Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp864-865

Influence of inserting AlN between AlSiON and 4H-SiC interface for the MIS structure on SiC

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1. Introduction

Developing high performance SiC devices requires solutions to serious issues, such as the gate insulator/SiC interface, reduction in the gate leakage current, and realization of normally -off transistors, by introducing a metal-insulator-semiconductor (MIS) structure. Investigation of the wide bandgap insulators with a high dielectric constant and small space charge for MIS structures is required. We have focused on high dielectric constant insulating films (high-k) containing compounds such as AlSiON, AlSiO, and YAlO films with aluminum[(1)(2)]. The relationship between the bandgap and the dielectric constant for various films is shown in Fig. 1. AlSiON film with a wide bandgap is a gate insulating film for wide bandgap semiconductors because it maintains low leakage current even at high temperature[(3)].

Recently it has been reported that the oxide/SiC interface has serious problems—a carbon rich region is generated near the SiO_2/SiC interface during the conventional thermal oxidation of SiC. It is also reported that such carbon rich regions are not laterally homogeneous but nucleated, generating micro-roughness at the SiO_2/SiC interface, as shown in Fig. 2(a)[(4)(5)]. We reported that those carbonated compounds were HF-resistant and remained after the HF etching, as illustrated in Fig. 2(b)[(6)]. It is thought that these carbonated compounds are the source of interfacial states and poor carrier mobility performance of SiC-FET. Therefore, suppression of interface roughness is required.

To improve the interface between the high-k layer and SiC, we proposed inserting an AlN layer as an inter layer, as shown in Fig. 2 (c). The reason for selecting this film is that it has a wide bandgap, as well as almost the same lattice constant as 4H-SiC (Fig. 1). In this paper, we investigated the roughness of the interface between AlN and SiC, and the electrical characteristics of the AlSiON/AlN/SiC MIS structure.

2. Experimental procedure

The buffer AlN layer was deposited on 4H-n type SiC(0001) by metal organic CVD (MOCVD) in a range from 500 to 900°C. Source gases are N_2 and trimethylaluminum, and H_2 serves as a carrier gas. The thermal oxide SiO_x film is deposited by thermal oxidation of SiC at 1100°C.

The roughness of as-grown SiC surface was investigated by AFM. Influence of AlN insertion on SiC and SiO_x/SiC interface was also investigated. The crystal type of the AlN film was measured by XRD. The insulating AlSiON film (40 nm thick) was deposited on AlN/SiC by physical vapor deposition (PVD)[(1)(3)]. The composition ratio of AlN and AlSiON was measured by XPS. The electrical properties of the AlSiON/AlN/SiC MIS structure were evaluated by the capacitance-voltage (C-V) characteristics.

3. Results and discussion

The composition ratios of Al and N in the AlN film are estimated to be 51 and 49%, respectively from the results of XPS. In AlSiON film, the composition of Al, Si, O, and N is 32, 18, 39, and 11%, respectively. AFM images of the surface of as-grown SiC and the SiO_x/SiC interface are shown in Figs. 3 (a) and (b). The average roughness of the surface of as-grown SiC and the interface of SiO_x/SiC are 0.4 and 1.6 nm, respectively. The roughness is increased by thermal oxidation. AlN films on SiC were etched by HF treatment. AFM images of the AlN/SiC interface at 500 and 750°C are shown in Figs. 3 (c) and (d), respectively. The average roughness of the AlN/SiC interface at 500 and 750°C are 0.7 and 0.8 nm, respectively. Increasing the deposition temperature increases the roughness; however, the average roughness of the AlN/SiC interface is less than the SiO_x/SiC interface. Therefore, AlN insertion is a better method for suppressing the roughness than the thermal oxidation method.

Figure 4 shows XRD spectra of AlN films deposited at various temperatures. No peak is observed in AlN film deposited at 500°C, suggesting that it is not a crystal, but an amorphous. In case of AlN films deposited at 600 and 750°C, one peak is observed on AlN (10-10) facet, meaning both the films are in crystal form. Moreover, two peaks are observed in AlN film deposited at 900°C on AlN(10-10) and AlN(0002) facets, indicating that these films are poly-crystals. The full width at half maximum (FWHM) of the AlN (10-10) peak is shown in Fig. 5. Note that the FWHM decreases as the growth temperature increases. Hence, AlN film crystallization is improved by increasing the growth temperature.

The C-V characteristics of AlSiON/AlN/SiC are shown in Figs. 6 (a) and (b). The C-V characteristics are improved by increasing the growth temperature of AlN film. The interface trap density of the MIS structure decreases by increasing the growth temperature from 500 to 750°C. The roughness of the AlN film deposited at 500 and that at 750°C is almost same, whereas the crystalline condition is different, suggesting that AlN film deposited at 750°C has less lattice mismatch near the SiC and, hence, a small number of interfacial dangling bonds are generated. Thus, the crystallization progresses. The interface trap is decreased by reducing the dangling bonds during high temperature growth of AlN film.

4. Conclusion

The insertion of AlN film between SiC and the insulating film effectively reduces the interfacial roughness. The roughness of the interface between AlN and SiC is half that of the thermal oxidation of SiC at 1100°C. The C-V characteristics of the AlSiON/AlN/SiC MIS structure with an AlN buffer layer are improved by increasing the growth temperature of the AlN film. The improvement of the film crystalline results from the reduction of interfacial dangling bonds. This demonstrates that AlSiON/AlN/SiC is an attractive MIS structure for SiC devices.

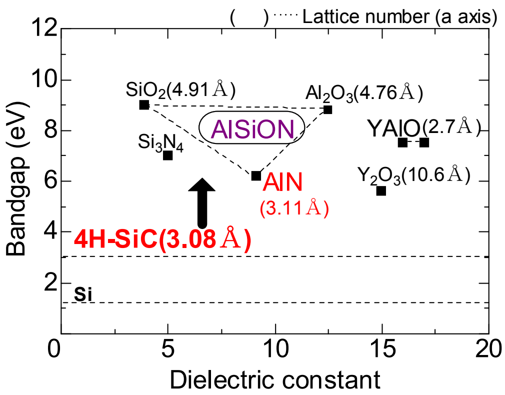


Fig. 1. Bandgap and dielectric constant of various insulating films.

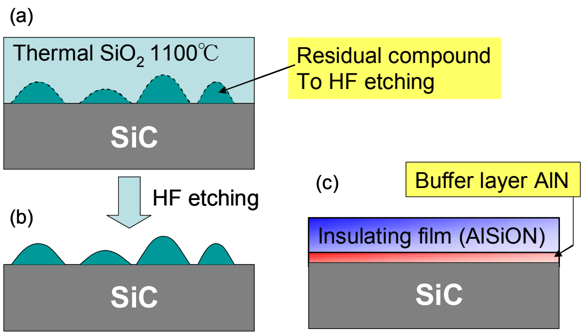
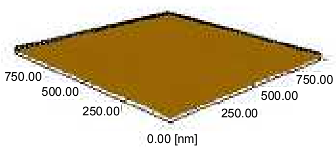
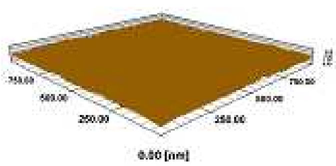


Fig. 2. Surface of thermal oxidized SiC (a) before and (b) after HF etching, and (c) the structure of the inserted AlN.

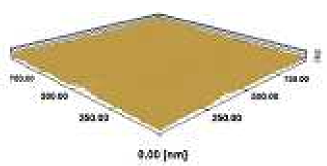


(a) As-grown SiC

(b) Interface of thermal-SiO_x/SiC



(c) Interface of AlN/SiC at 500℃



(d) Interface of AlN/SiC at 750℃

Fig. 3. AFM images of the SiC surface after HF wet treatment.

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Acknowledgments

This study was supported by the JSPS Global COE Program “Center for Electronics Devices Innovation.”

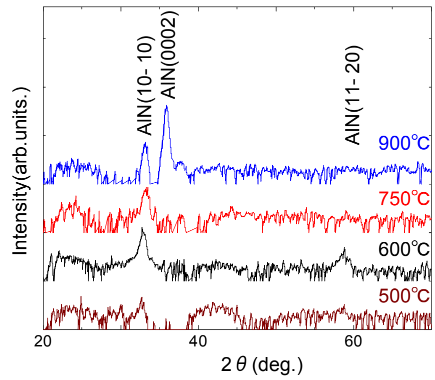

Fig. 4. XRD spectra of AlN films deposited on SiC at various temperatures.

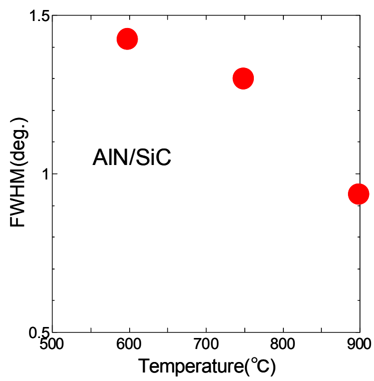

Fig. 5. FWHM of AlN(10-10).

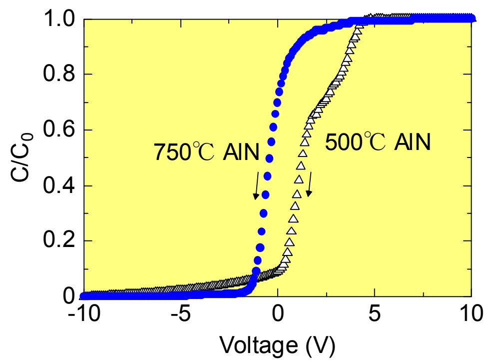

Fig. 6. C-V characteristics of AlSiON/AlN/SiC.