2nd SiC User Forum
Potential of SiC in Power Electronic Applications
— Report of Conclusions —

European Center for Power Electronics e. V. (ECPE)
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Andreas Lindemann
Otto-von-Guericke-Universität Magdeburg
Lehrstuhl für Leistungselektronik — Chair for Power Electronics
www.Uni-Magdeburg.de/llge

General

After the first Silicon Carbide (SiC) User Forum organised by ECPE in 2006, technology has developed further — in particular new power electronic systems with SiC components and new SiC devices have been reported. Time had thus come to continue the exchange between experts involved in converter and device development. The second SiC User Forum has focused on typical power electronic systems, the use of SiC is highly promising for i. e., 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. Renowned experts from all over the world have been invited to give an overview in keynotes, to in depth explain their research and development work in technical presentations and to share their knowledge in discussion forums as an indispensable part of the event.

The SiC User Forum this way became a platform to share experience and ideas, to discuss and find out which power electronic systems are predestinated for usage of SiC and how to appropriately design-in those novel, almost ideal but also challenging components. It aimed at finding and pointing out approaches to exploit the high potential of SiC and to support its beneficial introduction in power electronic systems.

SiC User Forum 2007 —attended by some 120 international participants —took place right after EPE conference 2007 in the Danish capital Copenhagen. Prof. Andreas Lindemann (Ottovon-Guericke-Universität Magdeburg, Germany) took the chair together with Dr. Hiromichi Ohashi (National Institute of Advanced Industrial Science and Technology, Japan) and Mr. Thomas Harder (ECPE). The major findings of the event are summarised in the following:

State of the Art

Series production of different converters using SiC Schottky diodes has been reported: A family of 690V AC drives makes use of their superior switching behaviour, which helps to reduce dynamic losses also in the Silicon IGBTs and thus permits to increase switching frequency to 16kHz. This way, the size of output sine wave filter can be reduced in such a significant way that it can be integrated in the converter unit. The motor thus can be operated through relatively long unshielded cables, keeping electromagnetic emissions of the drive system and bearing currents low. Here, SiC devices have shown to be an enabling technology to achieve a highly effective and integrated system design. Basically the same applies for switched mode power supplies — often including an input stage for power factor correction — where power density can be increased reducing the size of inductive components and switching losses, which on the one hand permits to shrink heat sinks and on the other hand is very useful to achieve an optimum efficiency.

This progress became possible due to the availability of SiC devices: Namely Schottky diodes up to 1200V breakdown voltage have reached a high level of maturity, with technologies to achieve surge current and avalanche ruggedness being known, and proven reliability. In addition, various types of transistors have been demonstrated and sampled; their usage however still is mainly subject to research as outlined in the following section. Anyway, device technology depends on material, where major progress towards the elimination of micropipes and the increase of wafer size to 100mm — which is relevant for cost reduction — has been reported. It should be further noted that SiC devices in today's volume production are using standard packaging technologies, which is a reason why they need to be operated in the usual temperature range of some $-55^\circ C \leq T_J \leq 175^\circ C$.

Outlook — Research

It seems to become possible to exploit the aforementioned benefits of SiC technology in systems for further applications, which is subject to current research: E. g. a photovoltaic inverter has been demonstrated with extraordinary efficiency which is a major technical feature and sales argument. It has been achieved replacing Silicon IGBTs and diodes with 1200V SiC MOSFET devices, showing resistive R_{DSon} conduction characteristics in forward and — when turned on — also in reverse direction; this is beneficial especially at currents lower than nominal current as they appear within each sine wave and as is also typical for frequent partial load operation. Further, switching losses are low due to the fast reverse recovery of body diode. There seems to be no particular need to operate the devices in this kind of converter beyond the aforementioned standard temperature range. Depending on the particular concept, this will partially also apply to high power converters for different kinds of applications: In the distribution network, converters would be useful to couple energy storage to the grid or as active filters; in railway traction, the bulky and heavy low frequency transformer might be replaced, or the drive motors might be supplied through inverters operated at frequencies higher than 300Hz as typical today, permitting to optimise the machines. In both cases, a switching frequency of about 2kHz together with blocking voltages in the range of several Kilovolts seems appropriate, which cannot be realised with today's high voltage Silicon IGBTs and diodes. Impressive results of long-term research have been presented during the event, e. g. a 180kVA pulse width modulated inverter with SiC devices for the distribution network, or also switching behaviour of cascaded SiC JFETs in a 5kV converter operated at 50kHz. Of course, an elevated range of operating temperature helps to increase converter power ratings; in some cases it seems even more advantageous, such as in automotive converters where a keynote highlighted the achievements in hybrid cars made with Silicon technology — e. g. the increase of power density — and the potential for further optimisation with SiC, the voltage range up to some 1000V seems to be sufficient for. This in general also applies for the more electric aircraft, where a tremendous change of electrical system is in progress, leading to a variable frequency or DC supply with nominal power in the order of magnitude of 100kW, requiring power electronic conversion on the generation and load side. Here however, an operating temperature of at least $200^\circ C$ together with a withstand capability against harsh environmental conditions such as shock and vibration are considered to be indispensable in addition. This demanding application might become a technology driver, because technology can be considered to be crucial here despite the related cost.

On behalf of the components, several types of SiC devices have been reported: Above some 5kV rated voltage, bipolar pn diodes will be preferable compared to unipolar Schottky- or also merged Schottky-pn devices. Extraordinary ratings have been demonstrated with a 19,7kV low current pn diode or a 3kV 600A pn diode module. The group of unipolar active switches has been represented by JFET and MOSFET. In spite of circuit designers' preference for familiar normally-off devices, the JFET can claim a high level of maturity also in terms of ruggedness, being not affected by oxide stability which is still subject to research. Among the bipolar devices, an NPN transistor with rated 1200V and 6A or a 4,5kV 120A SiC commutated gate turn-off thyristor have been reported. Generally, forward drift of bipolar SiC devices will need to be addressed by future work. Further, high temperature packaging technology is an important issue, where results of research on a basically disc-shaped package, being rated for 400°C and using an appropriate high-temperature resin, have been reported. Still, reliability of novel devices and components needs to be proven. On material level, research is focused on minimisation of dislocations and on further increase of wafer diameter to 150mm. It has been noted that Gallium Nitride(GaN) devices might increasingly compete to SiC. Regarding high temperature systems, an adaptation of other components such as passives — e.g. capacitors and magnetics with cores — seems necessary in addition. Increasing operating voltage above the level reached with Silicon devices may also pose questions regarding isolation materials.

Conclusion

SiC Schottky diodes are nowadays available in production volumes and they are applied in power electronic converters offered in the market. The potential to increase switching frequency — leading to superior system performance, a higher degree of integration or a decrease of system cost respectively — clearly turns out to be the main motivation for their introduction. Results of current research show a significant potential to make use of this also in other applications such as transportation in automobiles, trains or aeroplanes, and energy supply such as through photovoltaic inverters or the distribution network. Its exploitation is expected to be enabled by the ongoing development of active switches, of high voltage devices and of high temperature packaging technology, together with the required proof of reliability and cost reduction, the fields of application being already established contribute to. The recent SiC User Forum shall support this desirable advancement; the next steps might be reported on the occasion of a similar event planned for the future.

Contact:
ECPE European Center for Power Electronics e.V.
Dipl.-Ing. Juergen Bublitz
Landgrabenstr. 94
D – 90443 Nuremberg
Tel.: +49 (0)911 / 810 288 12
FAX +49 (0)911 / 810 288 28
E-Mail: juergen.bublitz@ecpe.org
Internet: www.ecpe.org