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Improvement of interface properties by NH_3 pretreatment for 4H-SiC(000-1) MOS structure

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1. Introduction

Silicon carbide (SiC) has received considerable attention for its potential use in high-power devices due to its high breakdown voltage with low series resistance, and its high temperature tolerance. SiC is expected to be useful in MOSFET applications. However, the high interface state density between SiO_2 and SiC limits inversion channel mobility to very low values. To reduce the interface state density, several oxidation and anneal methods have been tried, for example nitridation of gate oxide by NO or N_2O gas [1-6] and high temperature H_2 annealing [7]. Nitrogen can be introduced at the MOS interface and it passivates interface defects. By NO or N_2O nitridation, the amount of introduced nitrogen at the MOS interface is reported to be a small percentage [2, 3]. Typical channel mobility of MOSFETs with nitride oxides is 30 - 40 cm^2/Vs [2]. Further improvement at the MOS interface may be possible. To realize this, NH_3 plasma pretreatment was performed to direct nitridation of the SiC surface and introduce a greater amount of nitrogen. The insulating layer is deposited continuously in order to obtain sufficient insulator thickness.

2. Experiments

The n-type 4H-SiC substrates with epilayers of Si and C-face were used. Effective doping density (N_d-N_a) of the epilayers was about 1×10^{16} cm^{-3}. The samples were cleaned using a standard RCA method. At the end of the cleaning, hydrofluoric acid treatment was performed. First, samples were irradiated to NH_3 plasma at 100 Pa of gas pressure and 200 W of RF power for 8 min. A few nanometer SiON layer was grown by NH_3 plasma pretreatment, which was confirmed by XPS. The nitrogen content of this SiON layer was over 10 percent. Then SiON film was deposited on them by plasma enhanced chemical vapor deposition (PECVD). For the SiON deposition, SiH_4, NH_3 and N_2 gases were used at 80 Pa of gas pressure and 40 W of RF power for 3 min. The thickness of SiON was 40nm, which was confirmed by spectroscopic ellipsometry. For comparison, some samples were fabricated by only SiON deposition without NH_3 plasma pretreatment. The sample temperature of the NH_3 treatment and the SiON deposition was 250℃. Then, aluminum was evaporated on the gate insulator as a gate electrode and on the backside of the samples as an ohmic contact. After the evaporation, post-metallization annealing was performed at 400℃ for 30 min in N_2/H_2. Dry thermal oxide samples with a thickness of 50 nm were fabricated to compare the interface properties.

3. Results and discussions

Figure 1 shows C-V curves of MOS capacitors with dry oxides for both Si- and C-faces. The C-V curves were measured from accumulation to depletion region. The solid line shows a high frequency (100 kHz) C-V curve and the dashed line shows a quasistatic C-V curve. The capacitance difference between high and low frequency is small on the Si-face, whereas it is very large on the C-face. This result means that the C-face has inferior interface properties compared to the Si-face. In addition, the C-V curve of the C-face has a hump around 2 V, indicating existence of deep interface states. Figure 2 shows C-V curves of the SiON sample. The capacitance difference is larger on the Si-face and smaller on the C-face compared to those in Fig. 1. This result means that the interface properties of the Si-face are degraded, while those of the C-face are greatly improved. In addition, the hump on the C-face disappears. In the SiON deposition, carbon does not exist in the insulator and no transition layer may exist. However, the positive flat band shifts appear by the SiON deposition. The flat band shift is 7.43 V on the Si-face and 5.91 V on the C-face. The oxide trap charges may appear in the deposition layer. Figure 3 shows the C-V curves of SiON sample with NH_3 plasma pretreatment. The capacitance difference is larger on the Si-face and smaller on the C-face. The flat band shift is 5.26 V on the Si-face and 6.22 V on the C-face. Therefore, the flat band shift is smaller on the Si-face and almost the same on the C-face compared to Fig. 2. This result means that the interface properties are improved on the C-face by NH_3 treatment while the oxide charge traps are almost same. The nitrogen and hydrogen in NH_3 plasma pretreatment are effective in improving interface properties. Elimination of carbon related defects may occur by NH_3 plasma pretreatment. In addition, the termination of dangling bonds by H may occur [7]. Figure 4 indicates Dit calculated by the Hi-Lo method for dry oxide, SiON, and SiON with NH_3 plasma prtreatment on the Si-face. The Dit of dry oxide and SiON are almost the same. However, the interface state density at E_c-E = 0.6 eV is especially increased in the SiON with NH_3 plasma pretreatment. Thus, a degraded effect occurs in the NH_3 plasma pretreatment on the Si-face. Figure 5 shows the Dit calculated by the Hi-Lo method for dry oxide, SiON, and SiON with NH_3 plasma pretreatment on the C-face. The Dit of dry oxide is significantly higher. The Dit of SiON is decreased by one order of magnitude compared to the Dit of dry oxide. The Dit of SiON with NH_3 plasma pretreatment is further decreased to around 1×10^{11} $cm^{-2}eV^{-1}$. In addition, the distribution of Dit in SiON with NH_3 plasma pretreatment is flat in the observed energy range. From the Dit profile, the shallow Dit above E_c-E = 0.2 eV is expected to be small. Thus, the NH_3 plasma pretreatment is effective for the C-face.

4. Conclusions

Effects of NH_3 plasma pretreatment and SiON deposition for 4H-SiC were investigated. The Dit is increased on the Si-face by NH_3 plasma pretreatment, while it is greatly decreased on the C-face compared to dry oxide by NH_3 plasma pretreatment. Thus, the NH_3 plasma pretreatment is effective for the C-face.

References

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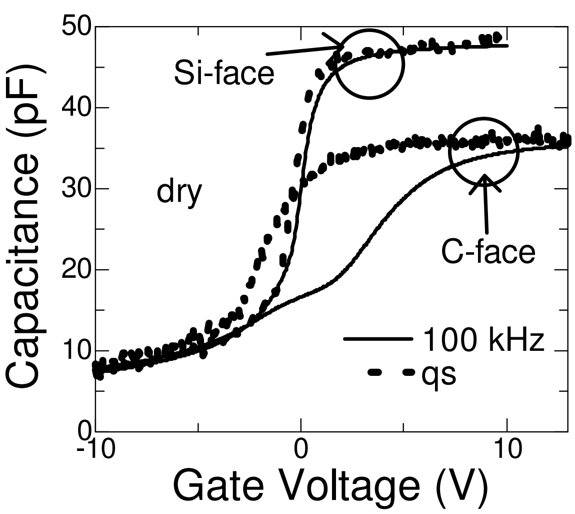

Fig.1 High frequency and quasistatic C-V curves for Si- and C-faces of 4H-SiC with dry oxide.

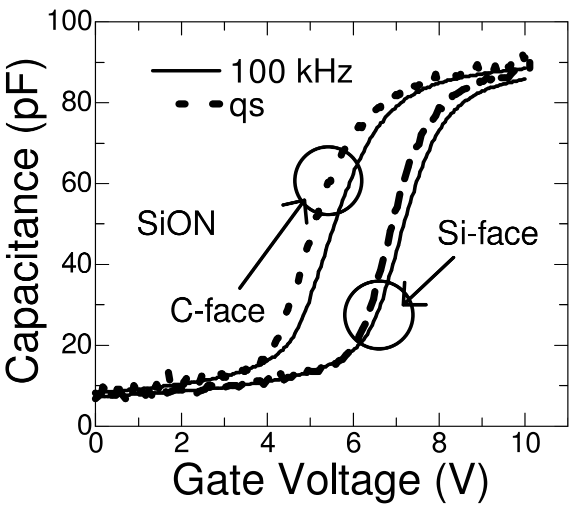

Fig.2 High frequency and quasistatic C-V curves for Si- and C-faces of 4H-SiC with SiON.

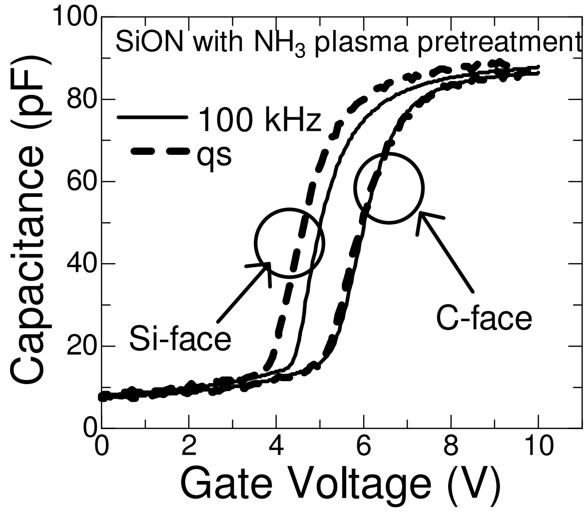

Fig.3 High frequency and quasistatic C-V curves for Si- and C-faces of 4H-SiC with SiON with NH_3 treatment.

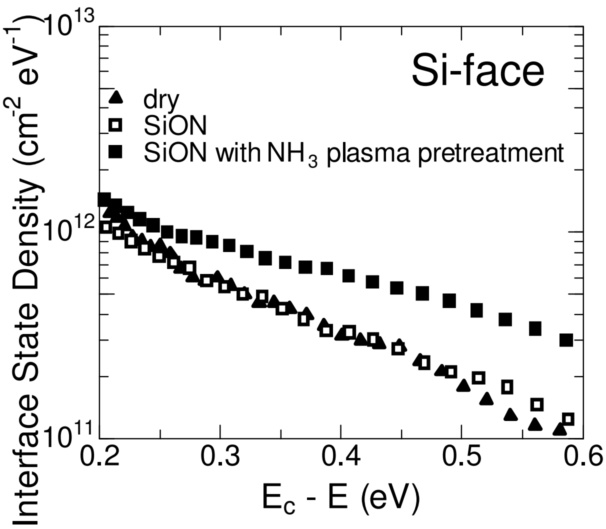

Fig.4 Interface state densities for various insulators on the Si-face.

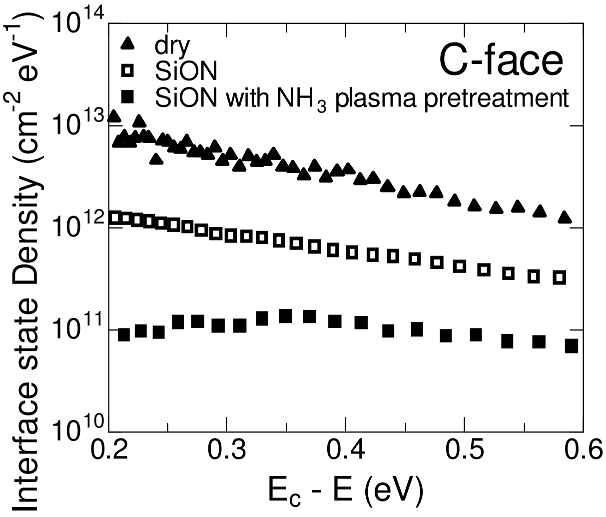

Fig.5 Interface state densities for various insulators on the C-face.