Development of SiC-MOSFET Chip Technology

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1. Introduction

Power devices that make it possible to use electric energy efficiently are equipped with semiconductor chips, such as transistors and diodes, which play a key role in current and voltage control. While Si semiconductor chips are mainly used at present, the application of wide band gap silicon carbide (SiC) semiconductors has begun to improve the performance and reduce the loss. Thanks to the excellent physical properties of SiC, SiC devices reduce the loss in power conversion by 50–70% and can function at higher frequencies than the conventional types. Using SiC devices based on the characteristics of systems can reduce the power loss of equipment and allow coolers and passive components to be made smaller.

To spread the use of SiC power devices that save both energy and resources, Mitsubishi Electric Corporation has been continuously working to improve their performance and reduce the costs. This report summarizes the latest development of SiC chips.

2. SiC Chip Development

2.1 Second-generation planar MOSFETs

We have been developing second-generation planar metal-oxide-semiconductor field effect transistors (MOSFETs) using our newly constructed 6-inch SiC wafer line. For these planar MOSFETs, the MOS cell structure was optimized using JFET doping technology, which has reduced the on-resistance and capacitance. As examples, Fig. 1 shows the on-state characteristics of a second-generation planar MOSFET with the blocking voltage of 1,200 V and Fig. 2 shows the dependence of the switching loss on the gate resistance.(1) For comparison, the figures also show the data for a first-generation MOSFET with the same active area. For the second-generation MOSFET, the on-resistance was reduced by approximately 15% thanks to the smaller cell pitch and other improvements. Figure 2 also shows that the switching loss was remarkably reduced thanks to the faster switching speed resulting from the reduced capacitance and other improvements. In addition, the 6-inch SiC wafer line can process thin SiC wafers for lower on-resistance, and so thin SiC wafers started to be used for the second-generation planar MOSFET.

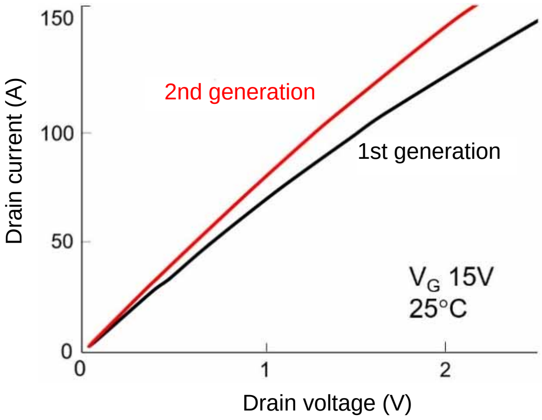
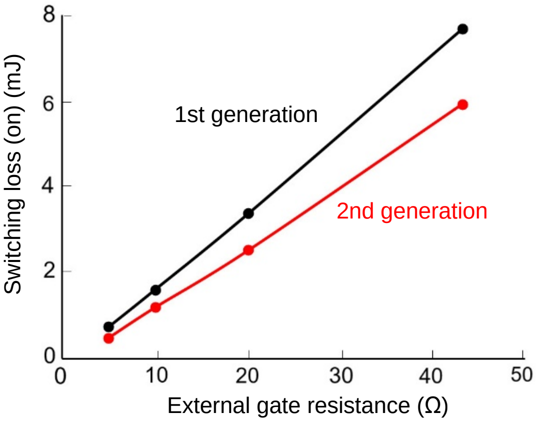
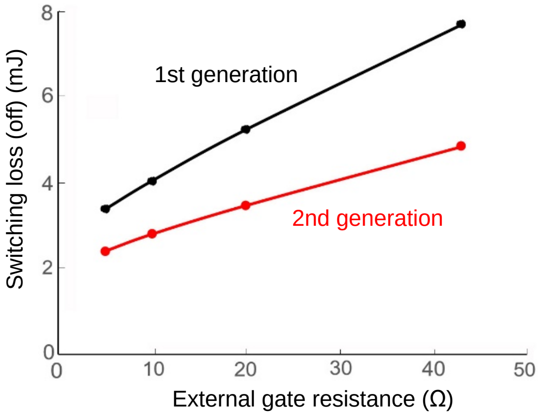


Fig. 1 On-state characteristics of second-generation planar MOSFET



(a) Loss when switches are on



(b) Loss when switches are off

Fig. 2 Switching losses of second-generation planar MOSFET

**Power Device Works*

Currently, we have been developing various types of second-generation planar MOSFETs with the blocking voltage ranging from 600 V to 3.3 kV, and have been successively applying them to power modules for commercialization.

2.2 Trench MOSFETs with new structure

We have been developing trench MOSFETs with our proprietary structure for SiC power modules.(2) Due to the physical properties of SiC, the electric field intensity in SiC chips unavoidably tends to increase; in particular, the intensity of the electric field to be applied to the gate oxide at the trench bottom becomes high. Therefore, SiC-MOSFETs require special consideration, unlike Si trench MOSFETs. Figure 3 illustrates the structure of a trench MOSFET that we have been developing. To weaken the electric field to be applied to the gate oxide at the trench bottom, a bottom p-well (BPW) is provided at the lower section of the trench. To stabilize the electric potential of this BPW, ion implantation of p-type dopants is performed diagonally to the trench sidewall for electric connection. For the section at the trench sidewall where currents pass, angled ion implantation of n-type dopants is performed to reduce the electric resistance. Figure 4 shows the on-resistance of a prototype trench MOSFET at room temperature. Figure 5 shows the blocking voltage characteristics. Compared to our planar MOSFET, the specific on-resistance of the trench MOSFET is approximately 50% lower at 1.84 mΩcm^2. The avalanche breakdown voltage is 1,560 V as designed.

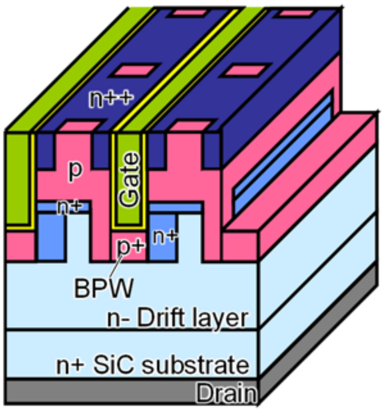


Fig. 3 Schematic cross-sectional structure of trench MOSFET

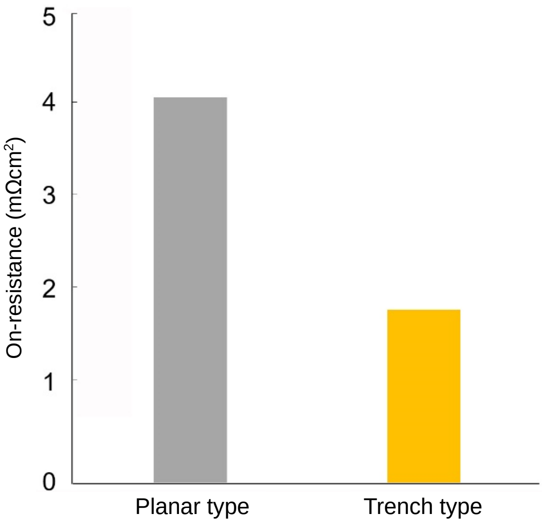


Fig. 4 Comparison of on-state resistance between planar and trench MOSFET

Such low resistance characteristic of trench MOSFETs will be used in the future to downsize chips in order to reduce the cost and increase the rated current of modules.

2.3 SBD-embedded MOSFETs

MOSFETs have pn diodes (body diodes) that enable the current to flow in the reverse direction thanks to their structure and they may be used as commutation diodes. However, with existing SiC-MOSFETs, when the body diodes are used, the on-state voltage sometimes increases. For MOSFETs with a large area and high blocking voltage, in particular, the SBDs as commutation diodes need to be connected in a row or screening testing of the body diodes is required to avoid the increase in on-state voltage.

For MOSFETs with the blocking voltage of 3.3 kV or higher, we have been developing SBD-embedded MOSFETs for which SBDs are built in the unit cells of the MOSFETs and that eliminate the need for SBDs as commutation diodes and screening test of the body diodes.(3) When a current flows in the reverse direction through the SBD built into an SBD-embedded MOSFET, the voltage to be applied to the pn junction of the body diode is reduced due to the voltage drop caused by the current flowing in the drift layer and thus no current is induced on the body diode.

Figure 6 shows the on-state characteristics of a prototype SBD-embedded MOSFET. The on-state characteristics are similar to those of a normal MOSFET

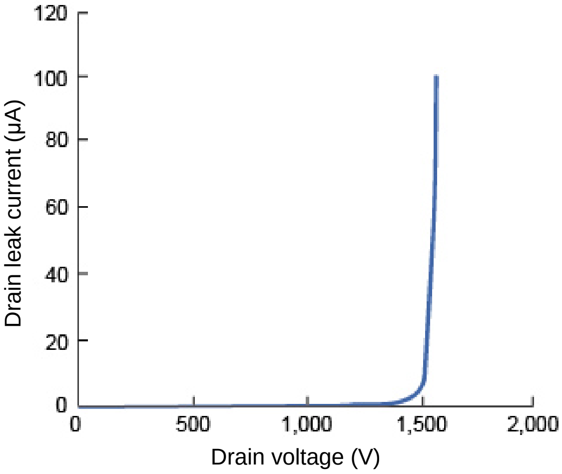


Fig. 5 Off-state characteristics of trench MOSFET

that can be controlled by gate voltage. Since the area of the electrodes of the built-in SBD can be made small, the increase in the specific on-resistance is small. Figure 7 shows the reverse current conduction characteristics of an SBD-embedded MOSFET when the MOSFET gate is off (V_G -5V) and on (V_G 15V). The figure shows that when the voltage is approximately 1 V (diffusion voltage of the SBD), a current starts flowing and the unipolar current flows linearly. When the MOSFET gate is set to on, the current flowing on the MOSFET channel is superposed on the SBD current, greatly reducing the resistance.

By applying SBD-embedded MOSFETs to modules it is possible to omit SBDs, which are used to be connected in a row, and to simplify testing, thus downsizing the modules and reducing the costs.

3. Conclusion

We will continue developing second-generation planar MOSFETs, trench MOSFETs, and SBD-embedded MOSFETs to further improve the performance of power devices. We intend to help save energy and resources in various systems by utilizing the characteristics of SiC.

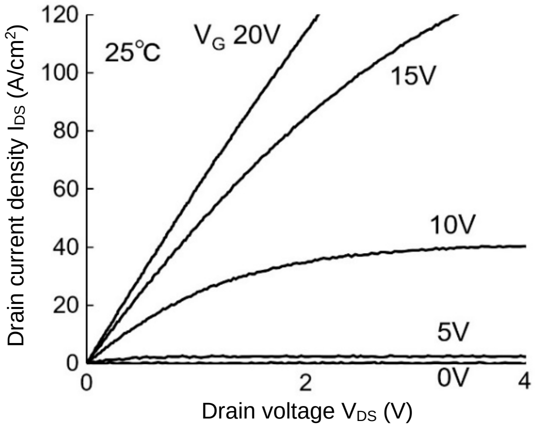


Fig. 6 On-state characteristics of SBD-embedded MOSFET

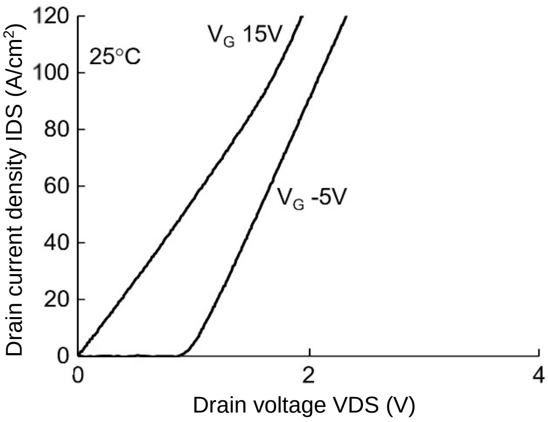


Fig. 7 Reverse current conduction characteristics of SBD-embedded MOSFET

References

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