ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
Tome IV (Year 2011). ISSN 2067-3809

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APPLICATION OF THE SILICON CARBIDE COMPONENTS IN POWER ELECTRONICS

ABSTRACT:
This paper presents research motivated by industrial demand for using power semiconductor devices based on SiC (Silicon Carbide). The paper deals with possibility of SiC devices application in traction vehicles. The main attention has been given to the topology of 3-phase voltage-source inverter with free- wheeling SiC schottky diode and 1-phase traction converter with middle frequency converter for auxiliary drives. The theoretical conclusions and simulation results are compared with experimental measurements on laboratory model with rated power of 2kVA.

KEYWORDS:
Silicon Carbide, Traction application, Power semiconductor device, Hybrid power integration, Electric vehicle

INTRODUCTION

Power semiconductor devices based on the SiC substrate is coming more and more popular with increasing development of the power electronics. Due to the advantageous qualities discovered at the SiC this material becomes very interesting object for research and development and subsequent using in the all sorts of applications where bigger and bigger exigencies on efficiency, magnitudes, weight and impact on surroundings are set.

SIC PROPERTIES

Crystals of SiC have analogical crystalline structure as diamond and therefore they belong among the hardest known materials, in the Moh's scale of the hardness they reach levels 9-10. Primarily SiC finds use as material called "Carborundum" and it used to exploit for grinding and polishing. Later it was used in the fire-resistant fireclay brickworks and heating shells for industry furnaces or in the composite materials.

With development of the electrotechnics the semiconductor features of SiC were detected and it started to add to the semiconductor substrate of blue shining LED diodes, later in the high shining diodes and in the last few years it has also started to assert in the field of the power electronics.

COMPARISON OF THE SIC WITH OTHER MATERIALS

SiC has several unique properties, which make SiC very interesting object for research and development, mainly in the area of high voltage applications. Fig.1 shows these features in comparison with commonly used semiconductor materials (Gallium Arsenide and Silicon).

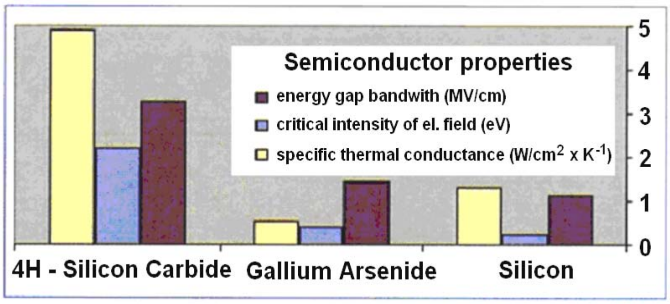

Figure 1. Comparison of individual semiconductor features [3]

PRACTICAL USING OF THE SIC

Meantime SiC diodes are the most used devices based on the Silicon Carbide. They are used in many applications. Blocking (freewheeling) diodes in the PFC applications has been the first example of using and it is still frequently used. Rectifying and freewheeling diodes in the switching sources and freewheeling diodes in voltage inverters or active switching rectifiers are the next using of SiC. Further we will discuss possibility of other devices based on the SiC:

At the first we will compare two version of classical 3-phase VSI (see Fig. 2).

The first version of VSI is mounted by classical silicon IGBTs as shown in Fig.3 in left part. The "hybrid" combination of silicon IGBTs and SiC Schottky freewheeling diodes present the second version of VSI (Fig. 3 in right part).

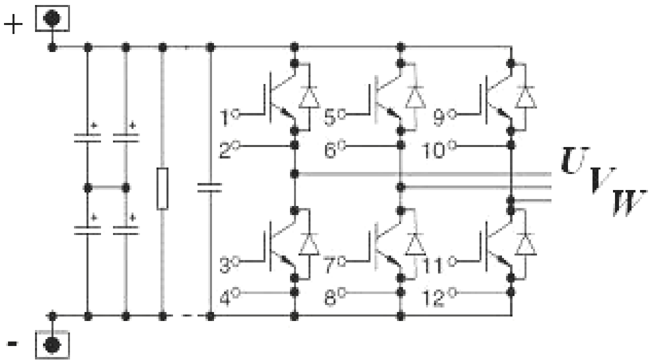

Figure 2. Topology of VSI

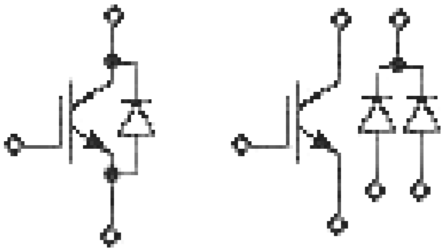

Figure 3. Detailed scheme of used semiconductor devices for VSI

The main advantage of SiC presents following figures 4 and 5 and it is coming-out from Schottky diode properties. The current waveform of silicon diode in the first version of VSI is shown in Fig. 4 and you can clearly see the classical recovering current area.

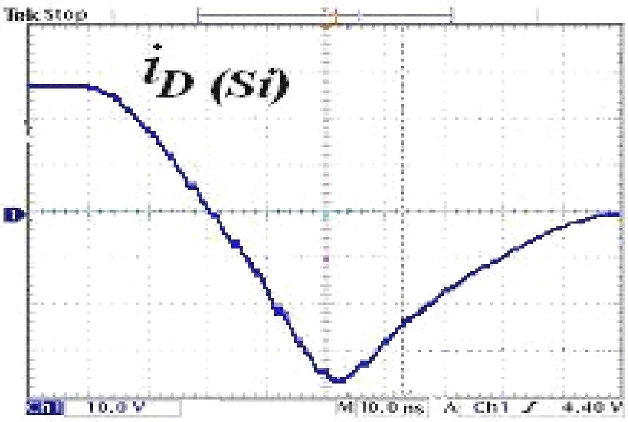

Figure 4. Current waveform of the ultrafast soft recovery epitaxial silicon diode

Against this fact the SiC Schottky diode has very positive waveform of recovering current area (Fig. 5) which is diametrically lower than at Si diode. This is advantage of Schottky structure and SiC material are able produce high voltage Schottky diodes and that is reason of such wave. The double SiC diode module from CREE is used.

Experimental example of star up of the hybrid VSI version presents Fig. 6. It is evident that using of SiC freewheeling diode has positive influence on current overshoot of collector current of IGBT tranzistor.

The testing has been provided under lower supply voltage 200V according to the used devices of 600V range (available free samples).

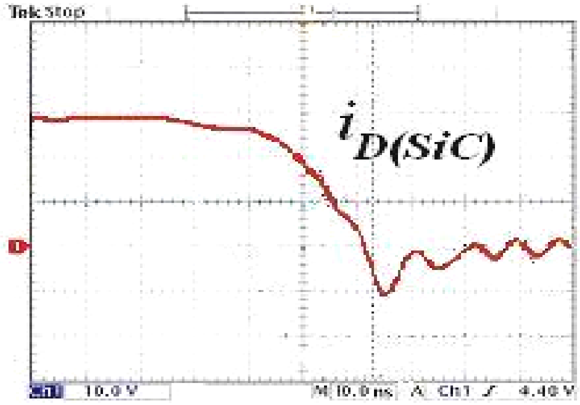

Figure 5. Current waveform of the SiC Schottky diode (produced by CREE as shown in Fig.9)

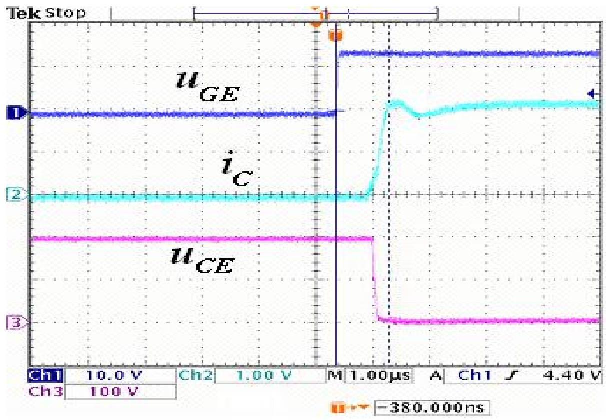

Figure 6. Start up of the hybrid VSI version

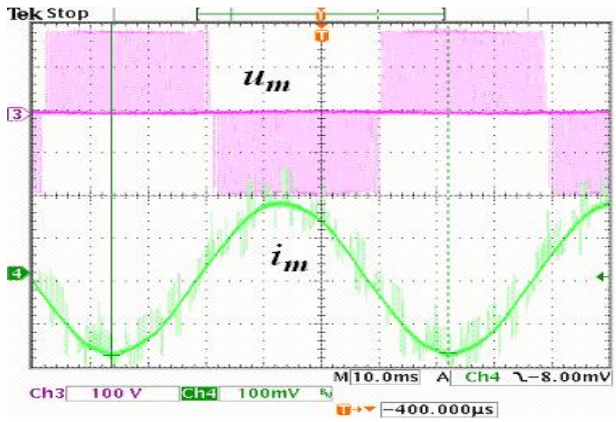

Figure 7. Principal scheme of device J-FET (cascade)

Typical output waveforms of VSI (line to line voltage UM and phase current IM) are shown in Fig. 7.

Fig. 8 – Fig. 11 present photos of experimental ptotypes of VSI with classical Si IGBTs and hybrid version with Si IGHTS and SiC Schottky diodes.

The hybrid version enables use 5-time higher switching frequency under the same conditions as standard topology with silicon IGBT transistors. It is done by expressively lower losses of SiC schottky diodes (Fig.5).

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For comparison of the appropriate running condition and losses we have used measuring of circuits values and steady-state temperature of the heat sink.

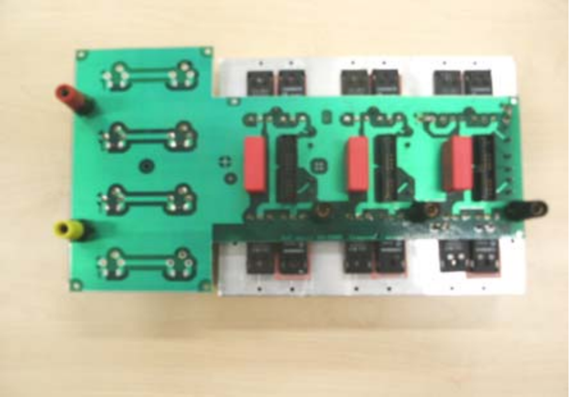

Figure 8. Prototype of hybrid VSI

Figure 9. Detail of hybrid VSI devices

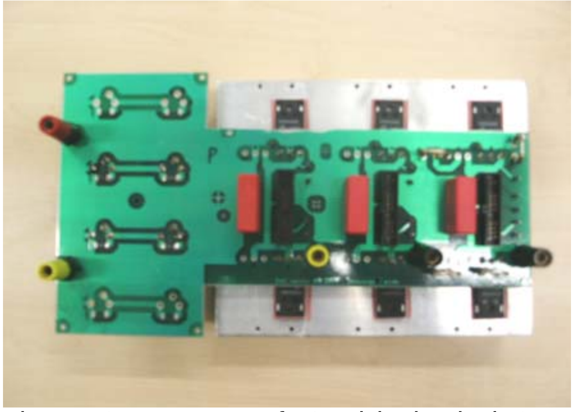

Figure 10. Prototype of VSI with classical IGBTs

Figure 11. Detail of VSI with classical device

The single phase traction converter for auxiliary drives is the second presented application of SiC (Fig. 12). The auxiliary drive converter presents galvanic insulation VSI for auxiliary drives. The input part is directly connected to the DC bus line of main traction converter, it means 1500 V or 3000 V according to the traction vehicle topology. Due to the voltage level the number of serial connections of input 1f VSI has to be placed. Input 1f VSIs fed the middle-frequency transformer (MFT) and the standard diode bride rectifier with SiC is connected on the MFT output. The key is in the using of high switching frequency up to 100 kHz to decrease of weight of auxiliary drive transformer. Output diode rectifier supply DC bus line where several of VSI + auxiliary drives are connected.

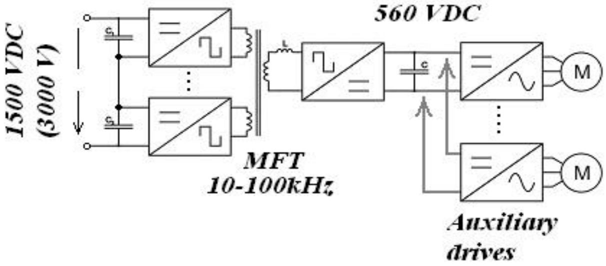

Figure 12. Principal scheme of auxiliary drives traction converter

Fig. 13 presents experimental results of stead state waveforms of MFT voltage and current (output values of input VSI as well). It is evident from the picture that the switching frequency is only 10kHz. This is fact of VSI design with IGBTs and control circuit based on the DSP TEXAS 2812, both aspects limited available switching frequency with reasonable rated power (DSP: A-D converters limited monitoring of analog values, IGBTs limited ratio between switching frequency and reasonable rated power).

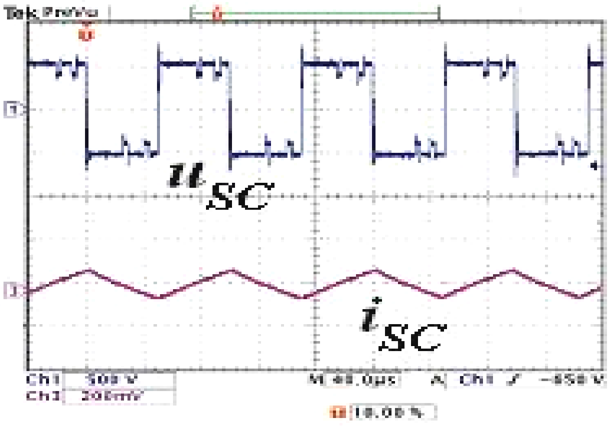

Figure 13. Steady state of voltage and current of MFT, rated power 2kVA

The next step is in a new design of the input single phase VSI based on power MOSFETs (to increase switching frequency with reasonable rated power) and mainly using of superior control system based on on analog circuits (analog operational amplifiers) to achieve 100kHz switching frequency.

Conclusion

This paper presents research motivated by industrial demand for using power semiconductor devices based on SiC. The main attention has been given to the topology of 3-phase voltage-source inverter with free-wheeling SiC schottky diode and comparing with topology with classical Si IGBTs. The 5-times increasing of switching frequency with the same loses is the main advantage of this hybrid structure. The second mentioned structure is 1-phase traction converter with middle frequency converter for auxiliary drives. Using SiC diodes in the secondary bridge rectifier brings opportunity to use high switching frequency approximately 50-100 kHz. Proposed converter runs at 10 kHz according to used devices and control system based on DSP Texas 2812 (problem with conversion speed of standard A-D converters).

Acknowledgment

This research work has been made within research project of Czech Science Foundation No. GACR 102/09/1164.

References

[1] Dahlquist, F. - Frank, W. and Deboy, G. SiC diodes improve boost converter. vyd. Infineon technologies, 2004, 3s, SiC Diodes Improve Boost Converters (PEE 4-04).pdf

[2] Richmond, J. – Hodge, S. and Palmour. J, Silicon karbide power application and roadmap. Publ. Cree inc, 2004, 4s, SiC Power Appl. and Devices Roadmap (PEE 7-04).pdf

[3] Friedrichs, P. – Rupp, R. Silicon Carbide Power Devices - Current Developments and Potential Applications. EPE 2005. ISBN : 90-75815-08-5.

[4] Hruška, M. Application of Silicon Carbide in the power electronics. Publ. in UWB in Pilsen, 2006, 21s.

[5] Kapels, H et. al. A revolutionary step towards energy saving power Electronic systems. vyd. Infineon technologies AG, 2001, 5s, SIC- PFC Inf. - SiC Schottky Diode - Revolutionary Step to Energy Saving.pdf

[6] Technical documentation, CoolMOS Power transistor – SPW35N60C3. publ. Infineon technologies, 2005, 11s, SPW35N60C3_Rev.2.4.pdf

[7] Technical documentation, SiC diode – SDT12S60. publ. Infineon technologies, 2002, 8s, 1-SDT12S60.pdf

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ACTA TECHNICA CORVINIENSIS
– BULLETIN of ENGINEERING
ISSN: 2067-3809 [CD-Rom, online]
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