NOVEL SWITCHING POWER SUPPLY UTILIZING SIC-JFET AND ITS POTENTIAL FOR THE DIGITAL ACCELERATOR *

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Abstract

A high power discrete SiC-JFET is developed aiming for applying to the KEK digital accelerator. The device is assembled on a 58 mm x 36 mm copper base plate and have the height of 7 mm. The size of the die is 4.16 mm x 4.16 mm. The device was tested with pulse discharge circuit and successful operation of 1 MHz-1kV-27 A, where switching loss was estimated to be 235 W, was confirmed. However under ultimate test condition of 900 V-48 A, where switching loss per pulse is 1.5 times higher than the above case, the device was failed at repetition frequency of 800 kHz because of thermal problem. Using this device, a H-bridge switching power supply will be assembled and tested by the end of this year.

INTRODUCTION

The KEK digital accelerator (DA) shown in Fig.1 is a small-scale induction synchrotron (IS) without a high-energy injector [1], where an induction cell is employed as an acceleration device. The concept of an IS was experimentally demonstrated in 2006 [2] through the use of the KEK 12 GeV PS. Commissioning of the DA is going on now [3]. The DA has no limitation of bandwidth in a lower side because the induction cell is a simple transformer driven by a switching power supply (SPS) that generates bipolar pulses. The present SPS, which is composed of 7 series connected MOSFET per one arm of a H-bridge because of the limitation of a heat deposit capacity and a withstand voltage of the MOSFET , carries an arm current of 20 A at 2 kV. Series connection of the MOSFETs has substantially induced a large complexity resulting in less reliability in a steady operation of the DA.

To solve these problems, the next generation of switching pulse modulator utilizing silicon carbide (SiC) devices is under development. The SiC device seems to be a promising candidate because advanced electrical and material properties of SiC power devices [4] allow us to realize a more reliable SPS with higher capabilities. The SiC power semiconductors are characterized by outstanding performance in their high voltage blocking capability, low voltage drop in their on-state, less switching time and thermal resistance. The conduction and switching losses can be reduced and the capability of operating temperature can be significantly improved as compared to Si devices. These robust and low loss characteristics of SiC devices are suited for the digital accelerator. But SiC switching devices are not commercially available. Therefore we have started to develop a prototype device cooperate with device manufacturers in expectation of future industrial accelerator.

In this paper, switching performance of the newly developed SiC-JFET under a couple of conditions, one is like in the present DA, the other is with heavier load, heat removal performance and a future plan will be described..

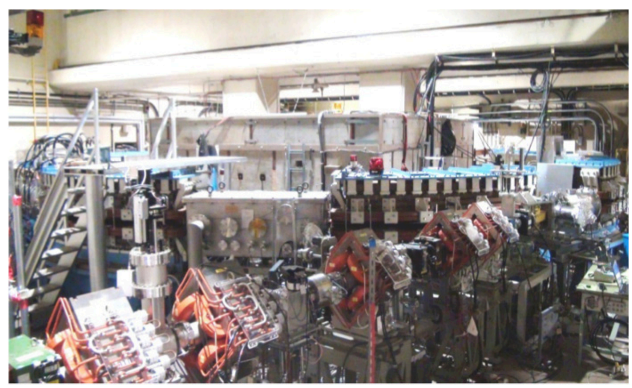

Figure 1: Photograph of the KEK-DA

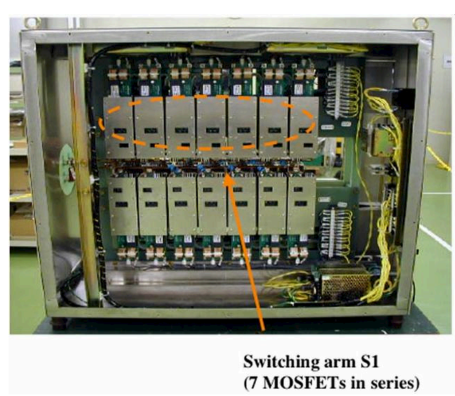

Figure 2: Photograph of a switching power supply (SPS)

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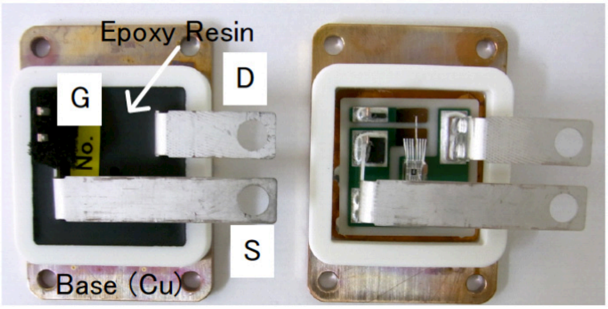

Figure 3: Appearance of the developed SiC-JFET

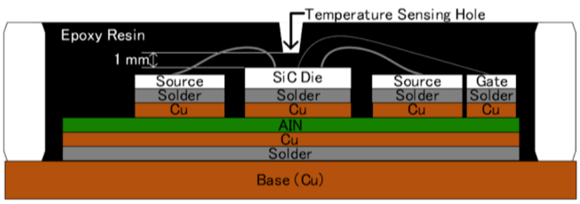

Figure 4: Cross-sectional view of the SiC-JFET

SiC-JFET

Appearances (completed and before molded) and a cross sectional view of the device package, which is jointly developed by KEK and Sun-A corporation, are shown in Fig. 1 and Fig.2, respectively. The device is assembled on a 58 mm x 36 mm copper base plate and have the height of 7 mm. The size of the die is 4.16 mm x 4.16 mm, which was manufactured by SiCED (Germany). The die is soldered on a metalized AlN substrate. Sixteen aluminum wires that have the diameter of 300 um were bonded for the source electrode, whereas one aluminum wire that has the diameter of 150 um was bonded for the gate electrode. Whole of the package is molded with epoxy resin. On the centre top of the case, there is a temperature-sensing hole that is bored to 1 mm above the SiC die.

EXPERIMENTAL RESULTS

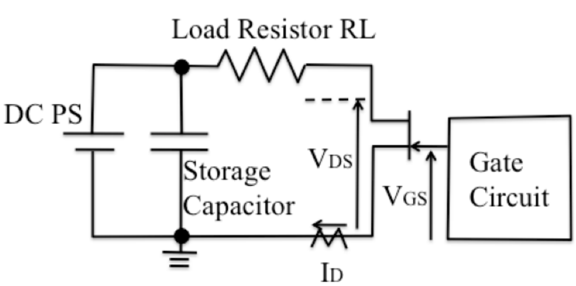

Figure 5: Experimental circuit

Test Circuit

The switching test circuit is shown in Fig. 5. The device was mounted on a water cooled heat sink, and the temperature differences between the inlet and outlet water, the case top temperature and the copper base temperature were measured during the switching test.

1 kV-27A Switching Test

At first, switching tests with the load resistance of 37.5 ohm, which correspond to be a little bit heavier load condition than the present FET switch in the DA, were conducted. It was concluded with a successful operation with a dc voltage of 1 kV, a drain current of 27 A and a repetition rate of 1 MHz. Voltage and current waveforms are shown in Figure 6.

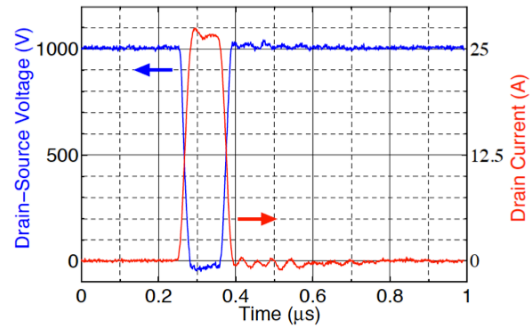

Figure 6: Voltage and current waveforms with charging voltage of 1 kV, repetition rate of 1 MHz, and load resistance of 37.5 ohm

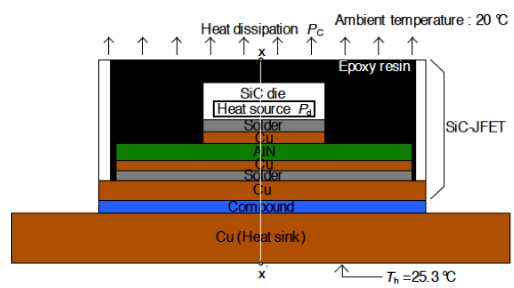

Figure 7: Thermal analysis model

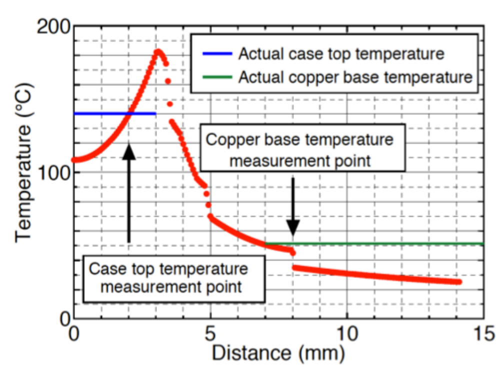

Figure 8: Temperature distribution along the centre axis of the device

Also thermal analysis was conducted for the experimental condition. The analysis model is shown in Fig.7. Calculated temperature distribution along the centre axis of the device is shown in Fig.8 assuming the switching loss of 235 W, which was estimated from the switching waveforms and temperature rise of cooling water. Comparison between calculated and measured temperature at the case top and the copper base are also shown in Fig.8, which indicate pretty good agreement. From the analysis result, maximum junction temperature is estimated to be 183 ℃.

900V-48A switching test

To research the limitation of this newly developed device, high power switching tests with a load resistance of 18.8 ohm were also conducted. Figure 9 shows the voltage and current waveforms with the condition of a dc voltage of 900 V and a flat top current of 48 A. In this high power switching test, overshoot voltage at voltage recovery period was observed. A snubber circuit composed of a 300 pf capacitor, a 55 ohm resistor, and a diode was connected in parallel with the SiC-JFET so that the overshoot voltage could be reduced.

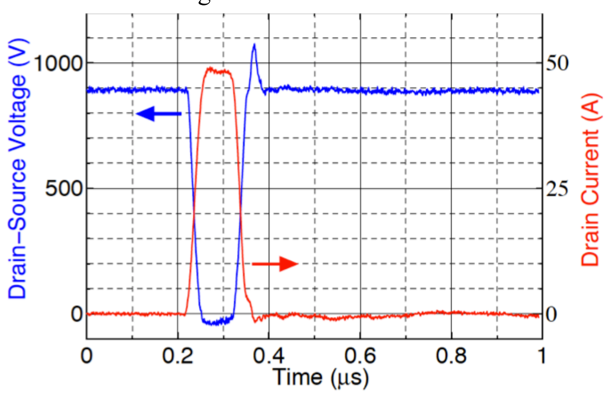

Figure 9: Voltage and current waveforms with a load resistance of 18.8 ohm.

In the same manner as the cases of 1kV-27A switching tests, continuous mode operation tests were attempted, which was resulted in device failure at repetition frequency of 800 kHz. Fig.10 shows the case top temperature rise curve with various operation frequencies. Obviously different temperature rise tendency was observed with the operation frequency of 800 kHz as compared to other frequencies.

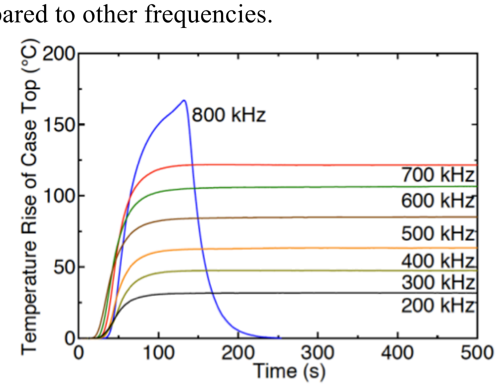

Figure 10: Voltage and current waveforms with a load resistance of 18.8 ohm.

From the switching waveform, switching loss per pulse at this condition is calculated to be 1.5 times larger than 1kV-27A case and average loss of about 300 W. And the maximum junction temperature is estimated to be higher than 200 ℃. Therefore it is supposed that device failure is caused by degradation of insulation material or meltdown of bonding solder because they are not designed under such high temperature.

FUTURE PLAN

It is concluded that the newly developed SiC-JFET is suited for the DA in the present work. Using this device, a H-bridge switching power supply is under assembling and will be tested by the end of this year. And as a 2nd step, two series connected switch is planned in the next year. By doing this, complete replacement of the FET switch by the SiC-JFET will be verified, where the number of switching element is reduced to 30 %.

Furthermore, next generation SiC-JFET utilizing higher withstand voltage device element with a more heat exchangeable package is under planning to achieve a series connection free SPS.

SUMMARY

- A discrete high power SiC-JFET is developed for the digital accelerator.
- With a load resistance of 37.5 ohm, which corresponds to a little bit heavier than the load condition of the present FET switch in DA, 1 MHz-1kV-27 A in continuous mode operation was successfully concluded.
- To the limitation of the newly developed SiC-JFET, it failed with 900V-48A at repetition frequency of 800 kHz, where the switching loss and maximum junction temperature are estimated to be about 300 W and higher than 200 ℃, respectively.
- Using this device, H-bridge switching power supply is under assembling and will be tested by the end of this year.
- Also developments of a new device with higher withstand voltage and higher heat extraction capability is under contemplation.

REFERENCES

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