiconductor)

Material advantage: EPC’s typical AlGaN/GaN HFET structure with three metal-semiconductor contacts for the source, gate and drain, offers high speed switching. (Courtesy of EPC Corporation)
EPC is investing similar effort to push customer education and has published a textbook, entitled “GaN Transistors for Efficient Power Conversion”. Lidow also emphasized cost’s importance to device adoption. “The lower costs are, the more people are motivated to start that journey,” he said. And in GaN deposition, the costliest manufacturing process step, EPC is also making progress. “Our costs have come down dramatically from experience in manufacturing and developing our second generation of MOCVD reactors,” Lidow said. “We needed a scalable platform that could lead to a high-volume, low cost third generation. With this machine we’re looking at a factor of two cost reduction. Scaling it further, we think we can get a factor of three.”

Larger manufacturing scale driven by early-adopting industries that such devices enable will combine with such steps to ultimately overcome wider resistance to adoption, Lidow predicted. “We’re churning product, making mistakes, and finding out how to fix them,” he said. “This reinforces my belief that GaN is a broad displacement for power MOSFETs. That was a question mark four years ago, but now it’s not.”

Kazuhide Ino, General Manager of SiC Power Device Production Division, Rohm Semiconductor
Ino received his Ph.D. degree in electronic engineering from Tohoku University, Sendai, Japan in 1998. He then worked as a Postdoctoral Fellow of the Japan Society for the Promotion of Science, at Tohoku University. He joined ROHM Co., Ltd., Kyoto, Japan in 1999. He is currently General Manager of the SiC Power Device Production Division and responsible for the development of SiC power devices such as SBDs and MOSFETs, Full SiC Modules, and Si-IGBT Modules. He works on business development for new material (SiC) power devices and modules.

Alex Lidow, Co-founder and Chief Executive Officer, Efficient Power Conversion Corporation (EPC)
EPC designs, develops, and produces GaN-on-silicon transistors and integrated circuits used in power management. Prior to founding EPC, Lidow was chief executive officer of International Rectifier Corporation, a company he joined in 1977. A co-inventor of the HEXFET power MOSFET, Lidow holds many patents in power semiconductor technology and has authored numerous publications on related subjects. Lidow earned his BS in applied physics from Caltech in 1975 and his PhD in applied physics from Stanford in 1977 as a Hertz Foundation Fellow.

Primit Parikh, President and Co-founder, Transphorm
Parikh jointly leads overall strategy at Transphorm, and is also responsible for P&L, customer relationships and products, engineering and manufacturing. Primit has over 10 years’ experience in business area leadership and over 15 years in GaN/semiconductor development, technical marketing and intellectual property. Prior to Transphorm, Parikh led GaN electronics at Nitres Inc. through its acquisition by Cree, where he served as head of Advanced Technology at Cree SBTC in charge of GaN development and government business. Parikh received his B.Tech. in EE from IIT, Mumbai and his Ph.D. in ECE from UCSB. He has more than 30 patents awarded/pending in the area of GaN materials, devices and circuits, and has co-authored more than 70 publications and presentations.

Mats Reimark, Senior Director, SiC Technology, Fairchild Semiconductor
Reimark leads Fairchild Semiconductor’s SiC activities as Senior Director SiC technology. Before joining the company, he held director-level positions in international organizations for more than 10 years and, prior to the its acquisition, was the CEO of TranSiC AB – a company specializing in the development and manufacturing of bipolar transistors in Silicon Carbide. Prior to joining TranSiC, Reimark spent many years at GM, with assignments such as Director, Hybrid Powertrain Engineering, Europe; Chief Engineer, Advanced Technology at Fiat-GM Powertrain; and Director, Engine and Controls Engineering at SAAB.

Ranbir Singh, Chief Executive Officer, GeneSiC Semiconductor
Singh received a Ph.D. and MS degrees in Electrical and Computer Engineering, North Carolina State University, Raleigh, NC, and B. Tech from Indian Institute of Technology, Delhi. Singh founded GeneSiC Semiconductor Inc. in 2004. Prior to that he conducted research on SiC power devices first at Cree Inc and then at the NIST, Gaithersburg, MD. In 2012, EE Times named Singh as among “Forty Innovators building the foundations of next generation electronics industry.” In 2011, he won the R&D100 award towards his efforts in commercializing 6.5kV SiC Thyristors. He has published over 130 journal and conference papers, is an author on 28 issued US patents, and has authored a book.