Guard-Ring Termination for High-Voltage SiC Schottky Barrier Diodes

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1. Introduction

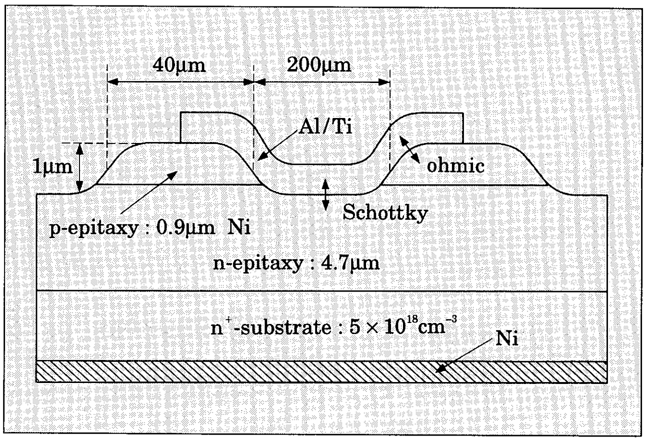
With the development of crystal growth technology, various SiC electronic devices have been studied.

Power devices are considered to be one of the important applications for the SiC, because it has been predicted that SiC devices can achieve a low forward resistance and a low switching loss at the same time[1], due to the large electric field strength. Several experiments have proved the predicted superiority of Au[2] or Pt[3] Schottky barrier diodes (SBD). Although edge termination to sustain a high voltage is one of the key technologies for SiC power devices, only a few structures have been studied so far[4]. Based on an analogy from silicon SBD's[5], Fuji Electric has proposed guard-ring termination, a simple and effective structure for SiC devices. In addition, we have demonstrated the device fabrication and shown the effectiveness of the guard-ring for high-voltage SiC SBD's.

2. Device Structure and Fabrication

The proposed structure is shown in Fig. 1. Al/Ti was chosen as the Schottky metal for this report. Since Al/Ti forms a Schottky contact with the n-drift region and an ohmic contact with the p-type region (the guard-ring), the electrical potential of the guard-ring is maintained the same as the anode electrode. In this configuration, because the maximum electric field (E max) is applied at the edge of the guard-ring, not at the edge of the Schottky contact, the breakdown voltage is determined by the mesa of the p-n junction. Another commonly used structure is the field plate. Field plate length for SiC should be shorter than for Si because space charge region is approximately one order smaller due to a higher E max (by about one order). This means that photo-alignment between the Schottky metal pattern and the contact-hole pattern should be more precise than in silicon. In addition, during high temperature annealing, Al/Ti or some other metal chemically reacts with silicon-dioxide, commonly used as the field plate insulator. The guard-ring structure avoids these two problems because the junction edge is defined at the guard-ring, and SiO_2 is not used in this structure.

Fig.1 Cross-section of a Schottky barrier diode with guard-ring



The diameter of the SBD was 200μm, and the width of the guard-ring was 40μm. It should be noted that a narrow guard-ring width is desirable in order to avoid minority carrier injection from the guard-ring when the forward biased.

The fabrication procedure is described in Fig. 2. The n-drift region and p-type region, which forms the guard-ring when completed, were grown by chemical vapor deposition (CVD) at 1,500°C on the *C*-face of 6H-SiC sublimation wafers. Doping concentration and thickness are $1.3 \times 16^{16}cm^{-3}$ and 4.7μm respectively for the n-drift region, and $7 \times 16^{16}cm^{-3}$ and 0.9μm respectively for the p-region. To form the mesa structure, we utilized a local oxidation technique with a 1μm silicon-nitride film as the oxidation mask. Fuji Electric has previously proposed this method to isolate p-n junctions[6]. The local oxidation procedure at 1,200°C for 4 hours in steam was repeated twice. The obtained mesa depth and angle was 1μm, and approximately 20 degrees. Next, Al/Ti was sputter deposited, and patterned. After Ni was deposited on the back side, the wafer was annealed at 1,050°C in order to form ohmic and Schottky contacts at the same time. For comparison, an SBD without a guard-ring was formed at the area where the p-type epitaxial layer was removed by oxidation. p-n diodes were also fabricated on the same wafer with the mesa structure in the same way as the

Fig.2 Process flow for device fabrication

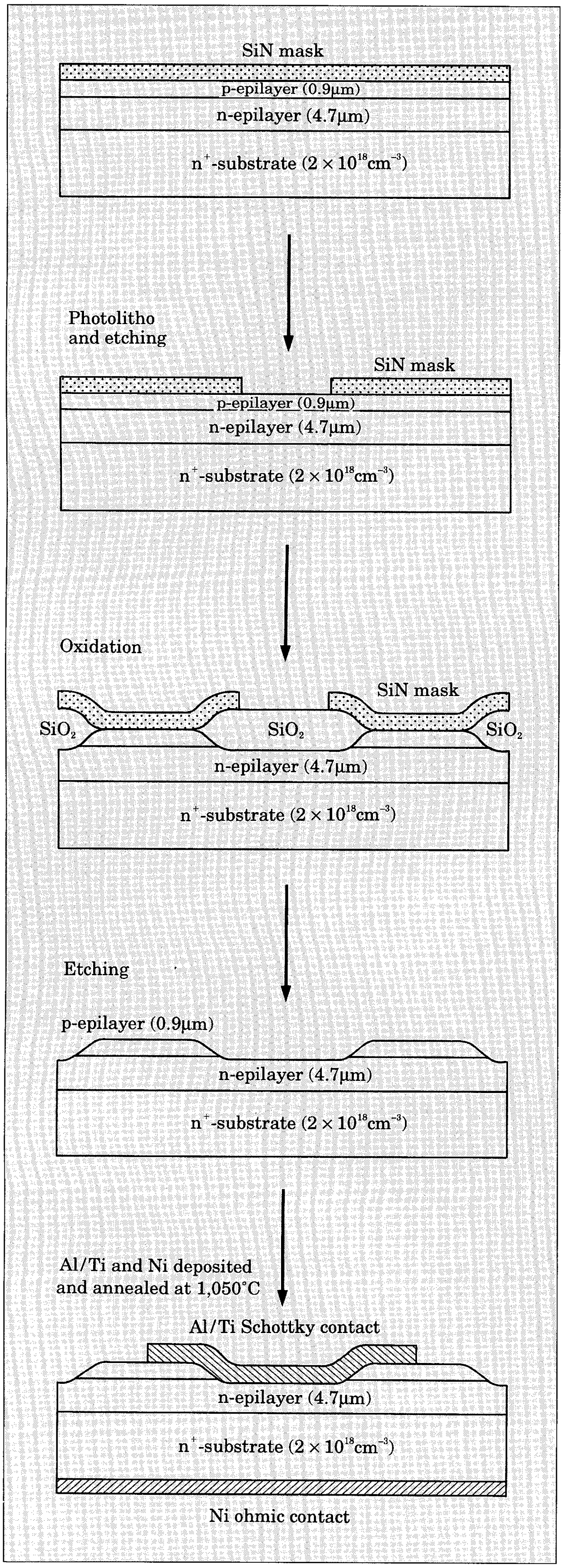
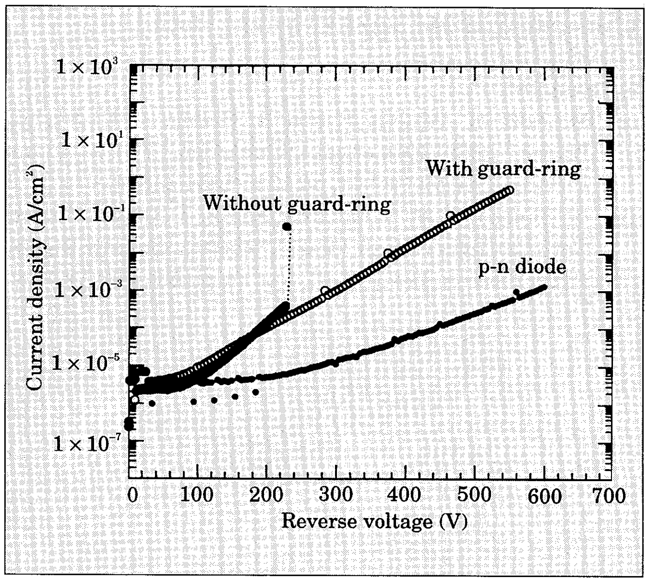


Fig.3 Comparison of reverse characteristics for Schottky barrier diodes with and without guard-rings, and a p-n junction diode



guard-ring. No passivation film was used for any of the devices. The annealing temperature is an important factor in obtaining a good quality SBD.

3. Results and Discussion

The reverse characteristics of a Schottky barrier diode with a guard-ring (SGD) and without a guard-ring (SD) are compared in Fig. 3. The SD shows a breakdown at 250V. On the other hand, the breakdown voltage of the SGD is 550V, more than twice that of the SD. In order to verify the breakdown voltage at the guard-ring, isolated p-n diodes were fabricated on the same wafer. The breakdown voltage of the p-n diode is about 600V, which is slightly larger than that of the SGD. The ideal breakdown voltage for the epi-layer was calculated to be 770V, assuming that the critical electric field is 2.2×10^6V/cm. The slight deterioration of the breakdown voltage from the p-n diode is believed to be caused by the large impact ionization rate created by the large leakage current in Fig. 3.

Figure 3 shows a guard-ring structure that does not increase the leakage current compared to SGD and SD devices. This is understood because a p-n junction has a lower leakage current than an SD device. These results show that the edge treatment is important to obtain an ideal breakdown voltage for SBD's in SiC, and the guard-ring structure effectively improves the breakdown voltage to be as high as that of a p-n junction.

4. Conclusion

Fuji Electric has proposed a guard-ring structure for edge termination of SiC Schottky barrier diodes, and has verified the effectiveness of guard-rings by fabricating devices. A Schottky barrier diode with a guard-ring formed by local oxidation, has achieved a breakdown voltage of about 550V, approximately twice that of an unterminated Schottky barrier diode.

References

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