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4H-SiC Power MOSFETs and SBDs of 1.7kV Rating

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1. Introduction

An SiC is an attractive material considering its application to the power device components since it possesses overwhelming material properties compared to the conventional Si. We have demonstrated 3.7kW motor drive with a power module consisted of SiC-MOSFETs and SiC-SBDs of 1.2kV rating, and less than 50% in power loss compared to the Si counterpart was successfully achieved [1]. In this paper, the favorable potential of the SiC is further investigated for higher voltage application, i.e. rating of 1.7kV. The 10A-class devices showed superior static and dynamic electrical characteristics.

2. Device Structures

Table I summarizes specifications of drift epilayers of the two kinds of devices. Impurity concentration (N_D-N_A) and thickness have been designed in each by numerical simulation to satisfactory block 1.7 kV drain/reverse bias and to reduce leakage current. For the junction termination, both devices employ a JTE (Junction Termination Extension) structure to guarantee a stable avalanche breakdown. Their active area is about 0.08 cm^2, which is large enough to handle current more than 10 A. The MOSFET consists of parallel conjunction of a unit cell with a tight alignment to reduce a specific on-resistance ($R_{on,sp}$), such that a channel length of 0.7 μm and a unit cell pitch of 13 μm. The SBD is realized with titanium as a Schottky metal [2].

3. Results and Discussion

Fig. 1 and 2 show typical static electrical characteristics of MOSFET and SBD, respectively. The MOSFET showed good pinch-off and drain current of 10 A at a moderate gate bias. The $R_{on,sp}$ of 9.8 mΩcm^2 at I_{DS} of 100 A/cm^2 was estimated with a V_{GS} of 20 V which corresponds to a gate oxide electric field of 2.5 MV/cm. Channel mobility was deduced to be about 10 cm^2/Vs. A stable avalanche breakdown of 1.8 kV with the V_{GS} of -5 V was also recorded. Similar avalanche characteristics and forward current of 10 A were obtained in the SBD shown in Fig. 2, and a differential on-resistance (R_{diff}) of 2.2 mΩcm^2 at J_F of 300 A/cm^2 was estimated.

Fig. 3 is a temperature dependence of the R_{diff} of the SBD. It increased by a factor of 3.5 at 200ºC, which is mainly caused by the decrease in the drift layer mobility. This tendency was also observed in the MOSFET. Fig. 4 is an avalanche breakdown voltage of the SBD as a function of temperature. It shows positive temperature coefficient, suggesting that our Schottky contact and JTE provide stable breakdown even at high temperatures.

Dynamic electrical characterization was performed on the SiC-MOSFET/SBDs. They were wire- and die-bonded to DBC substrates in a half-bridge configuration, and their switching characteristics were measured by a double pulse method. Fig. 5 shows a switching loss as a function of a gate resistance which is connected to a gate electrode of the MOSFET. The DC supply voltage is set at 1 kV. The lower gate resistance leads to a lower switching loss, since it affects rise and fall time. This effect was also observed in our 1.2kV/10A SiC module [3]. Fig. 6 is a comparison of the total switching loss between a conventional Si-IGBT module and that of the SiC-MOSFET/SBD. The loss can be reduced to less than 20% of the Si module. This drastic improvement is ascribed to a great reduction in the diode recovery and MOSFET turn-off losses owing to a negligible influence of the minority carriers in the unipolar devices. The lower on-resistance in the transistor also takes effect in the DC loss. These results are encouraging for the practical application of the SiC modules toward the power electronics of 1.7kV-class.

4. Conclusions

4H-SiC power MOSFETs and SBDs which are designated as a 1.7kV rating were fabricated. Static characterization revealed MOSFET's $R_{on,sp}$ of 9.8 mΩcm^2 with a stable avalanche breakdown of 1.8 kV. The SBD exhibited low forward voltage and high reverse blocking of 1.8 kV. A great reduction to less than 20% in the switching loss was obtained in the SiC-MOSFET/SBD system compared to that of the conventional Si counterpart. The results present superior performance of high voltage SiC unipolar devices.

Acknowledgements

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References

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Table I Summary of the drift layer of MOSFET and SBD.

	MOSFET	SBD
N_D-N_A [cm^{-3}]	7E+15	5E+15
Thickness [μm]	15	15

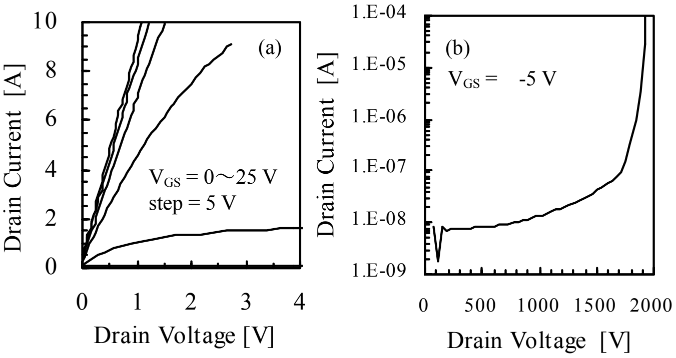

Fig. 1 (a) I_{DS}-V_{DS} and (b) blocking characteristics of the 10A-class MOSFET. $R_{on,sp}$ of 9.8 mΩcm^2 and avalanche breakdown voltage of 1.8 kV were recorded.

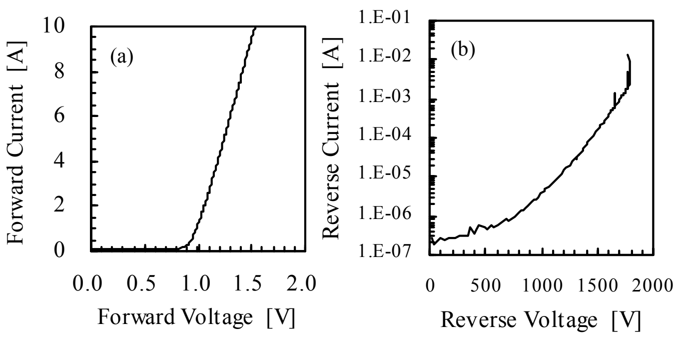

Fig. 2 (a) Forward and (b) Reverse blocking characteristics of the 10A-class SBD. R_{diff} of 2.2 mΩcm^2 and avalanche breakdown voltage of 1.8 kV were recorded.

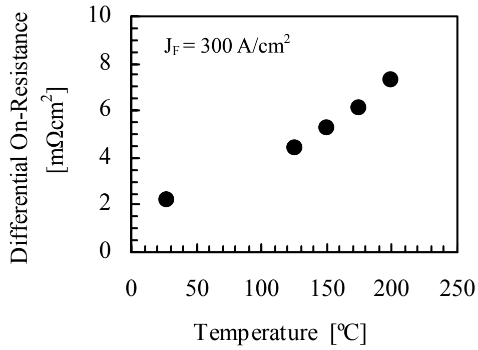

Fig. 3 Temperature dependence of R_{diff} of the SBD. Positive temperature coefficient was observed

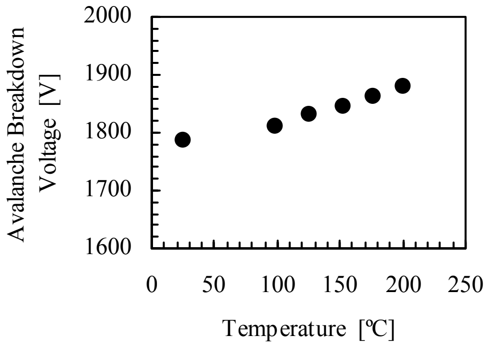

Fig. 4 Temperature dependence of avalanche breakdown voltage of the SBD. Positive temperature coefficient was observed.

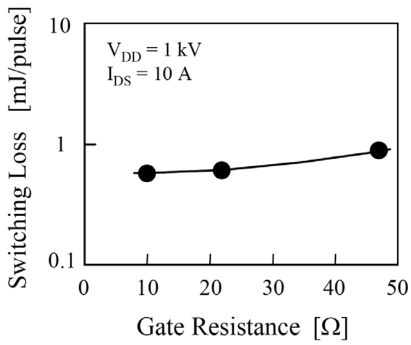

Fig. 5 Switching loss of the SiC module as a function of the gate resistance. Lower gate resistance leads to a lower loss.

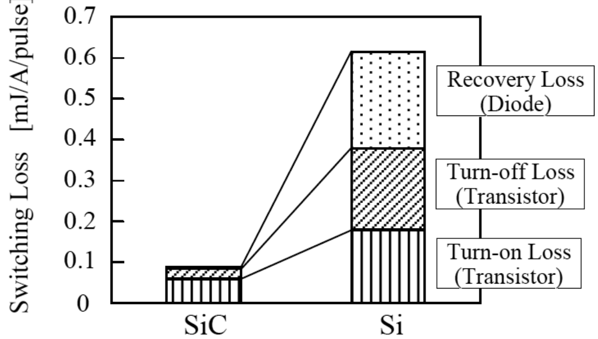

Fig. 6 Comparison of the total switching loss between the Si- and SiC-modules. About 80% reduction by replacing the Si to the SiC was estimated.