§9. Study on Application of Next Generation Power Devices for the Fusion System

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Research and development of next generation semiconductor power devices as the successor of existing Si devices, such as SiC and GaN, have remarkably progressed recent years. A 600-V class SiC diode has been already available and 1200-V class SiC MOSFETs will be launched into the markets in the next several years. Their high carrier mobility can realize high speed and low loss switching, and their wide bandgap can realize high withstand voltage and high temperature operation. In the future, appearance of 10-kV class devices will be expected. Application of these new devices makes high capacity power supplies small-size, highly-efficient, highly-functional. Especially applying to nuclear fusion reactor power supplies such as plasma heating devices and superconducting coils has many advantages because these power supplies require high switching frequency, high withstand voltage, large current and high efficiency.

As a first step, we manufactured a 1-kW boost chopper using a SiC Schottky Barrier Diode (SBD) and evaluated its characteristics. Figure 1 shows the circuit schematic of the chopper and Table 1 summarizes the major parameters. The employed SiC diode (Infineon, IDT16S60C) has a high withstand voltage of 600 V due to its wide bandgap even though it is SBD. In order to realize high speed switching, a Si super-junction MOSFET (Infineon, SPW52N50C3) was applied, which has high withstand voltage. The voltage and current waveforms of the MOSFET and the turn-off current waveform of the SiC SBD under the following operational conditions are shown in Fig.2: carrier frequency of 100 kHz, input voltage V_{in} of 170 V, output voltage V_{out} of 310 V. In the turn-off current waveform of the SBD, there was a ringing, however very high speed switching was realized because there was no minority-carrier storage effect at turn-off, which is typical for pn-junction diode. Therefore, the significant reduction of switching losses and high frequency operation can be expected.

One power supply configuration that consists of a frequency converter and a high frequency transformer shown in Fig.3 has been proposed for the NBI heating device in order to downsize a boost transformer. According to this configuration, however, the switching losses of the converter will increase due to high frequency operation. Moreover, high generator voltage (18 kV) requires the series connection of the switching devices to reduce the voltage stress; as a result, conduction losses will increase. Employing of the high-voltage and low-loss wide bandgap devices can be the solution for these problems.

As the next step, analysis of the operation and losses of the NBI power supply will be investigated through numerical circuit simulation. Comparative study between existing Si converters and the next generation device converters from the viewpoints of the converter losses and sizes is planned. Characteristics evaluation of the SiC and GaN devices is also planned through experiments using the boost chopper, and based on these results, other applications such as the power supply of superconducting coils will be investigated.

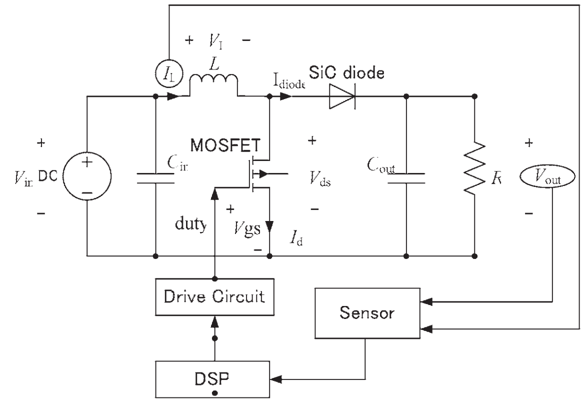
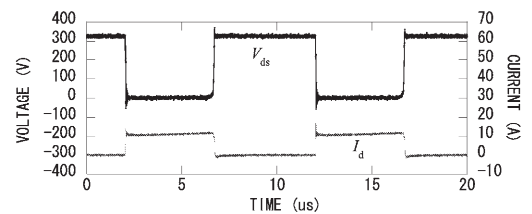


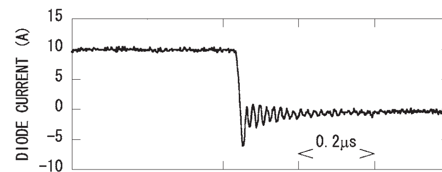
Fig. 1. Experimental circuit configuration of a boost chopper using a SiC Schottky barrier diode.

Table I. Major parameters of the boost chopper.

Rating power	1 kW
SiC SBD rating	600 V / 16 A
MOSFETrating	560 V / 52 A, R_{on} = 0.07 Ω
Input Inductor L	1 mH
Input capacitor C_{in}	1500 μF
Output capacitor C_{out}	1000 μF
Load resistor R	99.4 Ω
Switching frequency	100 kHz



(a) Waveforms of the MOSFET drain current (I_d) and drain-source voltage (V_{ds}).



(b) SiC diode turn-off current waveform.

Fig. 2. Waveforms of the MOSFET and the SiC diode.

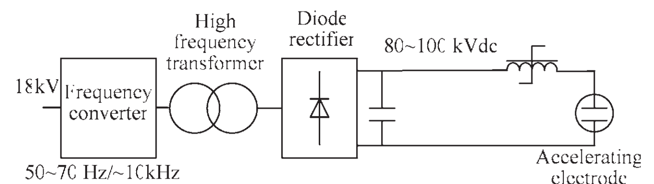


Fig. 3. Configuration of the power supply for NBI heating device.