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Hafnium Content Dependence of Bottom Interfacial Layer and Its Impact on $Hf_xAl_{1-x}O_y$ High-k nMOSCAPs and nMOSFETs Characteristics

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1. Introduction

High-k materials have been extensively studied for recent years. From the view point that conventional CMOS process technology can be applied to the high-k gate dielectrics, $Hf_xAl_{1-x}O_y$ was one of the candidates in terms of thermal stability and dielectric constant. On the other hand, mobility lowering is common issue for high-k gate dielectrics. Interfacial layer (IFL) between high-k and Si substrate was examined to improve the mobility [1]. However, Hf content dependence of HfAlO and related interface characteristics including electrical characteristics were little investigated.

In this paper, we report Hf content dependences of bottom interfacial layer and dielectric constant of $Hf_xAl_{1-x}O_y$ and those influences on electrical characteristics of MOSFETs with $Hf_xAl_{1-x}O_y$ for the first time.

2. Experimental

$Hf_xAl_{1-x}O_y$ was deposited at 500ºC by LP-MOCVD on (a) chemical oxide layer (SC2), (b) thermally grown oxynitride with NO gas (NO-oxide), (c) NH_3 annealed surface of (100) Si substrate with LOCOS isolation, respectively. Used precursors of $Hf(O\text{-}tC_4H_9)_4$, $Al(C_4H_9)_3$ were regulated by N_2 gas. O_2 gas was used as an oxidant. After high-k gate dielectric deposition, PDA (800˚C, 30s) and polysilicon deposition were performed, followed by conventional MOSFET fabrication process with the maximum thermal budget of 1050˚C for 1s. Hf content of X defined by X=Hf/(Hf+Al) was widely varied for several samples, and was determined by RBS and spectroscopic ellipsometry (SE). HfAlO thickness was calibrated by SE and cross sectional TEM.

3. Results and Discussion

Figure 1 shows a schematic cross section of $Hf_xAl_{1-x}O_y$ MOS structure. Relative permittivity and physical thickness of both of HfAlO and IFL could depend on X. Figure 2 shows typical CV curve of HfAlO (3nm, X=75%) MOSCAP deposited on chemical oxide. Quantum mechanical CV curve [2] was well fitted. Figure 3 shows the J_g(@V_{fb}-1V)-capacitive effective thickness (CET, @V_g=-2V) characteristics of nMOSCAPs on chemical oxide with X from 0% to 100%. J_g and CET minimized simultaneously at X=80%. Figure 4 shows the X-dependence of CET for three types of substrate. Samples with SC2 and ON-oxide show the same dependence on X, however, NH_3 sample shows decrease monotonically for X. This suggests that CET including HfAlO and IFL are strongly influenced by the initial surface condition. Although CET at X=80% of Fig. 4(c) is comparable with that of ON-oxide sample, its transconductance shows much smaller than that of ON-oxide sample (Fig.5), indicating N-rich IFL has unfavorable effect on electrical characteristics. Figure 6 shows X-dependence of relative permittivity of HfAlO (k_1) on chemical oxide obtained from thickness dependence of CV measurement. The permittivity gives a peak value at X=75%. Its IFL thickness gives smaller value around X=0.5-0.75 shown in Fig. 7. The X-dependence of Fig. 4(a), (b) can be explained by the results of Fig. 6 and Fig. 7. We observed by XPS that the IFL thickness at 100% increased after PDA at 800˚C while thickness increase was much smaller at X=80%.Thus, the concave behavior in Fig. 7 can be explained by a crossover of the increase of IFL thickness due to oxygen diffusion and an increase of relative permittivity of IFL as X increases.

Figure 8 shows the X-dependence of effective mobility of HfAlO (2nm on ON-oxide) nMOSFETs. The mobility shows almost linear dependence on X. However, Figure 9 shows that I_{on} maximizes at X=80%. This can be strongly related to the X-dependence of IFL and HfAlO. Since T_{inv} with HfAlO on ON-oxide minimized at X=80% similar to the CET of Fig. 4(b), the decrease of I_{on} at X=100% strongly suggests the existence of thicker IFL and lower k_1 than X=80%. Figure 10 shows the X-dependence of charge pumping current (I_{CP}) of HfAlO nMOSFETs used in Fig. 9. Although the I_{CP} increases with X>20%, effective mobility increases (Fig. 8). This means that the increase of D_{it} little affects the X-dependence of mobility in $Hf_xAl_{1-x}O_y$ nMOSFETs.

4. Conclusion

We observed that $Hf_xAl_{1-x}O_y$ gate dielectric on chemical oxide and oxynitride showed maximum value of relative permittivity with X around 80%. The thickness and permittivity of interfacial layer and permittivity of HfAlO strongly depends on X and initial surface for high-k deposition. These X-dependences strongly influenced the drain current of nMOSFETs with $Hf_xAl_{1-x}O_y$.

References

[1] Y. Morisaki et. al, IEDM2002 Paper No. 34.4
[2] S. Saito et. al. ,IEEE EDL-23(2002) p.348

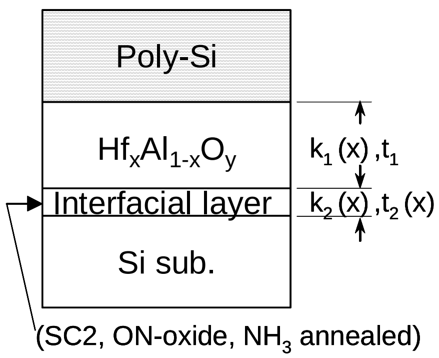

Fig. 1 Schematic cross section of HfAlO MOS structure. HfAlO was deposited on three types of surface.

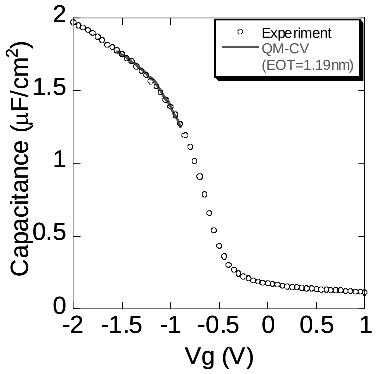

Fig.2 Typical CV curve of nMOSCAP (HfAlO, X=75%, 3nm) on chemical oxide.

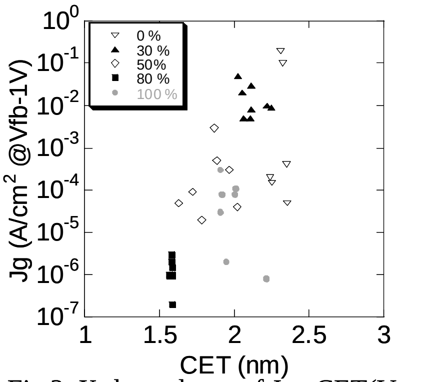

Fig.3 X-dependence of Jg –CET(Vg=-2V) of $Hf_xAl_{1-x}O_y$ (Tphys=4nm) nMOSCAPs on chemical oxide.

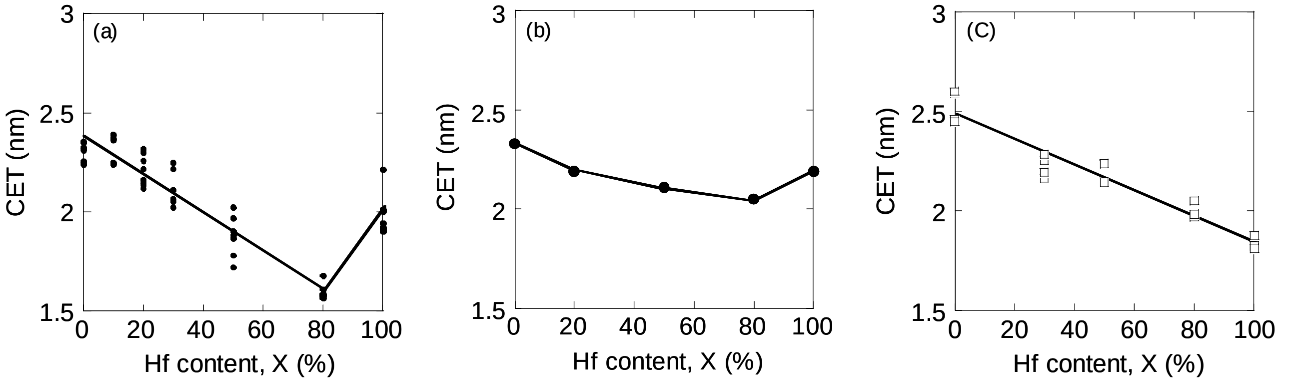

Fig. 4 X-dependence of gate capacitances. (a) HfAlO (4nm) on chemical oxide, (b) HfAlO (2nm) on ON-oxide, (c) HfAlO (2nm) on NH_3 annealed Si surface. CET at Vg=-2V was used.

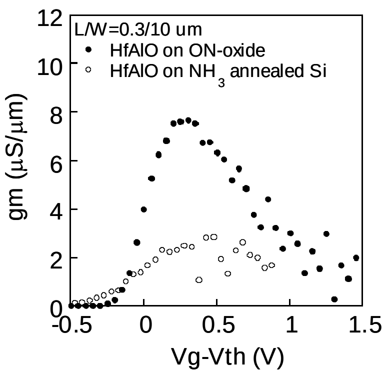

Fig. 5 g_m vs. Vg-Vth of HfAlO on ON-oxide, HfAlO on NH_3 annealed Si surface. HfAlO was 2nm, X=80%.

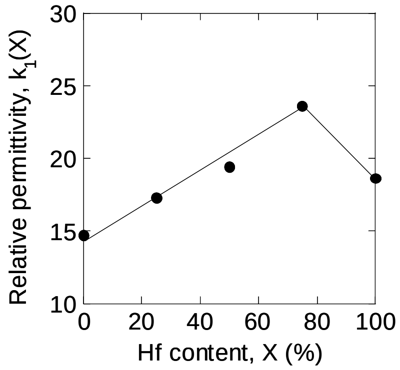

Fig. 6 X-dependence of relative permittivity of HfAlO nMOSCAPs.

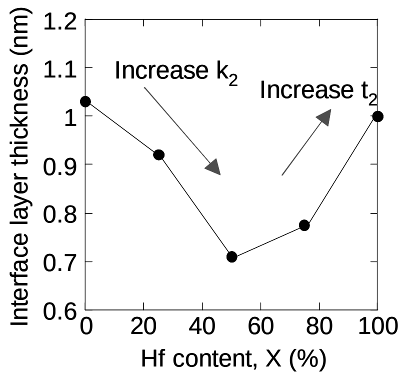

Fig. 7 X-dependence of interface layer thickness of HfAlO nMOSCAPs.

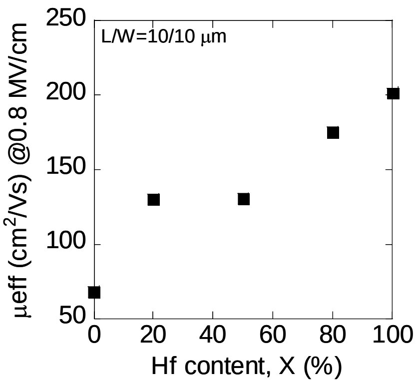

Fig.8 X-dependence of effective mobility of HfAlO (2nm on ON-oxide) nMOSFETs.

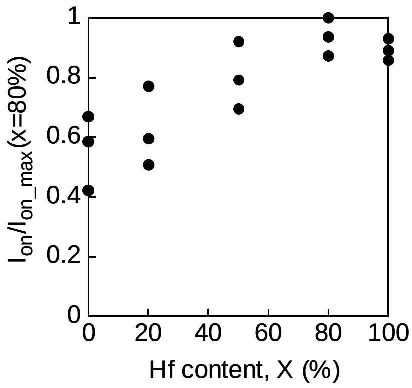

Fig. 9 X-dependence of Ion of HfAlO (2nm on ON-oxide) nMOSFETs.

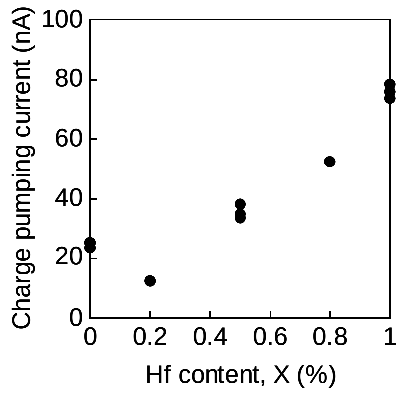

Fig.10 X-dependence of charge pumping current of HfAlO (2nm on ON-oxide) nMOSFETs.