

New Generation 6500V/600A Full SiC Power Module for High Speed Railway Traction Application

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1. Introduction

Silicon IGBTs have reached performance limits for high-speed railway traction. Wide Bandgap SiC features low switching loss, high operating temperature and high frequency.

A novel low stray inductance 6500V/600A full SiC MOSFET half-bridge module is proposed in this work. Identical package Si IGBT (6500V/300A) is set as benchmark for comprehensive comparison.

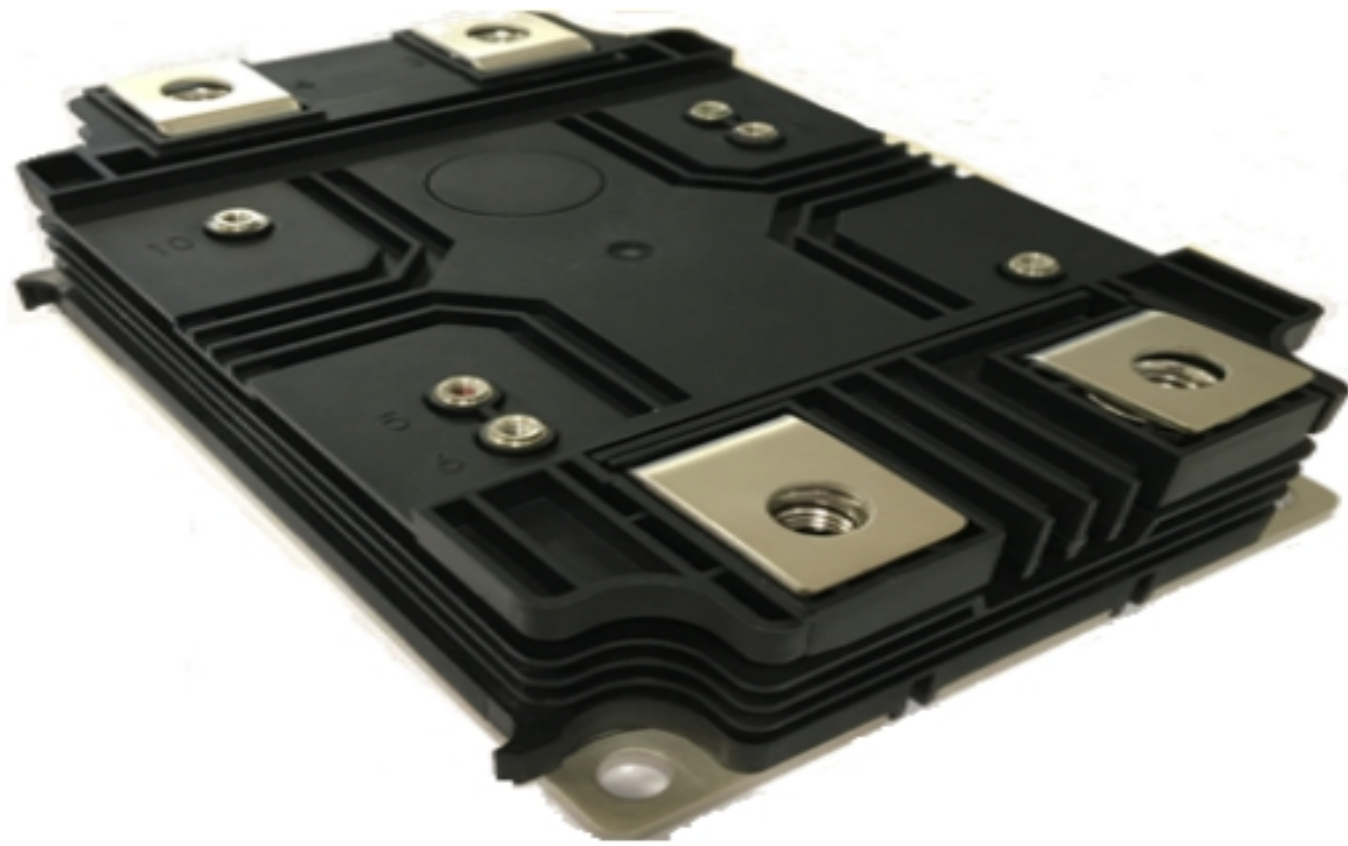


Fig. 1 : Appearance of 6500V/600A SiC module

2. Test Setup

- Static test: 25°C & 150°C output characteristic
- Dynamic test: Double Pulse Test (DPT) for switching loss
- Test condition: $V_{DC}=3600V$, $I_C=300A$
- Half-bridge packaging supports single-module DPT circuit

3. Electrical Characteristic Comparison

• Static Performance

SiC MOSFET presents linear on-state characteristic with much lower $V_{DS(on)}$:

300A, 25°C: $V_{DS_SiC} = 1V$, $V_{CE_IGBT} = 3V$

300A, 150°C: $V_{DS_SiC} = 2.2V$, $V_{CE_IGBT} = 3.9V$

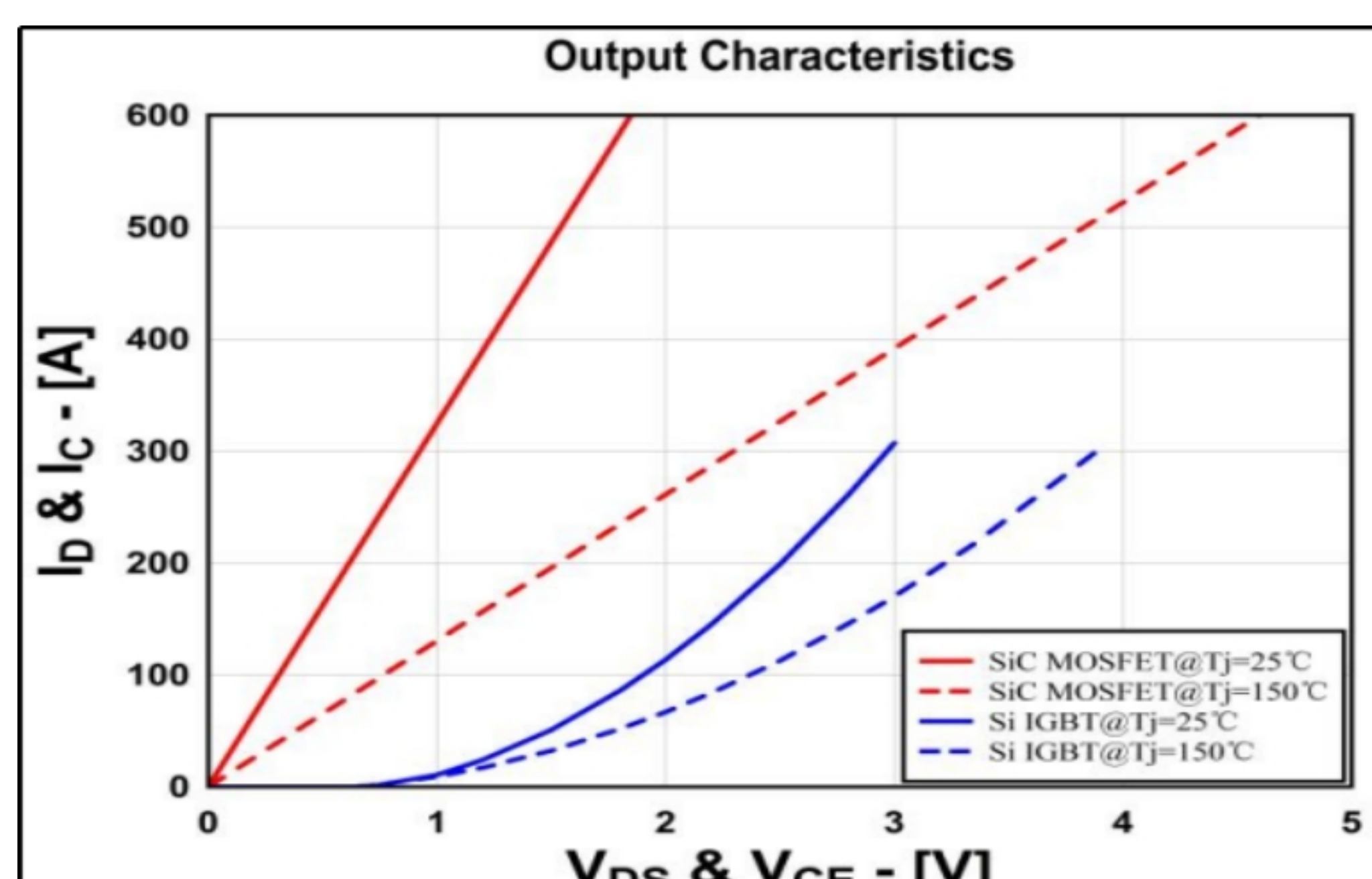
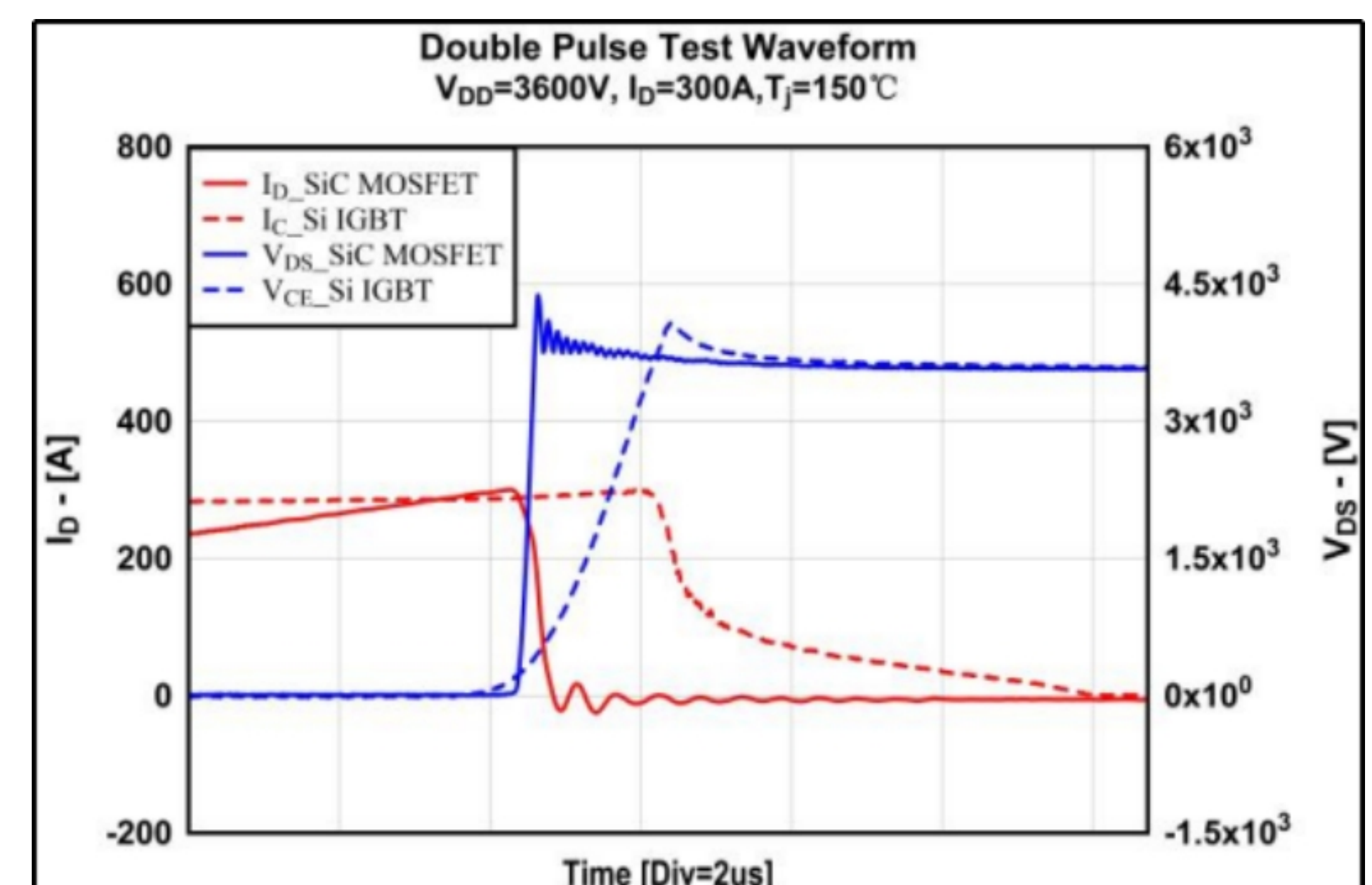


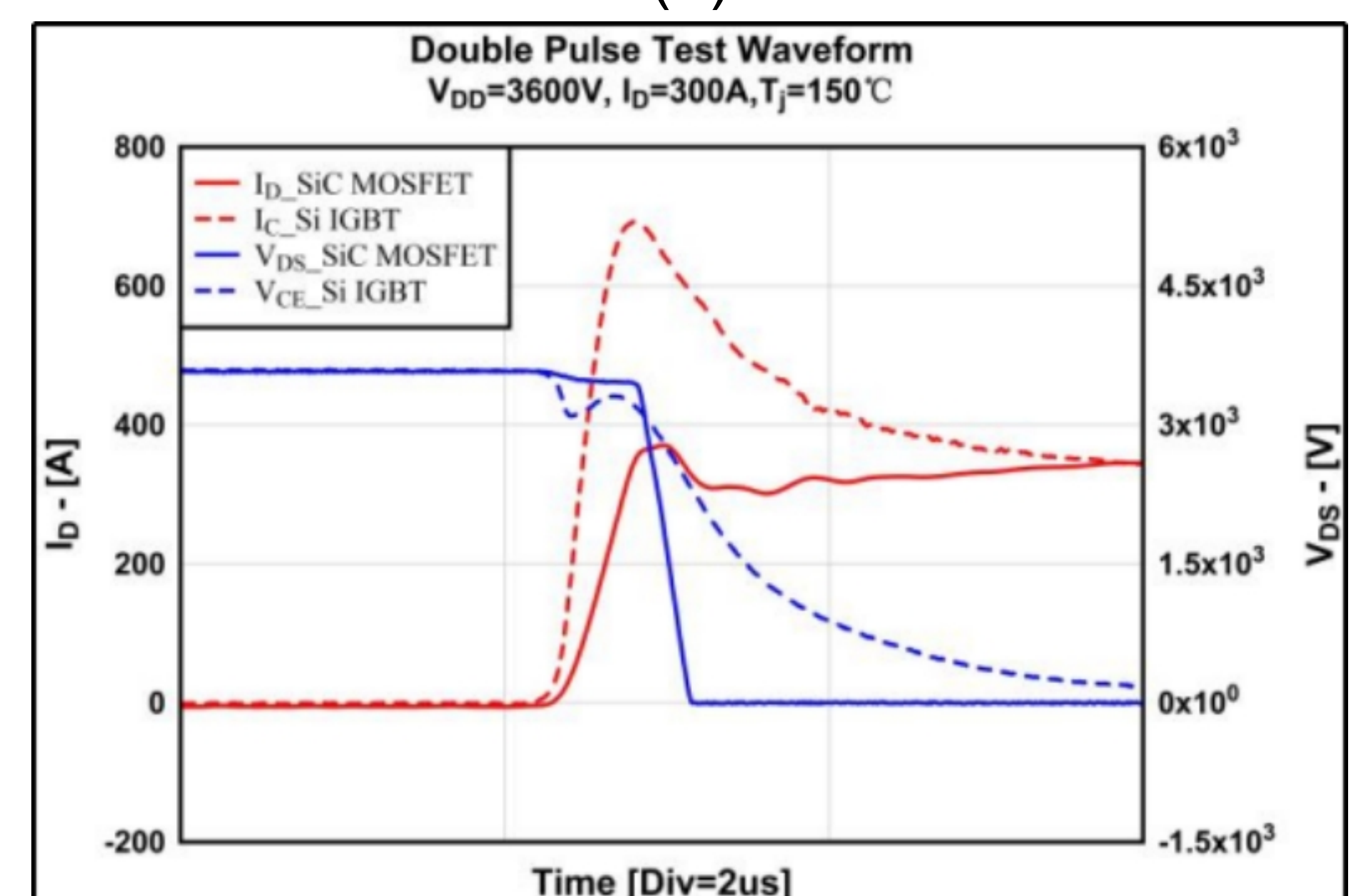
Fig. 2 : Comparison of static characteristics

• Dynamic Switching Loss

SiC has no tail current, much higher dv/dt during turn-off; Ultra-low reverse recovery current (70A vs 390A of IGBT);



(a)



(b)

Fig. 3 : Comparison of turn-off waveforms (a) and turn-on waveforms (b) between SiC MOSFET power module and silicon-based IGBT module

Total switching loss of SiC is only 1/9 of Si IGBT.

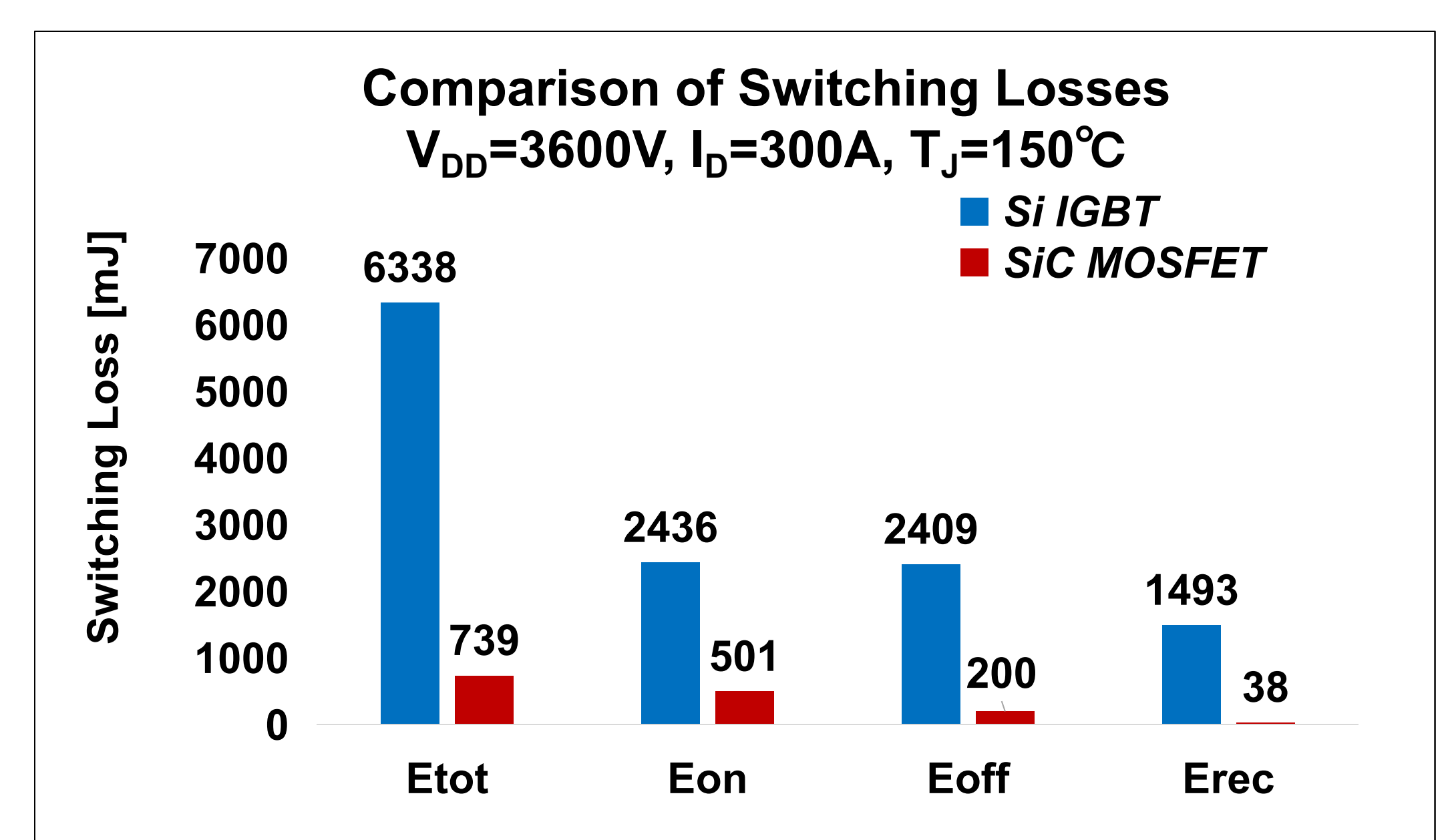


Fig. 4 : Comparison of switching losses between full SiC power module and Si IGBT module

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4. Railway Traction Application Performance

- Operating condition:

Module Type	Si IGBT	SiC MOSFET
Bus Voltage [V]	3600	3600
Output Current [Arms]	300	300
Switching Frequency [Hz]	500	1500
Output Frequency [Hz]	207	207
Modulation Ratio	0.16	0.16
Power Factor	0.87	0.87
Control Strategy	SPWM	SPWM
Heatsink Base Temperature [°C]	85	85

Table 1 Operating conditions for Si IGBT module and SiC MOSFET module

- Simulation result:

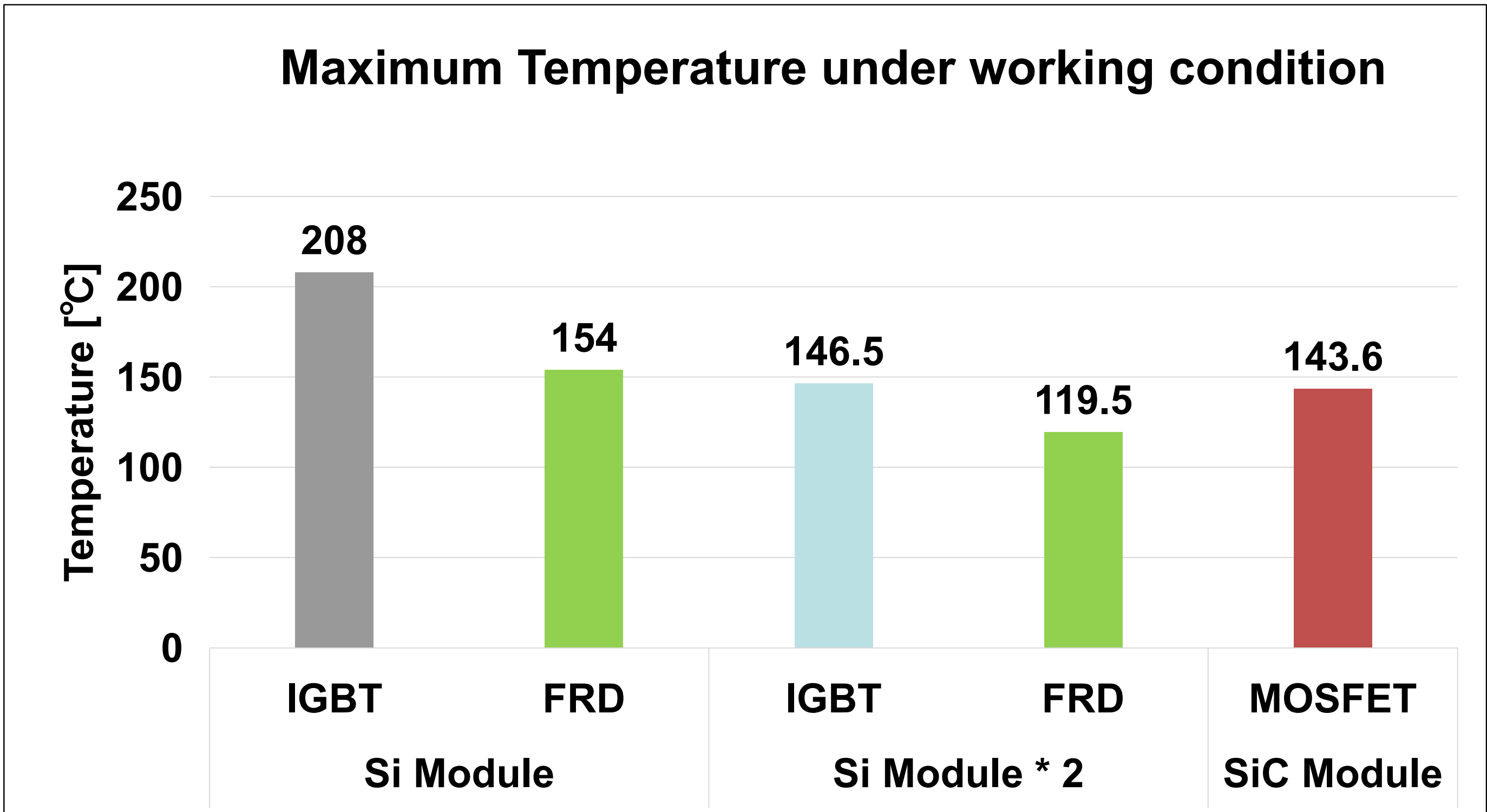


Fig. 5 : Comparison of maximum temperature under working condition

- Conclusion: 1 piece 6500V SiC module equals 2 parallel Si IGBT modules, realizing inverter miniaturization & weight reduction.

5. Reliability Test Results

The SiC module passes all standard power semiconductor reliability tests:

- Power Cycling: >80,000 cycles ($\Delta T_j=100^{\circ}\text{C}$, $T_{j\text{max}} = 175^{\circ}\text{C}$)
- HTRB / HTGB / H3TRB: 1000h without failure under rated stress

No.	Test Item	Test Conditions	Module Performance
1	PC	$\Delta T_j=100^{\circ}\text{C}$, $T_{j\text{max}}=175^{\circ}\text{C}$, $t_{\text{on}}=3\text{s}$, $t_{\text{off}}=3\text{s}$	80000 cycles
2	HTRB	$V_{\text{DS}}=5200\text{V}$, $V_{\text{GS}}=0\text{V}$, $T_j=150^{\circ}\text{C}$	1000 h
3	HTGB ₁	$V_{\text{GS}}=+23\text{V}$, $T_j=150^{\circ}\text{C}$	1000 h
4	HTGB ₂	$V_{\text{GS}}=-15\text{V}$, $T_j=150^{\circ}\text{C}$	1000 h
5	H ³ TRB	$V_{\text{DS}}=80\text{V}$, $T_j=85^{\circ}\text{C}$, Humidity=85%	1000 h

Table 2 Reliability result of SiC MOSFET module

6. Conclusion & Outlook

- The 6500V full SiC module achieves far lower conduction & switching loss than Si IGBT;
- Single SiC module can replace two parallel IGBTs for high-speed traction inverters;
- Excellent reliability satisfies railway long-lifetime requirements.

Prospect:

- Max junction temperature can be upgraded to 200°C;
- High cost is the main bottleneck for mass application;
- Future focus on manufacturing process optimization & yield improvement.

References

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