Performance Comparison of 1200 V SiC MOSFET and Si IGBT Used in Power Integrated Module for 1100 V Solar Boost Stage

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APPLICATION NOTE

Introduction

This application note compares the performance of two power integrated modules (PIMs) in the boost stage of an 1100 V solar inverter. One PIM used state−of−the−art silicon 1200 V IGBT (part number NXH100B120H3Q0 [1]) defined as PIM−IGBT and the other PIM used a new 1200 V SiC MOSFET (part number NXH40B120MNQ0 [2]) defined as PIM−SIC. These two PIMs utilized the same Q0 package technology and SiC Schottky boost diode. They are pin−to−pin compatible allowing customers to upgrade from Si IGBT to the SiC MOSFET version. Due to faster switching characteristics of the SiC device, this paper explains gate driver and PCB layout topics which must be considered when using fast switching devices like SiC MOSFETs.

Performance Comparison

For the design of a solar inverter, the critical operating conditions include:

- maximum solar panel input current
- inverter dc bus voltage
- dc inductor ripple
- budget of cooling system (forced air or convection cooling)

It is important to evaluate the highest junction temperature (T_j) of the semiconductor device under all conditions, and guarantee they do not exceed the rated value in the datasheet. Users also prefer to operate as close as possible to the T_j limit (after allowing for a safety margin) to lower the overall cost/Watt. Loss and T_j simulation is a useful method to answer above questions. High temperature (for example 125°C) characteristic is more important than room temperature because designers must consider worst conditions while solar inverters work at full load and high environment temperature. In this paper, only high temperature data is considered.

Key performance comparison of Si IGBT and SiC MOSFET is shown in Table 1.

Until 2019, a common output current of a solar string was around 12 A. These two PIMs were designed for connecting two strings in parallel for a MPPT (maximum power point tracking) of 26 A. Table 1 shows current of 30 A which is a typical operating point. SiC has faster switching speed because of unipolar device nature (no turn off tail current) and smaller Qg. Due to lower switching losses (E_{on} and E_{off}), PIM−SIC has a significantly lower total loss compared with PIM−IGBT under the same operating conditions. Figure 1 shows a comparison of conduction loss and switching loss for the switches used in the two PIMs.

Table 1. KEY PERFORMANCE COMPARISON OF SI IGBT AND SIC MOSFET

Parameter	PIM−IGBT	PIM−SIC
Rated Current	50 A	38 A
Voltage Drop (30 A)	1.55 V	1.85 V
E_{on} (30 A)	400 (μJ)	240 (μJ)
E_{off} (30 A)	1730 (μJ)	140 (μJ)
Q_g (0 to 15 V)	410 (nC)	80 (nC)
Gate Voltage	+15 V/−9 V	+20 V/−4 V
R_{thjc} (°C/W)	0.51	0.81
Cost	100%	180%

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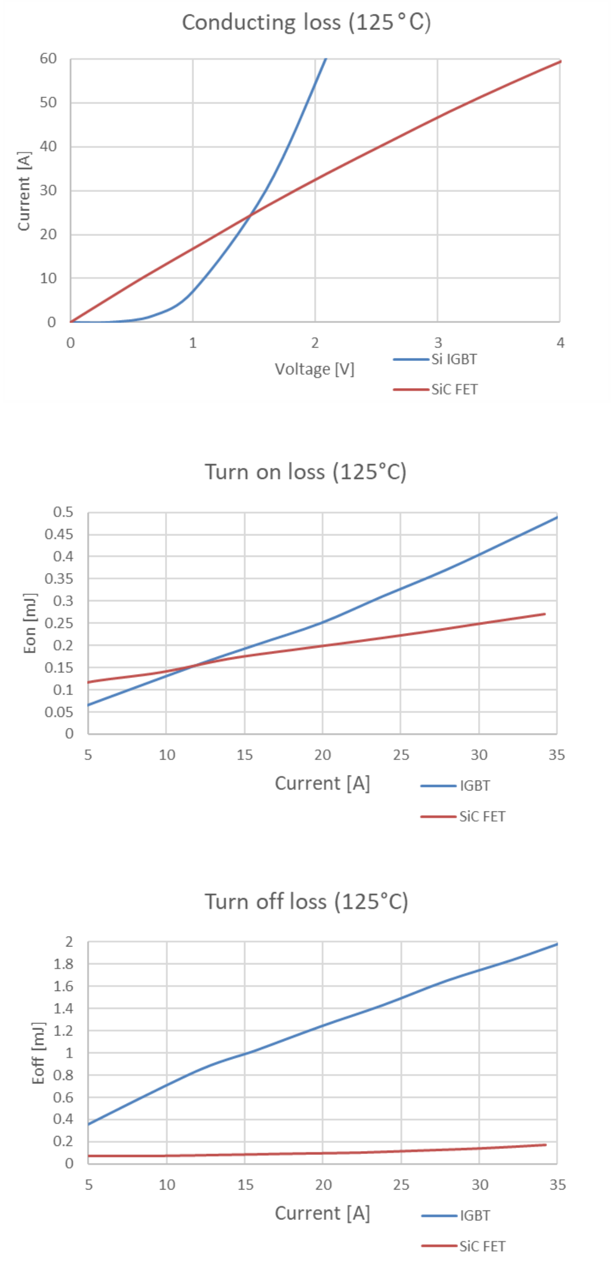

Figure 1. Comparison of Conduction Loss and Switching Loss

Table 2. SYSTEM PARAMETERS OF A TYPICAL SOLAR BOOST CONVERTER

Parameter	Value
PV Input Voltage/Current	500 V/25 A
Output DC Bus Voltage	800 V
Switching Frequency	16 kHz
Inductor	600 μH
Module Case Temperature	95°C

System parameters of a typical solar boost converter using an IGBT solution are shown in Table 2. SiC MOSFETs are more expensive than IGBTs due to a more complex manufacturing process. It is reasonable to design SiC MOSFET with a smaller die size. This smaller die area results in higher thermal resistance, which is not favorable for reducing T_j. Table 3 shows the power loss and T_j simulation results for a circuit using PIM−IGBT and PIM−SIC operating under the same conditions. The Si IGBT has significantly higher E_{off} due to slower dv/dt di/dt and tail current. For conduction loss, the SiC MOSFET has lower Vds when current is below cross point of 25 A due to unipolar nature.

Assumed the dc inductor has fix inductance value (no saturation), the switch current waveform is shown as the red line in Figure 2. PIM−IGBT and PIM−SIC have similar conducting loss and turn on loss in conditions given in Table 3. PIM−IGBT has much higher turn off losses than PIM−SIC. Gate driver parameters, such as gate resistance (R_g), also have strong impact on E_{on} and E_{off}. Only $R_g = 5\ \Omega$ is discussed in this paper for simplifying the comparison.

Table 3. COMPARISON OF LOSS SIMULATION

Parameter	PIM−IGBT	PIM−SIC
Conducting Loss	13.33 W	12.17 W
Switching Frequency	16 kHz	16 kHz
Turn On Loss E_{on}	3.8 W	3.17 W
Turn Off Loss E_{off}	34.66 W	3.06 W
Total Loss	51.79 W	18.39 W
T_j (T_c = 95°C)	137.9°C	109.9°C

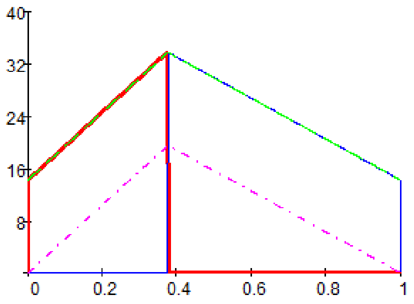

Figure 2. IGBT Current Waveform

System cost is one of the most critical considerations for a solar application. If a SiC solution is used, the PIM is more expensive. This is justified only if using a SiC solution reduces the cost of other parts of the inverter such as a lower cost inductor and a cheaper and lighter cooling system.

An optimal design of PIM−SIC increases switching frequency (f_{sw}) to 40 kHz, so the inductor size is reduced to 1/3 as 200 μH. Heatsink size is also reduced. Alternatively the heatsink size can be kept the same and the cooling is changed from forced air cooling to natural cooling. As a result of the reduction of heatsink size, the PIM case temperature is assumed to rise to 110°C whereas it was 95°C in the previous configuration.

Loss simulation results under these new conditions are shown in Table 4 and compared with the PIM−IGBT losses from the previous table. Even when operating at a higher frequency, the PIM−SIC solution has lower losses than the PIM−IGBT solution, indicating a higher system efficiency of SiC solution.

Table 4. COMPARISON OF LOSS SIMULATION

Parameter	Si IGBT	SiC MOSFET
Conduction Loss	13.33 W	13.6 W
Switching Frequency	16 kHz	40 kHz
Turn On Loss E_{on}	3.8 W	7.22 W
Turn Off Loss E_{off}	34.66 W	8.34 W
Total Loss	51.79 W	29.16 W
T_j	137.9°C (T_c = 95°C)	133.6°C (T_c = 110°C)

Design Consideration

Users have to pay attention at circuit design and layout while adopting SiC PIMs, because of their faster switching characteristics. A comparison of the switching speed of PIM−IGBT and PIM−SIC at maximum dv/dt and maximum di/dt is shown in Figure 3.

Place a low parasitic inductance film capacitor as close as possible to the module to make the following commuting loop as small as possible:

- film capacitor − SiC MOSFET − SiC diode

This reduces the inductance of that loop, and reduces the radiated EMI generated from that loop.

Figure 4 gave an example of the film capacitors (Wurth part# 890493427007CS) that were placed closely to pins of DC+ and DC−.

The gate driver positive bias voltage of SiC MOSFET is selected as +20 V. Higher voltage reduces conducting loss. This gives a 5 V margin to the maximum positive V_{gs} value is +25 V. Negative bias voltage of −4 V is selected which provides sufficient margin to maximum negative V_{gs} value of −15 V. The negative bias increases the cost of the gate driver but gave smaller E_{off} and less V_{gs} ringing during turn off. 2 W isolated dc−dc power supplies from Mornsun (QA01C +20 V/−4 V and QA151 +15 V/−8 V) were used here. Optocoupler FOD3120 [3] from ON Semiconductor provides galvanic isolation between control signal and power circuit. It has maximum 2.5 A peak output current. Because gate current goes as high as 5 A, BJT pairs of 2SA2016 and 2SC5569 [4] were used to buffer gate current up to 7 A.

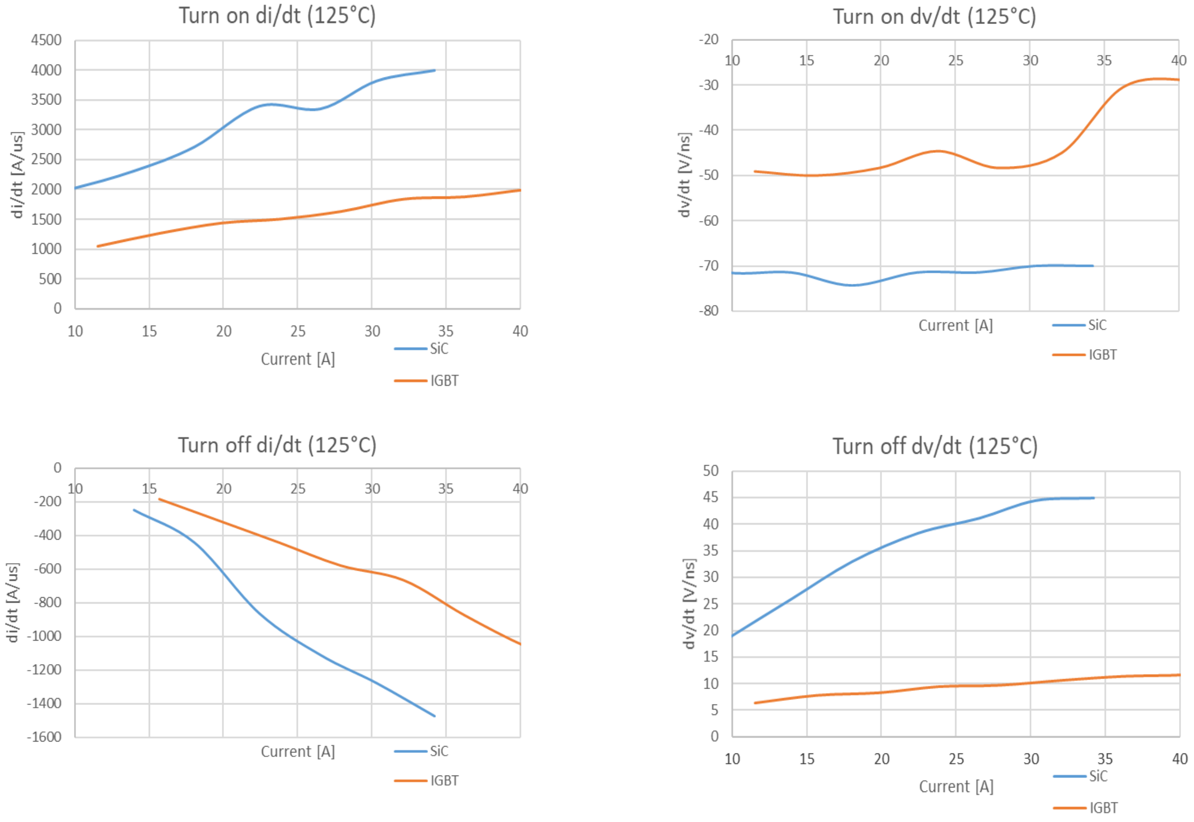

Figure 3. Comparison of Switching Speed

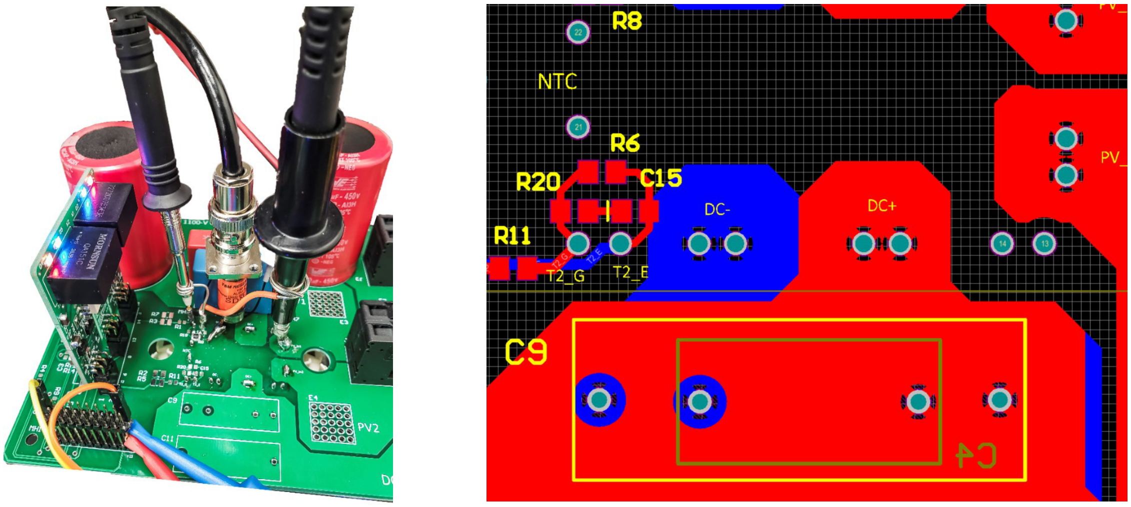

Figure 4. PCB Layout Example

Measuring voltage and current of SiC application becomes more challenging due to faster rising and falling time [5]. High bandwidth equipment and probing techniques are necessary as shown in Figure 4. The equipment used is shown in Table 5.

As shown in Figure 5, the rise time of SiC MOSFET is in range of ns. Based on Tr = 0.35/BW [6], bandwidth of all equipment must be over 300 MHz.

Long grounding loop of voltage probe should be avoided, otherwise unwanted loop inductance brings overshoot and ringing noise to scope waveform. Short ground leads were soldered here as an example. Differential voltage probe is not recommended here due to limited bandwidth (usually up to 200 MHz) and long grounding loop.

Rogowski coil (part# Iwatsu SS−665, 30 MHz bandwidth) is a preferred tool of measuring IGBT switching current, because it is very easy to assemble and disassemble into a target circuit. However, the fast speed of SiC device goes beyond bandwidth of normal Rogowski coil. For comparison purpose, the same SiC MOSFET switching current was measured by both Rogowski coil and co−axial current shunt as shown in Figure 4. A comparison waveform is shown in Figure 5, the Rogowski coil filtered out some fast portion and induced a certain offset. Shunt resistor is able to precisely capture turn on current overshoot due to high dv/dt capacitance charge current of the commuting pair SiC schottky diode. When comparing IGBT current waveforms, there is no significant difference between shunt resistor and Rogowski coil due to IGBT's lower di/dt and dv/dt.

Table 5.

V_{gs} Gate Voltage	Tek TPP1000 (1 GHz Bandwidth)
V_{ds} Voltage	Tek P5100A (500 MHz Bandwidth)
I_d Switching Current	T&M Research SDN−414−10 (0.1 Ω, 2 GHz Bandwidth)

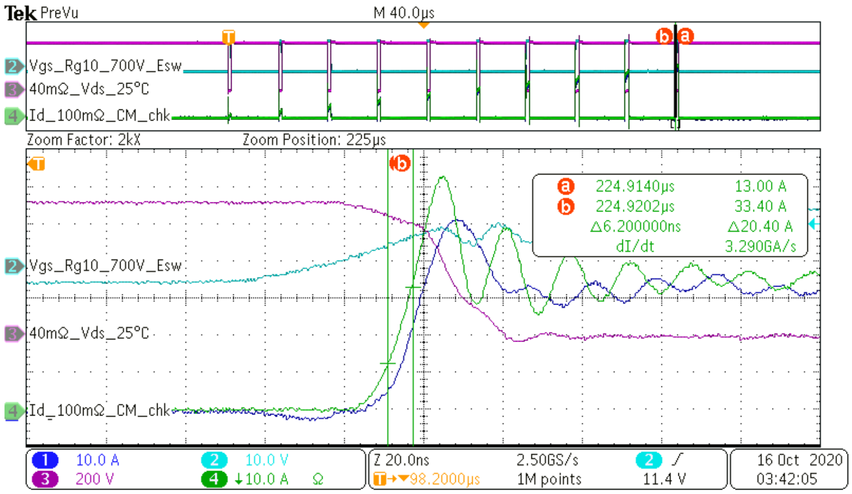

Figure 5. CH1: Current Measured by Rogowski Coil; CH2: V_{gs} by Passive Probe TPP1000; CH3: V_{ds} by Passive Probe P5100A; CH4: Current Measured by Co−axial Shunt

In order to reduce ringing of gate voltage V_{gs} during switching, it is recommend to keep the gate driver loop parasitic inductance Lg as small as possible. Actions shown in Figure 4 include: place gate driver IC closer to PIM, use wider copper trace on PCB, place return trace close to active trace so magnetic cancelation reduces common inductance. A comparison of V_{gs} turn off waveform with optimized L_g is shown in Figure 6.

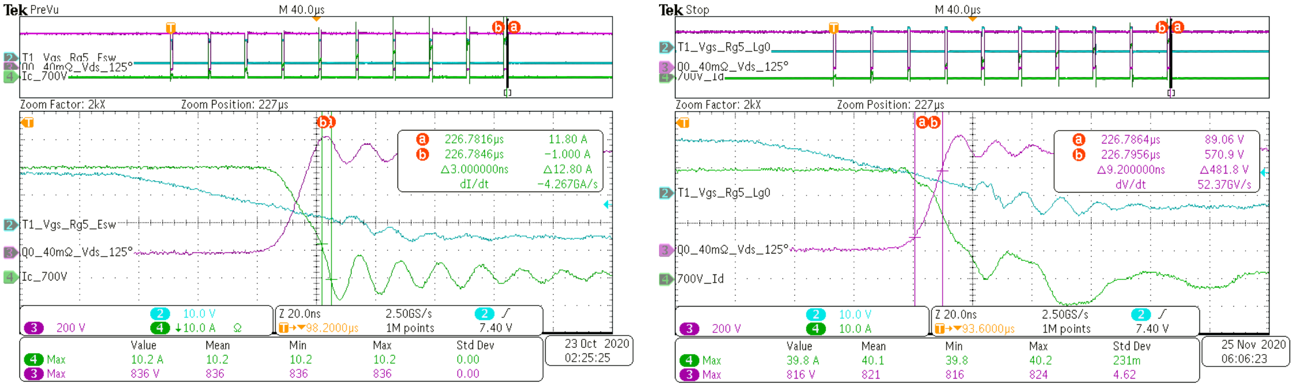

Figure 6. Optimized L_g at Left Figure (CH2: V_{gs}) which has less Ringing, Compared with Right Figure

Summary

After comparing the performance of a boost module using IGBTs and a boost module using SiC MOSFETs, this application note showed the efficiency benefits of using a SiC MOSFET module even at a much higher switching frequency than with an IGBT module. Careful attention must be made to the circuit layout and measurement methods because of the fast switching speeds of the SiC component.

References

[1] ON Semiconductor datasheet NXH100B120H3Q0SG. https://www.onsemi.com/pub/Collateral/NXH100B120H3Q0−D.PDF

[2] ON Semiconductor datasheet NXH40B120MNQ0SNG. https://www.onsemi.com/pub/Collateral/NXH40B120MNQ0−D.PDF

[3] ON Semiconductor datasheet FOD3120 https://www.onsemi.com/pub/Collateral/FOD3120−D.pdf

[4] ON Semiconductor datasheet 2SA2016/2SC5569 https://www.onsemi.com/pub/Collateral/EN6309−D.PDF

[5] Z. Zhang, B. Guo, F. F. Wang, E. A. Jones, L. M. Tolbert and B. J. Blalock, ”Methodology for Wide Band−Gap Device Dynamic Characterization,” in IEEE Transactions on Power Electronics, vol. 32, no. 12, pp. 9307−9318, Dec. 2017, doi: 10.1109/TPEL.2017.2655491.

[6] Application Note (No. EA 60W−6053−14), Tektronix, January, 2016

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