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Effect of N bonding structure in AlON on leakage current of 4H-SiC MOS capacitor

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Abstract

We have investigated the effect of the N content in ALD-grown AlON on electrical properties of AlON/SiO_2/4H-SiC MOS structures. The density of positive and negative charged defects in AlON decreases with increasing the N content. In addition, we found that increasing the leakage current with the N content at a high voltage region is related to the amount of Al-N bond. Thus, we concluded that it is impotent to form Al-ON bonds in AlON layer with suppressing the formation of Al-N and Al-NO_2 bonds.

1. Introduction

4H-silicon carbide (SiC) is a wide bandgap semiconductor whose properties are well-suited for high-power MOSFETs. Aluminum oxide (Al_2O_3) is one of the promising candidates for a gate insulator of SiC MOSFET alternative to SiO_2. This is because Al_2O_3 has a large dielectric constant (ε~10), a large energy bandgap, a good thermal stability, and large conduction and valence band offsets for 4H-SiC [1]. In addition, a high channel mobility (311 cm^2/Vs) in Al_2O_3/SiC-MOSFET was reported [2]. However, there is a concern that an Al_2O_3 layer includes a high density of negative fixed charges [3].

Nitrogen (N) incorporation into Al_2O_3 layer can dramatically decrease the negative fixed charge density in the layer [3]. On the other hand, it was reported that the leakage current of polycrystalline AlN insulator layer is higher than that of Al_2O_3 [4-5]. Thus, we have a concern of increasing leakage current by raising the N content in N-incorporated Al_2O_3 layer. However, the effect of the N content on the chemical bonding state and the current conduction property in AlON layer has not been understood in detail yet. In this study, we investigated the relationship between the N content and the electrical properties of AlON/SiO_2/4H-SiC MOS capacitor.

2. Sample preparation

A 10 nm-thick gate SiO_2 layer was formed using low pressure chemical vapor deposition on an n-type Si-face 4H-SiC(0001) epitaxial layer with a N concentration of 7–9×10^{15} cm^{-3}. After the formation of a gate SiO_2 layer, annealing was performed in NO gas. A 130 nm-thick AlON layer was deposited on the SiO_2 layer using atomic layer deposition (ALD) method with which AlN and Al_2O_3 layers were alternatively deposited. Combinations of precursors for ALD of AlN and Al_2O_3 were trimethyl-aluminium (TMA)+N_2 plasma and TMA+O_2 plasma, respectively. The N content in AlON was controlled by the cycle number of an AlN layer. The designed N contents in AlON layer were 11%, 37%, and 41%. The post deposition annealing was performed for mixing stack structure in order to form a uniform AlON layer.

3. Results and discussion

Figure 1 shows current-voltage (*I-V*) characteristics in AlON MOS capacitors with various N contents and the control SiO_2 MOS capacitor. The leakage current of the control SiO_2 sample monotonically increases above 40 V. In contrast, we can distinguish some parts of different leakage characteristics in *I-V* curves of AlON samples. The current at a low voltage region below 40 V decreases with increasing the N content. On the other hand, at a high voltage region around 70 V, the current increases with the N content.

In order to investigate the conduction mechanisms of leakage current, the repeated *I-V* measurement was performed as shown in Figs. 2(a)-2(c). In the 11%-N content case, the current at a low voltage region around 10 V increases with the repeat number of the measurement (the 1st sweep: 0–20 V to the 3rd sweep: 0–40 V) as shown in Fig. 2(a). In contrast, after applying a voltage over 30 V, the current decreases with increasing the number of repeats (the 3rd sweep: 0–40 V to the 8th sweep: 0–50 V). It means that there are two types of leakage mechanism. Considering that an electric field in the 10 nm-thick SiO_2 layer was estimated to be 0.48 MV/cm at 10 V in this structure, we suggest that the direct tunneling and the Fowler-Nordheim (F-N) current are not dominant in this measurement condition. Thus, increasing the leakage current at a low voltage region with the number of repeats is attributed to the injection of positive charges into the AlON layer from electrode. As a result, the electric field in SiO_2 is enhanced by the injected positive charges, which causes

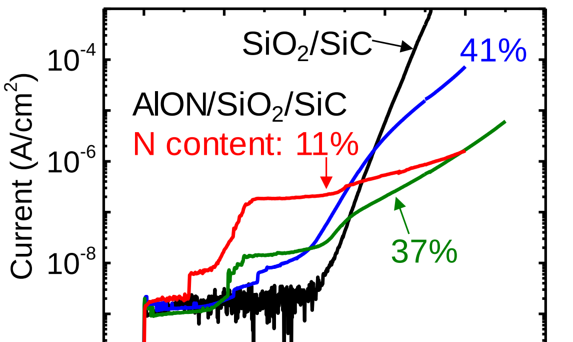

Fig. 1 *I-V* characteristics of AlON/SiO_2/4H-SiC capacitors with different N contents and the SiO_2/4H-SiC MOS capacitor.

increasing the leakage current. In contrast, decreasing the current with the number of repeats at a high voltage region suggests the injection of negative charges into the insulator layer from SiC.

In the 37%-N content case, the current increases at a voltage over 40 V in the 4th sweep (0–50 V) and the rising edge of the current sifts with increasing the number of repeats from the 4th to 6th sweeps. The *I-V* characteristics show two kinds of conduction mechanism. From F-N and Poole-Frenkel (P-F) plots, the conduction mechanism around 40 V can be attributed to the F-N current in SiO_2, and then that around 60 V is the P-F emission current in AlON. The shift of the rising edge of the current with the number of repeats can be related to the injection of negative charges into the insulator from SiC.

In the 41%-N content case, the *I-V* characteristic shows monotonically increasing in contrast to lower-N-content samples. Furthermore, the current characteristics show no dependence on the number of repeats. This result means that applying the voltage hardly causes charging in AlON in this sample, suggesting that the density of charge trapping sites in AlON decreases with increasing the N content.

Figure 3(a) shows the N1s core level spectra measured by X-ray photoelectron spectra (XPS) and those can be deconvoluted to 4 components labeled to N_{p1} to N_{p4}. N_{p1}, N_{p3}, and N_{p4} are identified to chemical bonding states of Al-NO_2, Al-NO, and Al-N, respectively, referring the previous report [6]. Figure 3(b) shows the designed N content dependence of the compositions of chemical bonding components of N. The intensities of Al-N and Al-NO bonds increase with the N content. As a result, we suggest that these bonds reduce the density of charge trapping sites in AlON layer. In addition, in the 41%-N content case, the intensity of the Al-N bond dramatically increases compared with that of 37%, while the Al-NO_2 peak intensity decreases and the Np_2 peak cannot be observed in the 41%-N content sample. It is considered that Al-NO_2 and N_{p2} bonding states make trap sites in the AlON layer, and the large leakage current at a high voltage is caused by increasing Al-N bonds in the layer. Thus, we concluded that it is impotent to form Al-ON bonds in AlON layer with suppressing the formation of Al-N and Al-NO_2 bonds.

4. Conclusions

We investigated the effect of the N content in AlON layer on the electrical properties of AlON/SiO_2/4H-SiC MOS capacitor. Positive and negative charges are injected into the AlON layer from metal and SiC, respectively, during the operation. The current conduction mechanism is the F-N current in SiO_2 and the P-F current in AlON. The trap density in the AlON layer decreases with increasing the N content. It is considered that charge trap site would be made by Al-NO_2 bond and Al-N bonds increase the leakage current at a high voltage region. Thus, the control of the chemical bonding states of N is essential to suppress the leakage current in AlON/SiC MOS structure.

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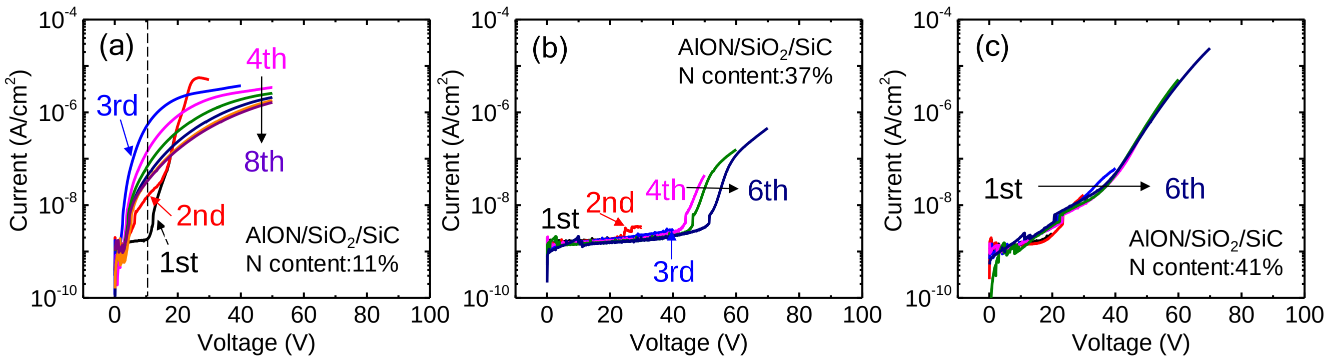

Fig. 2 Repeated I-V measurement for AlON/SiO_2/SiC samples with N contents of (a) 11%, (b) 33%, and (c) 41%.

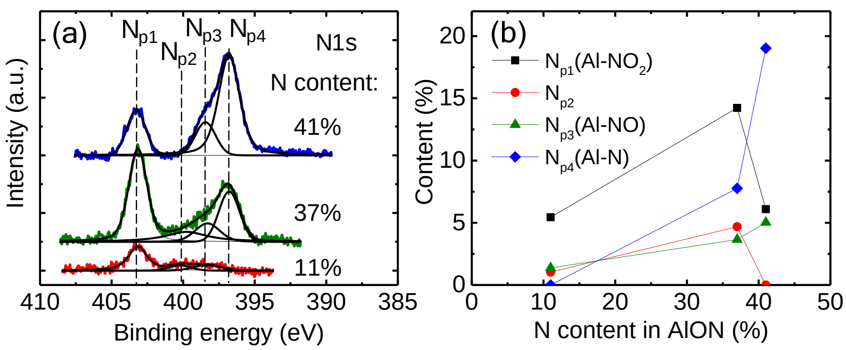

Fig. 3 (a) XPS spectra of N1s in AlON/SiC samples with various N contents. (b) The designed N content dependence of the composition of chemical bonding components of N in AlON layers.