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Nitrogen profile engineering in the interfacial SiON for HfAlOx gate dielectric

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1. Introduction

The aggressive reduction of the gate insulator thickness in CMOSFET leads to excessive gate leakage currents. HfAlOx and HfSiON have been intensively studied as candidates of an alternative gate insulator with high dielectric constant (high-k). In the case of HfAlOx, the intermixing of HfAlOx and underlying SiO_2 causes serious degradation in the device performance [1] while it is not much in the case of the HfSiON because it contains Si-O in itself [2]. The interfacial reaction can be suppressed by using nitrided interfacial layer (IL). Nitrogen concentration at the surface of the Si substrate should be low to obtain a good mobility, while that at the surface of SiON should be high to prevent the interfacial reaction. Moreover, such a nitrogen profile should be achieved in a SiON whose equivalent oxide thickness less than 1nm.

In this study, the effects of nitrogen profile in SiON-IL on the mobility in FETs with HfAlOx/SiON gate dielectric was examined.

2. Device fabrication

Poly-Si gate FETs were made using standard CMOS process. After STI and well formation, an interfacial layer (IL) was formed. In order to control the nitrogen profile in the IL, two kinds of processes were used. One is the plasma nitridation of SiO_2. The other is re-oxidation of NH_3 formed SiN. Just after the IL formation, a HfAlOx thin film was deposited by ALD. TEMAHf, TMA and H_2O are used as precursors [3]. The Hf concentration is set to be 29%. Post high-k deposition annealing (PDA) was done in N_2 diluted 0.2% O_2 atmosphere. The gate electrode was a 150nm-thick poly-Si. Dopant activation was done at 1000°C using RTA. A final sintering anneal was performed in a 3% H_2 /N_2 environment for 30 minutes at 400°C.

3. Results and Discussion

3.1 Mobility reduction caused by the IL

In order to extract the mobility reduction by the IL, TEOS-SiO_2 was deposited instead of HfAlOx on a SiON formed by re-oxidation. As can be seen in Fig. 1, the mobility for the FET with TEOS-SiO_2 is almost the same as that for HfAlOx. Figure 2 shows the base oxide thickness dependence of electron mobility in HfAlOx/SiON. Plasma nitridation was used in this experiment. The electron mobility increases with increasing the base oxide thickness. These results suggest that the IL-limited mobility is the major cause of the mobility reduction in HfAlOx/SiON.

3.2 Nitrogen profile control

Angle resolved X-ray photoelectron spectroscopy (Theta-3000, Thermo Electron) was used to investigate the depth profiles of chemical elements in SiON-IL.

It was reported that N_2O re-oxidation formed SiON (OI-SiN) has good interfacial properties even for its EOT less than 1nm [4]. However, SiO_2 like layer exists both at the top and bottom interface in OI-SiN, as shown in Fig. 3. This oxygen-rich layer diffuses into HfAlOx during PDA and activation annealing, leaving defects at HfAlOx/SiON interface. We used NO as an oxidizing gas instead of N_2O because both nitridation and oxidation occur during the re-oxidation process, leading to higher nitrogen concentration in the obtained IL. The change in the nitrogen profile during the PDA should be taken into account in setting the re-oxidation period (see Fig. 4). The optimized nitrogen profile in SiON-IL is shown in Fig. 5.

Plasma nitridation of thin SiO_2 is another way to obtain SiON good for HfAlOx. However, the minimum thickness of base oxide in which nitrogen profile can be controlled is 0.9nm and the resultant EOT of the SiON is about 1nm. Therefore, HfAlOx thickness should be less than 1.5nm in order to obtain the EOT of less than 1.5nm (Fig. 6). In the case of the NO re-oxidation formed SiON, 1.5nm-EOT was obtained with HfAlOx thickness of 2.5nm. By making the HfAlOx thinner, EOT of 1.2nm was obtained, as shown in Figs. 6 and 7.

3.3 Electrical properties

The distribution of EOT over a 300mm-wafer is ±2.5%, which is as small as that of optical thickness of HfAlOx, indicating that the interfacial reaction is well suppressed. The electron and hole mobility for HfAlOx/SiON were shown in Fig. 8. The electron mobility for both NO re-oxdized IL and plasma nitrided IL are about twice as much as those for N_2O re-oxidized IL. However, they are still less than that of SiO_2, especially at lower effective field, which is due to the remote coulomb scattering caused by the charges in HfAlOx[5]. The I_{on}/I_{off} of 340(μA/μm)/20(pA/μm) was obtained for nFET(L=90nm).

Conclusions

The mobility reduction due to the SiON-IL was successfully suppressed for HfAlOx/SiON gate dielectric by nitrogen profile engineering using NO annealing of NH_3 formed SiN. Electron and hole mobility of 75/77% of that for SiO_2 were obtained for HfAlOx/SiON with EOT=1.5nm.

References
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[2] T. Aoyama *et al.*, IWGI 2003, p.174
[3] T. Kawahara *et al.*, IWGI 2003, p.32
[4] S. Tujikawa *et al.*, VLSI 2002, p.202
[5] S. Saito *et al.*, IEDM 2003, p.797

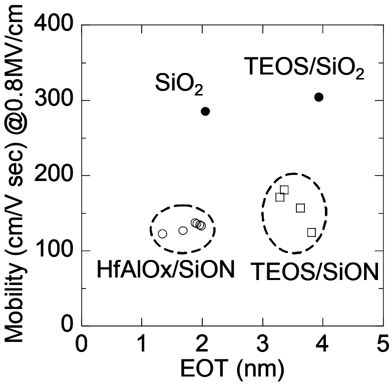

Fig. 1 High field electron mobility for HfAlOx/SiON compared with TEOS-SiO_2/SiON, TEOS-SiO_2/SiO_2 and SiO_2 .

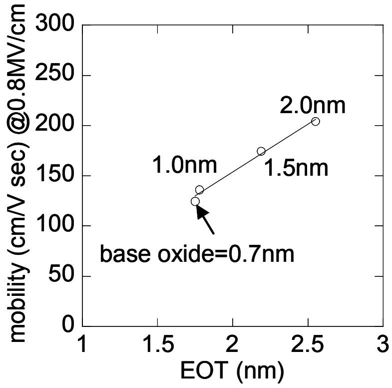

Fig. 2 High field electron mobility for HfAlOx/plasma-SiON as a function of base oxide thickness.

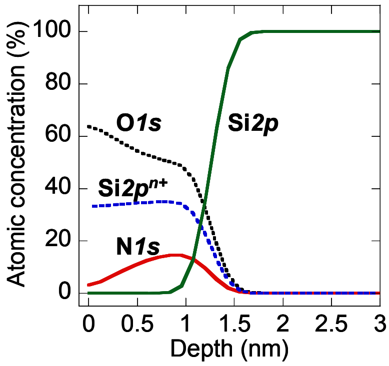

Fig. 3 Depth profiles of N, O and Si in N_2O re-oxidized SiON measured by angle resolved XPS (AR-XPS).

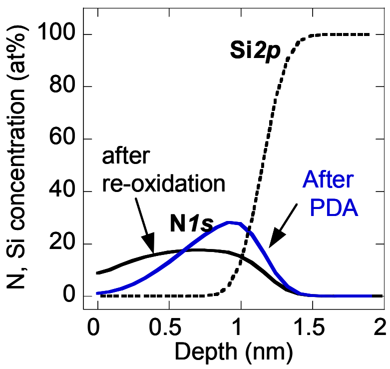

Fig. 4 Nitrogen profile change during PDA process. Nitrogen moves to the substrate during the PDA.

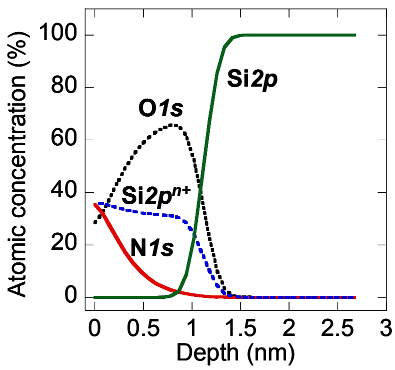

Fig. 5 Depth profiles of N, O and Si in optimized SiON-IL formed by NO re-oxidization of NH_3-SiN.

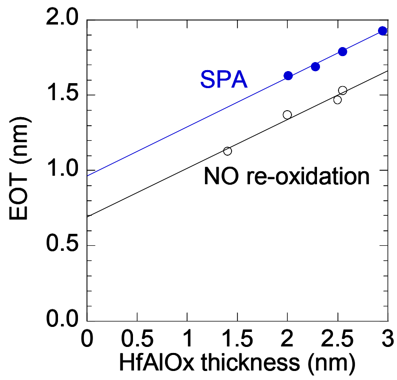

Fig. 6 HfAlOx thickness dependence of equivalent oxide thickness (EOT). The EOT of plasma SiON-IL and NO re-oxdized IL about 1 and 0.7nm, respectively.

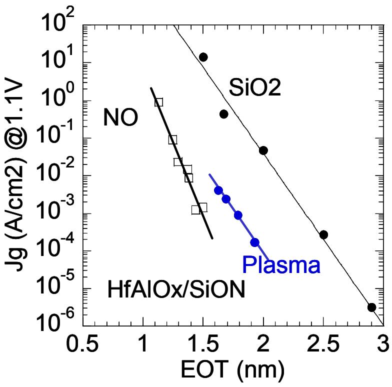

Fig. 7 EOT dependence of gate leakage. Plasma-SiON-IL and NO-re-oxidized IL is compared.

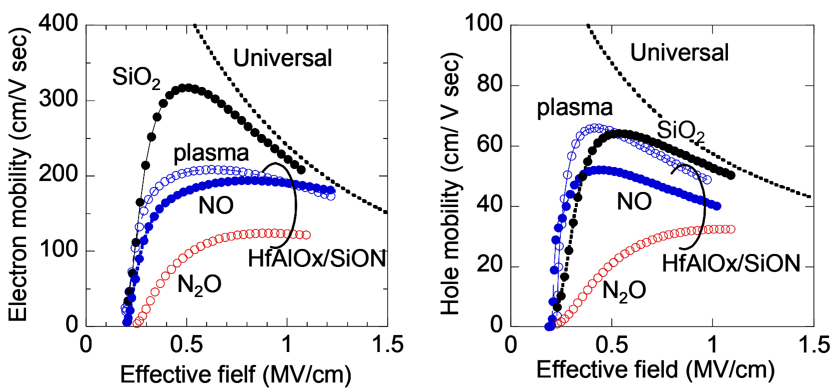

Fig. 8 Electron and hole mobility in the FET. HfAlOx with plasma SiON-IL (EOT=1.68nm) and NO re-oxidation SiON-IL (EOT=1.5nm) are compared with SiO_2 (1.65nm)