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Integration Issues of HfO_2-Al_2O_3 Laminate for Gate and Capacitor Dielectric

Jong-Ho Lee

Advanced Process Development Team, System LSI Division, Samsung Electronics Co., Ltd.
San #24 Nongseo-Ri, Giheung-Eup, Yongin-City, Kyunggi-Do, Korea, 449-711
Phone: +82-31-209-6350 E-mail: jongh.lee@samsung.com

1. Introduction

The aggressive scaling of CMOS and memory devices is quickly driving the need for high-k dielectric and the intensive studies on high-k narrow down to HfO_2 based materials among the many candidates [1]. Although the industry has seen the promising results from HfO_2 based high-k such as HfAlO(N) and HfSiO(N) for gate dielectric and HfAlO for capacitor dielectric, high-k gate dielectric introduction is thought to be premature for CMOS devices up to now and application of high-k capacitor dielectric for memory devices is also faced with urgent problems to full in the year of mass-production. In this paper, some key issues of high-k gate and capacitor dielectric in terms of device integration will be described.

2. Integration Issues of High-k Gate Dielectrics

Experimental

Al_2O_3 or HfAlO(HfO_2-Al_2O_3 laminate) film was deposited by ALD(Atomic Layer Deposition) on Si substrate. HfAlON denotes nitrogen incorporated HfAlO by in-situ 3-step post-deposition annealing including thermal nitridation [2]. $HfCl_4$, TMA[$Al(CH_3)_3$], and H_2O were used as ALD reactants. After poly-Si gate deposition, standard CMOS integration process was applied.

Process Induced Flatband Voltage Shift

HfAlO combines the characteristic features of both constituents, *i.e.*, positive fixed charges of HfO_2 and negative fixed charges of Al_2O_3 [3,4]. Consequently, there is little difference in V_{fb} (flatband voltage) of HfAlON compared to SiO_2 as shown in Fig.1(a). However, the V_{fb} increased by 200~250mV after full logic process (Fig.1(b)). The cause of this V_{fb} shift after device integration is not clear up to now.

Gate Depletion

The possibility of phosphorus diffusion from poly-Si gate into the Al_2O_3 was already reported [3]. The phosphorous diffusion could be dubbed a sort of sucking. In case of HfO_2, the phosphorous sucking is thought to be more severe than Al_2O_3. As a result, the gate depletion of MOS capacitor with HfAlON is larger than with SiO_2 (Fig.1(b)). The degree of phosphorous sucking depends on combinations of high-k materials and may generate the reliability problem, especially for nMOSFET.

Undercut formation during wet cleaning

Fig.2 shows TEM view of gate edge with Al_2O_3 after wet cleaning in CMOS integration. The careful selection of wet chemicals is required to minimize the undercut formation which brings about the abnormal V_{th} increase at short channel MOSFET (Fig.3).

Threshold Voltage Shift from Poly-Si Reoxidation

Fig. 4 shows V_{th} roll-ff characteristics with various poly-Si reoxidation process conditions. As reported [5], excess oxygen severely reduces the capacitance in the high-k (HfAlO). Currently, we can simply prevent this high V_{th} problem by skipping poly-Si reoxidation. However, from the poly-Si reoxidation results, the special regard should be paid to the fact that the oxidant during the following integration process after gate patterning plays an important role for transistor performance.

Boron Penetration

Fig.5 shows the drop of channel breakdown voltage of pMOSFET due to the boron penetration under a certain physical thickness of HfAlO. The boron penetration was suppressed through the thermal nitridation and relatively good current performance with low leakage currents was obtained (Fig.6).

3 Integration Issues of High-k Capacitor Dielectrics

Poor Step Coverage and Low Throughput of ALD HfO_2

As HfO_2-Al_2O_3 laminate film is applied to capacitor application, there are two major drawbacks using solid source ($HfCl_4$) which is being generally used for gate dielectric application. First, HfO_2 using $HfCl_4$ shows poor step coverage (~42%) on high aspect ratio (40:1) as shown in Fig.7. Secondly, the saturation time (1.6sec) of the self-limiting reaction for $HfCl_4$ is longer than that of liquid precursor(0.8sec), TEMAH(Tetrakis-Ethyl-Methyl-Amido-Hafnium) as shown in Fig.8.

Insufficient Evaluation for Liquid Precursors

Fig.9 shows that the leakage current of MIS capacitor using TEMAH is comparable to that of $HfCl_4$. Even if TEMAH is expected to be a promising candidate for HfO_2 deposition by ALD, quite a few items to be checked still remain in terms of the precursor-decomposition behavior. In addition, other hafnium liquid precursors should be evaluated using the various oxidizing reactants such as H_2O, ozone, and radical oxygen.

3. Conclusions

Several integration issues of high-k dielectric (HfO_2-Al_2O_3) were reviewed. The process technologies for high-k gate and capacitor dielectric can help mutually for the development of reliable precursors and mass-productive equipment.

References

[1] H. Iwai, et al., IEDM Tech, Dig., p.627 (2002)
[2] H-S Jung, et al., IEDM, p.853 (2002)
[3] J-H Lee, et al., IEDM, p.645 (2000)
[4] J-H Lee, et al, VLSI Tech, Dig., p.84 (2002)
[5] C. Hobbs, et al, IEDM, p.651 (2001)

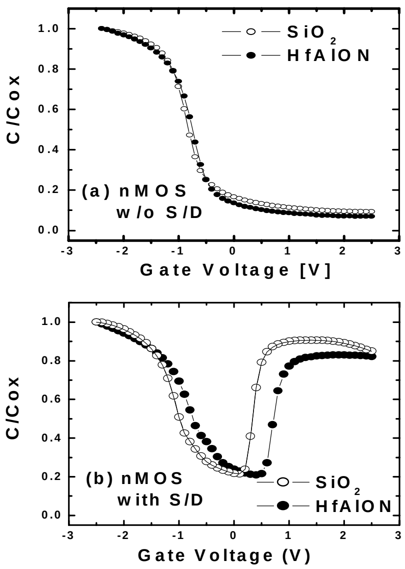

Fig. 1. C-V curves of nMOSCAP (a) before and (b) after full logic process

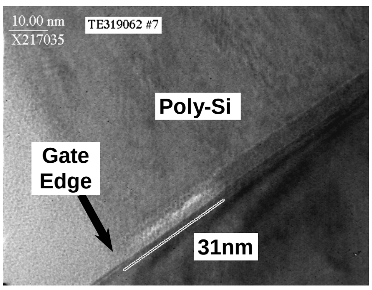

Fig. 2. Cross-sectional TEM view of gate edge with Al_2O_3

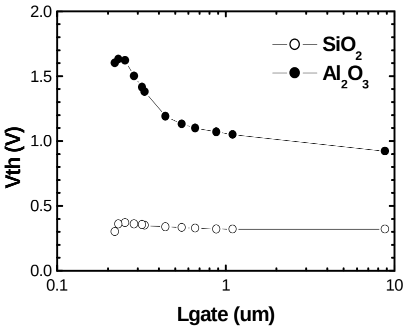

Fig. 3. Vth roll-off characteristics of Al_2O_3 compared to that of SiO_2

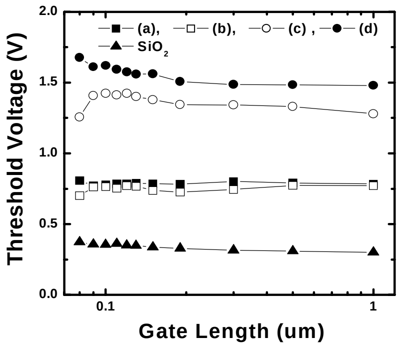

Fig. 4. Vth roll-off characteristics of HfAlO with various poly-Si reoxidation conditions such as (a) skip, (b) N_2, (c) low partial pressure O_2, and (d) high partial pressure O_2 ambient

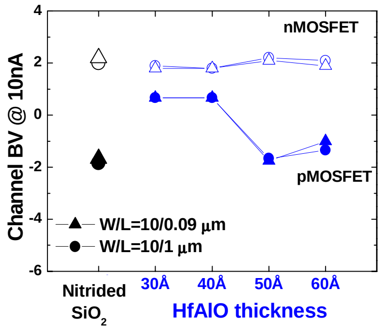

Fig. 5. Channel BV at 10nA with various HfAlO thickness

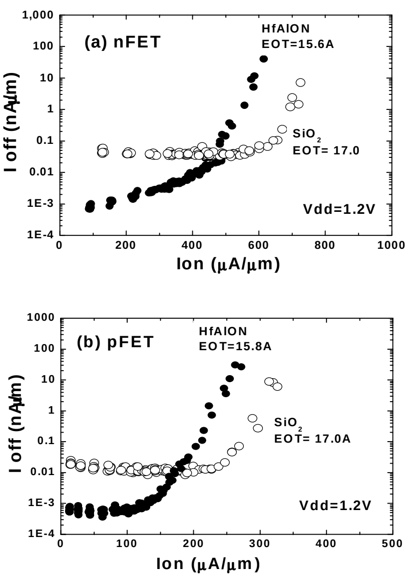

Fig. 6. I_{on} - I_{off} characteristics of (a) nFET and (b) pFET with HfAlON

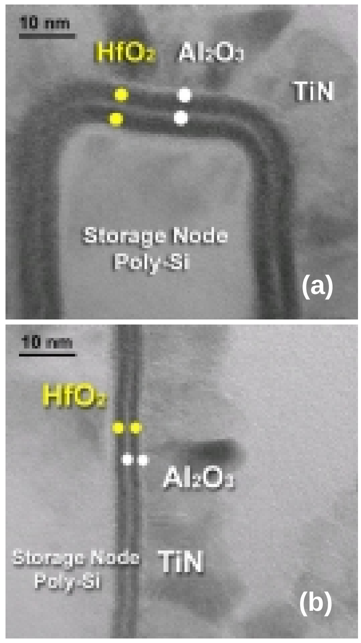

Fig. 7. TEM views of HfO_2-Al_2O_3 laminate using solid source ($HfCl_4$) on (a) top and (b) bottom of cylinder-type MIS capacitor

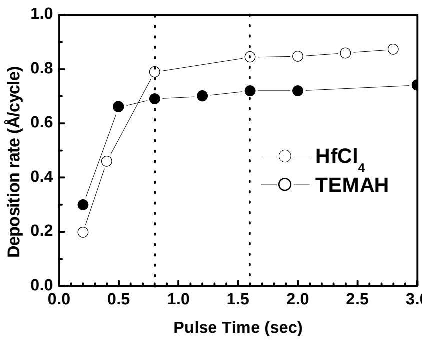

Fig. 8. Deposition rate of HfO_2 as a function of Hf source dose

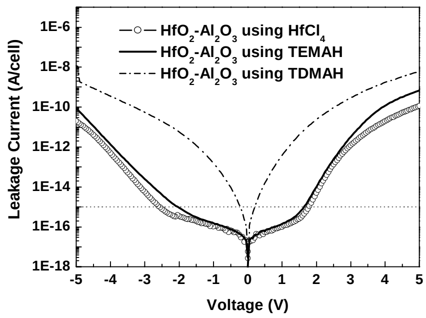

Fig. 9. Comparison of leakage current of MIS capacitor with HfO_2-Al_2O_3 laminate using solid Hf source and liquid precursor at the same EOT(22Å)