The Fabrication Of Insulating Layer On 4H-SiC By Hot Wire Nitridation

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Abstract. Nitride layer was formed on SiC surface by the hot wire assisted nitridation. The surface was characterized by XPS to discuss the effects of hot wire assistance. The nitride layer comprised of SiO_xN_y and Si_3N_4, and the interfacial layer was mainly Si_3N_4. Nitrogen concentration in the nitride layer increased with increasing substrate temperature and reaction time.

Keywords: 4H-SiC, hot wire, nitridation, XPS

PACS : 81.07.Bc

INTRODUCTION

With wide bandgap, high thermal conductivity, and high electron saturation velocity, 4H-SiC is a good candidate for high-temperature and radiation-hard applications. Compared with the currently dominant Si-based devices, 4H-SiC devices have the potential to offer higher frequency, more compact systems with reduced cooling demand, and have therefore been actively pursued in power device research [1].

Although, the bulk properties of SiO_2 grown on SiC are similar to those grown on Si, the SiO_2/SiC interface was inferior compared to its Si counterpart [2]. The high density of interface states at as-grown SiO_2/SiC resulted in degrading the channel mobility of n-4H-MOSFETs [3]. These trap states have been believed to be caused by residual carbon clusters, Si dangling bonds and C dangling bonds [4]. Interfacial nitridation has emerged as an efficient method for passivating interface traps and improving 4H-SiC MOSFETs performance .

Many papers reported that nitrogen atoms play a critical role in the passivation of the interface defects on SiO_2/SiC interface. It is expected that a silicon nitride layer might achieve a high quality passivation layer on SiC surface. Previously, we found that the nitride layer could be grown on SiC surface by a plasma nitridation method using mixed gasses of NH_3 and N_2, but it also resulted in the increase of roughness of the interface between nitride layer and SiC substrate. The hot wire assisted method

CP1136, *Nanoscience and Nanotechnology, International Conference on Nanoscience and Nanotechnology, (NANO-Sci-Tech 2008),* edited by M. Rusop and T. Soga

was expected to reduce the damage at the SiC surface as compared to the plasma assisted process. In this paper, we report the formation of nitride layer by hot wire nitridation.

EXPERIMENTAL

The nitride layer were grown on the Si-face of n-type 4H-SiC (Research grade) wafers purchased from Cree, Inc. Prior to nitridation, the native oxide layer of the sample was removed by HF (5%) etching. The nitride layer was formed on SiC surface by the hot wire niridation. The hot wire was made from tungsten (W), and the temperature of wire was 2000℃. The nitride layer was grown on SiC surface at the temperature from 900 to 1500°C in the NH_3 ambient, in order to investigate the dependence of the N ratio on the substrate temperature. The NH_3 gas was diluted to 50% with N_2. The preparation time was changed from 5 to 60 min to discuss the time dependence of the nitrogen concentration. These results were compared with the data of the samples prepared by thermal nitridation, to discuss the effect of hot wire assistance. X-ray photoelectron spectroscopy (XPS) was carried out to investigate the chemical composition and bonds of the insulating layer.

RESULTS AND DISCUSSIONS

Figure 1 shows XPS spectra of SiC surface exposed to the NH_3 for 15 min. at 1500°C with hot wire assistance. The N 1s peak was detected around 398 eV.

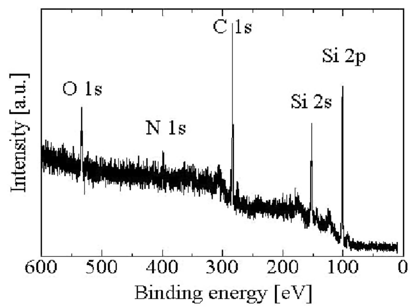

FIGURE 1. XPS spectra of nitridation layer prepared at 1500°C. The measurement was carried out after etching for 3 sec with Ar.

This suggested that nitride layer was formed on the SiC surface. The hot wire assistance seemed to be effective to form the N radicals, which reacted with SiC. However, the O 1s peak was observed on the XPS spectra. This indicated that oxidation also simultaneously proceeded during nitridation. Furthermore, N 1s peak disappeared after 30s etching. This indicated that the nitride layer was very thin.

Figure 2 shows the Si 2p ans N 1s spectra of the sample prepared by hot wire nitridation at 1100°C. Si 2p spectra were fitted with three peaks. The peak located at 100.7 eV was attributed to 4H-SiC and the peak located at 101.4 eV was a signature of the silicon nitride formation [5], while the peak located at 102.5 eV was likely attributed to silicon oxynitride formation [6]. In addition, N 1s spectra were fitted with two peaks. The peak located at 397.8 eV was attributed to Si_3N_4 and the peak located at 399 eV was assigned to SiO_xN_y chemical states, in agreement with the analysis of Si 2p spectra, while Si appeared in two chemical states corresponding to the two states for nitrogen. The peak area of Si-N and Si-ON binding decreased after 10 s etching. Furthermore, the area of Si-N peak was larger than that of Si-ON and it was consistent to the result of the N 1s spectra after 10s etching. This result suggested that mixture of SiO_xN_y and silicon nitride was formed during nitridation, and silicon nitride layer was formed near the 4H-SiC surface.

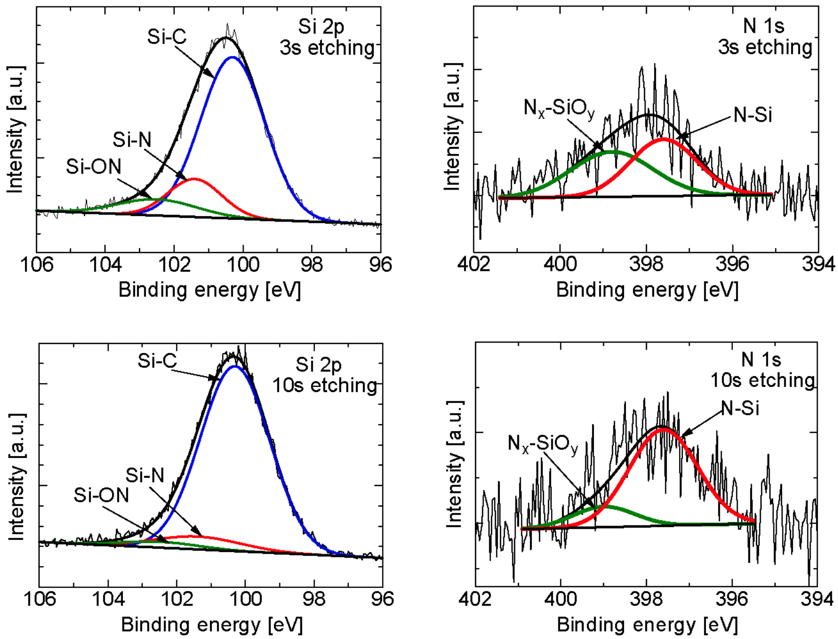

FIGURE 2. Si 2p and N 1s spectra of XPS measurement

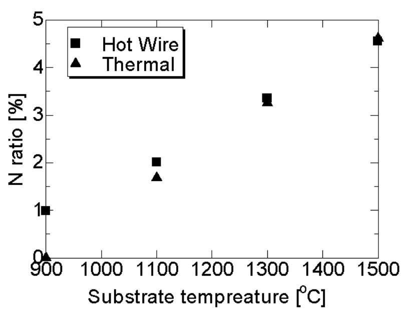

FIGURE 3. N ratio vs. Substrate temperature

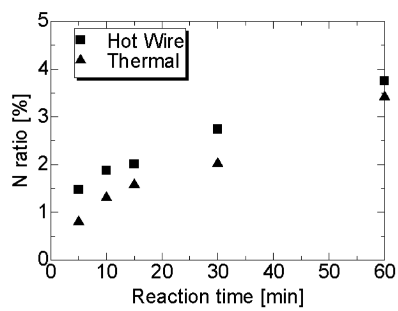

FIGURE 4. N ratio vs. Reaction time

Fig.3. shows the dependence of N ratio in the insulating layer on the substrate temperature. In the cases of both the hot wire nitridation and the thermal nitridation, the N ratio increased with increasing substrate temperature. This suggested the substrate temperature was an important parameter to determine the nitridation rate.

As shown in Fig.3, almost no difference was observed in the N ratio of the sample prepared at 1500°C with hot wire assistance and that of the sample without assistance. This indicated that the effect of hot wire assistance was more significant at lower temperature. It was supposed that there were few N radicals that reacted with SiC surface in thermal nitridation process without hot wire assistance, because the decomposition rate of ammonia was low at low temperature. In the case of hot wire nitridation, N peak was detected even at low temperature as shown in Fig.3. It indicated that NH_3 gas decomposed into N related radicals because of the catalytic effect of the W wire heated at 2000°C. These radicals actively reacted with SiC surface. It also suggested that the temperature became the predominating factor in the nitridation reaction at high substrate temperature. This was the reason why there was small difference between N ratio of the sample prepared by hot wire nitridation and that of the sample by thermal nitridation at 1500°C.

Fig.4. shows the dependence of N ratio on reaction time. It indicated N ratio increased with increasing reaction time. The N ratio of the samlpe prepared by hot wire nitridation was higher than that of thermal nitridation. The reaction rate of hot wire nitridation was higher than that of thermal nitridation. In the case of nitridation of Si surface, the reaction at the Si surface limited the growth rate of thin nitride layer [7]. The thickness of nitride layer on SiC surface was extremely smaller than that on Si surface, so the surface reaction was expected to limit the growth rate in nitridation of SiC surface. The radicals produced by hot wire were effective to activate the reaction at the SiC surface.

CONCLUSION

Nitride layer was fabricated on SiC surface by the hot wire nitridation method. Near the surface, the nitride layer consisted of SiO_xN_y and Si_3N_4. The Si_3N_4 layer with no oxide seemed to be formed near the interface between nitride layer and SiC surface. The hot wire assisted process was expected to be an effective method to produce insulating layer on SiC surface.

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