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Leakage Current Suppression Using Passivation of Defect by Anodic Oxidation for 4H-SiC Schottky Contacts

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1. Introduction

A 4H-SiC Schottky barrier diode is a useful device for power electronic systems, because of their fast recovery from turn-on to turn-off, high blocking voltage and low on-resistance [1]. Current capacities of commercial diodes are still less than 50 A, and such capacities are not enough for very high power electronic systems. Therefore, increase of the current capacity is required for widespread utilization of 4H-SiC Schottky barrier diodes. Because crystalline defects and surface roughness associated with the defects on a surface degrade characteristics of the Schottky barrier [2-5], it is necessary to reduce crystalline defects on the surface. However, it is difficult to completely eliminate the crystalline defects by just improving the crystal growth technique. Therefore, a technique to suppress the negative influence of the crystalline defects is required.

It is known that the anodic oxidation can form insulating oxide films on Si and SiC [6,7], and, in many cases, there is a barrier at the interface between the semiconductor and the solution for the anodic oxidation. For n-type semiconductors, the anodic current corresponds to the leakage current of the barrier at the interface with the solution, and thus the current will be enhanced by presence of crystalline defects [7]. Therefore, by application of anodic oxidation, oxide films will be selectively formed on the regions with crystalline defects causing leakage current, and the oxide films with high electrical resistivity will cover crystalline defects. We consider that when Schottky contacts are formed on the anodic oxidized n-type 4H-SiC surface, the oxide films suppress the leakage current due to crystalline defects under the Schottky contacts [8]. We refer to this leakage current suppression technique as passivation of defects by anodic oxidation (PDA). So far, we have reported leakage current suppression by PDA for Schottky contacts on n-type 4H-SiC [8]. However, increase of series resistance in a forward conduction is also expected after PDA. Therefore, in this paper, we report on both the leakage current and the series resistance before and after PDA for n-type 4H-SiC Schottky contacts.

2. Experiments

Samples employed in this study were cut from an epitaxial 4H-SiC wafer, and the epitaxial layer was grown on (0001) Si face 4H-SiC substrates with 8° off toward <11$\bar{2}$0>. The donor concentration of the epitaxial layer was 2×10^{16} cm^{-3}, and this concentration is an order of magnitude larger than that in the previous experiment [8]. Ohmic contacts were fabricated to the substrate-side by Al evaporation. Ni contacts with a diameter of 1 mm were evaporated on the surface as Schottky contacts. The number of Ni contacts was 49 on each sample, and we measured current-voltage (*I-V*) characteristics of these contacts. After that, Ni Schottky contacts were removed by using HF, and then the anodic oxidation, i.e. PDA, was carried out on the samples. In PDA, the SiC surface was immersed in 100 mM $Zn(NO_3)_2$ aqueous solutions and oxidized by an anodic voltage of 5 V vs. SCE, which is the same condition as that in the previous experiment [8]. After PDA, Ni Schottky contacts were evaporated again at the same positions as those before PDA and *I-V* characteristics for the contacts were measured.

3. Results and discussion

Figure 1 shows the histogram of leakage current densities for Ni contacts on a sample before and after 5 min PDA at reverse bias of 20 V. There were many contacts with leakage current density larger than 10^{-4} A/cm^2 before PDA. After application of 5 min PDA, leakage current densities for any contacts on this sample were lower than 10^{-4} A/cm^2. The averages of leakage current densities for all the contacts before and after 5 min PDA are 2.44×10^{-3} A/cm^2 and 4.48×10^{-3} A/cm^2, respectively. Therefore, 5 min PDA reduced the leakage current density of Ni Schotky contacts.

We also estimated series resistance of the contacts from forward current by the following equation [9],

$$\frac{d(V)}{d(\ln J)} = RA_{eff}\,J + \frac{nkT}{q}, \qquad (1)$$

where J is the forward current density, R the series resistance, A_{eff} the effective area of the diode, n the ideality factor of the Schottky contact, and k the Boltzmann constant. The histogram of the estimated series resistances is shown in Fig. 2. Series resistances for any contacts before PDA were lower than 40 Ω, while, after 5 min PDA, most of contacts show the resistance larger than 40 Ω. The average series resistances are 22.8 Ω and 71.7 Ω before and after 5 min PDA, respectively. Therefore, 5 min PDA can decrease the leakage current but increases the series resistance.

Then we applied 30 s PDA for another sample to prevent increase of series resistance. For the contacts on the sample before and after 30 s PDA, we show the histograms of leakage currents and series resistance in Figs. 3 and 4, respectively. As shown in Fig. 3, number of contacts with leakage current density lower than 10^{-7} A/cm^2 significantly increases, and the average leakage current densities before and after 30 s PDA are 2.23×10^{-3} A/cm^2 and 3.06×10^{-4} A/cm^2, respectively. Thus the leakage current can be suppressed by PDA with period of only 30 s. On the other hand, the average series resistances are 15.4 Ω and 14.2 Ω before and after 30 s PDA, respectively, and as shown in Fig. 4, change in the histogram of series resistances by 30 s PDA is almost negligible. These results suggest that 30 s PDA suppresses the leakage current with minor series resistance increase.

4. Conclusions

In this study, we applied PDA with two different time periods to Ni Schottky contacts on epitaxial 4H-SiC. We found that PDA can suppress the leakage current without significant series resistance increase if the PDA time period is adjusted.

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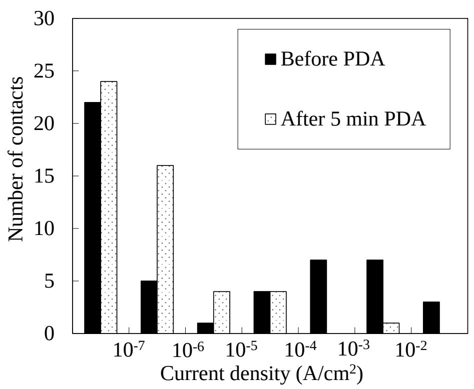

Fig. 1 Histogram of leakage current densities at −20 V for Ni contacts on 4H-SiC before and after 5 min PDA.

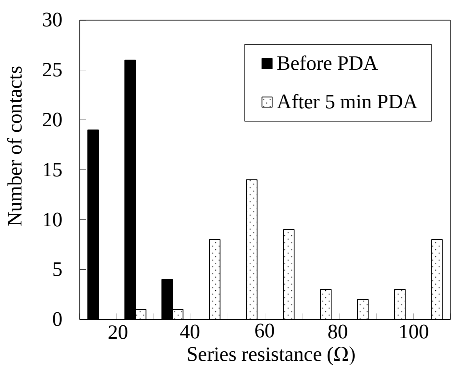

Fig. 2 Histogram of series resistances for Ni contacts on 4H-SiC before and after 5 min PDA.

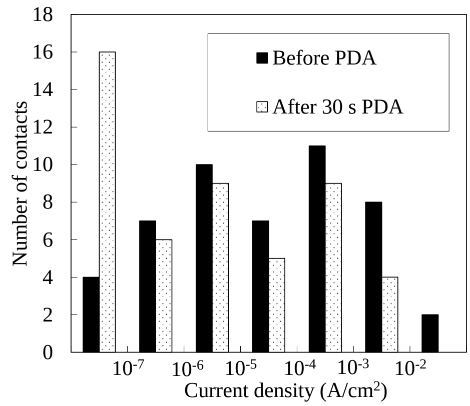

Fig. 3 Histogram of leakage current densities at −20 V for Ni contacts on 4H-SiC before and after 30 s PDA.

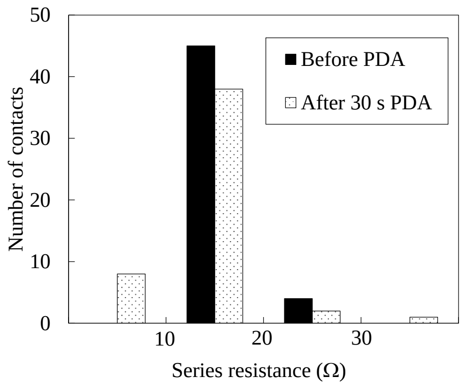

Fig. 4 Histogram of series resistances for Ni contacts on 4H-SiC before and after 30 s PDA.