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SiC/SiO_2 Structure Formed at ~200° C with Excellent Electrical Characteristics

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1. Introduction

Silicon carbide (SiC) is expected for the application to power devices, high frequency devices, and devices operated under high temperatures. Oxidation of SiC for the fabrication of MOS structure requires high temperatures above 1050 °C [1,2], which is more than 200 °C higher than the Si oxidation temperature. It is suggested that the high temperature heating causes loss of Si atoms, resulting in the formation of graphitic carbon at the SiC/SiO_2 interface [3]. Consequently, the interfacial properties are worse than those for the Si/SiO_2 interfaces, e.g., more than one order magnitude higher interface state density [1,2]. Therefore, it seems important to develop a low temperature oxidation method for the improvement of the electrical characteristics of SiC-based MOS devices.

In the present paper, we have succeeded in the formation of SiC/SiO_2 structure at 200 °C by use of perchloric acid ($HClO_4$). The oxide layers are found to possess a low interface state density of $1x10^{11}$ $cm^{-2}eV^{-1}$.

2. Experiments

MOS structure was formed from a nitrogen-doped n-type SiC epitaxial layer of ~10 μm thickness with the donor density of $6x10^{15}$ cm^{-3} formed on 6H-SiC(0001) wafers. After cleaning the wafers using the RCA method, they were immersed in concentrated (72 %) $HClO_4$ solutions at the boiling temperature of 203 °C. Then, the specimens were heated at temperatures ranging between 900 and 1100 °C in nitrogen, followed by the deposition of aluminum (Al) dots of 0.15 mm diameter.

3. Results and discussion

Figure 1 shows the cross-sectional SEM for the SiC/SiO_2 structure formed by the immersion of SiC in $HClO_4$. It is clearly seen that a SiO_2 layer of 80 nm thickness is formed in spite of the low oxidation temperature of ~200 °C, and it possesses uniform thickness with the smooth interface. In the case of thermal oxidation of SiC, such a thick SiO_2 layer can only be formed at temperatures higher than 1050 °C [4].

Figure 2 shows the thickness of the SiO_2 layers on SiC as a function of the time of immersion in $HClO_4$. The oxide thickness increased linearly with the immersion time, indicating the reaction limited behavior. This result shows that the diffusion of the oxidizing species is not the rate-determining step, unlike usual thermal oxidation [5].

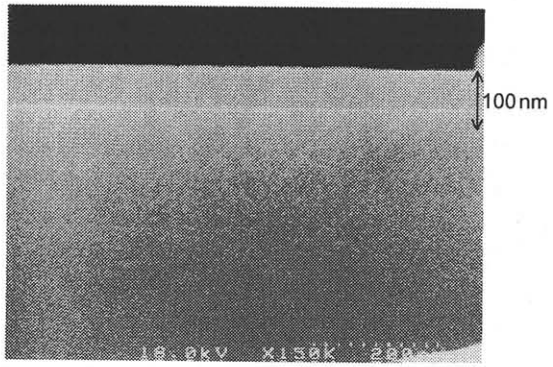

Fig. 1 Cross-sectional SEM for the SiO_2 layer formed on SiC by the immersion in $HClO_4$ at 203 °C.

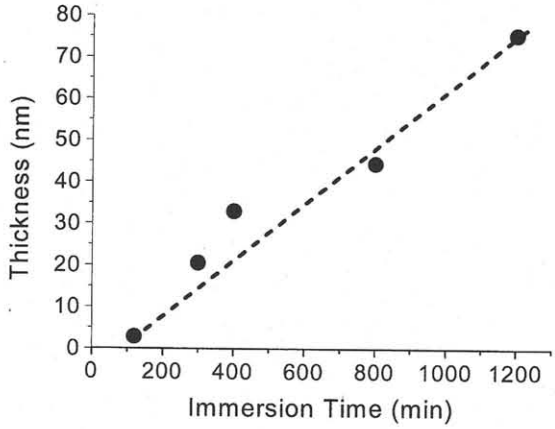

Fig. 2 Thickness of the SiO_2 layers vs. the time of immersion of SiC in $HClO_4$ at 203 °C.

We think that dissociated oxygen ions (O^-) formed by the following reactions are the reacting species:

$$HClO_4 \rightarrow H^+ + ClO_4^-$$

$$ClO_4^- \rightarrow ClO_3 + O^-$$

The decomposition of $HClO_4$ at 203 °C is evident from the change in the color of the solution from transparent to yellowish. The formation of O^- ions is likely because the ions have positive electron affinity of 1.47 eV, in contrast to negative electron affinity of –7.27 eV for O^{2-} ions [6]. The inward migration of O^- ions is likely to be enhanced by an electrical field in the SiO_2 layer induced by ClO_4^- ions adsorbed on the surface. The interfacial reaction proceeds smoothly because of the high reactivity of O^- ions.

Figure 3 shows the current-voltage (I-V) curves for the <Al/SiO_2/6H-SiC(0001)> MOS diodes with the SiO_2 layers formed in $HClO_4$. With no treatment, the leakage current density was high. The post-oxidation heat treatment at 900 °C greatly decreased the leakage current density, and it became less than $1x10^{-8}$ cm^{-2}. It is found from XPS measurements that chlorine (Cl) species with the atomic concentration of 0.2 % is contained in the SiO_2 layers without heat treatment, while no Cl-species is present after the heat treatment. Therefore, it is highly probable that the decrease in the leakage current density results from the desorption of the Cl-species which acts as trap states.

Figure 4 shows the capacitance-voltage (C-V) curves for the <Al/SiO_2/6H-SiC(0001)> MOS diodes with the SiO_2 layers formed in $HClO_4$ in which post-oxidation heat treatment was performed at 950 °C. From the comparison between the high frequency (solid line) and quasi-static (dotted line) C-V curves, the interface state density at 0.5 eV below the conduction band minimum is determined to be $1x10^{11}$ $eV^{-1}cm^{-2}$. This low interface state density is attributable to the low process temperature. In fact, we have observed that the interface state density increases by a factor of three when the post-oxidation heat treatment temperature is increased to 1100 °C. We also observed that the amount of graphitic carbon at the interface is increased by a factor of five by raising the post-oxidation heat treatment temperature to 1100 °C.

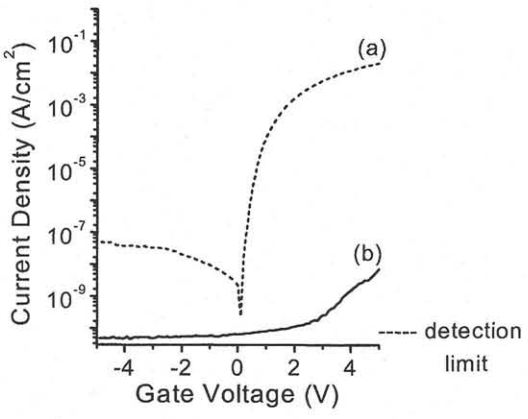

Fig. 3 I-V curves for the <Al/SiO_2/6H-SiC(0001)> MOS diodes with the SiO_2 layer formed in $HClO_4$ at 203 °C: a) with no heat treatment; b) with post-oxidation heat treatment at 900 °C in nitrogen.

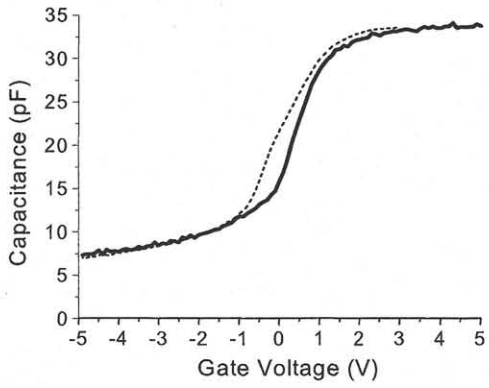

Fig. 4 C-V curves for the <Al/SiO_2/6H-SiC(0001)> MOS diodes with the SiO_2 layer formed in $HClO_4$ at 203 °C in which post-oxidation heat treatment is performed at 950 °C in nitrogen.

4. Conclusions

We have developed a method of fabricating SiC-based MOS structure at the low temperature. The immersion of SiC in $HClO_4$ at ~200 °C forms SiO_2 layers and the thickness increases linearly with the immersion time. The leakage current density for the MOS diodes is high without post-oxidation heat treatment, but it is greatly decreased by the heat treatment at 900 °C. The MOS diodes with the post-oxidation heat treatment possess a low interface state density of $1x10^{11}$ $eV^{-1}cm^{-2}$, which is attributable to the low temperature process, resulting in almost no formation of graphitic carbon at the interface.

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