Influence of Alkali Earth Elements Capping on Electrical Characteristics of La_2O_3 Gated MOS Device

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Introduction

Mobility degradation of high-k gated MOSFET caused by fixed charges has been one of the major problems for equivalent oxide thickness (EOT) scaling (1). It has been reported that La_2O_3 can achieve an EOT below 1 nm by forming a La-silicate layer with fairly nice performance (2). However, it also suffers from the fixed charge-related mobility degradation at an EOT below 1.3 nm. Recently, it has been reported that incorporation of Mg into La_2O_3 suppresses the generation of fixed charges and contributes to mobility improvement has been observed (3). In this paper, capping effect of Mg, SrO or BaO, alkali earth elements, have been investigated and its influence on electrical characteristics are discussed.

Experiment

La_2O_3 dielectrics were deposited on 300-nm-thick SiO_2 isolated n-Si(100) wafers after SPM cleaning and HF treatment. La_2O_3 layers were deposited by e-beam evaporation at a pressure of 10^{-8} Pa. The thickness of La_2O_3 layer was changed from 2 to 4 nm to reveal the V_{fb} dependence on EOT of the capacitors. Either Mg, SrO or BaO layer was successively evaporated onto the formed La_2O_3 layer as the same way with the La_2O_3 layer. Then, a 60-nm-thick W layer was *in situ* deposited by RF sputtering. To avoid the absorption of any moisture or carbon-related contamination, the wafers were not exposed to air during the depositions. W was patterned by reactive ion etching (RIE) using SF_6 chemistry to form gate electrodes. Wafers were then post-metallization annealed (PMA) using a rapid thermal annealing (RTA) furnace in forming gas (FG)(N_2:H_2= 97%:3%) ambient at 500 ^{o}C for 30 min. Finally, an Al layer was deposited on the backside of the substrate as a bottom contact by thermal evaporation. The schematic illustration of the as-deposited gate stack structure is shown in figure 1.

Result and Discussion

W/Mg/La_2O_3/Si gate stack structure MOS capacitors were fabricated with a Mg capping thickness of 1.0 nm. Figure 2 shows V_{fb} dependence on EOT of the capacitors with and without Mg capping layer. The negative shift in V_{fb} is well suppressed with the Mg capping presumable owing to the suppression of the fixed charge generation. Then, W/SrO/La_2O_3/Si gate stack structure MOS capacitors were fabricated. Three kinds of SrO capping thickness were evaluated; 0.5, 1.0 and 1.5 nm. V_{fb} dependence on EOT of the capacitors is shown in figure 3. With the increase in capping thickness, V_{fb} moves to negative direction, which seems to be enhancing the roll-off characteristics. Meanwhile, below 1.1 nm of EOT, a positive V_{fb} shift (roll-up) characteristics appears. Due to this roll-up characteristic, the V_{fb} of the capacitors coincide to a same value at EOT of 0.8 nm, independent on the capping thickness of SrO. It can be considered that the roll-off and roll-up characteristics are caused by the change in polarity of the net fixed charges. Then, W/BaO/La_2O_3/Si gate stack structure MOS capacitors were fabricated. A 2-nm-thick La_2O_3 layer was capped by 1.0 and 1.5-nm-thick BaO. Figure 4 shows C-V characteristic of the capacitors. EOT increases with increasing BaO capping. The increase indicates that Si-rich La-silicate was formed at Si/La_2O_3 interface by BaO capping after PMA. It has been reported that ionic conductivity of $La_iBa_jSi_kO_l$ is larger than that of $La_{i'}Si_{k'}O_{l'}$ compound (4). It is considered that the Si-rich La-silicate was formed by oxygen supplying. Therefore, the capping thickness of BaO should be minimized to avoid EOT increasing. Then, capacitors with 0.3-nm-thick BaO capping were fabricated. V_{fb} dependence on EOT of the capacitors is shown in figure 5. V_{fb} shift changes from negative to positive at EOT value of 1.2 nm. The trend is the same as the SrO capping, however, the amount of roll-up characteristic is larger with BaO capping.

Conclusion

The impact of alkali earth elements capping onto La_2O_3 gated MOS device on electrical characteristics have been conducted. The V_{fb} roll-off and roll-up, which can not be caused by Mg capping, have been observed with SrO or BaO capping. The main reason can be considered as the change in the fixed charges. Mg capping can well suppress the negative shift of V_{fb} at EOT value above 1.0 nm and the SrO or BaO capping seems to be effective in the suppression of the negative shift in V_{fb} at EOT values below 0.8 nm.

Acknowledgement

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References

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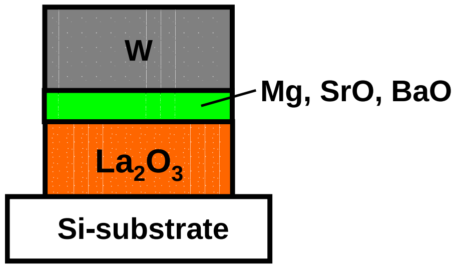

Figure 1. Schematic illustration of the MOS structure in as-deposited condition.

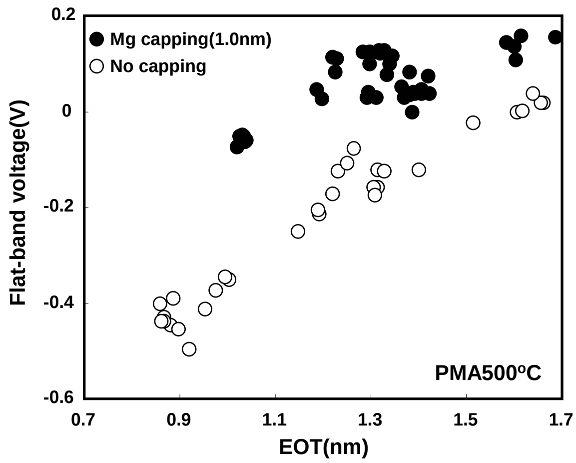

Figure 3. V_{fb} dependence on EOT with and without Mg capping. The negative shift in V_{fb} is well suppressed with the Mg capping.

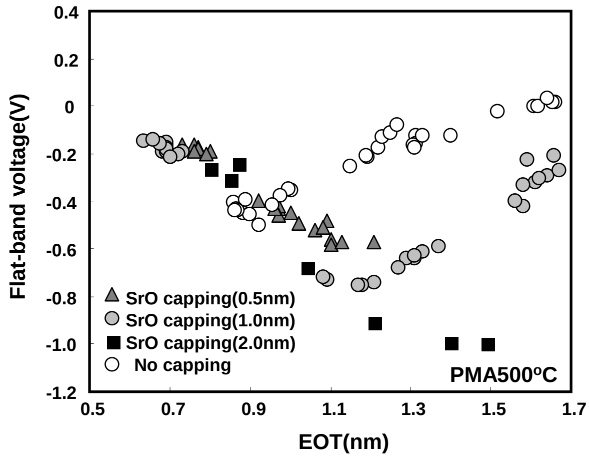

Figure 4. V_{fb} dependence on EOT at various SrO capping thickness.

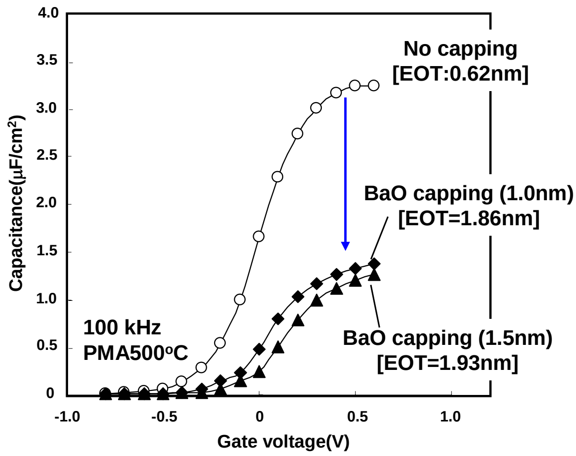

Figure 5. C-V characteristics of BaO capped La_2O_3/Si capacitors. EOT increases with large BaO capping thickness.

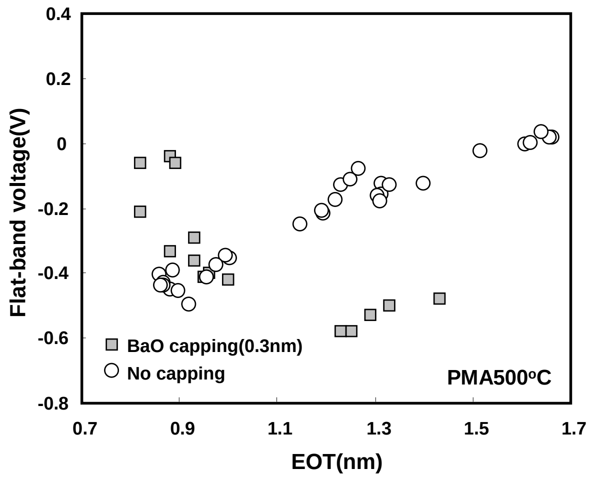

Figure 6. V_{fb} dependence on EOT with and without thin BaO capping.