ANNEALING EFFECTS OF SCHOTTKY CONTACTS ON THE CHARACTERISTICS OF 4H-SIC SCHOTTKY BARRIER DIODES

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ABSTRACT
This paper reports on the relationship between the microstructure and the device performance of Pt/4H-SiC schottky barrier diodes (SBDs). The evolution of microstructure in the metal/SiC interfaces annealed at different temperatures was characterized using X-ray scattering techniques. The reverse characteristics of the devices were degraded with annealing temperatures. The maximum breakdown voltages of as-deposited devices and 850°C annealed devices are 1300 V and 626 V, respectively. However, the forward characteristics of the devices were found out to improve with annealing temperatures. X-ray scattering analysis showed that Pt-silicides were formed by annealing performed at or higher than 650°C. The formation of silicides was shown to increase the roughness of the Pt/SiC interface. It is believed that the forward characteristics of the SBDs be strongly dependent on the crystallity of silicides formed in the Pt/SiC interface during the annealing process.

INTRODUCTION
SiC has been given significant attention as a potential material for high-frequency, high-power, and high-temperature applications due to its unique electrical and thermal properties. These properties include a high electric field at breakdown (2 x 10^6 V/cm), a high electron velocity (2 x 10^7 cm/sec), a large band gap (2.86 eV for 6H and 3.2 eV for 4H), and a high thermal conductivity (4 W/K cm) [1]. In particular, the extremely high critical electric field of SiC makes it a prime candidate for high-voltage applications, such as high-power rectifiers. Rectifiers utilize SBDs to suppress high-voltage transients induced on the power line during current switching [2]. For a negligible dissipation of power during the switching, the reverse current transient of the SBD must be suppressed, maintaining a high reverse voltage without breakdown. There have been a lot of reports on the design and the fabrication of a SiC SBD to achieve its theoretical breakdown voltage [3]. However, there are only a few reports found on the relationship between
the microstructure and the device performance of 4H-SiC SBDs. In this study, we attempted to establish the relationship between the current-voltage characteristics of Pt/4H-SiC SBDs and the microstructure of the Pt/4H-SiC interface annealed at various temperatures. It was found out that the annealing conditions for the schottky contact have a significant impact on the device performance. The evolution of microstructure in the Pt/4H-SiC interface was characterized using X-ray scattering techniques.

EXPERIMENT

Single crystal 4H-SiC wafer with a nitrogen doped (N_D ~ 1.2 x 10^{19}/cm^3) epi-layer with 10 μm thickness was used to fabricate the SBDs. The substrates were cleaned according to the standard chemical cleaning procedure. The processing details for the fabrication of 4H-SiC SBDs are found elsewhere [ Baliga ] except that Al shadow mask was employed as the shadow mask for the Boron implantation [4]. Pt schottky contact ( t=3000 Å ) was deposited by the sputtering method through a metal shadow mask in a vacuum (~1x10^4 torr). The implant dose and energy were 1.0×10^{15} cm^{-2} and 30 keV, respectively. Ohmic contacts were formed by evaporation of Ni ( t=3000 Å ) in a vacuum( 7~9×10^6 torr ) for the backside blanket. The ohmic contact was annealed at around 1050 °C for 30 min in Ar ambient to remove the implant damage. To investigate the annealing effects on the device performance, the devices were annealed at various temperature ( RT, 500 °C, 650 °C, 750 °C, and 800 °C ) right after the formation of schottky contact. The microstructure of the Pt/SiC interfaces was characterized using X-ray scattering techniques. The I-V characteristics of device were measured using a Sony tektronix 370 programmable curve tracer.

RESULTS AND DISCUSSIONS

The structure of the fabricated device and its typical current-voltage characteristics are shown in Figure 1. The maximum blocking voltage obtained through this study was 1300 V ( for samples with as-deposited schottky contact ).

Figure 1. Schematic device structure of 4H-SiC SBD and its typical I-V characteristics showing the maximum breakdown voltage of 1300 V (device with as-deposited schottky contact)
Figures 2 (a) and (b) show the variation of forward and reverse bias I-V characteristics of Pt/SiC schottky barrier diodes annealed at different temperatures. It is shown that the forward current density of diodes is enhanced with the annealing temperature. The current density of devices annealed at 850 °C is as high as 420 mA/cm² at 5 V. The current density of devices with the as-deposited schottky contact is about 140 times lower than the value for the samples that were annealed at 850 °C. Apart from the forward characteristics, the breakdown voltage of devices is found out to decrease with the annealing temperature. The ideality factor of the samples annealed were shown to vary in a range 1.2 (850 °C) to 4.5 (as-deposited). The barrier heights are expected to be higher for samples annealed at lower temperature. The degradation of breakdown voltage of devices annealed at high temperature can be explained by the calculated specific-on resistance. Figure 3 compares the specific-on resistance (R_on) of as-deposited samples and of samples annealed at 850 °C. The distribution of specific-on resistance of as-deposited samples is shown to be about 1 order higher than that of annealed samples. It is known that the breakdown voltage is reversely proportional to R_on [5].

The electrical characteristics of devices are examined in view of the microstructure of the interface between schottky contact and 4H-SiC. Figure 4 shows the intensity of reflected X-ray
from the surface and interface of Pt/4H-SiC layers annealed at different temperatures.

Figure 3. Breakdown dependence of specific-on resistance; (a) as-deposited and (b) annealed at 850 °C.

It is evident that the roughness of the interface is suddenly increased for the samples annealed at temperatures higher than 650 °C. The higher reflectivity for the samples annealed at 500 °C compared to the as-deposited samples can be attributed to the improvement of crystallinity of Pt. From X-ray scattering analysis it was shown that Pt silicides form at temperatures higher than 650 °C, while the crystallinity of Pt itself is improved with temperature below 650 °C.

Figure 4. Intensity of reflected X-ray from the surface and interface of Pt/4H-SiC layers annealed at different temperatures.
Figure 5. Rocking curves of (a) Pt (111) diffraction when the Pt/4H-SiC layer are annealed at different temperatures (as-deposited, 500 °C annealed, and 650 °C annealed) and (b) Pt$_2$Si annealed at 750 °C and 850 °C.

Figure 5 (a) compares the rocking curves of Pt (111) diffraction when the Pt/4H-SiC layer are annealed at different temperatures (as-deposited, 500 °C annealed, and 650 °C annealed). Fig. 5 (b) shows the rocking curves for Pt$_2$Si. Long-scan X-ray diffraction exhibited that there is no Pt phase left after annealing the sample at 850 °C [6]. It is concluded that the higher current density of samples annealed at higher temperature stem from the better crystallinity of Pt (below 650 °C) and Pt$_2$Si (above 650 °C). It is worthwhile noting that the formation of silicides results in the increase of roughness of Pt/4H-SiC interface [7]. This can be easily understood by comparing Figure 4 and Figure 5. The forward and reverse characteristics in Pt/4H-SiC SBDs are found to be dominated by the interface state which are controlled by the thermal annealing.

CONCLUSIONS

Electrical characteristics of Pt/4H-SiC SBDs were interpreted in light of the evolution of microstructure of the Pt/4H-SiC interface by using X-ray scattering techniques. Devices with the as-deposited Pt schottky contact exhibited the maximum breakdown voltage of 1300 V. The reverse characteristics of the devices were degraded with annealing temperatures. It was shown
that the forward characteristics of the devices improve with annealing temperatures. X-ray scattering analysis showed that Pt-silicides were formed by annealing at or higher than 650 °C. The formation of silicides was shown to increase the roughness of the Pt/SiC interface. The forward and reverse characteristics in Pt/4H-SiC SBDs are found to be dominated by the interface state which are controlled by the thermal annealing.

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