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WIDE BANDGAP SEMICONDUCTORS, THEY'RE SPECIAL

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Recent advances in wide band gap semiconductor s (typically compound, like Gallium Nitride (GaN) and Silicon Carbide (SiC), but also elementary, like Diamond) for power applications were a big hit during the IEDM 2014 conference. The IEDM invited plenary speech by J.W. Palmour of Cree, showed impressive data on the yield and performances of SiC devices on 15 cm substrates — micro-pipes still are a threat but their density has decreased so much that yield is almost unaffected. The presentation included an unusual testimonial for widegap semiconductors.

US President Barack Obama himself in a speech held at NCSU on January 15, 2014, supporting a $140 million proposal to bring a manufacturing innovation hub to Raleigh, with Jayant Baliga as a principal investigator. "Wide bandgap semiconductors, they're special because they use up to 90 percent less power; they can operate at higher temperatures than normal semiconductors. So that means they can make everything from cell phones to industrial motors to electric cars smaller, faster, cheaper. There are still going to be applications for traditional semiconductors, but these can be focused on certain areas that will vastly improve energy efficiency, vastly improve the quality of our lives." See the transcript of Barack Obama's speech, http://www.bizjournals.com/triangle/ transcript-of-president-obamasspeech.html?page=all .

As pointed out by Prof. Baliga in the invited paper Social Impact of Power Semiconductor Devices, those play a fundamental role in a sustainable society and involve an impressive range of applications, from transportation to air conditioning and refrigeration to lighting. Two-digit improvements in efficiency have led, during the last 20 years, to staggering results in terms of energy consumption and decrease in carbon dioxide emissions.

Cars are one of the major sources of carbon dioxide emission and 93.5% of the energy used for transportation is based on fossil fuels. This could be improved in the future with a more widespread use of Hybrid Electrical Vehicles (HEV) and EVs. Researchers from Toyota Central R&D Labs presented a novel SiC vertical JFET for automotive applications, allowing for a 50% reduction of switching losses vs. conventional MOSFETs. Despite their impressive performances, widegap semiconductor power devices based on SiC or GaN should be targeted towards specific applications where they bring real advantages in terms of performance but also cost vs. Si. A complex SWAT analysis of different technologies for power switching is discussed, by researchers from Infineon. In a nutshell, Si still dominates for low price applications, SiC for high-end, high voltage applications, GaN (but only in the GaN-on-Si variety) for high-end and medium voltage applications. Widegap power semiconductor devices will also play a fundamental role in smart power grids. SiC devices with ultrahigh breakdown voltage (>10 kV) for UHV applications in power grids (researchers from Kyoto University, AIST and Kansai Electric Power). An optimized PiN SiC process is described with high temperature performances up to 250 C and 70% expected power reduction expected vs. Si converters operating at a switching frequency of 2 kHz.

GaN has become widespread in our homes thanks to the introduction of GaN-based LED high-efficiency lighting (as recognized by the recent Nobel prize in physics to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura), but very soon domestic appliances exploiting GaN power devices will become widespread, at least in Japan. PV conditioners using 600 V GaN-on-Si devices will be sold on the Japanese market starting January 2015. The PV conditioner exploits a JEDEC-qualified GaN-on-Si process using a cascode configuration with a normally-off Si MOSFET. The 1500 V breakdown voltages ensures reliability in the targeted 600 V application, with a 40% loss reduction and size reduction when compared to a Si implementation; the switching frequency is 27 MHz and careful packaging alleviates EMI problems. In the future, 900 V e-mode devices will be on the market. Bulk GaN substrates could be the ultimate solution for GaN electronics, in particular for vertical devices. Researchers from the Advanced Research Projects Agency show an overview of available widegap power solution, having in mind a target price of 0.1 $/A at 40 KHz switching frequency. Contrary to common belief, the SiC solution is not necessarily more expensive than the Si one—the cost is higher but also the power density is larger. For GaN-on-GaN vertical devices, the current solutions are monothermal GaN boules or GaN transferred substrates obtained by epitaxial lift-off.

A last area of interest is diamond power electronics, for which the main challenge remains n-type doping in bipolar diodes and transistors. A possible solution for power diamond devices avoiding the issues related to doping is the surface H-termination (already proposed about 20 years back), that induces a surface 2D hole gas, allowing for the development of diamond-based MESFETs and MOSFETs. Very good results in terms of stability and high voltage operation were presented by Waseda University researchers. The technology exploited here is a MOSFET with an Al2O3 layer. The proposed process also has good properties in terms of high-temperature behavior up to 400 C.

IEDM 2014 had sessions where many technological developments were reported, and the contribution of the session invited speakers well summarized the contents of the sessions: Dr. Tetsu Ueda, from Panasonic reported on the potential of the GaN HEMTs in the power switching applications. Prof. Gaudenzio Meneghesso, from the University of Padova, provided an important overview of the most critical parasitic effects today present in these devices that need to be taken care of, to allow for a large market penetration.

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