2nd-Generation SiC-SBD

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In order to deal with environmental problems such as global warming and to achieve a low-carbon society, energy conservation through high-efficiency power electronics equipment and the use of renewable energy are being promoted. Under such circumstances, the market for power semiconductors used in power electronics equipment is expanding in a variety of fields, including automobiles, railways, energy systems, and industrial equipment.

Conventional power semiconductor devices using silicon (Si) are approaching theoretical property limits due to material properties. For this reason, silicon carbide (SiC), which has a band gap approximately three times larger and a breakdown field strength approximately ten times greater than Si, is expected to be the material used for power semiconductors that surpass the property limitations of those that use Si in order to further reduce the size and increase the efficiency of power electronics devices(1). Fuji Electric has mass-produced SiC-based Schottky barrier diodes (SBDs), planar gate metal-oxide-semiconductor field-effect transistors (MOSFETs), and trench gate MOSFETs, which are used in power conditioning systems (PCSs) for solar power generation, industrial inverters, and inverters used in railcars(2)-(11).

Figures 1(a) and 1(b) show the hybrid SiC module product with Si-IGBT and SiC-SBD developed by Fuji Electric, and Fig. 1(c) shows the SiC-SBD discrete product.

This article describes a 2nd-generation SiC-SBD with improved characteristics and forward surge withstand capability compared with the 1st-generation SiC-SBD. This product series is available in the rated voltages of 650 V and 1,200 V, and the product with the rated voltage of 650 V is discussed in this article.

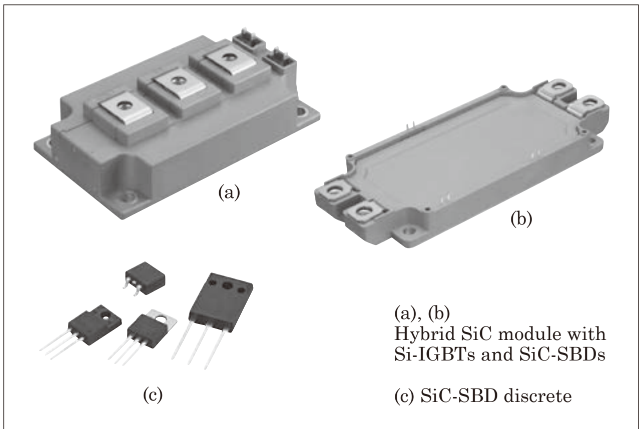

Fig.1 Examples of products in which Fuji Electric's SiC elements are used

1. Structure

Figure 2 shows the structure of the 1st-generation SiC-SBD and the 2nd-generation SiC-SBD. Both of them have a junction barrier Schottky (JBS) structure with a p^+ layer on the device surface, and have lower leakage current than SBDs with a conventional structure.

The structure of the 2nd-generation SiC-SBD has the following characteristics that differ from the 1st generation.

(a) The Schottky junction was optimized to lower the barrier height and reduce the forward voltage V_F.

(b) The drift resistance was reduced by optimizing the JBS structure and the drift layer, and the V_F and the peak surge forward current I_{FSM}* were improved.

(c) The thickness of the n^+SiC substrate was reduced to approximately one thirds, which reduced the substrate resistance and improved V_F and I_{FSM}.

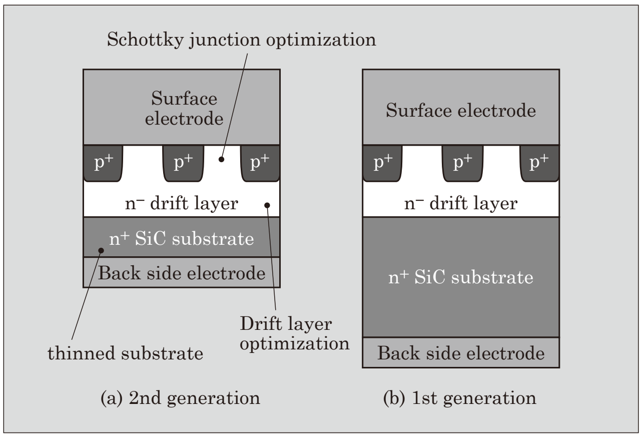

Fig.2 Structure of the 1st-generation and the 2nd-generation SiC-SBD

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* Peak surge forward current I_{FSM}: Forward surge withstand capability equivalent to the peak non-repeating current of a commercial sine half-wave (50 Hz or 60 Hz) allowed without device breakdown.

In the JBS structure, the current flows in the Schottky region formed by the surface electrode and the n⁻ drift layer during normal operation. When a high surge current flows in the forward direction, such as during a lightning strike, the pn junction diode composed of the p+ layer and n⁻ drift layer operates, causing a large current to flow through the ohmic region of the surface electrode and p⁺ layer(12). In the 2nd-generation SiC-SBD, the contact resistance of the ohmic region, which is the interface between the p⁺ layer and the surface electrode in Fig. 2, was reduced using our unique processing technology to make it easier for the pn junction diode to operate, thereby improving the I_{FSM}.

2. Features

2.1 Forward voltage and ohmic contact resistance R_C of the 2nd-generation SiC-SBD

Figure 3 shows the comparison of V_F of SiC-SBD with 650 V blocking voltage 10-A devices between the 1st and 2nd generations. The reduced drift resistance and substrate resistance has led to the improvement in V_F compared with the 1st generation.

Figure 4 shows the ohmic contact resistance R_C between the p⁺ layer and the surface electrode of SiC-SBD. The R_C of the 2nd-generation SiC-SBD is reduced by approximately 99.7% compared with the 1st generation.

2.2 Resistance of the 2nd-generation SiC-SBD 650 V

Figure 5 shows the forward I_F-V_F characteristics of the SiC-SBD 650-V blocking voltage device. In the 2nd generation, V_F at forward current I_F = 10 A was reduced by 18% at junction temperature T_{vj} = 25 °C and by 21% at T_{vj} = 175 °C compared with the 1st generation.

Figure 6 shows the temperature characteristics of V_F when I_F = 10 A. The SiC-SBD of the 2nd generation is more than 18% lower in the entire temperature range from −50 °C to +175 °C.

Figure 7 shows the I_F-V_F characteristics in the high current region of a 650-V blocking voltage device. In

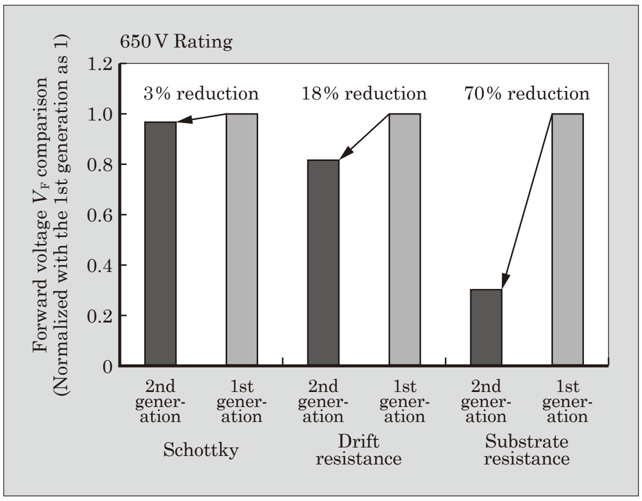

Fig.3 Comparison of the SiC-SBD V_F components between the 1st generation (each resistance normalized to 1) and the 2nd generation

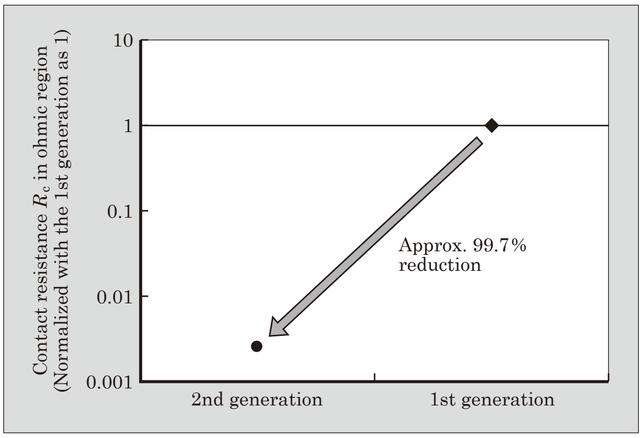

Fig.4 Comparison of ohmic contact resistance R_C between p⁺ layer and surface electrode between 1st generation (normalized to 1) and 2nd generation

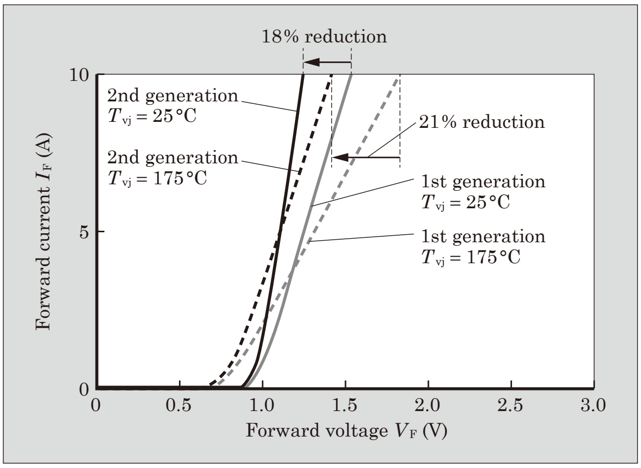

Fig.5 650-V/10-A I_F-V_F characteristic rated current range of the 1st- and 2nd-generation SiC-SBDs

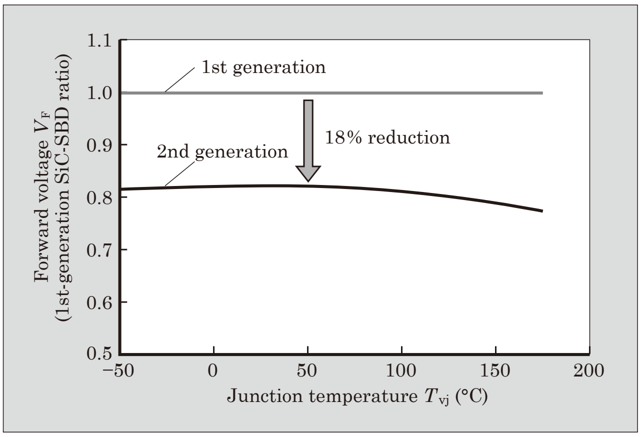

Fig.6 V_F temperature characteristics of 650-V SiC-SBD 2nd generation (V_F of 1st generation normalized to 1)

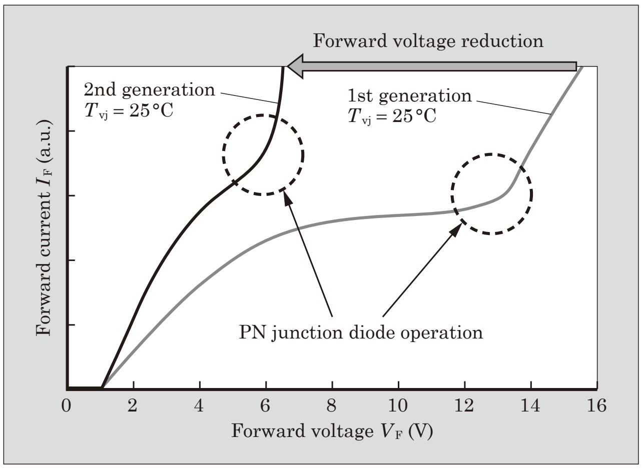

Fig.7 I_F-V_F characteristic of 1st- and 2nd-generation 650-V blocking voltage SiC-SBD in high current region

the 2nd generation, pn junction diodes are easier to operate than in the 1st generation due to the reduced contact resistance. As a result, the V_F during high-current flow is reduced, and the generated loss becomes smaller. It has been confirmed that this effect improves the forward surge withstand capability.

Figure 8 shows the V_F-I_{FSM} characteristics of 650-V blocking voltage SiC-SBD. Compared with the 1st generation, the 2nd-generation SiC-SBD has 18% lower V_F (10 A) and 75% higher I_{FSM}.

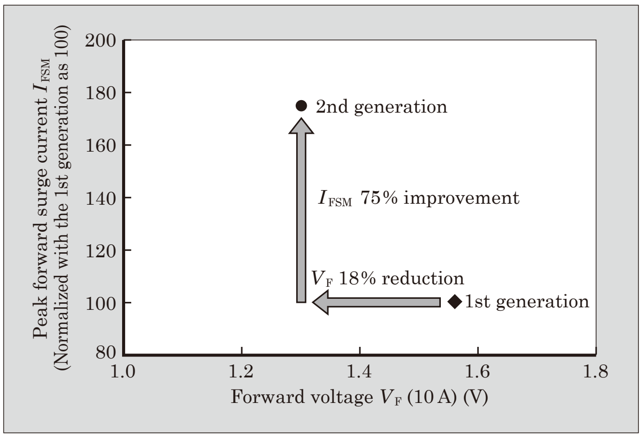

Fig.8 V_F-I_{FSM} characteristics of 1st- and 2nd-generation 650-V blocking voltage SiC-SBD

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