Preparation and Characterization of Deposited Tetraethylorthosilicate-SiO2/SiC MIS Structure

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Abstract. The SiO_2 layer was deposited on the 4H-SiC Si face by the thermal decomposition of tetraethylorthosilicate(TEOS) in N_2 atmosphere to from MIS diodes. The post deposition annealing was effective to improve the interface properties. The interface state density of the deposited SiO_2/SiC MIS structure was estimated to be the order of 10^{11} $cm^{-2}eV^{-1}$ by Terman method. The direct nitridation of SiC surface prior to the deposition of the SiO_2 layer was effective to reduce the interface state density.

Introduction

The chractristics of SiC MOSFET is still limited by low channel mobility and reliability, though its performance has been optimized by various methods. The formation of SiO_2 layer on SiC by the thermal oxidation is one of the attracting factors of SiC. The high density of interface traps near the conduction band edge is believed to be responsible for low inversion channel mobility in n-channel MOSFETs. Many efforts have been carried out to reduce or to passivate these traps. The post oxidation annealing in NO or N_2O ambient has been the most common method to reduce the density of interface states [1].The deposited insulator is a viable candidate as an alternative gate dielectric material in SiC MISFETs.

We have tried to use nitride layer as the insulating layer of SiC MIS devices[2,3,4]. It has been difficult to get the nitride layer thicker than several nm by direct nitridation method. The direct nitridation layer seemed to be useful for interfacial layer between deposited oxide and SiC to control the interface properties.

In this paper, The SiO_2 layer was deposited on the 4H-SiC Si face by the thermal decomposition of tetraethylorthosilicate(TEOS) in N_2 atmosphere to from MIS diodes. The post deposition annealing was carried out to improve the quality of the SiO_2 layer and the interface properties. The thin nitride layer was formed on SiC by direct nitridation prior to the deposition of the SiO_2 layer..

Experimental

The substrate was the Si face of n-type 4H-SiC (research grade, N_D = $1.2\text{x}10^{17}cm^{-3}$). The sacrificial oxide layer was formed at 1100°C in wet O_2 atmosphere for 1hour and removed by HF to obtain a clean surface. Deposition of SiO_2 layer was carried out by thermal decomposition of TEOS in pure N_2 ambient at 750°C for 10min. After the deposition of SiO_2 layer, the samples were annealed in N_2 atmosphere at 800 - 1200°C for 10min to improve the quality of SiO_2 layer and also the interface properties. The SiO_2 layer was also grown by the conventional oxidation process to prepare a standard sample. The FTIR measurement and the CV measurement were carried out to discuss the effects of the post deposition annealing.

A thin nitride layer was formed on the SiC surface by direct nitridation with pure N_2 at 1400°C for 15min, to be used as an interfacial layer between SiO_2 and SiC. This layer was expected to be effective to improve the interface properties between SiO_2 and SiC. After the direct nitridation, the SiO_2 layer was deposited to form the MIS diode. Before and after the deposition of SiO_2, the sample

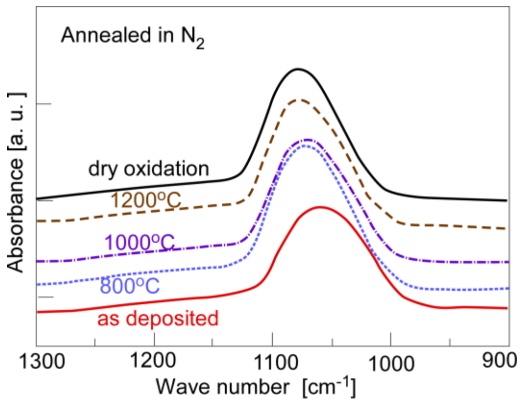

Fig. 1 FTIR spectrum of the samples before and after the annealing

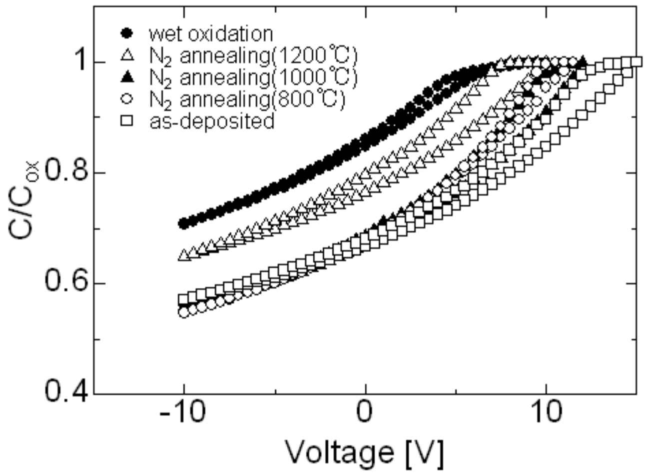

Fig. 2 Capacitance-Voltage curves of SiO_2/SiC MIS strictures after annealing in N_2.

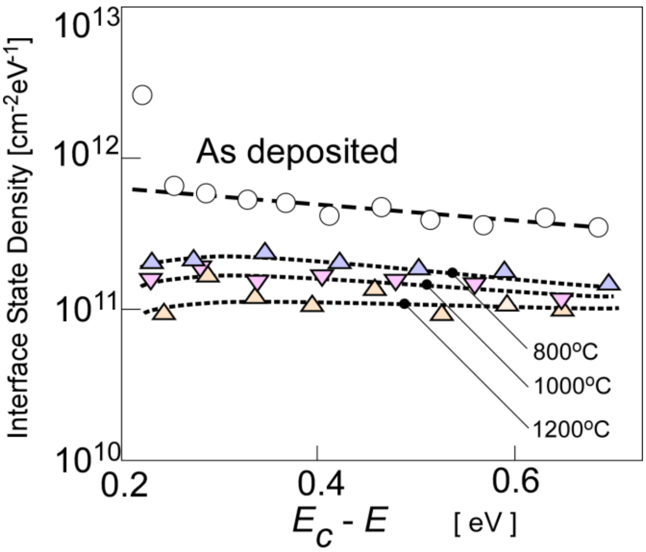

Fig. 3 Interface state densities of deposited SiO_2/SiC MIS strucutres after annealing in N_2..

surface was characterized by XPS. The interface state density of the SiO_2/Nnitride/SiC structure was estimated from CV measurement by Terman method to discuss the effect of the direct nitridation layer. The IV characteristics of MIS Schottky diode was used to estimate the interface state density between the thin nitride layer and the SiC substrate.

Results and Discussions

Post Deposition Annealing. Figure 1 shows the FTIR spectrum near 1050 cm^{-1} around which the absorption of the Si-O bond appears. The samples were annealed in pure N_2 for 30min. The absorption peaks shifted toward that of SiO_2 layer prepared by thermal oxidation, with increasing of the annealing temperature. This indicated that the quality of the deposited SiO_2 improved by the high temperature annealing.

The normalized CV curves of SiO_2/SiC MIS diodes are shown in Fig.2. The thickness of SiO_2 layer was about 50nm. The samples were annealed in N_2. The hysteresis loop of carrier injection type was observed for all samples with deposited SiO_2. The value of the flat band voltage decreased as increasing annealing temperature. The rather small decrease of the MIS capacitance at depression region was resulted from the high donor concentration of the research grade substrate. The annealing in H_2 showed almost the same result.

Figure 3 shows the interface state density estimated from the CV curves in Fig. 2 by Terman method. The curve from depletion to accumulation was used for the estimation of the interface state density. The higher annealing temperature resulted in the lower interface state density. The high temperature annealing was effective also to the improvement of interface quality.

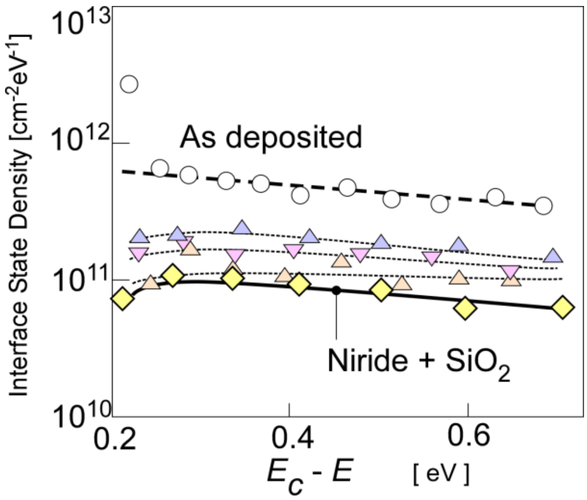

Fig. 4 Interface state density of SiO_2/Nitreide/SiC MIS structre.

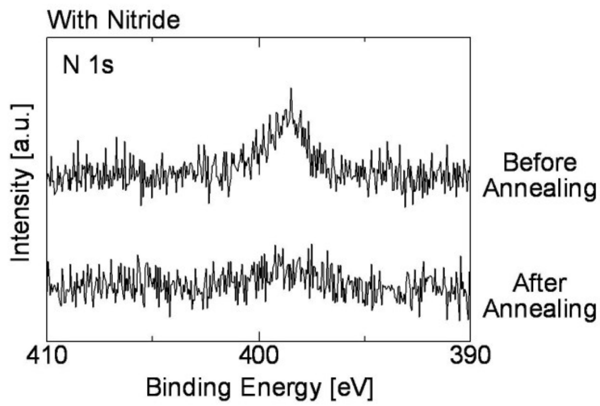

Fig. 5 N1s peaks detected at the nitrided SiC surface before and afer the anealing.in the deposition chamber of SiO_2.

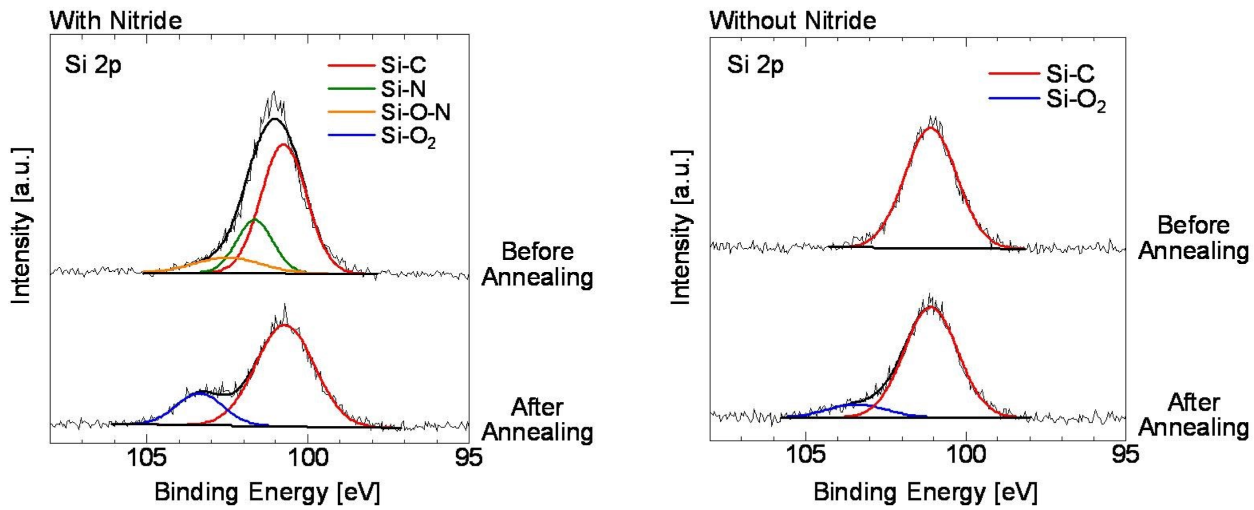

Fig. 6 Si2p peaks detected at the SiC surface with qnd without the diredt nitridation lyer before and after the annealing in the deposition chamber of SiO_2.

Interfacial Nitride Layer. Figure 4 shows the interface state density of the SiO_2/Nitride/SiC structure together with the data shown in Fig. 3. The nitride layer was formed by direct nitridation of the SiC surface in pure N_2 at 1400°C for 15min, just before the deposition of SiO_2. The lowest value of interface state density was obtained for the sample with the direct nitridation layer. The direct nitridation seemed to be effective to reduce the interface state density.

It had been shown in our previous report that the direct nitridation layer was not so stable and disappeared after the deposition of SiO_2[4]. The deposition of SiO_2 was carried out at 750°C and it took about 30 min to obtain the deposition temperature of 750°C after setting the sample in the deposition chamber. The surface of SiC might be oxidized during elevating the temperature in the deposition chamber with the residual O_2. The XPS measurement was carried out on the SiC surface at several process situations to identify the reaction that caused the disappearance of the N atoms on the SiC surface. Figure 5 shows the N1s spectrum from SiC surface just after nitridation and after annealed in the deposition chamber of SiO_2. No spectrum was detected on the SiC surface after annealing in the deposition chamber. This indicated that the nitride layer was lost during the annealing in the deposition chamber.

Figure 6 shows the Si2p spectrum from the SiC surface with and without the direct nitridation layer detected at the same time as the data shown in Fig. 5. The Si-N bonds was detected at the surface of nitrided SiC before annealing, but only Si-O bonds appeared at the surface after annealing. The amount of Si-O bonds at the annealed surface of the nitrided SiC was much more than that of the SiC without nitridation.

Table I Interface state density estimated from the IV curves of MIS Schottky contacts.

Sample	Interface State Density [$cm^{-2}eV^{-1}$]
befor annealing	4.4×10^{12}
after annealing	7.8×10^{11}

The interface state density between the thin insulating layer and SiC was estimated from the current - voltage characteristics of MIS Schottky contact before and after the annealing[3,5], and are listed on Table I. The interface state density decreased after the annealing in the deposition chamber.

Discussion. The high carrier concentration(N_D = $1.2 \times 10^{17} cm^{-3}$) of the research grade substrate resulted in rather small changes in the CV curves as shown in Fig. 2. The high temperature annealing in N_2 atmosphere was effective to improve the interface properties of the deposited SiO_2/SiC MIS structure. The direct nitridation prior to the deposition of SiO_2 was also effective to reduce the interface state density between the deposited SiO_2 and SiC substrate. The nitrided layer seemed to be oxidized more easily than the bare SiC surface during elevating the temperature up to the deposition temperature in the reaction chamber, as shown in Fig. 4. Shirasawa et al reported that stable epitaxial SiON layer was formed on SiC surface by annealing SiC in N_2 atmosphere at 1350°C[6], but they did not reported the high temperature stability of the SiON layer formed on SiC. Results shown in Figs. 5 and 6 and Table I indicated that the oxidation of nitride layer was the dominant process for the reduction of the interface state density.

Summary

The deposited SiO_2 is one of the promising candidates for SiC MIS structure. The post deposition annealing was effective to improve the quality of SiO_2 layer and interface property. The direct nitridation of SiC surface was effective to reduce the interface state density. The nitride layer was easily oxidized during annealing in the deposition chamber of SiO_2. The oxidation of nitride layer seemed to be the dominant process for the reduction of the interface state density.

Acknowledgement

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