Improvement of Al$_2$O$_3$/InGaAs Interfaces by Ultrathin Ga Oxide Passivation

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Fig. 2 Comparison of interface trap densities (D$_{it}$) with different GaO$_x$ passivation cycle of 0, 30, and 50 cycles.

Fig. 1 C-V characteristics for (a) ALD-Al$_2$O$_3$ (10 nm)/50-cycle ALD-GaO$_x$/InGaAs, (b) ALD-Al$_2$O$_3$ (10 nm)/30-cycle ALD-GaO$_x$/InGaAs, and (c) ALD-Al$_2$O$_3$ (10 nm)/50-cycle ALD-GaO$_x$/InGaAs structures with Au electrodes. 30-cycle GaO$_x$ interface layer reduced capacitance under the negative bias, but 50-cycle one bounded back these capacitances. Frequency dispersions around $V_{fb}$ and under accumulation were slightly affected by the GaO$_x$ insertion as compared to the control sample. Figure 2 shows interface trap density (D$_{it}$) with different GaO$_x$ deposition cycles, estimated by conductance method [assuming $D_N = 2.5q/5Gp(0)$. It is clear that $D_N$ around the midgap of InGaAs bandgap was reduced extensively by 30-cycle GaO$_x$ insertion. Minimum $D_N$ as low as 2.4x10$^{11}$ cm$^{-2}$ eV$^{-1}$ was achieved. MOSFET performances also showed the improvement of effective mobility by ultrathin GaO$_x$ passivation. This study is granted by JSPS through FIRST program initiated by CSTP.

Recently, high-k/III-V interface control has been investigated extensively for MOSFET applications. Previous studies have shown that the interface GaO$_x$ species on GaAs and InGaAs surfaces may be the most important key issue for III-V interfacial control [1-5].

Analog to Al$_2$O$_3$ ALD using the Al(CH$_3$)$_3$ (TMA) precursor would suggest GaO$_x$ growth by using Ga(CH$_3$)$_3$ (TMG). However, ALD of GaO$_x$ films using TMG is known to be difficult [6]. In this paper, we report the growth of ultrathin GaO$_x$ layer using TMG and the impact of GaO$_x$ passivation on Al$_2$O$_3$/In$_{0.53}$Ga$_{0.47}$As MOS structure.

GaO$_x$ growth carried out by repeating the cycle of TMG and H$_2$O supplies at 250 °C. The oxide thicknesses were measured by spectroscopic ellipsometry with using the reference refractive-index data for GaO$_x$. GaO$_x$ growth on GaAs and InGaAs substrates could be detected when the deposition was continued for more than 30 cycles. The GaO$_x$ film thickness was becoming saturated at ~0.40 nm with the deposition cycle of up to 150 cycles. These results revealed that ultrathin GaO$_x$ layers can be grown while thick GaO$_x$ films could not be formed. With 30-cycle GaO$_x$ ALD growth, XPS spectra confirmed the monolayer growth on InGaAs surface. GaO$_x$ thickness from XPS measurement was 0.11 nm, which was consistent well with ellipsometry result. Using TMG, self-limiting growth of ultrathin GaO$_x$ layer on GaAs and InGaAs substrates can be realized. Self-cleaning effect of AsO$_x$ by TMG was also observed similarly to TMA.

We investigate the effect of ultrathin interfacial GaO$_x$ layer on the Al$_2$O$_3$/InGaAs MOS structure. Prior to ALD, the n-InGaAs/InP(100) substrates were treated in NH$_3$/H$_2$O solution for 1 min and rinsed in deionized water. GaO$_x$ and Al$_2$O$_3$ deposition was carried out consecutively at 250 °C. The deposition cycle number of GaO$_x$ was varied from 0, 30 and 50. Post deposition annealing was done in vacuum at 400 °C for 2 min and the post metallization annealing was performed in Ar at 350 °C for 2 min. Figure 1 shows C-V characteristics for (a) ALD-Al$_2$O$_3$ (10 nm)/InGaAs, (b) ALD-Al$_2$O$_3$ (10 nm)/30-cycle ALD-GaO$_x$/InGaAs, and (c) ALD-Al$_2$O$_3$ (10 nm)/50-cycle ALD-GaO$_x$/InGaAs structures with Au electrodes.

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