Impact of Oxygen Radical Treatment on Improvement of Al₂O₃/SiC Interface

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Abstract

Oxygen radical treatment on a deposited-Al₂O₃ gate insulator on 4H-SiC has been examined in order to improve the interface properties. We have investigated the relationship between the interface state density (D_{it}) and chemical bonding states in detail. We achieved the reduction of D_{it} by 5.6×10¹¹ cm⁻²eV⁻¹ at around E_C -0.4 eV with an oxygen radical treatment at room temperature.

1. Introduction

The wide-bandgap semiconductor 4H-SiC is an attractive material for high-power metal-oxide-semiconductor field effect transistors (MOSFETs) [1]. However, there is a problem of a high channel resistance due to its poor electron channel mobility. The major reasons of channel mobility limitation are trapping of channel electrons and Coulomb scattering with trapped charge due to a high interface state density (D_{it}) of gate insulator/SiC interface [2].

Previously, thermal oxidation processes for gate insulator formation of SiO_2 thin film have been well reported [3]. However, D_{it} at SiO₂/SiC interface is generally a quite high value of 10^{12} ~ 10^{13} cm⁻²eV⁻¹ due to the formation of C clusters [4]. To avoid the formation of C clusters with thermal oxidation of SiC, we focused on deposition method. An Al₂O₃ film is often prepared using atomic layer deposition (ALD) method. ALD-Al₂O₃ gate insulator is one of the promising alternatives to SiO₂ for SiC MOS structure, which has a large dielectric constant, a large energy bandgap, and large conduction and valence band offsets for 4H-SiC [5]. In addition, the post-deposition oxygen radical treatment at a low temperature for ALD Al₂O₃ film promises further reduction of D_{it} by terminating the dangling bonds on SiC surface. In this study, we investigated the effect of oxygen radical process on Al₂O₃/SiC interface for improving the interface properties.

2. Sample preparation

N-type 4H-SiC(0001) wafer with a 10 μ m-thick SiC epitaxial layer with a N concentration of 8.2×10^{15} cm⁻³ was used as a substrate. After chemical cleaning with standard RCA method, a 15 nm-thick Al₂O₃ layer was formed on SiC substrate using ALD with precursors of tri-methyl-aluminum and H₂O. The substrate temperature during ALD was 350 °C. After the formation of Al₂O₃ film, oxygen radical treatment was performed at room temperature. The oxygen radicals were generated using radical source with inductivity coupled plasma at a RF power of 400 W. The pressure of O_2 gas was 4.5×10^{-2} Pa. The oxidation time was ranging from 0 to 5 min. Then, Al gate electrodes were deposited on the Al₂O₃ film with vacuum evaporation method to form MOS capacitors.

3. Results and discussion

Figure 1 shows the *C-V* characteristics of as-deposited and radical-processed samples at 300 K. The larger frequency dispersion in the depletion regions is observed in the *C-V* characteristics of the as-deposited sample than that of radical-processed one. This result suggests that the D_{it} can be reduced with oxygen radical treatment.

The D_{it} was estimated with both of the high (1) MHz)-low (1 kHz) frequency method and conductance method [6]. In the conductance method, G-V measurement was carried out at 50 and 300 K, and the D_{it} was estimated based on the surface potential fluctuation model. Figure 2 shows the D_{it} distribution estimated for as-deposited and radical-processed samples. Both 1 and 5 min-radical-processed samples have a lower D_{it} under 10^{12} cm⁻²eV⁻¹ than that of the as-deposited sample, at around $E_{\rm C}$ -0.4 eV. This result indicates that $D_{\rm it}$ is effectively reduced with the oxygen radical treatment. On the other hand, in the case of the energy region from $E_{\rm C}$ -0.1 eV to the conduction band edge, there is an obvious oxidation time dependence of D_{it} value. From these results, we consider a possibility that the origin of defect states would be different between the energy regions of around $E_{\rm C}$ -0.4 eV and near the conduction band edge.

Figures 3(a) and 3(b) show the Alls and Sils core-level spectra measured with hard X-ray photoelectron spectros-(HAXPES) for as-deposited and copy 1 min-radical-processed samples, respectively. In the Alls spectra, the main peak at 1563.3 eV can be related to Al_2O_3 . The peak positions of Al-Si and Al-O-Si are expected to be 1560.6 and 1564.6 eV, respectively, from previously reported Al2p spectrum [7, 8]. We can find that the main peak of 1 min-radical-processed sample broadens to a lower energy side. This result suggests the formation of Al-Si bonds and/or the reduction of Al₂O₃ by radical oxidation. In the Sils spectra, we can also observe that the main peak related to SiC substrate broadens to a lower energy side, towards the expected position of Si-Al bond at 1840.1 eV [8]. Therefore, it is reasonable to conclude that Al-Si bonds were formed by radical oxidation treatment. In addition, the Sils

peak from SiC substrate obviously broadens to a higher energy side. This result also indicates the formation of Si suboxide by radical oxidation.

Here, we discuss the oxygen radical effect on the reduction of D_{it} . From the HAXPES measurement, the formation of Al-Si bonds and Si sub-oxides were observed after the oxygen radical treatment. It is considered that Al and O atoms play a role in the termination of Si dangling bonds on SiC surface. However, the formation of excess Si oxide layer might be counterproductive for the interface because of the excess C creation. Controlling the condition of radical oxidation should be a key to improve the interface properties.

4. Conclusions

We examined oxygen radical treatment to improve the electrical property of Al₂O₃/SiC interface. We revealed the D_{it} distribution and discussed its relationship with chemical property. The D_{it} lower than 10^{12} cm⁻²eV⁻¹ at around E_C -0.4 eV is achieved with the oxygen radical treatment. D_{it} value from E_C -0.1 eV to conduction band was reduced with increasing the time of oxygen radical treatment at room tem-



Fig. 1 *C-V* characteristics of samples before and after oxygen radical treatment for 1 min.



Fig. 2 D_{it} distributions in as-deposited and radical-processed samples. D_{it} was estimated by high-low method (solid symbols) and conductance method (open symbols).

perature. The factor of these improvements is considered to be the formation of Al-Si bonds and Si suboxides to terminate the dangling bonds on SiC-substrate surface.

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Fig. 3 (a) Al1s and (b) Si1s core-level spectra measured with HAXPES for Al_2O_3/SiC structures before and after oxygen radical treatment for 1 min.