DESIGN AND DEVELOPMENT OF ACCELERATOR MAGNET POWER SUPPLY BASED ON SIC-MOSFET*

Yang Li#, Fengli Long, Zhenhua Hou, Institute of High Energy Physics, CAS, Beijing, China

Abstract

SiC is a new type of semiconducting material with rapid development after the first generation and the second generation of semiconductor materials represented by silicon and gallium arsenide. SiC-MOSFET has a high frequency, high breakdown voltage, high temperature, radiation and many other points, suitable for future use in the accelerator magnet power supply. In this paper, the development and operation of a SiC-MOSFET-based accelerator magnet power supply are described in detail. The experiment results show that the performance of this power supply is superior to that of the same specification using Si-MOSFET. The power supply adopts one-way AC power supply, and the output stage adopts the full bridge circuit topology. The power device adopts C2M0040120D SiC-MOSFET, the working frequency is 30 kHz, the output current is ± 20A, the output voltage is ± 20V, and power is 400W. The Digital Power Supply Control Module (DPSCM) is used to realize high-precision digital closed-loop control, which supports on-line debugging and PC control. Power supply can be used to correct the magnet power, with high efficiency, high stability, and fast response and so on.

INTRODUCTION

The envelopment of power electronics is an important port of power supply technology. Actually the envelopment of power electronics is the envelopment of device. The power-core of the Power Supply is power switching device based on Insulated Gate Bipolar Transistor (IGBT) and semiconductor field effect transistor (MOSFET). Power devices have gone through the development process from transistors, thyristors, and now to MOSFET, IGBT. The main semiconductor material of these devices is silicon. Because of perfect performance of power electronic devices with silicon based materials has its structure design and manufacturing process and close to the theoretical limit by the material properties determined, rely on silicon devices continue to improve and enhance the power electronic device and system performance potential is very limited.

SiC-MOSFET is made of third generation semiconductor material. Due to the characteristics of the structure, wide band gap semiconductor material with high breakdown electric field, high thermal conductivity, more suitable for the production of high temperature, high frequency, radiation resistance and high power devices.

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#liyang@ihep.ac.cn

A ±20A, ± 20V power supply was made by using SiC-MOSFET. The power supply adopts modular design, which is composed of two half bridge power modules

The design of power supply module adopts CREE official reference design. This module is the driving circuit and the SiC MOSFET half bridge assembly, which meets the requirements of SiC-MOSFET.

The Figure 1 shows the schematic diagram of the module, and Fig. 2 shows the printed circuit board. [1]

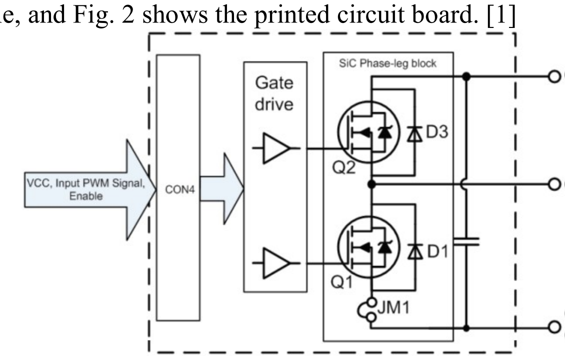

Figure 1: Schematic diagram of the module.

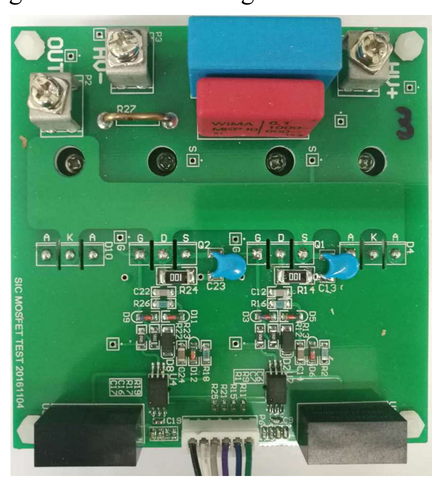

Figure 2: Printed circuit board of the module.

Although the SiC device can tolerate high temperature, but the heat sink (Fig. 3) is still needed, so as to avoid the MOSFET temperature is too high.

TEMPERATURE TEST

By the conduction of the internal resistance, the MOSFET will produce conduction loss, and in the form of heat energy to the heat sink. In the experiment, we hope that the smaller the heat loss of the power device. In order to verify the thermal loss of Si power devices and SiC power devices, two sets of experiments were conducted to test the operating temperature of the power device and the heat generated on the heat sink. The test is carried out at the same current and frequency and the

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energy saving characteristics of the SiC device are obtained through the comparison experiment.

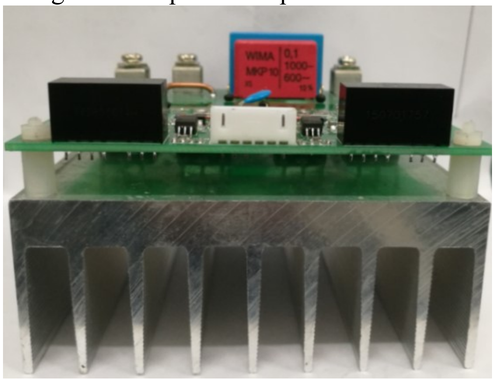

Figure 3: The module with the heat sink.

Test circuit is synchronous buck (Fig. 4); a power module of the two MOSFET consists of a synchronous buck circuit. Compared with SiC MOSFET and Si MOSFET, under the same test conditions, the temperature rise of SiC MOSFET was significantly less than that of common Si devices.

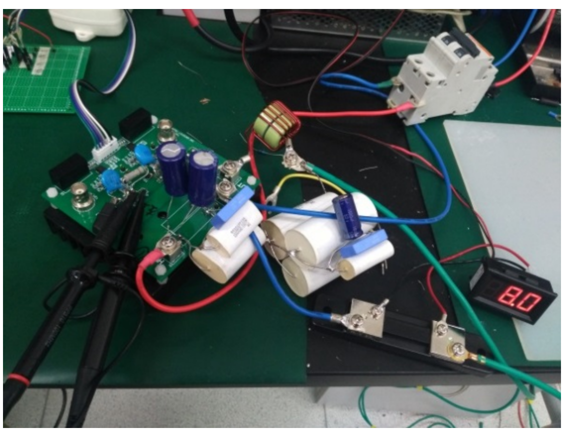

Figure 4: The test circuit of synchronous buck.

We use FLUKE Ti27 thermal imager to take pictures of the modules in the experiment. The heat generated by the SiC MOSFET (Fig. 5) and Si MOSFET (Fig. 6) modules is analysed. [2]

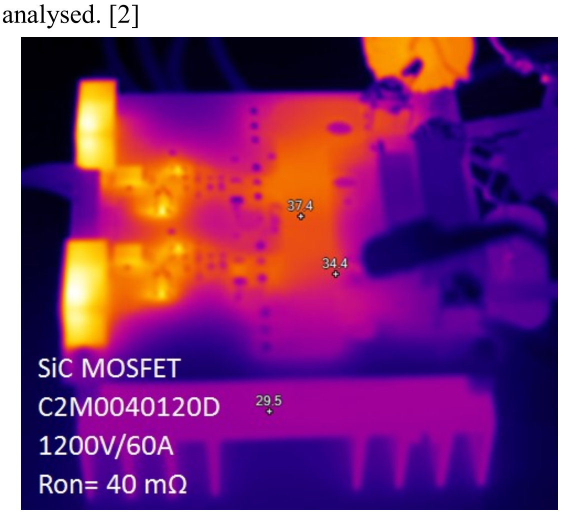

Figure 5: The temperature of SiC MOSFET modules.

Figure 6 is the case of Si MOSFET. Compared to the SiC MOSFET module, the heat sink temperature is significantly higher

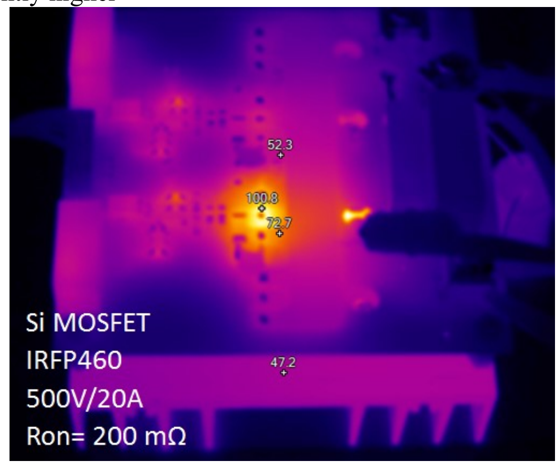

Figure 6: The temperature of Si MOSFET modules.

Table 1 shows the temperature test data of the two kind of MOSFET. [3]

Table 1: Module Temperature Test

	SiC MOSFET	Si MOSFET
Model	C2M0040120D	IRFP460
Rated current	60A@25℃	20A@25℃
Rated voltage	1200V	500V
Conduction Resistance	40mΩ	200mΩ
Frequency	40kHz	40kHz
Test current	10A	8A
Tube temperature	37.4℃	100.8℃
Heat sink Temperature	29.5℃	47.2℃

POWER EFFICIENCY TEST

In the hard switching mode, the efficiency of the power supply is tested (Table 2). Only the forward current efficiency is tested at different current values. Because of the hard switching mode, the power efficiency is not high. Because of the lack of the efficiency analyser, the measured data may be inaccurate.

Table 2: Power Efficiency Test

I set (A)	V in (V)	I in (I)	V out (V)	I out (I)	E (%)
1	24.123	0.07	1.0427	1.0151	62.68%
2	24.122	0.247	2.0896	2.033	71.30%
3	24.121	0.54	3.136	3.052	73.48%
4	24.122	0.947	4.1836	4.0716	74.57%
5	24.123	1.469	5.2311	5.0906	75.15%
6	24.123	2.108	6.279	6.109	75.43%
7	24.123	2.862	7.326	7.128	75.64%
8	24.122	3.727	8.375	8.145	75.88%
9	24.122	4.718	9.424	9.163	75.88%
10	24.121	5.841	10.46	10.18	75.58%

STABILITY TEST

The stability of the output current of the power supply is tested (Table 3). Tests were carried out for 1 hours, respectively, on the 5A, 10A, 15A output current stability of the three stalls were measured in short term. The test instrument is a 6 1/2 bit digital multimeter Keithley2700, with a load of 1 ohm resistance.

Table 3: Stability Test (1h)

I set (A)	I min (A)	I max (A)	Stability (ppm)
5	5.0887	5.08909	38
10	10.1821	10.18259	24
15	15.2762	15.27714	30

For the use of resistive load, temperature rise caused by the stability of drift is more serious, as can be seen from the data graph, in the initial stage of the test, there are obvious fluctuations, and then become stable. The test data show that the short-term stability of power supply is better than 100ppm (part per million).

DIGITAL CONTROLLER

The power supply is controlled by the self-developed Digital Power Supply Control Module (DPSCM). The DPSCM hardware includes two 3U card, one named Main Board (MB), and the other one named ADC/DACs board (Fig. 7).

Figure 7: MB & ADC/DAC board of DPSCM.

The operation of the DPSCM is through the interface of LABVIEW. Three are several lists in the interface which have different function to display or set the parameter.

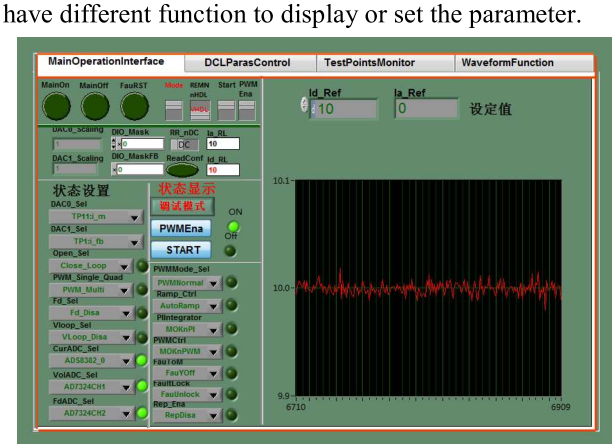

Figure 8: Monitor of 10A current output.

In the Figure 8, the control mode of power supply such as the operation of open loop or close loop can be changed. The output current can be set.

The Figure 9 shows the interface of parameter setting of power supply. In this interface, every control parameter can be modified and saved.

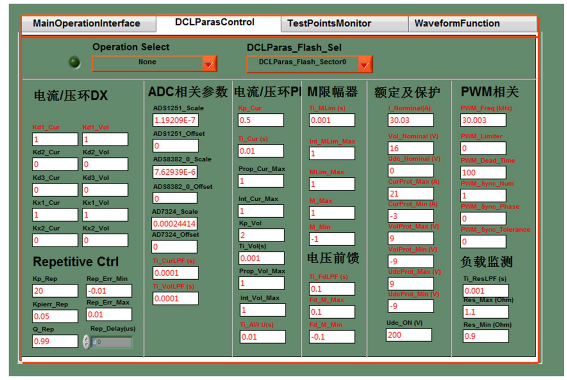

Figure 9: Interface of parameter setting.

The Figure 10 shows the gate waveform of SiC MOSFET. It is can be seen that the MOSFET is working at double frequency.

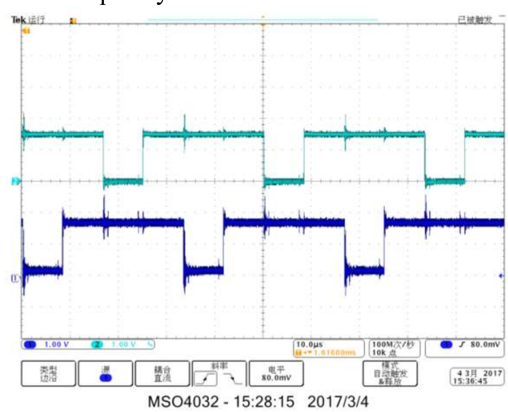

Figure 10: Driving waveform of SiC MOSFET.

CONCLUSION

The design and development shows that SiC MOSFET can be well used in the accelerator magnet power supply, and has a higher voltage than the traditional Si MOSFET, lower conduction resistance, low heat, and can work at higher working temperature and frequency.

ACKNOWLEDGEMENT

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