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Effect of reactive species on surface structure of SiC irradiated by remote nitrogen plasmas

リモート窒素プラズマが照射されたSiC材料の表面構造に対する活性種の影響評価

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We examined the atomic concentrations and the weight densities of SiC surfaces irradiated by remote nitrogen plasmas. To compare the effects of atomic nitrogen and molecular nitrogen at the metastable $A^3\Sigma_u^+$ state, we irradiated remote nitrogen plasmas at different distances from the sample. The experimental results indicate that $N_2(A^3\Sigma_u^+)$ has higher efficiency than atomic nitrogen for surface nitriding of SiC. In addition, it has been found that Si and C are removed from the surface by the irradiation of the remote nitrogen plasma. The experimental results suggest that the irradiation of atomic nitrogen produces volatile molecules, while nitride species are kept on the surface rather efficiently by the irradiation of $N_2(A^3\Sigma_u^+)$.

1. Introduction

An issue in the development of SiC based power transistors is the effective passivation of the interface between the current channel region and the gate insulation layer. A solution to this issue is the nitriding of the SiC surface. Although thermal nitriding using ammonia has been tried to date, the performance of the passivation is insufficient.

Another method is to use nitrogen plasma. Two types of reactive species are produced in nitrogen plasmas: atomic nitrogen and molecular nitrogen at the metastable $A^3\Sigma_u^+$ state ($N_2(A^3\Sigma_u^+)$). We have compared the efficiencies of the two reactive species in the nitriding of SiC surface, and we have shown that $N_2(A^3\Sigma_u^+)$ has higher efficiency than atomic nitrogen [1]. In this work, we examined the atomic concentration and the weight density of SiC surface irradiated by remote nitrogen plasma.

2. Experiment

We employed a remote nitrogen plasma source. The nitrogen plasma was produced in a slender quartz tube with an inner diameter of 8 mm. Pure nitrogen gas was fed from the top of the quartz tube at a flow rate of 288 ccm, and the gas pressure was adjusted to 0.5 Torr. A 4H-SiC sample was transferred from a load lock chamber to the exit side of the quartz tube. A microwave resonator was attached on the outside of the quartz tube. The resonator was connected to a microwave power supply at 2.45 GHz. The microwave power was 100 W. The microwave resonator was movable in the axial direction of the quartz tube, so that the distance between the active discharge plasma and the SiC sample was changed between 7 and 12 cm. The surface of the SiC sample irradiated by the remote nitrogen plasma was analyzed by Rutherford back scattering spectroscopy (RBS),

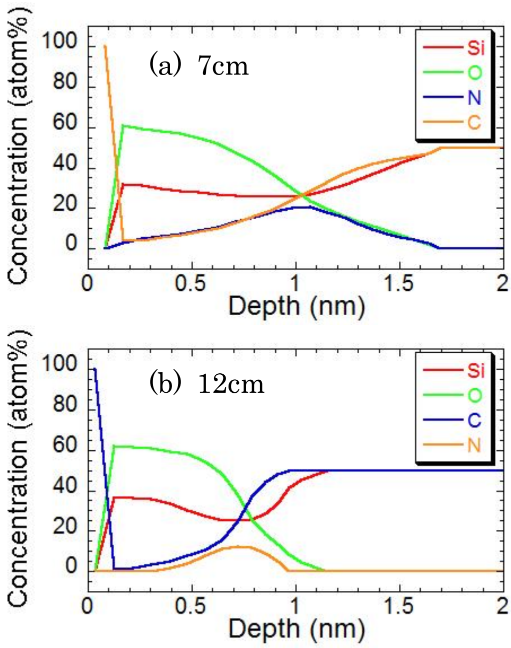

Fig. 1 Depth profiles of the atomic concentrations on the carbon-side surfaces of SiC irradiated by the remote nitrogen plasmas at distances of (a) 7 cm and (b) 12 cm from the samples.

Table I Weight density of SiC surface irradiated by remote nitrogen plasma.

	Weight density (g/cm^3)
Irradiated SiC (7 cm)	2.0
Irradiated SiC (12 cm)	1.8
Virgin SiC	3.2

x-ray photoelectron spectroscopy (XPS), and x-ray reflectivity (XRR).

3. Results

Figure 1 shows the depth profiles of the atomic concentrations, which were obtained by the RBS analysis, at the centers of carbon-side surfaces of SiC samples irradiated by the remote nitrogen plasmas for 3 minutes. The atomic concentrations obtained at two distances between the sample and the microwave resonator are compared. As shown in the figure, the irradiation of the remote nitrogen plasma at a shorter distance resulted in a higher concentration of atomic nitrogen. The same result was obtained by the XPS analysis [1]. In addition, it is known from Fig. 1 that the SiC sample irradiated at a short distance from the microwave resonator had a deeper nitride layer. Another point shown in Fig. 1 is the lower concentrations of Si and C on the nitride layers. The concentrations of C were especially low and were close to zero on the top surfaces of the samples.

Table I shows the weight density of the nitride layer, which was evaluated by the XRR analysis. As shown in the table, the irradiated samples had lower weight densities than virgin SiC. The lower weight density with small concentrations of Si and C suggests the removal of Si and C (especially C) from the surface by the irradiation of the remote nitrogen plasma. In addition, it should be pointed out that the nitride layer irradiated at a longer distance had a lower weight density.

Figure 2 shows the fluxes of atomic nitrogen, $N_2(A^3\Sigma_u^+)$, and ionized molecular nitrogen as a function of the distance between the microwave resonator and the measurement position. The measurement position was the same as that of the SiC sample. The density of atomic nitrogen was measured by vacuum ultraviolet absorption spectroscopy, while the $N_2(A^3\Sigma_u^+)$ density was measured by cavity ringdown absorption spectroscopy [2]. The fluxes were obtained from the densities and the gas temperature. The ion flux was evaluated from the ion saturation current of a Langmuir probe. As shown in Fig. 2, the flux of atomic nitrogen is constant with respect to the distance from the microwave resonator, while the

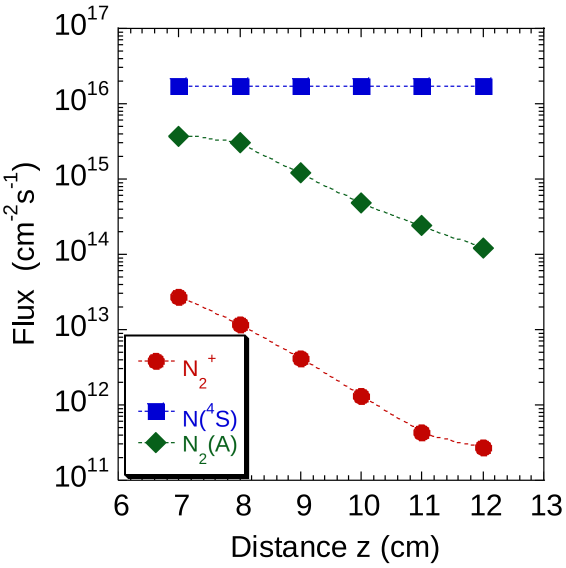

Fig. 2 Fluxes of reactive nitrogen species as a function of the distance from the microwave resonator.

$N_2(A^3\Sigma_u^+)$ flux decreased with the distance steeply.

4. Discussion

Since the flux of atomic nitrogen provided from the plasma was independent of the distance from the microwave resonator as shown in Fig. 2, the efficient nitriding at a shorter distance (Fig. 1) is understood reasonably by supposing that $N_2(A^3\Sigma_u^+)$ has higher efficiency than atomic nitrogen for the nitriding of SiC. This is consistent with our previous report [1].

A new understanding obtained by the RBS and XRR analyses is that the irradiation of the remote nitrogen plasma induces the removal of Si and C, resulting in a lower weight density of the SiC surface. This may be due to the production of volatile molecules such as HCN. An interesting result is the lower weight density of the sample irradiated at a longer distance. This suggests that the irradiation of atomic nitrogen results in the production of volatile molecules, while nitride species would be kept on the surface by the irradiation of $N_2(A^3\Sigma_u^+)$ rather efficiently. Further investigations are necessary for understanding the difference in the surface kinetics of atomic nitrogen and $N_2(A^3\Sigma_u^+)$.

References

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