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

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Next generation semiconductor power devices such as SiC and GaN are recently under intense development as the successor of presently mainstream Si devices. A 600-V SiC Schottky barrier diode (SBD) has been already available in the market and development of a 19-kV SiC pin diode was reported. Launching of a 10-kV class high voltage diode which exceeds performance limitation of Si devices is also expected in the near future. Moreover, sample products of 1200-V SiC JFET are presently available. High carrier mobility of these next generation devices realizes high-speed and low-loss switching, and their wide bandgap realizes high withstand voltage and high temperature operation. Application of these new devices makes high capacity power supplies small, highly-efficient, highly-functional; hence applying of them to nuclear fusion reactor devices such as plasma heating devices and superconducting coils has many advantages.

To investigate characteristics of SiC devices, we fabricated a 1-kW boost chopper using SiC devices presently available: a JFET (SiCED, Cascode) and a SBD (Infineon, SDP06S60). Fig. 1 shows a circuit configuration and Table 1 summarizes major parameters of the chopper. Turn-on and turn-off waveforms of current i_{JFET} and voltage v_{DS} are shown in Fig. 2 under the condition of output power, 450 W; carrier frequency, 100 kHz; input voltage V_{in}, 210 V; output voltage V_{out}, 285 V. Results showed the JFET achieved very fast switching, however turn-off loss was three times larger than turn-on loss. Measured efficiency of the chopper reached 97.6% under the same operational condition as Fig. 2, and it became 97.5% in the case of output power of 700 W. In addition, efficiency higher than 97% was achieved over the switching frequency range of 50 to 150 kHz.

Application of next generation devices to a NBI power supply has great advantages because it requires very high voltage and quick response. One of proposed circuit configurations for the NBI power supply is drawn in Fig. 3, which has cascade configuration of power supply units. Each power supply unit consists of a low voltage side diode rectifier, an inverter, a high frequency transformer and a series-connected high voltage side rectifier for an accelerator electrode. In order to obtain waveforms of both side diode rectifiers, numerical circuit simulation was done for one power supply unit. Based on the simulation results and a device datasheet, we estimated power losses of both the rectifiers, in the case of employing of Si diodes (Mitsubishi, FD1500AU-120DA, 6 kV, 1200 A). As a result, their total power losses were estimated at 2.72 MJ per one pulse operation (80 kV; 100 A; transformer frequency, 10 kHz; pulse duration, 500 ms). On the other hand, we also carried out simulation of the case of applying of SiC pin diode reported in ref. 1) to both the rectifiers. Under the assumption that recovery loss of the SiC diode can be reduced to 1/30 compared to a Si diode[1)], total power losses of rectifiers were drastically reduced to 99.7 kJ because switching losses of the high voltage side rectifier became very small. As a result, downsizing of the power supply system is expected because loss reduction contributes reduction of cooling equipment.

These results suggest application of SiC devices has the possibility of realization of a small-size high-efficiency power converter with a high operational frequency.

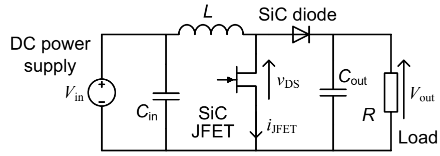
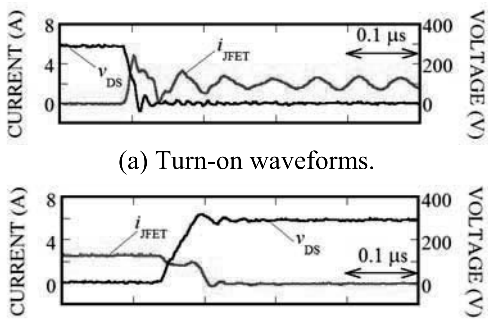


Fig. 1. Circuit configuration of the boost chopper.

Table I. Major parameters of the boost chopper.

Rating power	1 kW
SiC SBD rating	600 V / 6 A
SiC JFETrating	1200 V / 5 A, R_{on} = 0.55-0.86 Ω
Input Inductor L	1 mH / 29.4 mΩ
Input capacitor C_{in}	1500 μF
Output capacitor C_{out}	2350 μF
Load resistor R	180 Ω
Switching frequency	50~150 kHz



(a) Turn-on waveforms.

(b) Turn-off waveforms.

Fig. 2. Current and voltage waveforms of the SiC JFET.

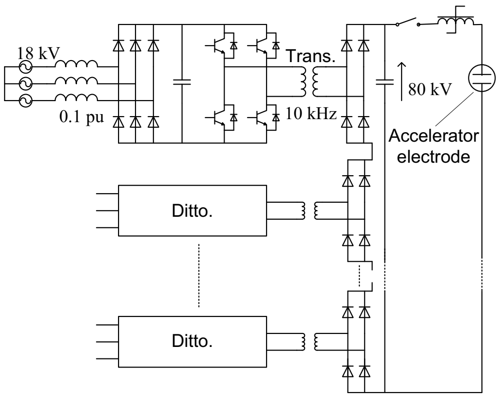


Fig. 3. Configuration of the power supply system for a NBI heating device.

1) Y. Sugawara *et al.*, "6.2 kV 4H-SiC pin Diode with Low Forward Voltage Drop," *Material Science Forum*, Vols. 338-342 (2000), pp. 1371-1374.