Advantages of SiC Schottky Diodes in Fast Switching Power Electronics Solutions

Silicon Carbide (SiC) is discussed as a future high performance replacement for silicon power components. The new technology enables products with almost ideal behaviour. Currently, SiC Schottky rectifiers are available as qualified standard products and this article will investigate how to utilise the advantages of the new technology in commercial module applications. The investigation is done based on the example of a standard boost circuit used in active power factor correction or DC/DC step up converters. **Michael Frisch, Tyco Electronics/Power Systems, Munich, Germany**

The theoretical advantages of SiC technology are obvious. The new technology promises new semiconductor products with a behaviour very close to that of ideal components such as:

- Reduced forward voltage drop: The static losses are significantly lower than in Si semiconductors with the same chip size. This leads to higher efficiency regarding static losses.
- High operating temperature: The operating temperature of SiC devices already extends to temperatures > 225°C. But in theory, much higher temperatures are also possible.
- Ultra low Q_{rr}: There is nearly no reverse recovery charge (Q_{rr}) stored in a SiC diode. The Q_{rr} of a hard switched freewheeling diode causes additional losses in the switch and is a root cause for EMC/EMI.
- Low leakage current: The leakage current of a SiC semiconductor is very low and doesn't rise siginificantly at higher temperatures.

The real world

It is currently not possible to utilise all the potential of the SiC technology into real advantages of new power electronic circuits. Within a cost-saving environment, a high purchase price is always the first barrier for any new technology. The volume cost of SiC components is a 2-digit factor higher than that of Si components with the same chip area. Usually, the high temperature capabilities of SiC technology would also lead to higher heatsink temperatures. However, other components that are mounted on the same heatsink are only available in Si technology with standard temperature rating. Therefore, this advantage can not be utilised. Also, the high T_{jmax} does not offer big advantages in

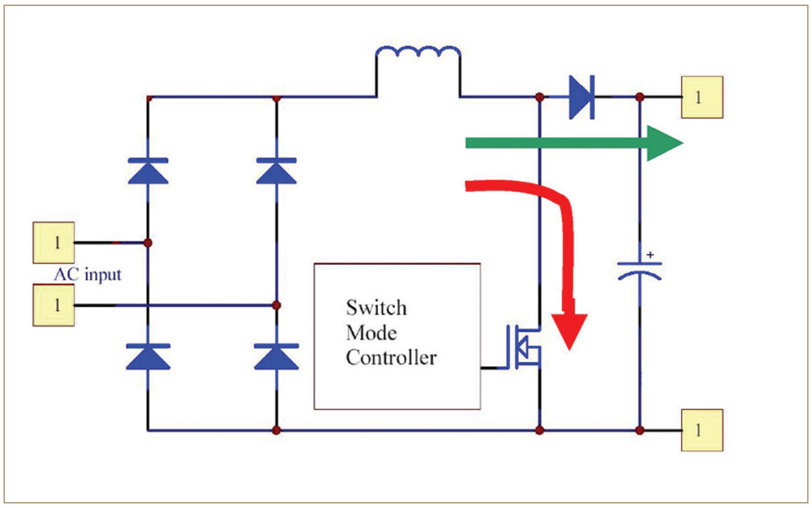


Figure 1: **PFC boost stage**

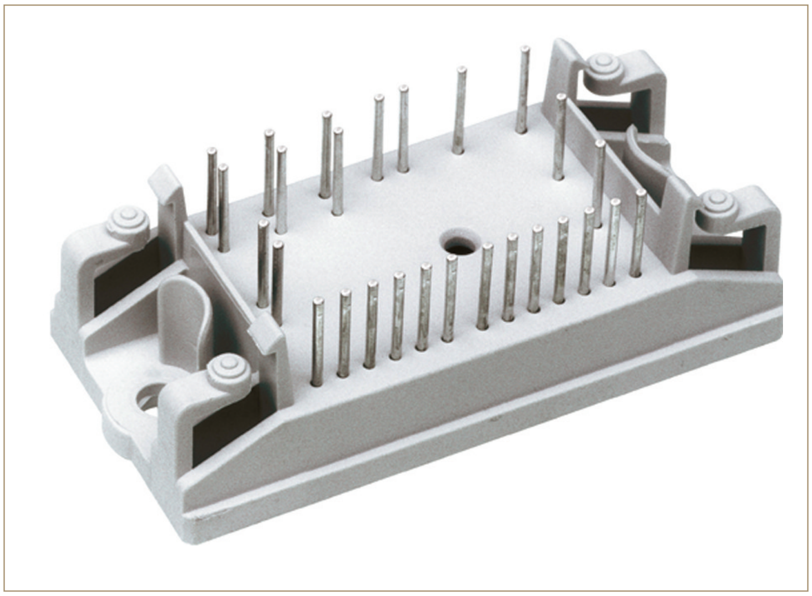


Figure 2: **Tyco Electronics flowPFC0 power module**

Figure 3: Schematics of the flowPFC0, in the benchmark only one boost phase is used

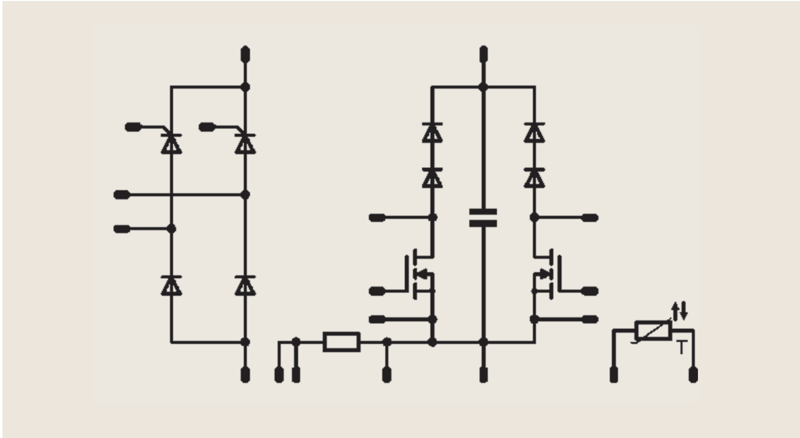
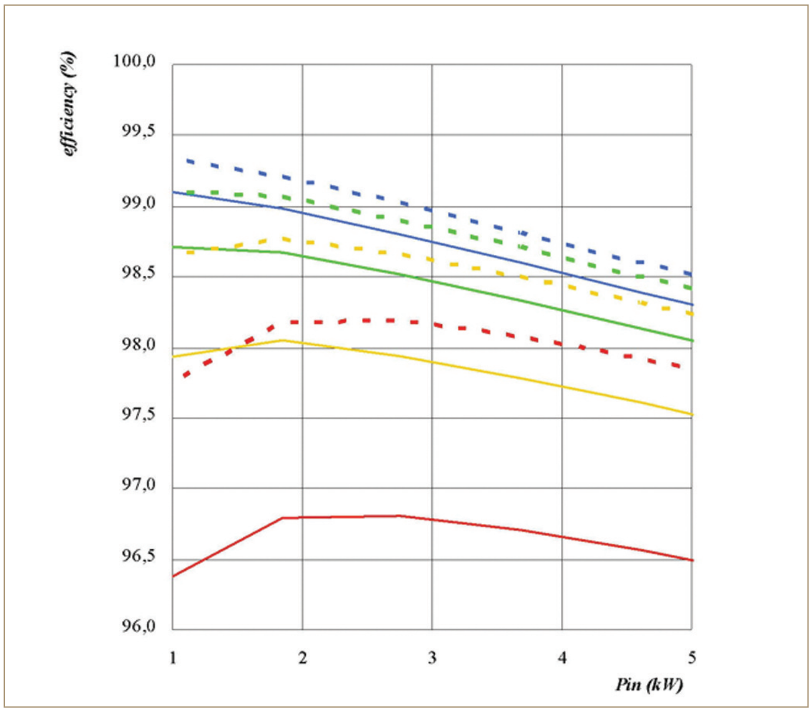


Figure 4: Efficiency comparison of single hyperfast FRED versus SiC-diode. The frequency steps are given from 25 to 200kHz in x2 steps



real applications. A higher junction temperature should theoretically allow a higher power rating which, in turn, increases the temperature swing of the component. The lifetime for soldered and wire-bonded components is dependent on the temperature rise of the chip. In most packages, it is either the chip soldering or the wire bonding that limits the lifetime and not the chip itself. Presently, the number of failures per mm² on a SiC wafer is much higher than for Si technology. This results in a limited chip size to achieve an acceptable yield. Finally, the highest rating for diode chips is approx. 20A/600V. For applications exceeding this value, a paralleling of the diodes is necessary.

The remaining advantage for SiC technology is its ideal dynamic behaviour. In hard switching applications, the switch-on losses of the transistor are mainly influenced by the corresponding diode. And this is where the SiC diode is able to reduce the switching losses in the transistor, since the reverse recovery current

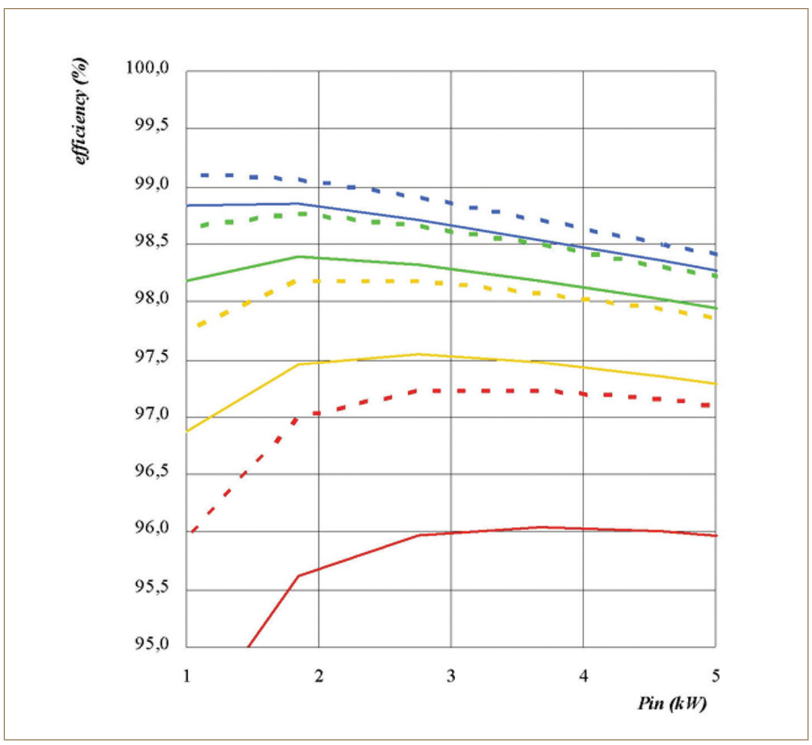


Figure 5: Efficiency comparison 2x fast 300V FRED versus SiC-diode. The frequency steps are given from 50 to 400kHz in x2 steps

of the diode needs to be added to the nominal switched current. This reverse recovery current not only increases the losses, it is also the main source of EMC/EMI emission in the application. In the following section, a boost stage with a SiC diode is compared to alternative solutions based on standard silicon technology.

Efficiency benchmark

In the comparison the active components of the PFC boost stage are benchmarked at 230VAC input and 400VDC output at 2kW input power. The input rectifier and choke are not included in the comparison (Figure 1). In all following tests cases, a CoolMOS MOSFET is used as the switching transistor together with a fast 600V FRED in Si technology, two fast 300V FRED in Si technology connected in series, and SiC diode as boost diodes. The components for the efficiency benchmark are assembled as bare dies into a Tyco Electronics flowPFC0 power module (Figures 2, 3).

The comparison with Single hyperfast FRED is carried out between Tyco Electronics test module with MOSFET SIPC44N50C3 and single Si-FRED FD120N60 (solid line in Figure 4) against standard module V23990-P800-D30 (only 1 boost phase used) with MOSFET SIPC44N50C3 and two paralleled SiC rectifiers SIDC02D06SiC02 (dashed line in Figure 4). This figure shows the comparison of the efficiency in a PFC-boost application depending on the diode technology.

At 50kHz, the losses of the standard circuit are already 32% higher. At 100kHz, the efficiency of the circuit with the SiC diode is 98.7%, as compared to only 98% of the circuit with the Si diodes. This means that the losses in the circuit with standard technology are approximately 59% higher. At 200kHz the losses of the standard technology are 76% higher. This practically disqualifies the standard Si technology for frequencies higher than 100kHz.

The comparison with two fast 300V FREDs has been carried out made between Tyco Electronics standard module V23990-P803-D30 (only one boost phase used) with MOSFET SIPC44N50C3 (CoolMOS) and two fast Si-FRED (solid line in Figure 5) versus Tyco Electronics module V23990-P800-D30 (only one boost phase used) with MOSFET SIPC44N50C3 (CoolMOS) and two paralleled SiC rectifiers IDC02D06SiC02 (dashed line in Figure 5).

The connection of two fast 300V diodes in series is the first alternative. This solution shows much lower losses than the circuit with a single Si diode (Figure 5). However, at 100kHz, the losses are again already 31% higher than with a SiC diode. At 200kHz, the losses using a SiC diode are 39% lower and at 400kHz 46% lower.

EMC and EMI

The electric noise and its compensation are highly dependent on the application in question. The effort for EMC filtering in applications connected to the public power grid is estimated at approximately 20 to 30% of the total cost. The reverse recovery current in hard switched applications is one of the main sources of EMC/EMI. Using SiC Schottky diodes, it is possible to reduce the filtering effort significantly. EMC/EMI debugging is often implemented as a separate development step after the selection of the semiconductors. This makes it difficult to compare the cost benefit ratio. However, in many fast switched applications, the SiC diode compensates for its higher price if the EMI filtering is taken into account.

Conclusion

For PFC-boost applications with switching frequencies above approximately 150kHz, SiC diodes are a good and also cost- efficient solution. For frequencies between 20 and 150kHz, two Si diodes in series is the best trade-off between efficiency and cost. The standard Si diode is clearly outperformed already at frequencies of >25kHz.

In special applications, such as efficiency driven solar inverters, SiC diodes bring considerable value already at much lower frequencies.

Many features of SiC technology cannot be utilised in today's power applications. However, considerable advantages can be realised in fast switching power applications. Once all the benefits of SiC technology become applicable a significant cost reduction of the power electronics system will be feasible because SiC technology will improve the efficiency and reduce EMC/EMI; higher efficiency will reduce the size of the heatsink; reduced EMC/EMI will reduce the filter components and the PCB area; the combination both above mentioned features will reduce the cost of the mechanic and passive components and the size of the electronic device; and finally reduced size and the increased efficiency will add value on the application.