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Interface characterization of Al_2O_3/AlGaN/GaN structure with inductively coupled plasma etching of AlGaN surface

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1. Introduction

AlGaN/GaN-based high electron mobility transistors (HEMTs) are promising for high power-switching devices, owing to its high-blocking voltage and low on-state resistance. To realize normally-off operation, a combination of recessed and insulated gate is often used to AlGaN/GaN HEMTs. The critical processes for fabricating such devices are the plasma-assisted dry etching to form the recessed gate region and the subsequent formation of insulator-semiconductor interface, because the interface quality affects seriously on the transistor performance. To obtain stable and reliable recessed oxide gate structures, a low electronic state density at the insulator/AlGaN interface is absolutely needed. However, little is known about the properties of the insulator/AlGaN/GaN interface employing dry-etched AlGaN surface. In this work, effects of the Cl_2-based ICP etching of AlGaN on interface properties of the Al_2O_3/AlGaN/GaN structures prepared by ALD was investigated, focusing on the interface state density distribution using a photo-assisted *C-V* measurement [1,2].

2. Experiment

Figure 1 shows the sample structure of the Al_2O_3/AlGaN/GaN MOS diode. The $Al_{0.2}Ga_{0.8}N$/GaN heterostructure with an AlGaN layer thickness of 34 nm was used in this work. The mobility and sheet resistance of two dimensional electron gas (2DEG) are 1754 cm^2/Vs and 496 Ω/sq., respectively. The AlGaN surface was etched by the ICP process with a Cl_2/BCl_3 gas mixture. The ICP and bias powers were 300 W and 5 W, respectively. The etching depth was 7 nm. An Al_2O_3 film with a nominal thickness of 20 nm was deposited on the sample surface by ALD.

3. Results & discussion

Figure 2 shows the typical capacitance-voltage (*C-V*) characteristics of the Al_2O_3/AlGaN/GaN structures at room temperature (RT). For the sample without the ICP etching, we observed an almost constant capacitance (C_{TOTAL}) determined by the Al_2O_3 and AlGaN layers in the bias range between -7 and -1V. The ICP-etched sample showed higher constant capacitance from -3 to 1V bias range. This results from difference in AlGaN layer thickness between the two samples. Furthermore, it is worth noting that the

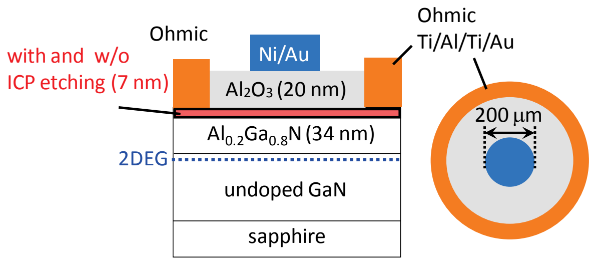

Fig. 1 Schematic illustration of Al_2O_3/AlGaN/GaN MOS diode.

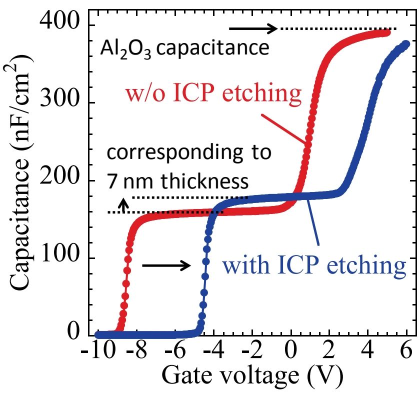

Fig. 2 The typical *C-V* characteristics of the Al_2O_3/AlGaN/GaN MOS diode with and without ICP etching at RT.

ICP-etched sample showed a *C-V* curve with a stretch-out of the *C-V* curve in the forward bias region. This result indicates that high-density electronic states at the Al_2O_3/AlGaN interface depress potential control of the AlGaN surface owing to the ICP etch-induced damage. Due to the depletion of 2DEG [3], we observed steep decreases in capacitance at the negative bias V_{th}, namely, the typical V_{th} values of the unetched and ICP etched samples were around -9 and -5V, respectively. However, we could not measure the thermal emission of electrons trapped at the midgap or deeper interface states at RT [1], because of an extremely long time constant for electron emission to the conduction band [1,2]. In this case, therefore, the interface states act as fixed charges, indicating the difficulty for estimating the interface states using the *C-V* measurement at RT.

Thus, photo-assisted *C-V* measurements were performed to evaluate near-midgap interface states [1,3]. Fig. 3 shows the photo-assisted *C-V* results. While under a deep

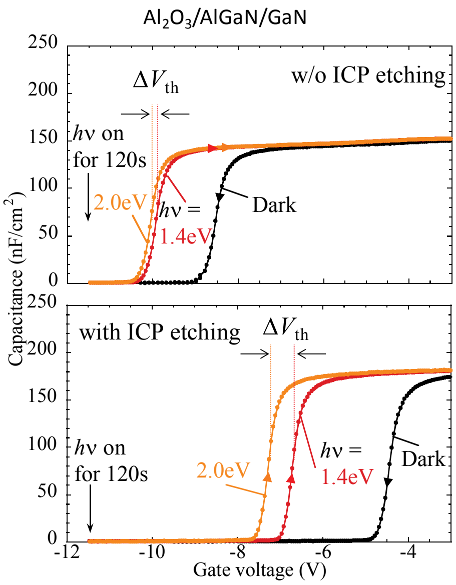

Fig. 3 The typical photo-assisted *C-V* characteristics of the Al_2O_3/AlGaN/GaN MOS diode with and without ICP etching.

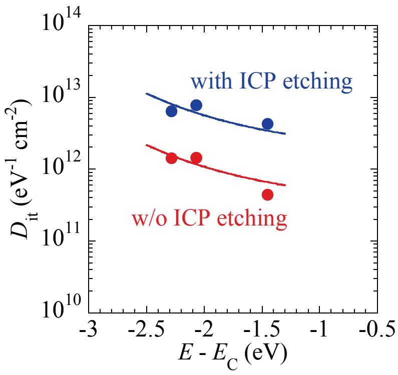

Fig. 4 Interface state density distributions estimated from photo-assisted *C-V* shifts as a function of interface potential energy at Al_2O_3/AlGaN.

negative bias, the sample surface was illuminated with a monochromatic light with photon energy of less than the bandgap of AlGaN. Consequently, we have observed the photo-assisted electron emission from the interface states with the energy range corresponding to the photon energy. This led to clear parallel *C–V* shifts towards the negative bias direction. As shown in Fig. 3, we observed the larger *C-V* shift (ΔV_{th}) between two photon energies for the sample with the ICP etching, indicating the higher state density at the Al_2O_3/AlGaN interface. To estimate the interface state density distribution D_{it} from the ΔV_{th} between two *C-V* curves with two photon energies, we use the following equation [1,3]:

$$D_{it} = (E = E_{AVG}) = \frac{C_{TOTAL}\Delta V_{th}}{q\Delta h\upsilon} \quad (1)$$

where $\Delta h\nu$ is the difference between two photon energies and E_{AVG} is the average interface energy. Fig. 4 shows the interface state density distribution determined by photo-assisted *C-V* measurement. Higher-states densities are

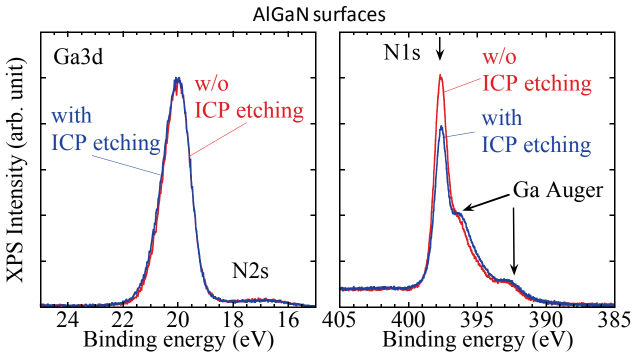

Fig. 5 (a) Ga3d and (b) N1s core level XPS spectra of the AlGaN surfaces with and without the ICP dry etching.

found at the Al_2O_3/AlGaN interface for the ICP-etched sample (8×10^{12} $cm^{-2}eV^{-1}$ or higher).

To investigate possible reason for the degradation of the interface properties at the Al_2O_3/AlGaN interface with ICP etching, we examined the chemical properties of the ICP-etched surface by X-ray photoelectron spectroscopy (XPS). Fig. 5 shows Ga3d and N1s core level XPS spectra of the AlGaN surfaces. The AlGaN surfaces before and after the ICP etching showed very similar Ga3d and N2s spectra, as shown Fig. 5(a). However, a slight increase in the line width was observed after ICP etching, indicating a slight disorder of chemical bonds at the AlGaN surface, resulting in high-density electronic states as a continuous energy level. Furthermore, the ICP etching process led to the decrease in the N1s XPS intensity as shown Fig. 5(b), indicating a preferential loss of N atoms from the AlGaN surface due to the ICP etching. During the ICP etching using the Cl_2/BCl_3 mixture, active Cl* and Cl_3* species are able to react with the AlGaN surfaces to form volatile products such as $GaCl_3$ and $AlCl_3$. In addition, NCl_3 can be produced by reaction between Cl-based radicals and N atoms. Thus, it seems that the formation of highly volatile NCl_3 causes a preferential loss of N atoms at the AlGaN surface, resulting in high-density electronic states including nitrogen vacancies (V_N) at the Al_2O_3/AlGaN interface.

4. Conclusion

The ICP etching caused slight disorder chemical bonds at the AlGaN surface and generation of formation V_N-related defects, resulting in poor *C-V* behavior. Photo-assisted *C-V* measurement technique was applied to evaluate the state density distribution at the Al_2O_3/AlGaN interface. For the ICP-etched sample, higher interface state densities were found at the Al_2O_3/AlGaN interface.

References

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