Performance Comparison of 1200V 100A SiC MOSFET and 1200V 100A Silicon IGBT

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Abstract—**This paper presents the characteristics of the first commercial 1200V 100A SiC MOSFET module and compares it with state-of-the-art silicon IGBT with the same rating. The results show that the 1200V SiC MOSFET has faster switching speed and much lower loss compared with silicon IGBT. Moreover, the silicon IGBT switching loss will increase significantly for higher operation temperature, while the SiC MOSFET switching loss is almost the same for different temperature. A loss model has been implemented in PLECs in order to simulation the losses. An 11kW single-phase inverter prototype with 600V dc bus and 380Vac output voltage has been built for evaluating and comparing the SiC MOSFET and Si IGBT performance. The test results match with the simulation very well and show that with 40 kHz switching frequency the inverter efficiency can be increased to 98.5% from 96.5% if replacing the Si IGBT with the SiC MOSFET module.**

I. INTRODUCTION

The emergence of SiC power devices will have a great impact on power utility applications due to their lower losses and higher operation frequency capability. The 1200V 100A SiC MOSFET module (CAS100H12AM1) [1] (Figure 1) becomes available on the market recently, which potentially can be used for the PV inverters, motor drivers and other power converter applications to boost the converter efficiency and reduce the system volume. The performance of the discrete SiC MOSFET has been discussed in many publications [2-7]. In this paper, the performance of the Cree 1200V 100A SiC MOSFET will be investigated and compared with the same rating Infineon silicon IGBT (FF100R12RT4) [8], particularly from the efficiency point of view. Loss dissipated in both conduction and switching transient is considered for the comparison. To further study the efficiency comparison, a single-phase 11kW prototype inverter is built with the both devices.

This paper will first present the characteristics of both SiC MOSFET and Si IGBT under static conduction and dynamic switching states. Then their performance for an inverter application will be given. Simulation results developed with PLECS thermal model will also be compared with test results to show validity of the loss breakdown on both devices.

Figure 1: 1200V 100A SiC MOSFET module

II. CHARACTERISTICS OF THE SIC MOSFET AND THE SI IGBT

(A) Conduction comparison

The conduction I-V characteristics of the two devices have been measured for both 25 ºC and 125 ºC. Figure.2 shows the forward I-V curves of both, it can be seen that the MOSFET has lower forward voltage drop under 90A. This feature enables that for single device, MOSFET has much less conduction loss than IGBT for low current

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situations. Further, under each temperature, SiC MOSFET displays a almost constant on resistance Rds(on) in entire range whereas a nonlinear V-I curve for the IGBT; Together with its positive temperature coefficient of ON resistance (higher temperature leads to a smaller Rds(on)) as shown in Figure 2, the MOSFET is suitable for parallel operation when large current is required.

Figure 3 shows the I-V curve with reversed conducting current through anti-paralleling diodes. With 0V gate source bias, the voltage drop of SiC diode (SiC JBS together with the MOSFET body diode) is greater than the IGBT (Si anti-paralleling diodes) indicating a larger conduction loss; However, the MOSFET can be turned on and operated under the synchronous rectifier mode, so the reverse current will also go through the channel instead of the anti-paralleling diode. The combined voltage drop (SiC JBS+MOSFET channel in Figure 3) will therefore be smaller than the IGBT.

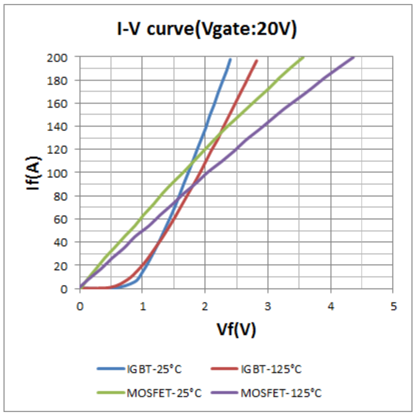


Figure 2. Forward I-V curves of the Si IGBT and SiC MOSFET

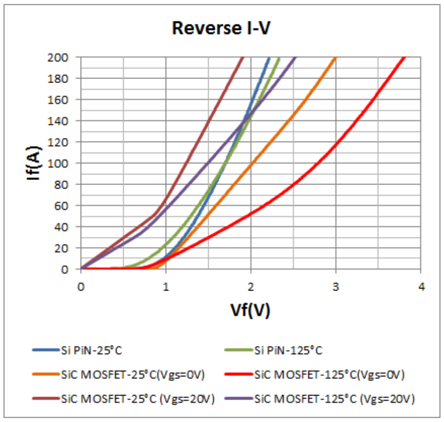
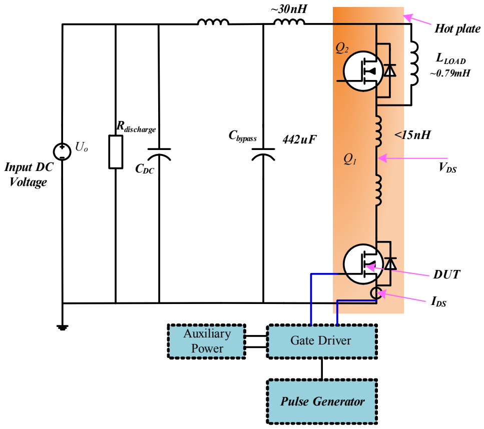


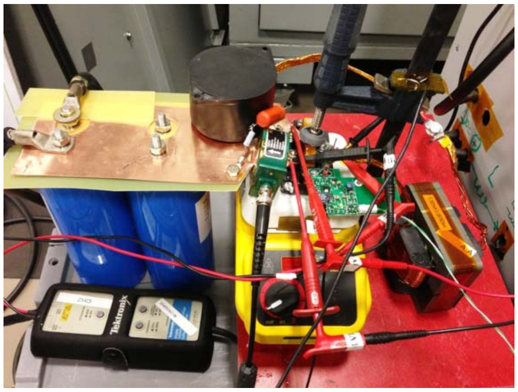
Figure 3. Reverse I-V curves of the Si IGBT and SiC MOSFET

(B) Dynamic comparison

A great portion of loss is contributed by switching transients when switching frequency is high. To study the switching loss occurred with the two devices, the dynamic switching performance has been characterized through an inductive load double pulses tester (Figure. 4). Special attention has been paid to minimize the loop inductance for a cleaner switching waveform with more accurate loss measurement. The loop inductance for the DC capacitor bus bar is around 30nH, and the stray inductance for the MOSFET terminals and internal wire bonding is less than 15nH per device according to the datasheet.



(a) MOSFET double pulse tester circuit diagram.



(b) Double pulse tester photo.

Figure 4. Double pulse tester circuit diagram and setup photo

The typical switching on and off waveforms for the MOSFET at 600V 100A are shown as Fig.5 and Fig.6. The oscillation is caused by the resonance between circuit stray inductance and parasitic capacitance.

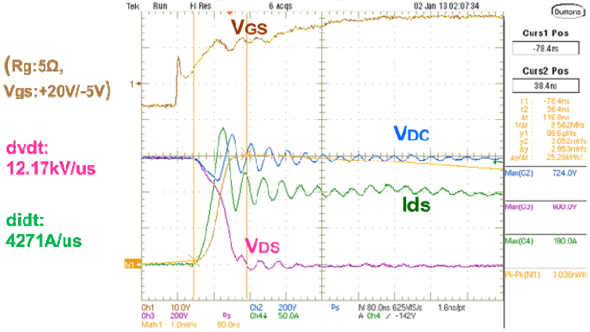


Figure 5. 1200V 100A SiC Module turns on at 100A with 600V dc bus

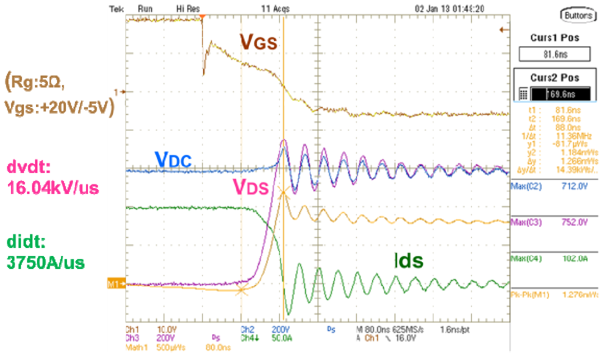


Figure 6. 1200V 100A SiC Module turns off at 100A with 600V dc bus

Switching energy losses including Eon, Eoff, and Erec have been measured for both Si IGBT and SiC MOSFET with the same test circuit and parameters, the results are plotted in Figure.7, Figure.8 and Figure.9 separately. It can be observed that the Si IGBT loss is highly dependent on the operation temperature and increases when temperature rises; while for the SiC MOSFET, the loss doesn't change much with the temperature variation, the turn on loss is even lower for the higher temperature which is caused by the negative temperature coefficient of the MOSFET threshold voltage, the switching losses under 125 °C for both devices have been listed in Table 1, it shows SiC MOSFET has significant lower loss than Si IGBT.

Table 1. Switching Loss Summary

Conditions: Vdc=600V; Ids=100A; Rg=5Ω; Vgs=-5V~20V; Tj=125°C			
Loss(mJ)	Cree SiC MOSFET	Infineon Si IGBT	Times of improvement
Eon	2.47	8.78	3.6X
Eoff	1.28	8.78	6.8X
Erec	0.53	5.93	11.2X

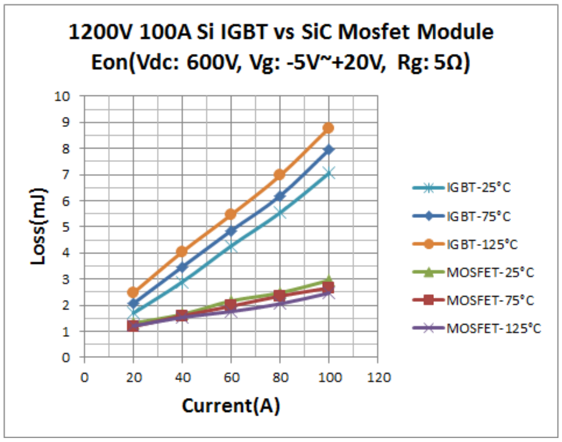


Figure 7. Eon Comparison of both Si IGBT and SiC MOSFET under different temperatures

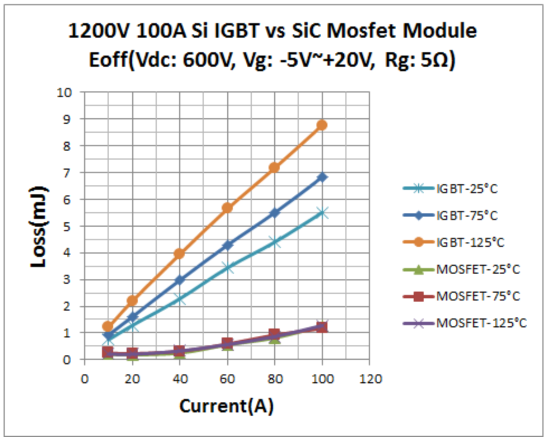


Figure 8. Eoff Comparison of both Si IGBT and SiC MOSFET under different temperatures

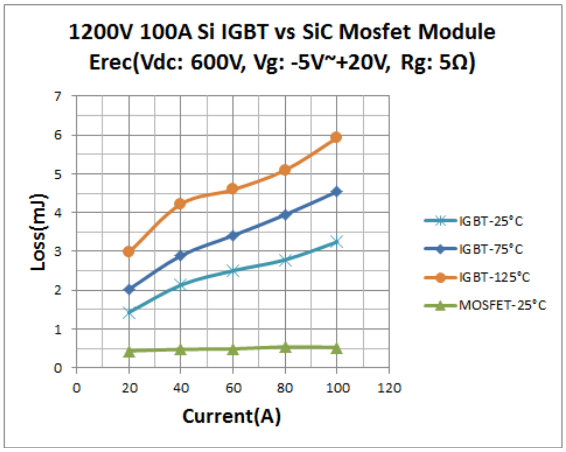


Figure 9. Erec Comparison of both Si IGBT and SiC MOSFET under different temperatures

III. INVERTER BASED ON THE SIC MOSFET AND THE SI IGBT

Full bridge inverter is one of the major applications for the 1200V 100A level devices. In order to evaluate the two devices for such application, an 11kW full bridge inverter has been built (Figure 10). One leg is SiC MOSFET and the other leg is Si IGBT, the modulation method is unipolar single frequency SPWM (Figure 11), only one leg is switched at high frequency while the other one is switched at output AC voltage frequency which is 60Hz for our test. With this configuration, we can choose either the MOSFET leg or the IGBT leg to operate at high frequency, the advantage of this design is that the hardware setup will not be changed for evaluating the two devices. Since the conduction loss will be almost the same when the device has been switched either at high frequency or at 60 Hz. The loss difference for different cases will be almost entirely caused by the difference of the switching loss. The nanocrysline core and litz wire has been used for building the filter inductor with the goal to minimize the inductor loss itself and its difference caused by the switching frequency variations.

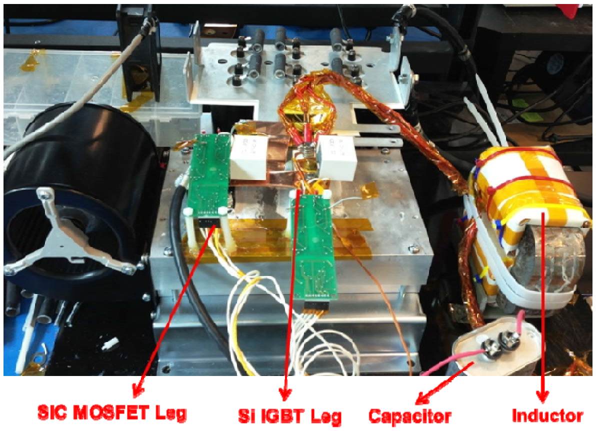


Figure 10. Single phase full bridge inverter

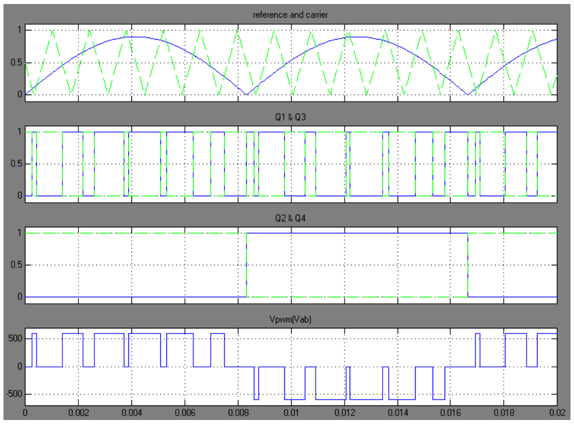


Figure 11. Unipolar SPWM scheme

Figure 12 shows a typical inverter operation waveform, and the inverter efficiency has been measured for the 9 cases as listed in Table 2. It has been estimated that the other loss except for power devices loss is about 43W which includes the inductor loss and DC bus capacitors paralleled resistors loss for all cases.

Table 2. Parameters for different test cases

Cases	IGBT Leg	MOSFET Leg	Results
1	20 kHz	60 Hz	Figure 13, 14, 17
2	30 kHz	60 Hz	
3	40 kHz	60 Hz	
4	60 Hz	20 kHz	Figure 15, 16, 17
5	60 Hz	30 kHz	
6	60 Hz	40 kHz	
7	10 kHz	10 kHz	Figure 17
8	15 kHz	15 kHz	
9	20 kHz	20 kHz	

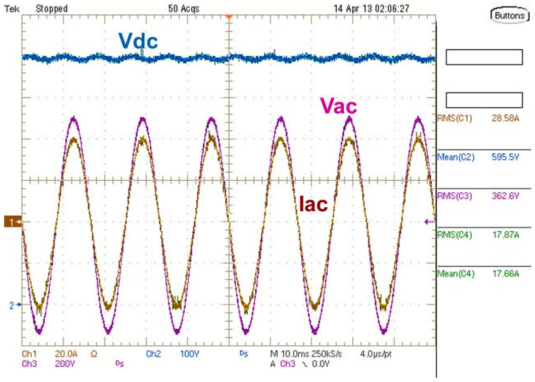


Figure 12. Inverter waveform

For cases 1-3, only the IGBT leg has been switched under high frequency. Figure 13 gives the measured total device loss and compares it with the simulation results. The loss simulation is based on the MOSFET and IGBT PLECS loss model which combines the characterization data given in the above section. It shows a good match between the measured and simulated loss which validates the loss model. The simulated loss breakdown has been given in Figure 14 where it can be found that the major loss is the IGBT switching loss.

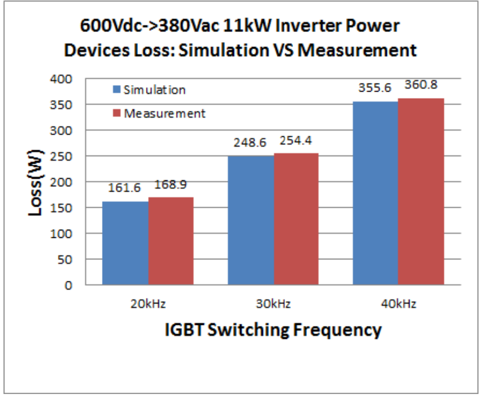


Figure 13. IGBT switching loss comparison between experiment and simulation

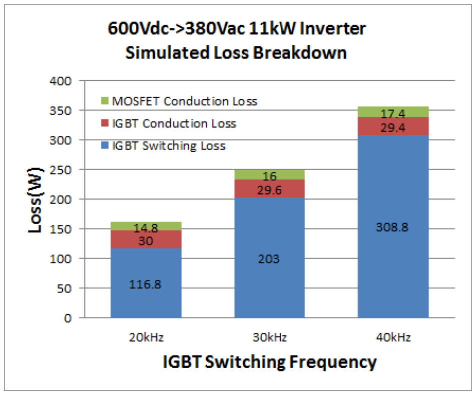


Figure 14. Inverter loss breakdown when the IGBT leg is switched at high frequency

Figure 15 and 16 show the results for cases 4-6, the conduction loss is almost the same for different switching frequency, the MOSFET switching loss is proportional to the switching frequency.

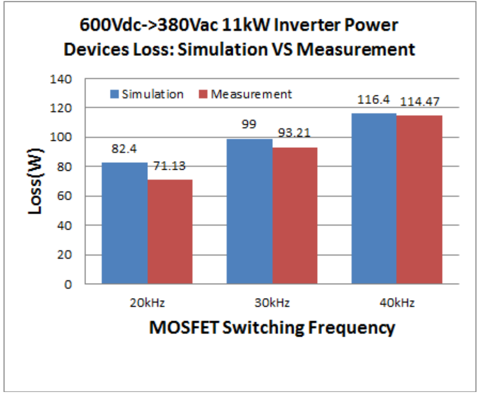


Figure 15. MOSFET switching loss comparison between experiment and simulation

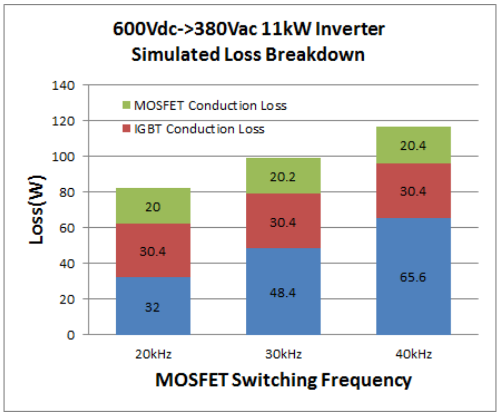


Figure 16. Inverter loss breakdown when MOSFET leg is switched under high frequency.

For Cases 7-9, the inverter is switched under bipolar SPWM scheme; legs with both devices are switched at high frequency.

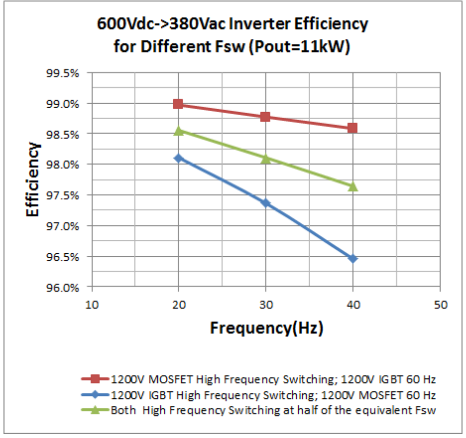


Figure 17. Inverter efficiency with (1) only switches MOSFET; (2) only switches IGBT; (3) switch both MOSFET and IGBT, at 20kHz, 30kHz and 40kHz respectively.

The inverter efficiency for all 9 cases has been plotted in Figure 17. As can be seen, for each operation mode, the efficiency decreases with higher switching frequency, indicating increased switching losses. Also can be seen is that the highest efficiency occurs when only SiC devices is utilized for high frequency switching, reaches 98.6% at its peak value, proposing that SiC MOSFET's lower switching losses compared with Si IGBT.

IV. CONLUSIONS

This paper discussed the switching transient and switching loss of the 1200V 100A SiC MOSFET, compared it with the same rating silicon IGBT, the results obtained from a prototype inverter show the advantage of SiC MOSFET regarding both conduction and switching loss.

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