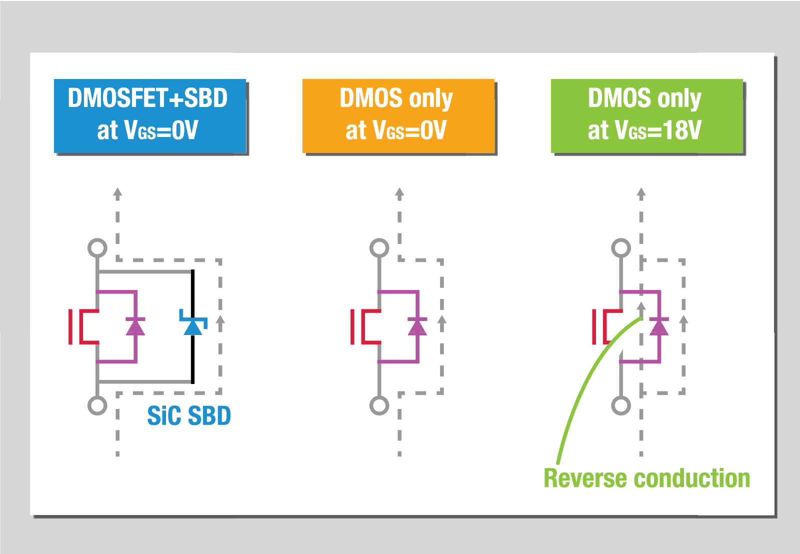
SiC MOSFET-Only Module Increases Current at Reduced On-Resistance

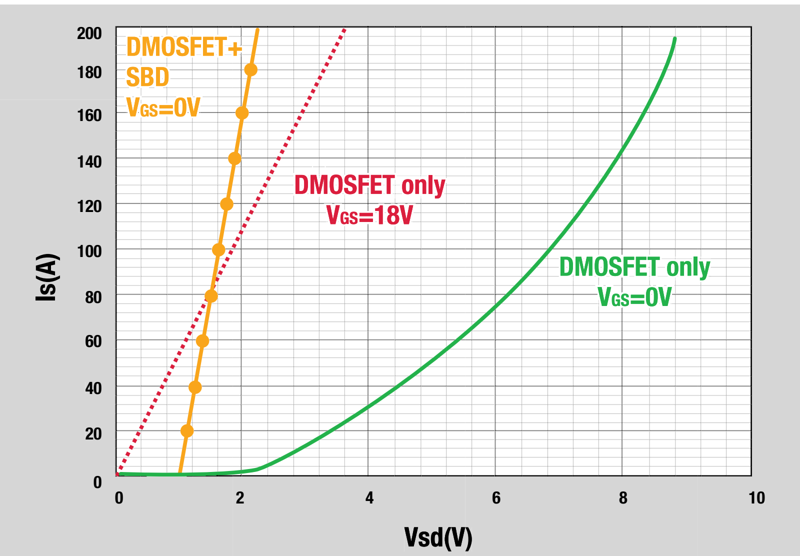
ROHM introduced last year a 1200 V / 120 A full Silicon Carbide power module composed of SiC Schottky barrier diodes (SBDs) and SiC MOSFETs. When compared with conventional IGBT modules, this module can reduce switching loss by 85 %. However, this module is not capable of supplying high currents demanded for industrial applications. Now a methodology to raise rated current has been presented on the example of the newly developed 1200 V / 180 A SiC module using the same package size. **M. Hayashiguchi, M. Miura, K. Hayashi, N. Hase and K. Ino, ROHM Co., Kyoto, Japan**

Several companies have started commercial production of SiC switching devices such as MOSFETs and JFETs. As industrial applications tend to require higher current levels of 100 A or more, ROHM started commercial production of full SiC modules in March 2012. However, its application is rather limited because of its rated current. Expanding the chip size is a straightforward way to achieve higher currents but this may not be the best way today because lowered manufacturing yield due to crystal defects will bring cost up. By making full use of the SiC characteristics two key technologies were employed to increase current rating, 1) eliminating anti-paralleled SBDs by turning on the MOSFETs to allow reverse current flow, and 2) parallel use of multiple MOSFET chips without current miss-sharing.



ABOVE Figure 1: **Current flow in reverse direction**

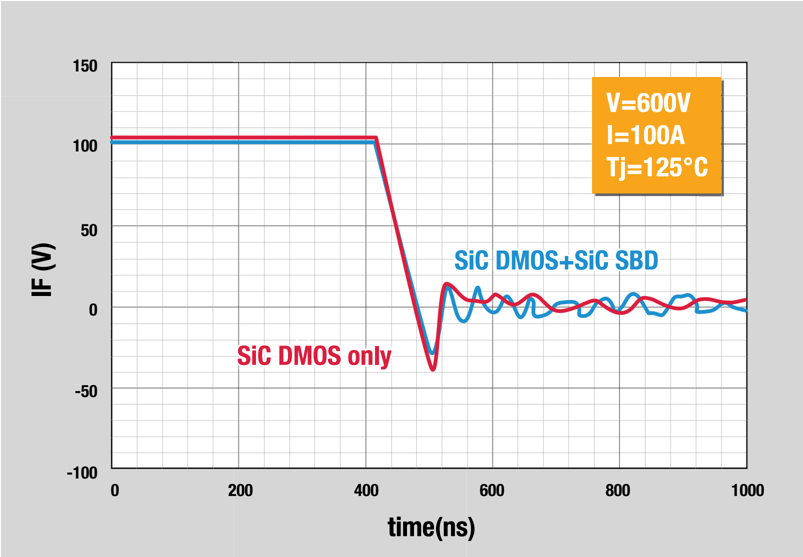
BELOW Figure 2: **Body diode and reverse conduction characteristics of 100 A SiC module**



Reverse conduction of SiC MOSFETs

The offset voltage of SiC PN diode is relatively high because SiC is a wide bandgap material and this may cause high conduction loss during commutation under Vgs=0 V condition. In many cases of inverter/converter drive, the turn-on signal is applied to the FETs at commutation-side after dead time is finished while it is impossible to operate IGBTs at third-quadrant – thus this turn-on signal does not produce any effect in IGBT-based power electronics. However, things are distinctly different in the case of MOSFETs – the relatively high Vf (forward voltage) of the body-diode can be reduced by turning on the MOS channel to allow reverse conduction as shown in Figures 1 and 2.

In MOSFET-only configuration utilizing



LEFT Figure 3: **Reverse recovery characteristics of body diode at 25°C**

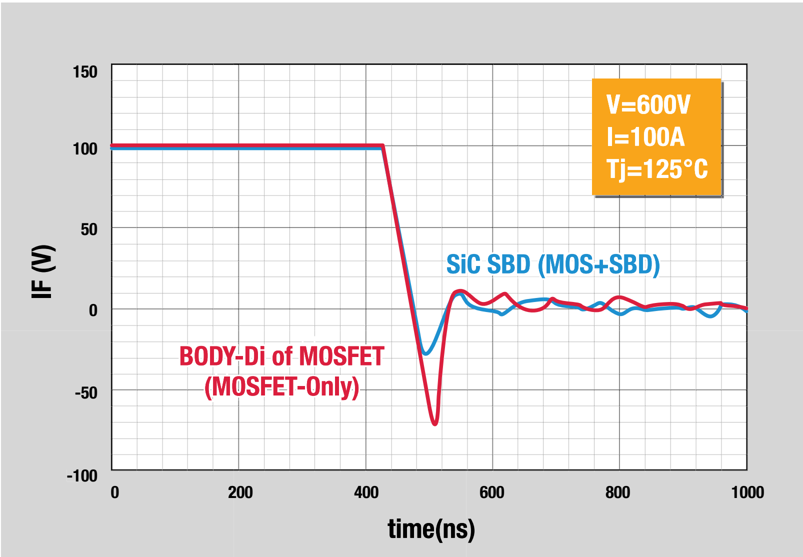


Figure 4: **Reverse recovery characteristics of body diode at 125°C**

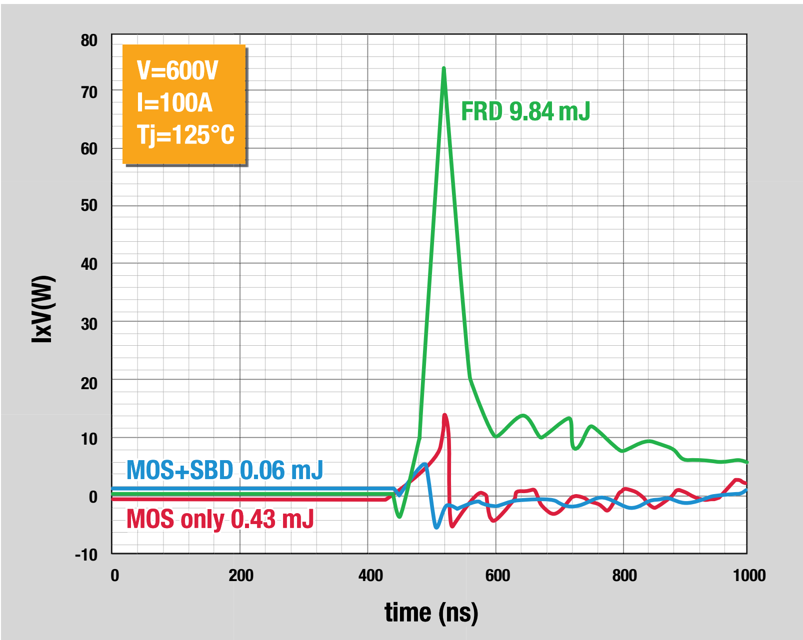


Figure 5: **Reverse recovery energy**

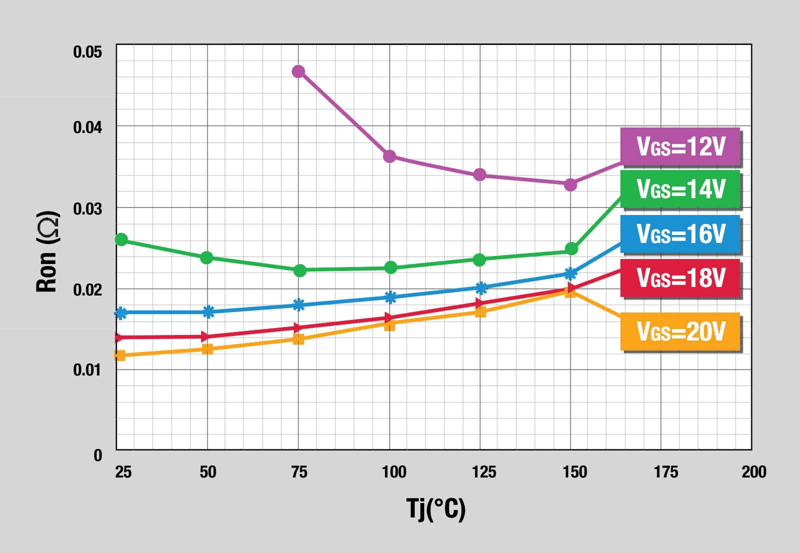
reverse conduction, the body diode is conducted only during dead time. Despite very short period of dead time to prevent shoot-through current, bipolar degradation of SiC devices can be still serious problem. SiC PN diode has been suffering defect expansion after forward conduction that results in increases in both on-resistance and leakage current. ROHM succeeded in suppressing defect expansion as reported in PCIM 2012 and confirmed the reliability of body-diode for 1000 h without any change in characteristics.

As for reverse recovery characteristics, body diode of SiC MOSFETs shows as fast recovery time as SBDs (Figures 3, 4), which leads to lower EMI noise and loss level not achieved by Si MOSFETs or even by Si-FRD. Recovery current of the body diode slightly increases at 125°C while that of SBDs is the same as RT, but reverse recovery energy is very small compared with Si-FRD (Figure 5). All of these facts contributed to realization of a SiC power module without additional free-wheeling diodes.

Paralleling SiC MOSFETs

If devices with negative temperature coefficient of on-resistance are connected in parallel, current might concentrate on a chip with the lowest R_{on} and cause thermal runaway in the worst case. However such risk is lower in the case of SiC MOSFETs as its temperature coefficient of on-resistance is positive (Figure 6) when its recommended on-state V_{gs} is applied (i.e. V_{gs}=18V) – the characteristics make parallel connection of the switching devices much easier.

Figure 7 shows the temperature change at chip surfaces observed by a pyrometer along with time. Four MOSFET chips are mounted and connected in parallel in one module, one chip out of the four chips has lower R_{on} and the rest has higher R_{on}. These chips were intentionally prepared to analyze the current crowding effect due to such R_{on} variation. The normal variation of



LEFT Figure 6: On-resistance vs junction temperature characteristics

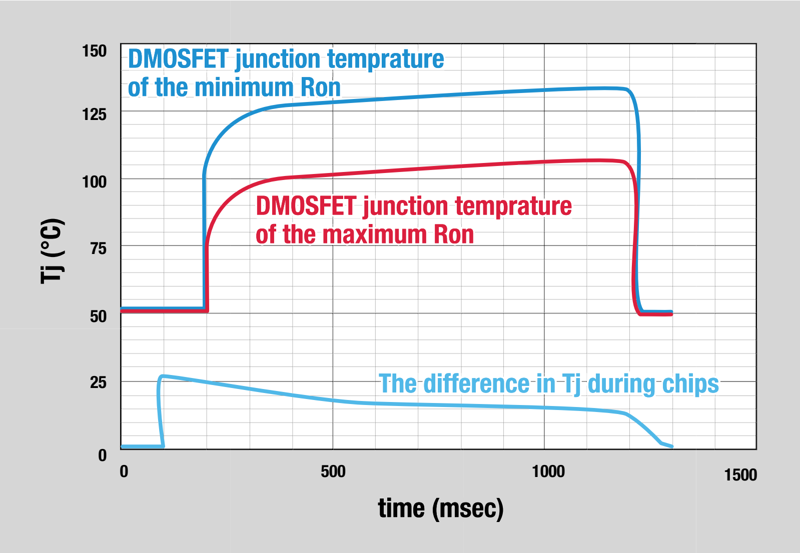


Figure 7: Temperature change during current conduction of the intentionally prepared module which consist of 3 MOSFET chips with higher on-resistance and 1 MOSFET chip with lower on-resistance in parallel

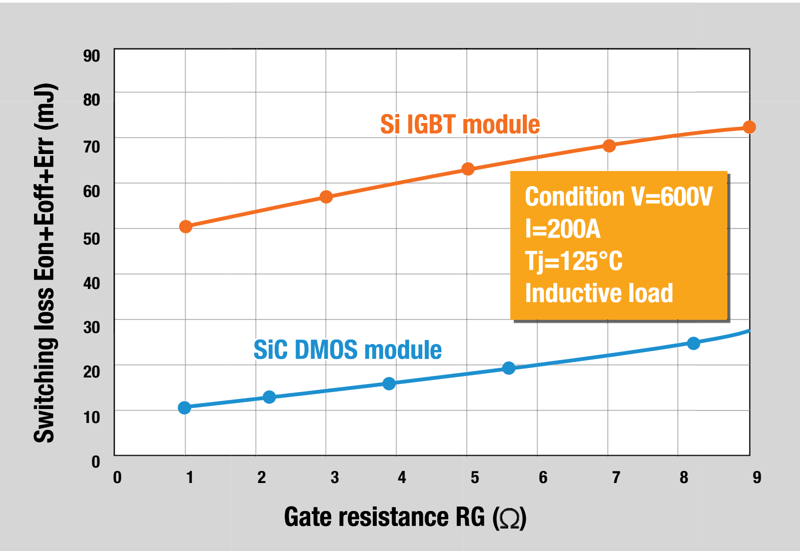


Figure 8: Comparison of total switching loss between Si IGBT module and 180 A SiC DMOS module

Ron, in the mass produced module, is less than half of that for this experiment.

As shown in Figure 7, temperature difference among chips is larger at the very beginning of conduction but it becomes smaller with time (12°C difference at 1 s) because of self-balancing effect due to positive temperature coefficient of R_{on}.

The other concern regarding parallel use is miss-sharing of gate current at turn-on. As for paralleled Si IGBT chips, due to its low internal gate resistance, the balance between each gate currents is easily influenced by the difference in stray inductance. Then the devices may be broken by rush current and resonant oscillation triggered by this.

Contrary to Si IGBTs, thanks to relatively high internal gate-resistance of SiC MOSFETs (several Ω), distribution of gate current among paralleled chips is well balanced without additional gate resistance put individually. These characteristics make multiple connections of SiC MOSFET chips in parallel much easier without miss-sharing of both drain and gate current, which helps to prevent thermal runaway or resonant oscillation.

Properties of 180 A SiC MOSFET module

By replacing SBDs with MOSFETs, rated current was increased from 120 A to 180 A in the same package size. Drain-source on-state voltage at drain current of 180 A is 2.3 V (R_{on}=12.8 mΩ: about 40 % less than 120A module). Due to no-tail current and fast recovery characteristics of SiC devices, total switching loss is reduced by 75 % against IGBT module if a small external gate resistor is used (see Figure 8). The module is reliable for body-diode conduction and will not show bipolar degradation because high reliability is confirmed in our SiC-MOSFETs.

Conclusion

Based on existing devices a new half-bridge power module containing only SiC MOSFETs rating 1200 V was developed. Maximum drain current increases from 120 A to 180 A while on-resistance decreases by 40 % within same package size by replacing external SiC Schottky Barrier Diodes by the improved internal MOSFET body diode.

Literature

"Low loss, High Current SiC MOSFET Module", Proceedings PCIM 2013 Europe, pages 325 - 332