

Advantages of SiC Schottky Diodes in Fast Switching Power Electronics Solutions

Michael Frisch Aug. 2007, Tyco Electronics / Power Systems

SiC is discussed as a future high performance replacement of the silicon power components. The new technology enables products with almost ideal behaviour. Currently, SiC Schottky rectifiers are already available as qualified standard products and this article will investigate how to utilize 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.

Theory

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

- ⇒ Forward voltage drop is reduced:
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 $> 225^{\circ}\text{C}$. 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 significantly at higher temperatures.

The Real World

It is currently not possible to utilize all the potential of the SiC technology into real advantages of new power electronic circuits. The reasons are the following.

- ⇒ Within a cost-saving environment, a high purchase price is always the 1st 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 heat sink temperatures. However, other components that are mounted on the same heatsink are only available in Si technology with standard temperature rating. Therefore, this cannot be utilized.
- ⇒ Also the high $T_j\text{-max}$ does not offer big advantages in 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.

- ⇒ Limited power rating:
Presently, the number of failures per mm^2 on a SiC wafer is much higher than for Si technology. This results in a limited chip size to achieve an acceptable yield.
- ⇒ 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 behavior. 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 of the diode needs to be added to the nominal switched current.

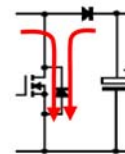


Figure 1: Reverse recovery current added to nominal current

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 $230V_{AC}$ input and $400V_{DC}$ output at 2kW input power. The input rectifier and choke are not included in the comparison.

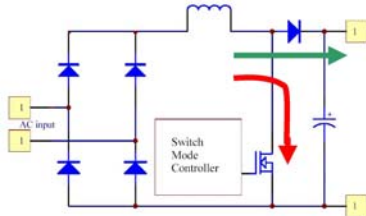


Figure 2: PFC boost stage

The following components are compared:
In all following tests cases, a CoolMOS™ mosfet is used as the switching transistor together with different boost diodes:

- fast 600V FRED in Si technology
- 2 fast 300V FRED in Si technology connected in series
- SiC diode

The components for the efficiency benchmark are assembled as bare dies into a Tyco Electronics flowPFC0 power module.

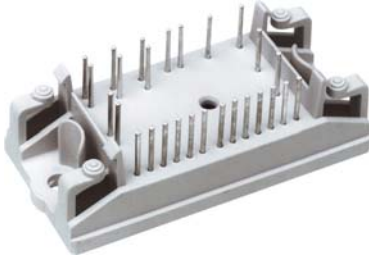


Figure 3: Tyco Electronics module: V23990-P800-D30

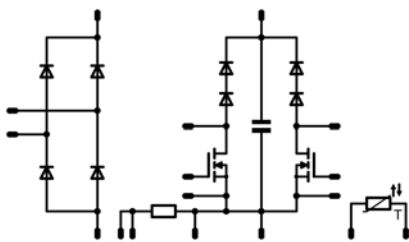


Figure 4: Schematics of the flowPFC0. In the benchmark only 1 boost phase is used.

Single Hyperfast FRED

The following comparison is carried out between:

- Tyco Electronics test module:
MOS-FET: SIPC44N50C3
Rectifier: single Si-FRED FD120N60 (solid line)
- Tyco Electronics standard module:
V23990-P800-D30 (only 1 boost phase used)
MOS-FET: SIPC44N50C3
Rectifier: 2 paralleled SiC rectifiers
SIDC02D06SiC02 (dashed line)

The following figure (figure 5) shows the comparison of the efficiency in a PFC-boost application depending on the diode technology.

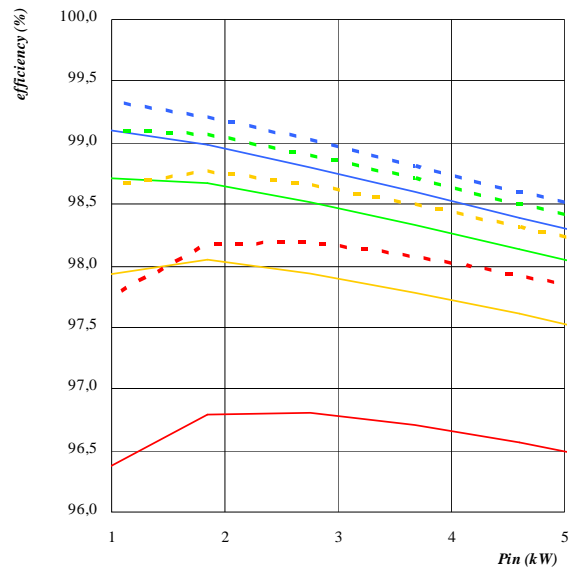


Figure 5: Efficiency comparison: single hyperfast FRED vs. SiC-diode:
The frequency steps are given from 25kHz to 200kHz in x2 steps.

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 approx. 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.

2 fast 300V FRED's

The following comparison is made between:

- Tyco Electronics standard module:
V23990-P803-D30 (only 1 boost phase used)
MOS-FET: SIPC44N50C3 (CoolMOS)
Rectifier: 2 x fast Si-FRED (solid line)
- Tyco Electronics module:
V23990-P800-D30 (only 1 boost phase used)
MOS-FET: SIPC44N50C3 (CoolMOS)
Rectifier: 2 paralleled SiC rectifiers
SIDC02D06SiC02 (dashed line)

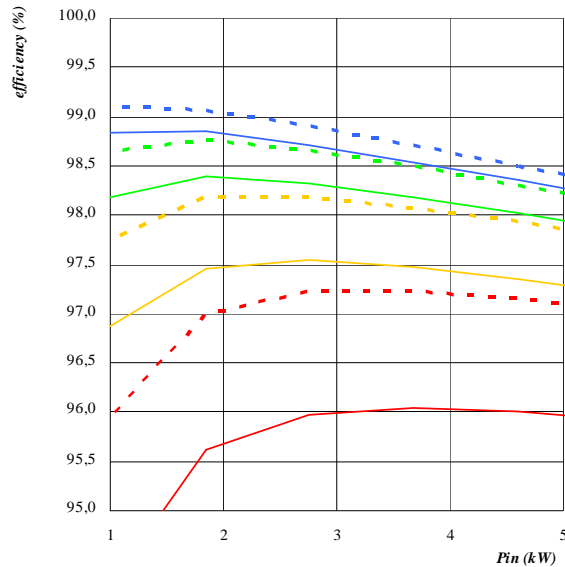


Figure 6: Efficiency comparison: 2x fast 300V FRED vs. SiC-diode:
The frequency steps are given from **50kHz to 400kHz** in x2 steps.

The connection of 2 fast 300V diodes in series is the 1st alternative. This solution shows much lower losses than the circuit with a single Si diode (Figure 6). 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/EMI

The electric noise and its compensation is highly dependent on the application in question. The effort for EMC filtering in applications connected to the public power grid is estimated at approx. 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 approx. 150kHz, SiC diodes are a good and also cost efficient solution. For frequencies between 20kHz 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 utilized in today's power applications. However, considerable advantages can be realized in fast switching power applications:

- ⇒ SiC technology will improve the efficiency and reduce EMC/EMI.
- ⇒ Higher efficiency will reduce the size of the heat sink
- ⇒ 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.
- ⇒ Reduced size and the increased efficiency will add value on the application.

References

- ⇒ Stuart Hodge Jr., Senior Member IEEE, Cree Inc. 2004 thinQ!TM Silicon Carbide Schottky Diodes: An SMPS Circuit Designer's Dream Comes True! Dr. Christian Miesner, Product Marketing Manager Silicon Carbide, Dr. Roland Rupp, Project Manager Development Silicon Carbide, Holger Kapels, Discrete Development Manager, Michael Krach, Project Manager Silicon Carbide, Dr. Ilia Zverev, Concept Engineering Manager
- ⇒ New Power Module Structure for Efficiency Improvement in Fast Switching - Power Applications (>50kHz, >1kW) Temesi, Zsadany, Frisch Mar. 2005, TYCO Electronics / Power Systems