

New 800A/1200V Full SiC Module

By using SiC-based semiconductors the performance of power electronic systems can be drastically improved.

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The evolution of SiC technology in power modules and its principle loss reduction potential are shown in Figure 1. Mitsubishi has developed two new full SiC module types with 800A and 1200A rated currents and 1200V rated voltage [1]; [2]. This article is describing the 800A module.

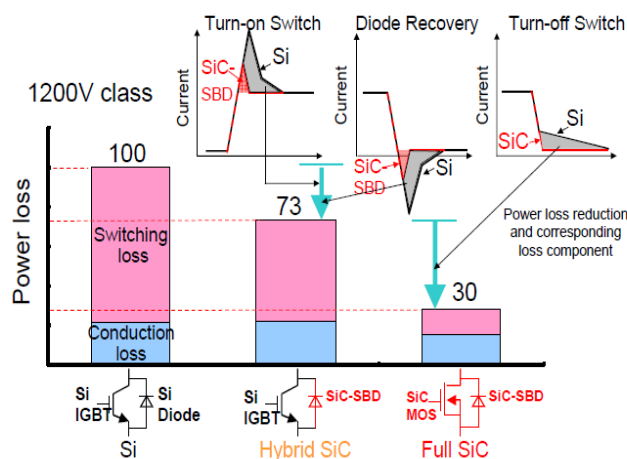


Figure 1: Evolution of SiC technology in power modules

Package outline and circuit diagram

The appearance of new 800A/1200V full SiC module (type name: FMF800DX-24A) and its internal circuit diagram are shown in Figure 2. The module contains 2 x 400A half bridge configurations. By externally paralleling the main P-, N- and AC-terminals an 800A/1200V 2in1 configuration is formed. By this paralleling approach the internal package inductance L_S has been decreased to less than 10nH, which is important for limiting the overvoltage spikes at chip level due to high di/dt at switching of SiC-MOSFET.

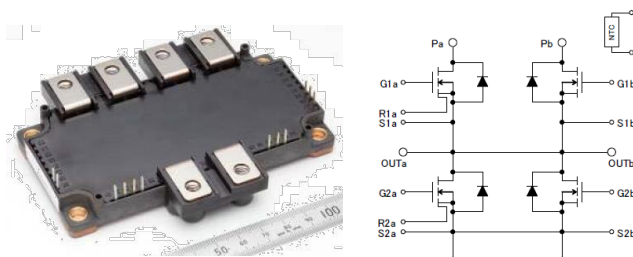


Figure 2: FMF800DX-24A package outline and internal circuit

The baseplate dimension of FMF800DX-24A is 62mm x 121mm. Thus the module size of new 800A/1200V full SiC module is about 1/2 compared with conventional Si-based IGBT modules having the same current rating, see Figure 3.

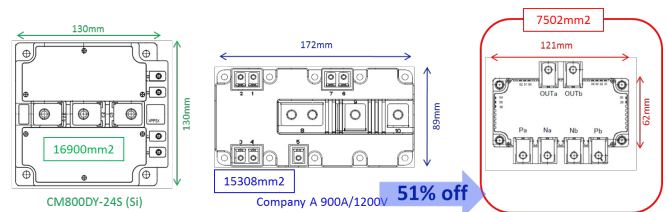


Figure 3: Footprint comparison

For monitoring the baseplate temperature TC a NTC-sensor located close to the MOSFET/FWDi chips is incorporated into the module. For short circuit and overcurrent protection MOSFET-chips with on-chip current sensing are used in one of the half bridge configurations (see Figure 2).

Main module parameters

The main parameters of 800A full SiC module are shown in Table 1. The values of V_{DS} , $R_{DS(on)}$ and V_{SD} are given on chip level.

Symbol	Parameter	FMF800DX-24A
V_{DSX}	Drain-source voltage (at $V_{GS}=-15V$)	1200V (max)
I_D	Drain current	800A
$I_{D(max)}$	Max. drain current (pulse)	1600A
$T_{J(max)}$	Max. junction temperature	150°C
$V_{DS(on)}$	Drain-source On-voltage @ I_D ; $T_J=150^\circ C$	2.4V (typ)
$R_{DS(on)}$	Drain-source On-resistance @ I_D ; $T_J=150^\circ C$	3.0mΩ (typ)
V_{SD}	Source-drain voltage @ $-I_D$; $T_J=150^\circ C$	2.2V (typ)
$V_{GS(+)}$	Gate-source On-voltage	13.5V...16.5V
$V_{GS(-)}$	Gate-source Off-voltage	-9V...-16.5V
$R_{th(j-c)Q}$	MOSFET thermal resistance	42 K/KW
$R_{th(j-c)D}$	FWDi thermal resistance	61 K/KW

Table 1: Main FMF800DX-24A parameters

Switching characteristics

Typical turn-on and turn-off switching waveforms at $V_{CC}=800V$; $T_J=150^\circ C$; $R_{G(on)}=R_{G(off)}=5\Omega$ are shown in Figure 4 and 5 for different drain currents $I_D=140A...1400A$.

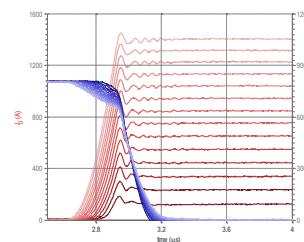


Figure 4: Turn-on waveforms

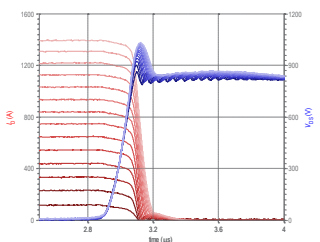


Figure 5: Turn-off waveforms

For limiting the turn-off overvoltage spike a cross-snubber capacitor of $C_S=6\mu F$ was connected between P- and N-terminals. The dependency of switching speed di/dt on drain current I_D is shown in Figure 6 and 7

for different junction temperatures $T_J=25^\circ\text{C}$; 75°C ; 125°C ; 150°C and different DC-link voltages $V_{CC}=600\text{V}$; 800V .

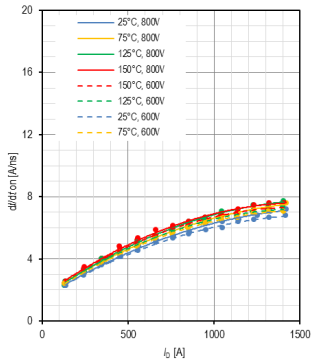


Figure 6: Turn-on di/dt versus I_D

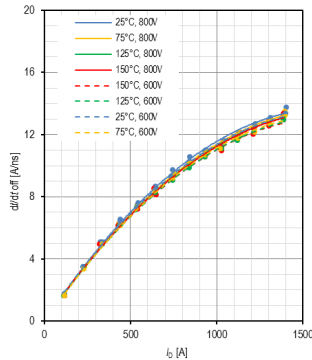


Figure 7: Turn-off di/dt versus I_D

Two comments can be derived from Figure 6 and 7:

- The current slopes at turn-on and turn-off don't show a strong dependency on chip temperature T_J and DC-link voltage V_{CC} . This behavior differs from today's IGBT-modules.
- The maximum di/dt at turning-off $I_D=1400\text{A}$ was about 13A/ns , which is quite similar to the switching speed known from today's high current 1200V IGBT-modules.

Loss comparison with Si-based IGBT modules

The typical forward characteristics of new 800A full SiC module and existing 800A Si-based IGBT module are compared in Figure 8.

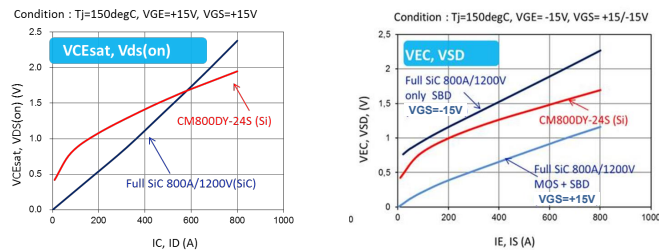


Figure 8: Forward characteristics

The comparison of switching energies in Figure 9 is indicating a key benefit of SiC technology: the switching losses can be drastically reduced compared with Si-based IGBT modules.

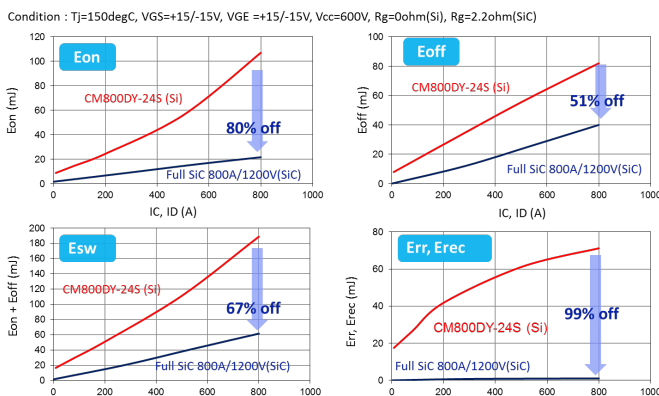


Figure 9: Switching energy comparison

This benefit can be seen in the power loss simulation results per Transistor/FWDi-pair in inverter operation for two different PWM frequencies 15kHz and 30kHz and the corresponding temperature rise $\Delta T(j-c)$ in Figure 10 and Figure 11.

The total power loss can be drastically reduced (by 71% for 15kHz and 76% for 30kHz) when full SiC-module is used. This loss reduction is mainly due to reduced switching loss. Conclusion: full SiC modules are very well suited for applications requiring high switching frequencies, where conventional Si-IGBT modules are reaching their thermal limit.

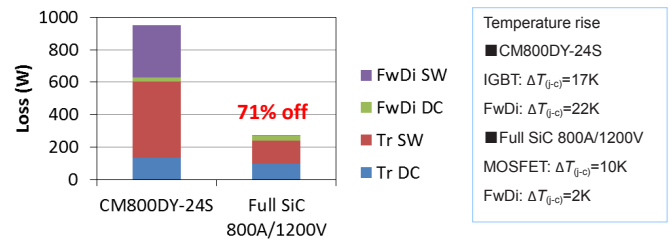


Figure 10: Loss and $\Delta T(j-c)$ simulation at $f_c=15\text{kHz}$; $V_{CC}=600\text{V}$; $I_O=400\text{A(peak)}$; $PF=0,8$; $M=1,0$

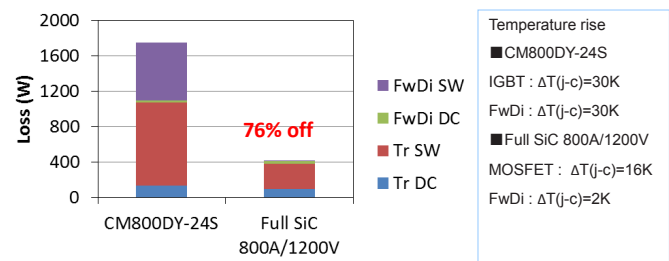


Figure 11: Loss and $\Delta T(j-c)$ simulation at $f_c=30\text{kHz}$; $V_{CC}=600\text{V}$; $I_O=400\text{A(peak)}$; $PF=0,8$; $M=1,0$

Gate Driver with SC-protection

The new $800\text{A}/1200\text{V}$ full SiC-Module can withstand a short circuit current for a limited time of $t_{SC(max)}=2,5\mu\text{s}$. This limit is given in the SCSOA specification.

For conventional Si-IGBT modules typically a short circuit capability of $t_{SC(max)}=10\mu\text{s}$ is specified. In such conventional IGBT drivers a blanking time between desat-detection and SC-turn-off of typically $t_{blank}=1\mu\text{s}$ is installed, which is sufficient to ensure both: no false SC protection tripping and safe SC-turn-off.

Considering the relatively short $t_{SC(max)}=2,5\mu\text{s}$ specified for the new $800\text{A}/1200\text{V}$ full SiC-module another SC-protection method is proposed, known as RTC (Real Time Current Control). For this purpose one p-side and one n-side SiC MOSFET chip are equipped with a current sense electrode (refer to Figure 2). The equivalent circuit and the external view of this SiC MOSFET chip are shown in Figure 12.

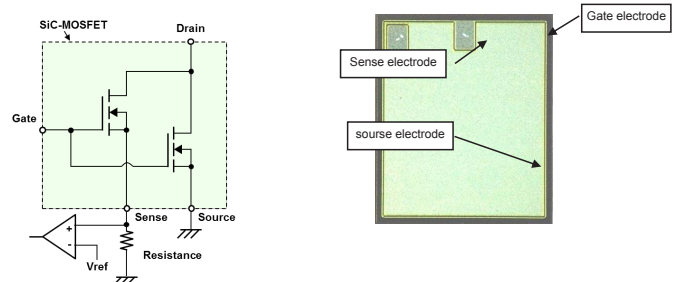


Figure 12: SiC MOSFET chip with current sense terminal

The functional block diagram of a dedicated gate driver for FMF800DX-24A using the proposed RTC protection is given in Figure 13. The measured short circuit waveforms during RTC operation are shown in Figure 14.

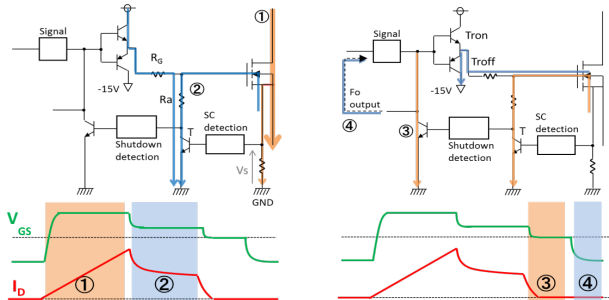


Figure 13: Principle of SC-protection by RTC

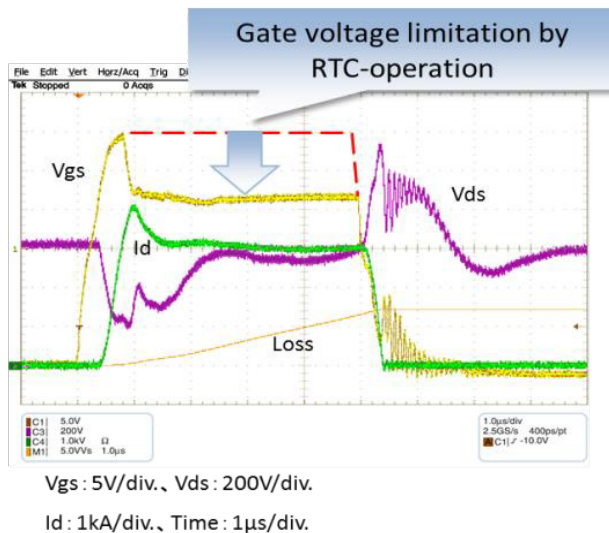


Figure 14: SC-waveforms during RTC-operation

During SC-turn-off operation by RTC four modes can be distinguished. In mode ① the main current I_D is increasing until the voltage V_s across the shunt resistance is reaching a defined trip level. After reaching this trip level the mode ② starts: the transistor T is turned on and the Gate-Source voltage is reduced from +15V to about +7V resulting in a decreased SC-saturation current. Due to this SC-current reduction the allowable short circuit time is increased again to the well-known from IGBT drivers $t_{sc(max)}=10\mu s$. Means from now on the conventional IGBT gate driver timing can be applied. During phase ③ the gate driver transistor $Tron$ is switched off and V_{GS} becomes Zero thus causing a soft turn-off of the short circuit current. In the final phase ④ the driver transistor $Troff$ is turned on thus applying a negative V_{GS} to the SiC MOSFET in off-state.

Summary and outlook

This paper is describing a new 800A/1200V full SiC dual module. Its type name is FMF800DX-24A. Compared with conventional Si-based IGBT modules the following unique points are confirmed:

- Module size reduced by 50%
- Switching loss ($E_{sw} = E_{on} + E_{off} + E_{rr}$) reduced by 75%
- Reliable SC-protection by RTC

Based on these features the new 800A/1200V full SiC module provides an interesting alternative to conventional IGBT modules in power electronic systems up to several 100kW, especially if one of the following system characteristics is of specific importance:

- Compact equipment size/high power density
- High efficiency
- High switching frequency (beyond the today's limit reachable with IGBT modules)

References

- [1] Press release No.2687 "Mitsubishi Electric to begin shipment of Silicon Carbide Power Modules Samples", Tokyo, July 9, 2012
- [2] Press release No.2733 "Mitsubishi Electric develops Large capacity SiC Power Module Technologies" Tokyo, February 14, 2013