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Ga_2O_3 and Al_2O_3 hybrid passivation for improving of HfO_2/InGaAs MIS characteristics

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HfO_2 is promising as one of the higher-k materials for next-generation gate stack while III-V compound semiconductors such as InGaAs have considerable potential as n-channel material for high performance MISFETs. Previous researches reported several techniques for improving of HfO_2/InGaAs MIS interface properties such as Al_2O_3 passivation [1], ALD temperature control [2], and Ga_2O_3 passivation by annealing process [3]. From our experiments, ultrathin Ga_2O_3-ALD passivation showed self cleaning of TMG on InGaAs and was very effective to improve Al_2O_3/InGaAs MIS structure [4]. Therefore in this paper, Ga_2O_3-ALD passivation was applied to investigate the effect on HfO_2/InGaAs MIS interface and Ga_2O_3 thickness was more controlled by hybrid Ga_2O_3 and Al_2O_3-ALD passivation.

MIS capacitors were fabricated on n-InGaAs(100) epitaxial wafers with doping concentration of 3 x 10^{16} cm^{-3}. Prior to ALD, all surfaces were treated in NH_4OH solution for 1 min and rinsed with deionized water. Then, 20-cycle Ga_2O_3 ALD, and hybrid 20-cycle Ga_2O_3 and 2-cycle Al_2O ALD were performed using $Al(CH_3)_3$, $Ga(CH_3)_3$, and H_2O as precursors at 250 °C to investigate the effect of these passivation layers. After that, 10-nm-thick HfO_2 gate insulator films were consecutively deposited using $[Hf(N(CH_3)_2)_4]_2$ and H_2O at same temperature. PDA was done in vacuum at 300 °C for 2 min. Au and Cr/Au were used as the gate electrode and back contact, respectively. Finally, PMA was performed in Ar at 350 °C for 2 min.

Figure 1 shows C-V characteristics of Au/HfO_2(10 nm)/InGaAs MIS structure without passivation, with Ga_2O_3 passivation, and hybrid Ga_2O_3 and Al_2O_3 passivation layers. 20-cycle Ga_2O_3 passivation reduced capacitance around V_{fb} and capacitance under the negative bias. Flat band voltage (V_{fb}) was shifted to negative but larger hysteresis was observed, compared to control sample. These results indicated increasing of negative fixed charges inside Ga_2O_3 passivation film. To reduce Ga_2O_3 film thickness and control atomic arrangement at the interface, 2-cycle Al_2O_3 passivation was supplied. From XPS measurement, Ga_2O_3 coverage was reduced from ~0.3 nm to ~0.2 nm and As oxide could not be detected after following with Al_2O_3 passivation. Hybrid passivation could more reduce frequency dispersion around V_{fb} and under accumulation, and gave negative shift of V_{fb}, compared to only Ga_2O_3 passivation.

Figure 2 shows interface trap density (D_{it}), evaluated by high-low frequency method. It is clear that D_{it}(min) was most reduced by hybrid 20-cycle Ga_2O_3 and 2-cyle Al_2O_3 passivation for HfO_2/InGaAs MIS structure. Minimum D_{it} as low as 3.83×10^{12} $cm^{-2}eV^{-1}$ was achieved. This study is granted by JSPS through FIRST program initiated by CSTP.

[1] R. Suzuki, *et al.*, APL 100, 132906 (2012); [2] R. Suzuki, *et al.*, APL 112, 084103 (2012); [3] Oda, *et al.*, present in ISDRS 2013; [4] W. Jevasuwan, *et al.*, APEX 7, 011201 (2014).

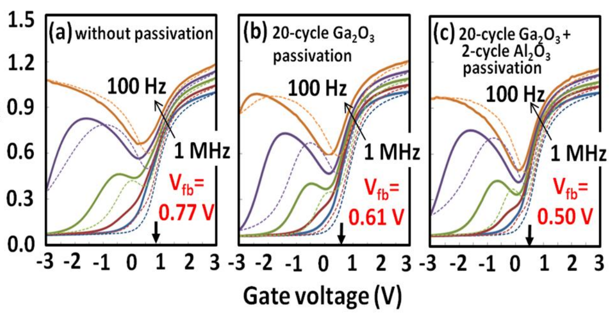

Fig. 1 C-V characteristics of Au/HfO_2(10 nm)/InGaAs MIS structure (a) without passivation, (b) with 20-cycle Ga_2O_3 passivation, and (d) with hybrid passivation of 20-cycle Ga_2O_3 and 2-cycle Al_2O_3.

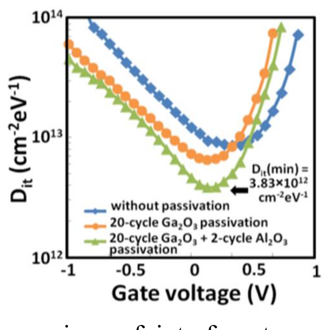

Fig. 2 Comparison of interface trap densities (D_{it}), evaluated by high-low frequency method, between Ga_2O_3 and hybrid passivations.