Potential of SiC and other Wide Bandgap Semiconductors in Power Electronic Applications

ECPE Seminar in cooperation with EPE Association

The third User Forum for the first time also considered other wide bandgap devices, in particular Gallium Nitride (GaN) as its subtitle expresses. The user Forum 2009 took place right after EPE conference in Barcelona. Prof. Andreas Lindemann (Otto-von-Guericke-Universität Magdeburg, Germany) took the chair together with Prof. José Millán (Centro Nacional de Microelectrónica --- CNM Barcelona, Spain) and Mr. Thomas Harder (ECPE).

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State of the Art

Starting in the beginning of the supply chain, the SiC material situation is not a concern anymore: While cost has decreased in the course of time, wafer quality has increased, permitting to produce devices with an area of some 25mm² with appropriate yield. This is suitable for a nominal power in the Kilowatt range and can be extended by parallel connection of devices.

Schottky diodes with voltage ratings of typically 600V and 1200 V are commercially available and used in different kinds of converters, often together with Silicon transistors; this combination permits to significantly reduce switching losses, thus to downsize the transistors or to increase efficiency. 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 RDS,on 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 problem: System manufacturers would require 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 in 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. Conventional and cost-effective processing is e. g. possible on Silicon wafers. First power devices --- such as 600V diodes --- have been reported. It will be interesting to see on the occasion of one of the next User Forums, how promising GaN diodes, transistors and possibly integrated circuits will penetrate power electronic applications.

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 reliability also when elevated temperature is applied.

Outlook and Conclusion

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 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 to achieve an up to now unrivalled efficiency of some 99% 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 future. This exciting development might be reported on the occasion of a similar User Forum planned for every two years in the future.

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