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Impact of Nitrogen Profile in Gate Oxynitride on CMOS Characteristics

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1. Introduction

Gate oxynitride which contains a small amount of nitrogen in silicon oxide has been proven to be useful for deep-submicron CMOS because it has high hot carrier immunity and acts as a good barrier to boron penetration [1],[2]. However, the most serious problem of gate oxynitride is the deterioration of *p*-MOSFETs drivability [3]. Although much research on the formation method and electrical characteristics of oxynitrides have been carried out, a systematic study on the relationship between the nitrogen profile or concentration and the electrical characteristics of CMOSFETs has not yet been made, sufficiently.

In this study, we grew NO or N_2O nitrided gate oxide at 800℃ or 900℃, and investigated the atomic configuration of nitrogen. Furthermore, we fabricated CMOSFETs, and evaluated the interface state density and the hot carrier immunity.

2. Experiment

We fabricated CMOSFETs with gate oxide and oxynitride. As a control, we grew gate pure oxide by furnace thermal oxidation in O_2 ambient at 800℃, which was followed by annealing in Ar ambient at 900℃. We grew gate oxynitride by furnace thermal nitridation of thermal oxide in NO and Ar mixture ambient at 800℃ (800℃-NO) or 900℃ (900℃-NO) or in N_2O ambient at 900 ℃ (900 ℃ -N_2O). We varied the peak nitrogen concentration (N_{peak}) in the oxynitride from 0.8 to 2.4 at.%. We confirmed the thickness of the gate oxide and oxynitride to be 5.5 nm with C-V measurements. After gate electrode formation, we carried out ion implantation to form the LDD structure. The 100-nm-thick SiO_2 sidewall spacer formation was followed by ion implantation for source and drain formation.

We evaluated N1s core level spectra, obtained by X-ray photoelectron spectroscopy (XPS), to investigate the chemical state of nitrogen in oxynitride. We evaluated the interface state density (N_{it}) extracted from the charge pumping measurement using devices with a 50 μm gate length and a 200 μm gate width [4]. We also evaluated the degradation of the saturation current under drain avalanche hot carrier (DAHC) stress using devices with a 0.24 μm gate length and a 10 μm gate width.

3. Results and Discussions

Fig. 1 shows the nitrogen depth profile in NO- and N_2O-oxynitrides measured with secondary ion mass spectroscopy. In NO-oxynitride, nitrogen exists closer to the interface than in N_2O-oxynitride. We further investigated the atomic configuration of nitrogen in three kinds of oxynitride, 800℃-NO, 900℃-NO and 900℃-N_2O by XPS. Fig. 2 shows N1s core level spectra measured at various take-off angles for 800℃-NO and 900℃-NO. For 900℃-NO, the peak shape is sharp and the position is at about 398 eV, which corresponds to $Si_3\equiv N$ bond in Si_3N_4 deposited by chemical vapor deposition [5]. On the other hand, N1s spectra consisted of two peaks at about 399 and 398 eV for 800℃-NO. The peak at about 399 eV appears in a lower take off angle than 398 eV. This indicates that the peak at about 398 and 399 eV corresponds to a nitrogen related bond existing near the interface and in the bulk of oxynitride, respectively [6]. Furthermore, in order to locate where nitrogen exists in 800℃-NO and 900℃-NO, we analyzed N1s spectra for samples with various thicknesses. Fig. 3 shows the dependence of N1s binding energy (B.E.) on oxynitride thickness. The B.E. at about 399 eV increases with the increase in the thickness although the B.E. at about 398 eV is almost constant. This energy shift might be caused by the X-ray induced charge up effect [7] and the extrapolated intercept is at about 398 eV. This implies that the peak at about 399 eV also corresponds to $Si_3\equiv N$ bond. These results suggest that nitrogen exists at the interface and in the bulk oxynitride for 800℃-NO, but nitrogen exists only close to the interface for 900℃-NO (Fig. 4).

In Fig. 5 and 6, we compared the dependence of N_{it} on N_{peak} for *n*-MOSFET and *p*-MOSFET, respectively. In this range of N_{peak} for *n*-MOSFET, N_{it} of 900℃-NO is less than that of the others, even than the pure oxide, and N_{it} of oxynitride increases as N_{peak} increase. For *p*-MOSFET, N_{it} of 900℃-NO with 0.8 at.% N_{peak} is the smallest. This indicates that 900℃-NO with 0.8 at.% N_{peak} has better interface characteristics than the others.

Fig. 7 shows the dependence of device lifetime on substrate current for the gate oxide and oxynitride under DAHC stress. N_{peak} of each oxynitride is 0.8 at.%. The lifetime is defined as the time to reach a 10% degradation in the saturation current measured at $V_d = V_g = 2.5$ V, where V_d and V_g are the drain and gate voltages, respectively. The oxynitride, especially 900℃-NO, yielded better hot carrier immunity than the pure oxide. Fig. 8 shows the dependence of N_{it} on N_{peak} for *n*-MOSFET after 10^4sec hot carrier stress. N_{it} of oxynitride decreases as N_{peak} increases and a superior suppression of hot carrier degradation with 900℃-NO was observed even if N_{peak} was the same.

4. Conclusion

We found that the nitrogen exists only at the interface for 900℃-NO although the nitrogen exists at the interface and in the bulk oxynitride for 800℃-NO and 900℃-N_2O. However, we also found that the chemical state of nitrogen for 800℃-NO and 900℃-NO might be the same. Furthermore, we found that the 900℃-NO has superior electrical interface characteristics and reliability. Therefore, we concluded that the nitrogen in the oxynitride should exist only at the interface.

References

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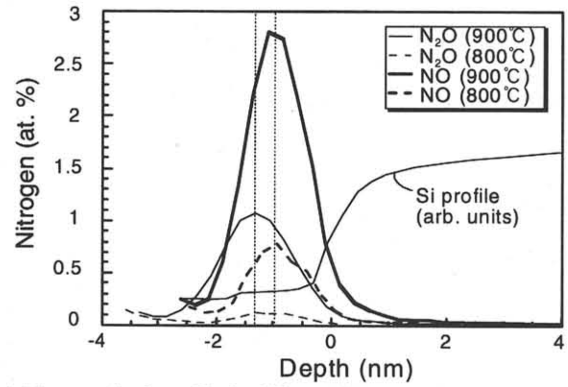

Fig. 1 Nitrogen depth profile for NO- and N_2O-oxynitride measured with secondary ion mass spectroscopy.

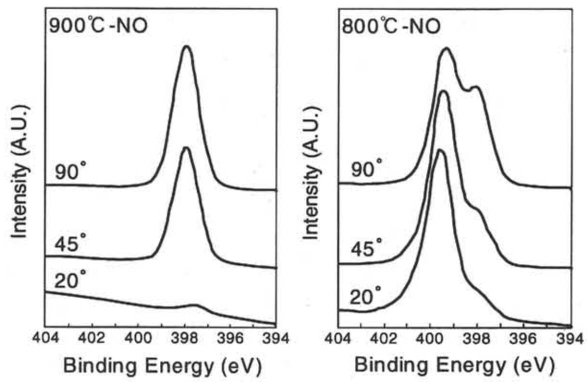

Fig. 2 N1s photoelectron spectra for various take-off angles of 800℃- and 900℃-NO oxynitride.

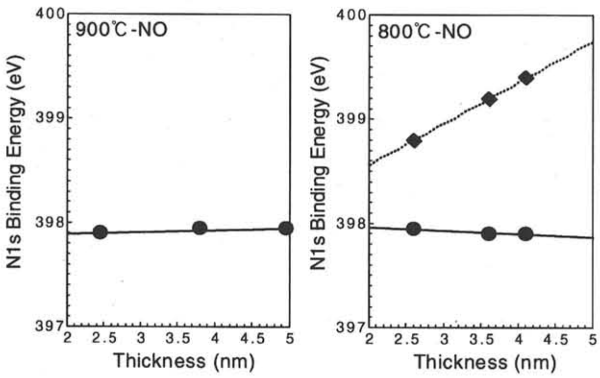

Fig. 3 Dependence of N1s binding energy on oxynitride thickness for 800℃- and 900℃-NO oxynitride.

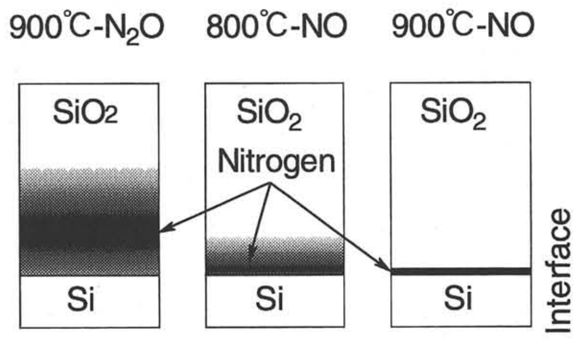

Fig. 4 Schematic cross-section of oxynitride.

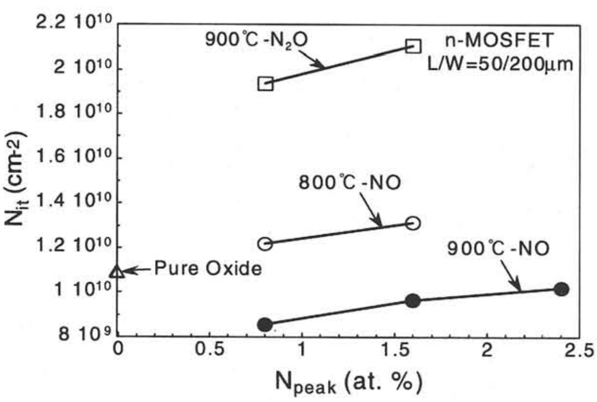

Fig. 5 Dependence of N_{it} on N_{peak} for *n*-MOSFET.

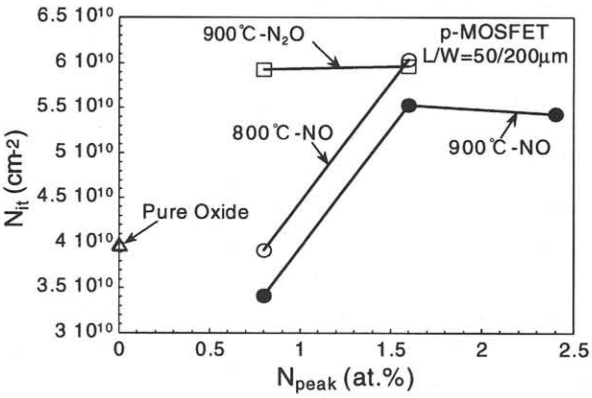

Fig. 6 Dependence of N_{it} on N_{peak} for *p*-MOSFET.

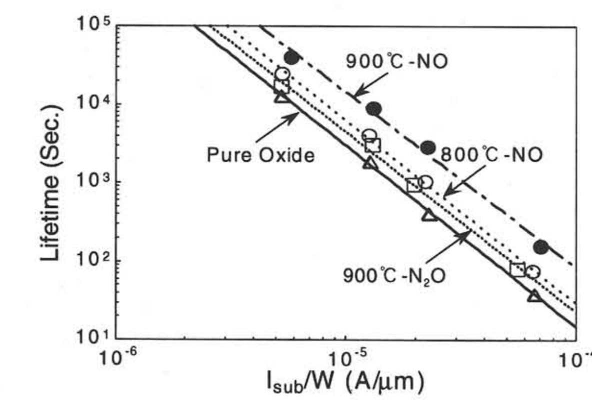

Fig. 7 Dependence of lifetime on substrate current under DAHC stress.

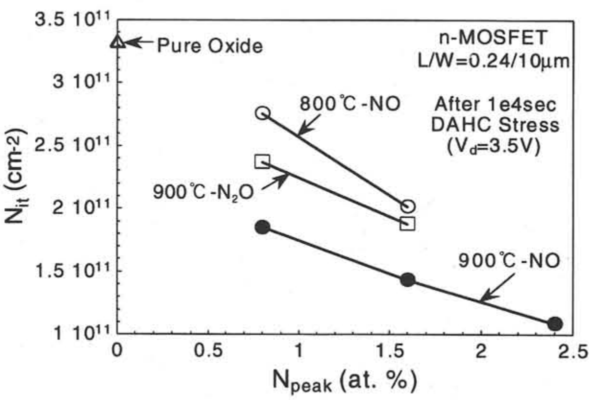

Fig. 8 Dependence of N_{it} on N_{peak} for *n*-MOSFET after 10^4 sec DAHC stress.