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Controlling anion composition at MIS interfaces on III-V channels by plasma processing

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1. Introduction

Scaling limit of Si LSIs has prompted intensive studies on MISFETs incorporating high-mobility materials such as Ge and III-V semiconductors. In order to form high-quality III-V MIS interfaces, the compositions and bonding structures of the cations and anions at the interface should be properly controlled [1]. We recently reported that deposition of SiO_2 or Al_2O_3 on nitride InGaAs formed the MIS interfaces that exhibit good capacitor characteristics [2]. Here the nitride layer formed by ECR plasma was thicker than 1 nm. From the viewpoint of EOT scaling, thinner nitride layers are preferable. In this paper, we investigate the effects of plasma cleaning and nitridation (< 0.5 nm) on InGaAs using on-line Auger electron spectroscopy (AES). Electrical characterization has shown that such lightly-nitrided Al_2O_3/InGaAs interfaces also show good MIS characteristics.

2. Experimental Procedures

Experiments were carried out using a high-vacuum compatible ALD system which was equipped with a remote RF plasma source and an analysis chamber for AES (Fig. 1). In order to fabricate MIS capacitors, n-type $In_{0.53}Ga_{0.47}As$(100) epitaxial wafers with doping concentration of 3 x 10^{16} cm^{-3} were etched in an NH_4OH solution for 1 minute. The InGaAs surface was then subjected to plasma cleaning using H_2 and/or plasma nitridation using N_2 at 250 °C under the RF power of 300 W. ALD of Al_2O_3 was carried out using trimethylaluminium ($Al(CH_3)_3$) and H_2O at 250 °C. A high $Al(CH_3)_3$ dose was used in the first and second ALD cycles to enhance the interface-forming reaction [3]. Finally, post deposition annealing was done at 400 °C for 2 minutes prior to the Au electrode deposition.

3. Experimental results and Discussion

Changes of the InGaAs surface by plasma cleaning/ nitridation are shown in Fig. 2. N KLL and O KLL signals were normalized with respect to In MNN intensity. NH_4OH-etched InGaAs is covered with the surface oxide as shown by the O KLL signal (Fig. 2(a)). H_2 plasma cleaning effectively removes this oxide layer (Fig. 2(b)). Plasma-nitrided surface clearly shows the N KLL signal which partly overlaps with In MNN (Fig. 2(c)). By combining the plasma cleaning and nitridation (Fig. 2(d)), the surface is covered mainly by a nitride layer containing a small amount of oxygen which might come from the residual oxygen in the present plasma chamber.

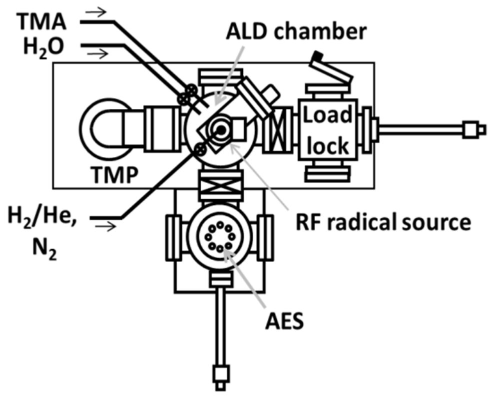

Fig. 1 Experimental setups of a high-vacuum compatible ALD system equipped with AES and remote RF plasma source.

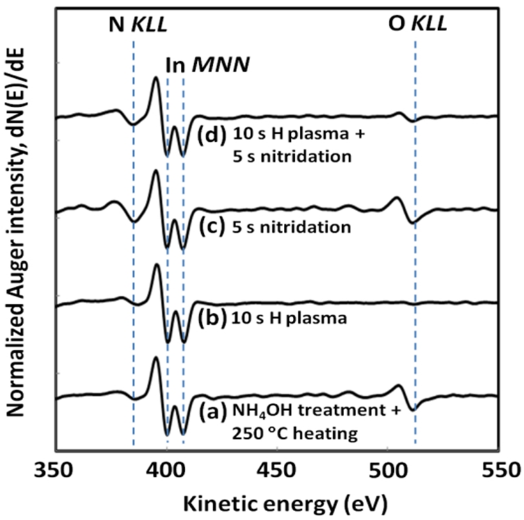

Fig. 2 AES spectra of InGaAs(100) substrate after various surface treatments at 250 °C.

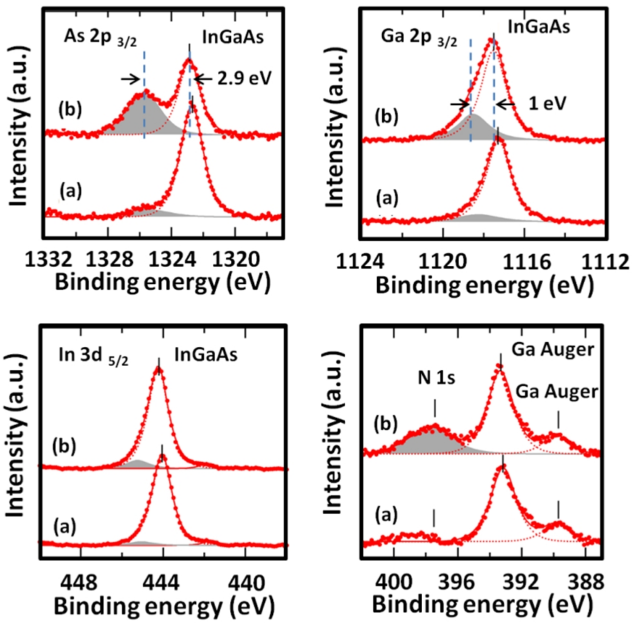

Fig. 3 Ga *2p*, As *2p*, In *3d* and N *1s* XPS spectra of Al_2O_3 (~1 nm)/InGaAs. Initial InGaAs surfaces were treated at 250 °C by (a) 10 s H_2 plasma and (b) 10 s H_2 plasma and 5s nitridation.

In order to probe the coverage and bonding states of N at the interface, the InGaAs surfaces with 1 nm-thick Al_2O_3 cap layer were analyzed by XPS (Fig. 3). Spectra (a) and (b) in each plot are for the cases of plasma cleaning only and plasma cleaning/nitridation combination, respectively. N 1s peak, which is overlapped with the tail of the Ga Auger peak, is clearly observed for the nitride interface. The N coverage is estimated to be approximately 2 monolayer (~0.5 nm) from the ratio of N 1s to In $3d_{5/2}$. Ga $2p_{3/2}$ and As $2p_{3/2}$ peaks have a component with chemical shift of 1.0 and 2.9 eV, respectively. This result indicates that both Ga-N and As-N bonds exist at the lightly-nitrided Al_2O_3/InGaAs interface. The chemical shift for Ga $2p_{3/2}$ agrees with that reported for the thick nitride [2], suggesting that N is the dominant anion at the interface.

The plasma cleaning and nitridation affect the MIS properties in distinct manners. Figure 4 compares the C-V characteristics for the Al_2O_3/InGaAs interfaces prepared with plasma cleaning only (a) and cleaning/nitridation combination (b). Reduction of the frequency dispersion under accumulation by plasma cleaning and nitridation indicates the smaller interface traps densities (D_{it}). Table I summarized the MIS capacitor properties for various surface treatment conditions. The ratio of the 100 and 1 MHz capacitances by measuring at V_{fb}+1V was used to quantify the frequency dispersion under accumulation. D_{it} was estimated by high/low frequency method. The MIS interfaces with nitridation shows well-behaved characteristics with nearly ideal V_{fb} and low D_{it}. H_2 plasma cleaning without nitridation degraded the properties as evidenced by a large positive shift in V_{fb} and increases in D_{it} and frequency dispersion under accumulation. These degraded properties can be recovered by adding the nitridation treatment as seen in Table I.

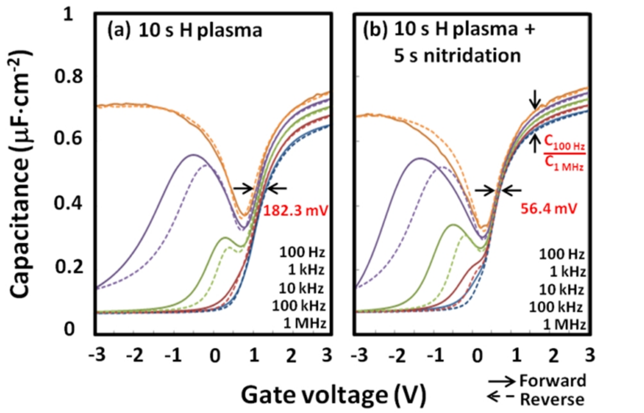

Fig. 4 C-V characteristics of Au/Al_2O_3(6 nm)/ n-InGaAs(100) capacitors with (a) 10 s H plasma and (b) 10 s H plasma with 5s nitridation at 250 °C.

Table I. Summary of MIS capacitor properties. V_{fb} is calculated for the 1 MHz data (Ideal V_{fb} = +0.55 V). D_{it} was estimated by high/low frequency method.

Conditions	V_{fb} shift (V)	Dit minimum ($\times 10^{12}$ $cm^{-2}eV^{-1}$)	$C_{100\ Hz}/C_{1\ MHz}$ @ V_{fb} +1 V
No plasma	+0.22	2.0	1.11
10 s H plasma	+0.47	3.5	1.62
5 s nitridation	0	1.3	1.10
10 s H plasma + 5 s nitridation	-0.07	1.2	1.09

Conclusions

The Al_2O_3/InGaAs capacitors with ~2 monolayer nitride interfaces showed well-behaved C-V characteristics. The H_2 plasma cleaning, which effectively removed the surface oxides of InGaAs, degraded the electrical properties, whereas the subsequent nitridation restored the MIS characteristics.

Acknowledgment

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References

[1] T. Yasuda *et al.*, Mater. Res. Soc. Symp. Proc. **1194E** (2010) A08-07-01~12.
[2] T. Hoshii *et al.*, Appl. Phys. Lett. **97** (2010) 132102.
[3] W. Jevasuwan *et al.*, presented at *the 2011 MRS Spring Meeting (San Francisco, April, 2011).*