Impact of ALD high-k materials on SiGe MOS interface properties with TiN gate

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1. Introduction

SiGe MOSFETs have stirred much attention as p-channel devices, because of the high hole mobility and the appropriate bandgap. However, the undesired formation of GeO_x in the interfacial layers (IL) can be regarded as an origin of the MOS interface degradation [1]. We have recently reported the improvement of SiGe MOS interface properties by employing TiN/ALD Y_2O_3 gate stacks with PMA at 450°C [2], whereas the effects of different high-k films on the SiGe MOS interface properties have not been fully studied yet. In this study, the impacts of ALD high-k materials, Y_2O_3, Al_2O_3, HfO_2 and ZrO_2, on the SiGe MOS interface properties including D_{it} are systematically examined with changing PMA temperature.

2. Experiment

7-nm-thick non-doped $Si_{0.78}Ge_{0.22}$/p-type Si(100) wafers were cleaned by de-ionized water, acetone and diluted HF. Subsequently, 7-nm-thick Y_2O_3, Al_2O_3, HfO_2 and ZrO_2 were deposited at 300˚C by ALD using $(CpMe)_3Y$, TMA, TDMAH, TDMAZ as the precursors, respectively, and H_2O as the oxidant. All the samples were followed by gate electrode formation using metal sputtering of 50-nm-thick TiN and thermal evaporation of 100-nm-thick Al. TiN was patterned by APM (NH_4OH:H_2O_2:H_2O=1:2:5) at 70˚C and Al was patterned by NMD-3 at room temperature. Then, the 100-nm-thick Al back contact was formed by thermal evaporation. PMA was finally performed for 1 min in N_2 ambient for all the TiN/ALD high-k/SiGe stacks at 300, 350, 400 to 450˚C.

3. Results and Discussion

Fig. 1(a) shows the minimum values of interface state density ($D_{it,min}$) as a function of PMA temperature. The lowest $D_{it,min}$ is obtained by TiN/Y_2O_3 stacks with PMA at 450˚C between all the TiN/high-k stacks under optimized PMA temperature. $D_{it,min}$ of all the high-k stacks reduces after PMA at 300˚C. However, $D_{it,min}$ further reduces with increasing PMA temperature until 450˚C only for the Y_2O_3 stacks, whereas $D_{it,min}$ increases for the Al_2O_3, HfO_2 and ZrO_2 stacks. Fig. 1(b) shows the areal slow trap density (ΔN_{st}) as a function of PMA temperature. It is found that the higher PMA temperature can reduce ΔN_{fix} for all the high-k stacks.

Fig. 2(a) and (b) show D_{it} as a function of the total amounts of Ge sub-oxides and the amounts of GeO_2, evaluated by Ge 3d XPS spectra, in IL of the Y_2O_3, Al_2O_3, HfO_2 and ZrO_2 stacks after PMA at 300 and 450˚C, respectively. It is found in the results after PMA at 300˚C that less amounts of Ge sub-oxides have tendency to provide lower D_{it} in all the high-k stacks, whereas the amounts of GeO_2 do not have correlated with D_{it}. This fact can be explained by considering that Ge sub-oxides can include more amounts of distorted Ge-O bonds, which can generate D_{it} because of the weaker bonding energy than GeO_2 [3]. After PMA at 450˚C, the tendency that less amounts of Ge sub-oxides still leads to lower D_{it} is still maintained for all the high-k stacks. On the other hand, further significant reduction of D_{it} is observed in the Y_2O_3 stacks after PMA at 450˚C. This reduction cannot be explained by the amount of Ge sub-oxides, because D_{it} in the Y_2O_3 stacks is lower by one of the magnitude than that in the Al_2O_3 stacks with the same amount of Ge sub-oxides. Thus, this significant reduction in D_{it} can be attributed to any mechanism inherent to Y_2O_3 such as incorporation of Y atoms into networks of Ge oxides and termination of dangling bonds [3].

4. Conclusions

We have shown that TiN/Y_2O_3/$Si_{0.78}Ge_{0.22}$ gate stacks with PMA at 450°C provide the best MOS interfacial properties. The physical origins of D_{it} reduction in the TiN/Y_2O_3 stacks with PMA are attributable to the reduction in amounts of distorted Ge-O bonds in Ge sub-oxides by scavenging and healing effects during PMA at 300°C, and termination of Ge dangling bonds by incorporation of Y atoms into GeO_x during PMA at 450°C.

Acknowledgements

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References [1] C.-H. Lee et al., *VLSI Symp.*, 2016, pp. 36. [2] T.-E. Lee et al., *VLSI Symp.*, 2019, T101. [3] L. Zhang et al., *ACS Appl. Mater. Interfaces*, 2016, 8, pp. 19110.

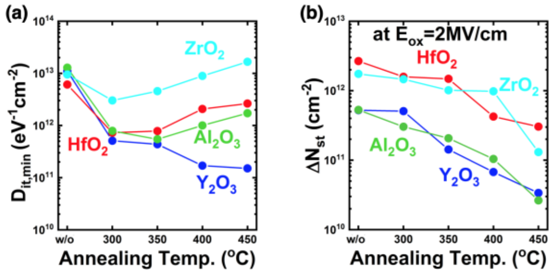

Fig.1: (a) $D_{it,min}$ and (b) ΔN_{st} as a function of PMA temperature.

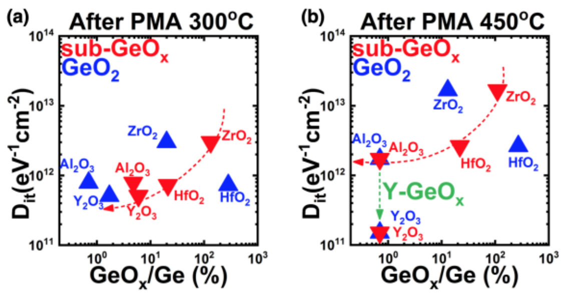

Fig.2: D_{it} as a function of the normalized total amounts of Ge sub-oxides and GeO_2 after PMA at (a) 300 and (b) 450 ˚C.