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Strong Impacts of Top Blocking Layer on Initial Flatband Voltage in Hf-based High-k Charge-Trapping Memory

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Abstract

Impacts of top blocking layers on initial flatband voltage are investigated in nMOS capacitors with a $HfSiO_2$ charge-trapping layer. While the top blocking layer on $HfSiO_2$ significantly affects the memory window in charge-trapping memory, we found that an initial flatband voltage also largely depends on the structure of top blocking layer such as Al_2O_3 and stacked Al_2O_3/SiON/Al_2O_3. Our experimental results indicate that this is related to oxygen vacancies in $HfSiO_2$ charge-trapping layer. The SiON thickness in top blocking layer is a key factor to control the initial flatband voltage.

1. Introduction

Charge-trapping (CT) memory devices have been realized by using the oxide-nitride-oxide (ONO) structure for a long time. The replacement of ONO with other CT structures using high-k dielectrics allows us to scale the equivalent oxide thickness (EOT) for lowering operating voltage. HfO_2-based high-k such as $HfSiO_2$ [1] and HfO_2 [2-3], and Al_2O_3-based high-k dielectrics such as Al_2O_3 [4-5] and $Al_2O_3/SiO_2/Al_2O_3$ [6] have been intensively studied as alternative CT layers and top blocking layers, respectively.

When high-k dielectric stacks are used in MOS devices, flatband voltages (V_{fb}) are anomalously shifted by interface dipoles [7-9] and oxygen vacancies [10-11] and so on. An initial V_{fb} significantly affects program/erase speed and the memory window. However, changes in the initial V_{fb} have rarely been investigated for CT structures with high-k dielectrics. In this paper, impacts of top Al_2O_3-based blocking layers combined with a $HfSiO_2$ CT layer on initial V_{fb} are investigated. It is found that a replacement of the top-Al_2O_3 blocking layer (Top-Al_2O_3) with $Al_2O_3/SiON/Al_2O_3$ (Top-AOA) induces a large positive V_{fb} shift. The possible mechanism is also discussed.

2. Experimental

nMOS capacitors with CT structures of top Al_2O_3-based blocking layer/$HfSiO_2$/bottom-oxide (Btm-Ox) were fabricated on p-type Si(100) substrate as shown in **Fig 1**. After the Btm-Ox formation, $HfSiO_2$ CT layers were deposited by atomic layer deposition (ALD) technique. The Si content {Si/(Si+Hf)} of ~20% is controlled in $HfSiO_2$ by changing cycle ratio in ALD [1]. Top-Al_2O_3 and Top-AOA blocking layers were also deposited by using ALD technique. N^+poly-Si gate electrodes were formed and then activation annealing was performed for 5sec at 950ºC. 100kHz capacitance-voltage (*C-V*) measurements were conducted to extract initial V_{fb} of these capacitors.

3. Results and Discussion

Figure 2 shows initial *C-V* curves of nMOS capacitors with Top-Al_2O_3/$HfSiO_2$/Btm-Ox and Top-AOA/$HfSiO_2$/Btm-Ox structures**.** A large positive shift is observed when the top blocking layer is changed from Top-Al_2O_3 to Top-AOA.

Figure 3 shows the V_{fb} for Top-AOA/$HfSiO_2$/Btm-Ox as a function of the SiON thickness in Top-AOA. Compared with Top-Al_2O_3, the V_{fb} remains almost unchanged for Top-AOA with thin SiON. The initial V_{fb} shifts to the positive gate direction about 1V for thick SiON. This result indicates that the SiON thickness in Top-AOA has a strong impact on the initial V_{fb}. The increase in initial V_{fb} raises program voltage for FN electron tunneling, as shown in **Fig. 4**.

Here we consider three possible origins for the large initial V_{fb} shift: (i) fixed charges in Top-AOA, (ii) interface dipoles in Top-AOA [7-9], and (iii) formation of oxygen vacancies in $HfSiO_2$ [10-11]. **Figure 5** shows the V_{fb} of nMOS capacitors for Top-AOA/$HfSiO_2$/Btm-Ox as a function of the Al_2O_3 thickness in Top-AOA. The initial V_{fb} is almost unchanged when the Al_2O_3 thickness is decreased in Top-AOA. Therefore, the positive initial V_{fb} shift by changing from Top-Al_2O_3 to Top-AOA is not related to fixed charges in Top-AOA [mechanism (i)].

Figure 6 shows the *C-V* curves for Top-OA, Top-AO and Top-AOA blocking layers. If interface dipoles in the Al_2O_3/SiON and SiON/Al_2O_3 interface are the main cause for the initial V_{fb} shift [mechanism (ii)], initial V_{fb} should be shifted by removing either Al_2O_3/SiON or SiON/Al_2O_3 interface. As shown in **Fig. 6**, the *C-V* curves are overlapped for Top-OA, Top-AO and Top-AOA except for Top-Al_2O_3. This result excludes the mechanism (ii) as the main cause for the positive initial V_{fb} shift in this study.

The above-mentioned discussions indicate that the mechanism (iii) is most likely. The positive shift in the initial V_{fb} is explained by considering formation of oxygen vacancies in $HfSiO_2$ according to the model for "V_{fb} roll-off" [10]. As illustrated in **Fig. 7**, in the case of Top-Al_2O_3 and Top-AOA with thin SiON, oxygen vacancies are formed in $HfSiO_2$ by out-diffusing oxygen atoms from $HfSiO_2$ to n^+poly-Si for oxidation at the n^+poly-Si/Al_2O_3 interface, assuming that Al_2O_3 has little function of an oxygen barrier. On the other hand, out-diffusion of oxygen atoms is suppressed from $HfSiO_2$ to n^+poly-Si for Top-AOA with thick SiON thanks to its oxygen barrier characteristic. The initial V_{fb} apparently shifts to the positive gate voltage direction when using thick SiON in Top-AOA as shown in **Fig. 3**.

We expect that "V_{fb} roll-off" might occur by decreasing the Btm-Ox thickness in the case of Top-AOA with thick SiON, if the model for "V_{fb} roll-off" is applicable as mentioned above. **Figure 8** shows the V_{fb} as a function of the Btm-Ox thickness. An abrupt negative shift in the initial V_{fb}, namely "V_{fb} roll-off", is observed when decreasing the Btm-Ox thickness. This V_{fb} roll-off behavior for Top-AOA with thick SiON is consistent with mechanism (iii). A large negative shift is not observed for Top-Al_2O_3 in **Fig. 8**, since oxygen vacancies are thought to have already been formed by interface oxidation of n^+poly-Si irrespective of the Btm-Ox thickness due to non-barrier properties of Al_2O_3.

4. Conclusions

The SiON thickness in a Top-AOA blocking layer has a strong impact on an initial V_{fb} in CT memory with $HfSiO_2$ CT layer. The initial V_{fb} shift is thought to be related to oxygen vacancy formation in $HfSiO_2$. Since oxygen vacancy is formed in $HfSiO_2$ by interfacial oxidation of both n^+poly-Si gate and Si substrate, we should pay attention to both thicknesses of SiON or SiO_2 films which are located above or below $HfSiO_2$ to control the initial V_{fb}.

Fig. 1 Process flow of MOS capacitors with $HfSiO_2$ charge-trapping layer. Top blocking layers of Al_2O_3 or AOA (Al_2O_3/SiON/Al_2O_3) are formed on $HfSiO_2$ by using ALD technique.

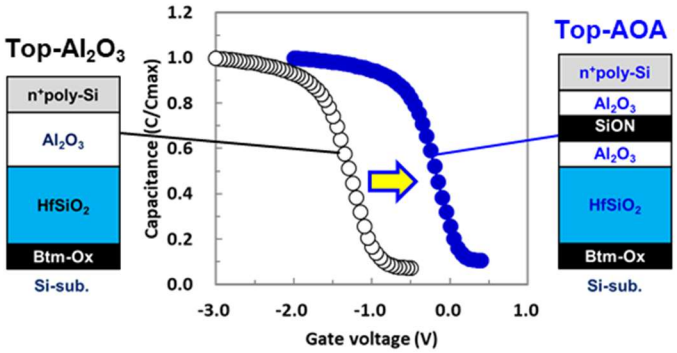

Fig. 2 Initial *C-V* curves for Top-Al_2O_3/$HfSiO_2$/Btm-Ox and Top-AOA/$HfSiO_2$/Btm-Ox structures. The *C-V* curve of Top-AOA shifts towards the positive gate voltage direction as compared to that of Top-Al_2O_3.

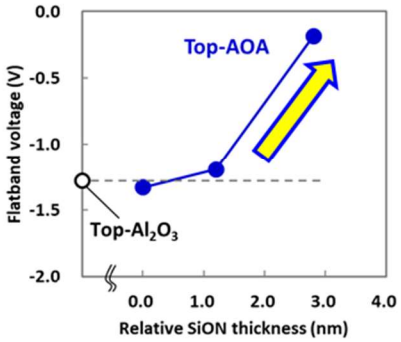

Fig. 3 Initial V_{fb} for Top-AOA/$HfSiO_2$/Btm-Ox as a function of SiON thickness in Top-AOA. An abrupt change is observed.

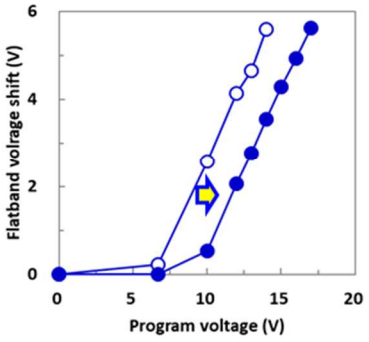

Fig. 4 V_{fb} shifts as a function of program voltage for Top-AOA with thin (open) and thick SiON (solid). Electrons are injected by FN tunneling.

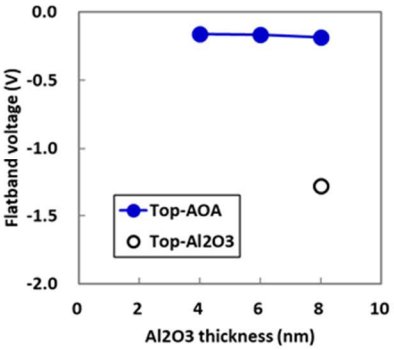

Fig. 5 Initial V_{fb} for Top-AOA/$HfSiO_2$/Btm-Ox as a function of Al_2O_3 thickness. V_{fb} remains unchanged.

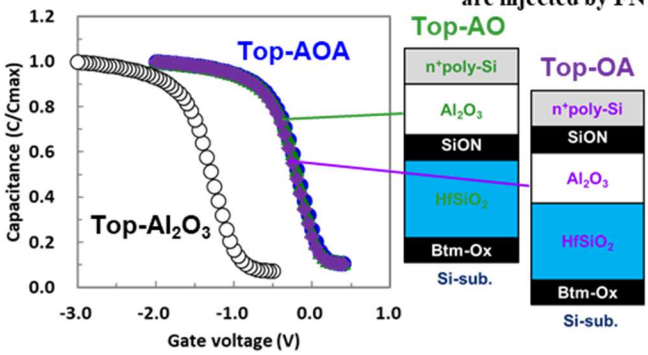

Fig. 6 Initial *C-V* curves for Top-OA/$HfSiO_2$/Btm-Ox and Top-AO/$HfSiO_2$/Btm-Ox structures. These curves are overlapped with that for Top-AOA/$HfSiO_2$/Btm-Ox.

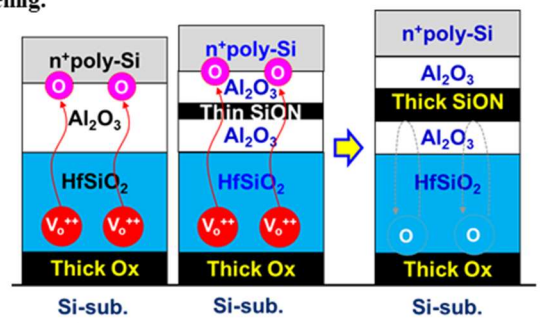

Fig. 7 Schematic illustration of oxygen vacancy (V_o^{++}) formation by out-diffusing oxygen atoms from $HfSiO_2$ to n^+poly-Si for oxidation at the n^+poly-Si/Al_2O_3 interface. Apparently, V_{fb} shifts to the positive gate voltage direction as shown in Fig. 3 because V_o^{++} formation is suppressed for thick SiON in Top-AOA.

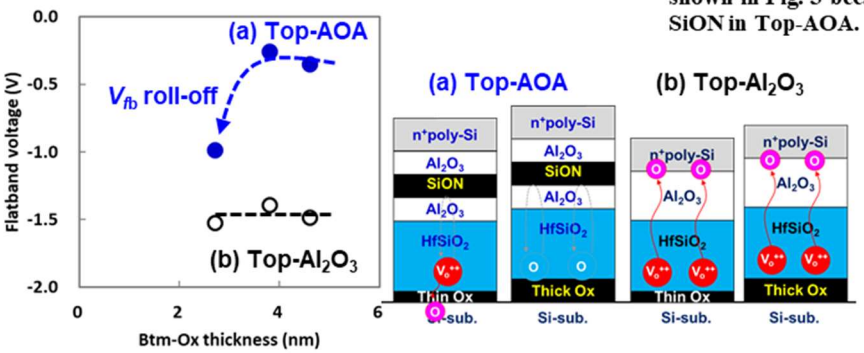

Fig. 8 Initial V_{fb} values (left) and schematic illustration of V_o^{++} formation (right) for (a) Top-AOA/$HfSiO_2$/Btm-Ox and (b) Top-Al_2O_3/$HfSiO_2$/Btm-Ox structures as a function of Btm-Ox thickness. (a) An abrupt negative V_{fb} sihft by decreasing the Btm-Ox thickness (V_{fb} roll-off) for Top-AOA and (b) almost no V_{fb} sihft are observed for Top-Al_2O_3.

References

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