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Impacts of Dry Etching of GaN and AlGaN Surfaces on Interface Properties of GaN-based MOS Structures

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1. Introduction

In a normally-off AlGaN/GaN HEMT with a recessed gate structure, a turn-on operation starts at a forward bias. Therefore, many groups have reported the normally-off HEMTs with recessed MOS gates. An insulated-gate structure can reduce gate leakage current and enhance the dynamic range of device operation. However, there remains anxiety that the plasma environment during the dry etching of AlGaN for the recessed gate structure induces various types of damage in the AlGaN layer and/or the 2DEG channel region.

The purpose of this study is to investigate impacts of dry etching of GaN and AlGaN surfaces on interface properties of GaN-based MOS structures.

2. Experiments

We used n-GaN and AlGaN/GaN layers grown by MOCVD. The 3-µm n-GaN layer doped with Si of 6 x 10^{16} cm^{-3} was grown on a free-standing GaN substrate (provided by Hitachi Cable Co.) with a dislocation density less than 2 x 10^6 cm^{-2}. For the AlGaN/GaN heterostructure on sapphire, a composition and a thickness of the barrier layer are 0.25 and 25 nm, respectively.

Figure 1 shows sample structures. To check crystalline quality and a donor density of the n-GaN layer on free-standing GaN substrate, a Ni/Au Schottky contact was formed on the n-GaN surface. For the MOS diode, the Al_2O_3 layer with thickness of 20 -25 nm was deposited on the n-GaN surface by atomic layer deposition (ALD). In ALD process, gas-phase precursors, H_2O as O source and trimethylaluminum (TMA) as Al source, are introduced into the reactor chamber in alternate pulse forms. The deposition was carried out at 300 °C. After the Al_2O_3 deposition, a post-annealing was carried out at 400 °C in N_2.

We have compared the interface properties of the Al_2O_3/n-GaN/n^+-GaN MOS samples with and without dry etching of the GaN surface, as shown in Fig. 1 (b). In the dry etching process at RT, we used reactive ion-beam etching system assisted using an electron-cyclotron-resonance (ECR) plasma with a gas mixture of $CH_4/H_2/Ar/N_2$. The etching rate is about 20 nm/min when we use a microwave power of 200 W and an acceleration voltage of 300 V.

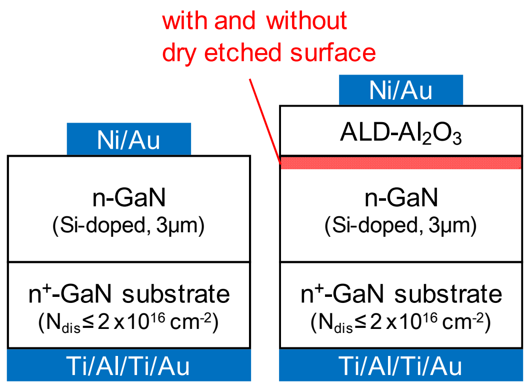


Fig.1 Sample structures for (a) Schottky and (b) MOS diodes.

3. Results and discussion

Figure 2 (a) shows typical I-V characteristics of the GaN Schottky diode measured at RT. A good linearity was seen at forward bias in the log (J)-V curve, as shown in the

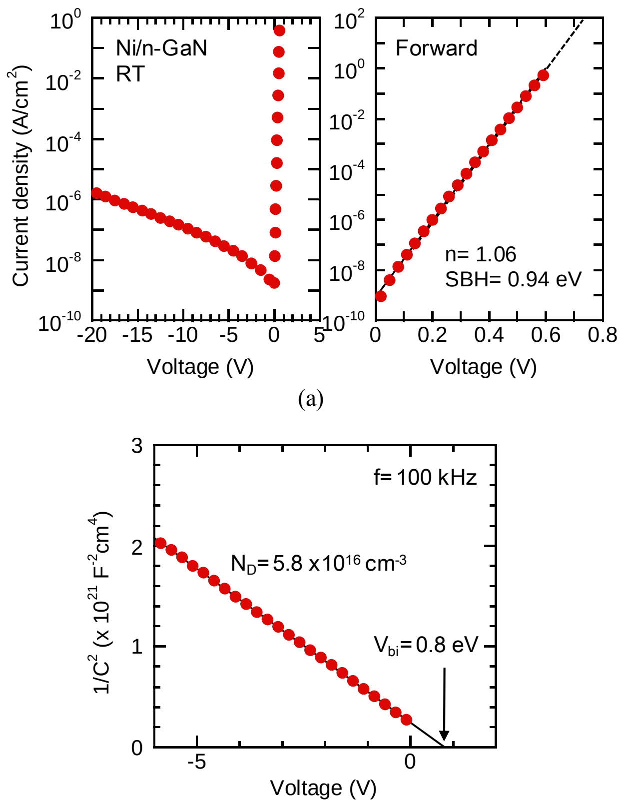
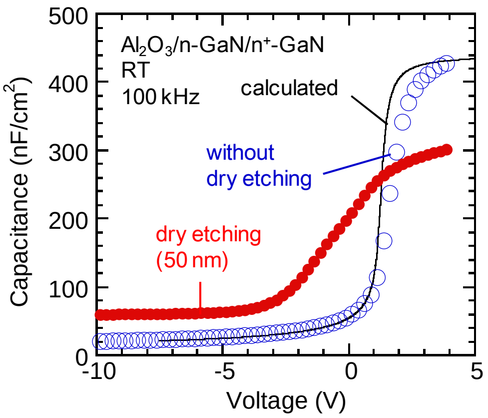


Fig.2 (a) I-V and (b) $1/C^2$-V characteristics of the Schottky sample.

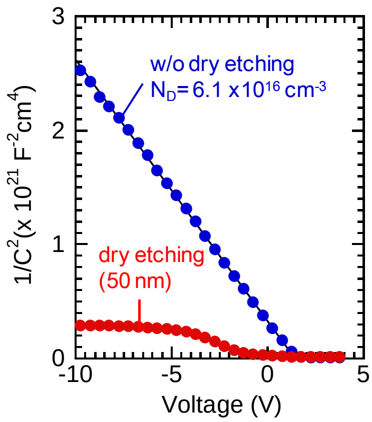
right-hand figure. We obtained a low ideality factor of 1.06 and a relatively high Schottky barrier height (SBH) of 0.94 eV. In the reverse bias region, in addition, low leakage currents with weak voltage dependence are observed. Suda et al. [1] very recently reported similar I-V results on the Ni contact on the HVPE-grown GaN substrate with low dislocation densities. An excellent linearity of $1/C^2$–V characteristics was observed in a wide range of reverse bias, as shown in Fig. 2 (b). From the $1/C^2$–V slope, we obtained the net donor concentration of 5.8 x 10^{16} cm^{-3}. In addition, the built-in potential (V_{bi}) observed gave SBH = 0.95 eV that is very close to that obtained by I-V characteristics. These results indicate that the epitaxial GaN layer grown on the free-standing GaN substrate with a low density of dislocation has high crystalline quality.

Figure 3 (a) shows typical C-V characteristics of Al_2O_3/n-GaN/n^+-GaN structures with and without dry etching of n-GaN surfaces. The solid line shows a theoretical curve using the donor density of 6.0 x 10^{16} cm^{-3}, the Al_2O_3 thickness of 20 nm and the Al_2O_3 permitivity of 9.5.

For the sample without dry etching process, the measured C-V curve is close to the ideal one (deep-depletion mode) calculated without assuming interface states. This indicates relatively low state densities at the Al_2O_3/n-GaN interface, probably arising from the high crystalline quality

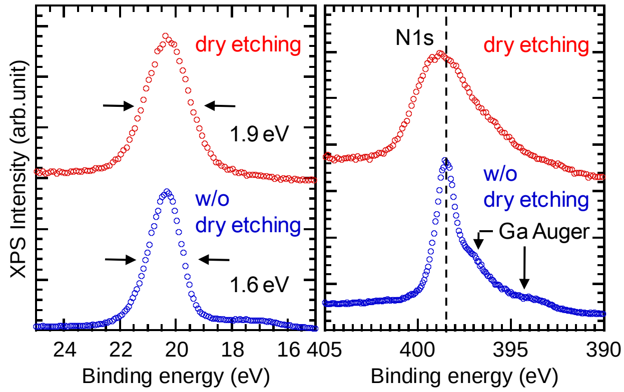


(a)



(b)

Fig.3 (a) C-V and (b) $1/C^2$-V plots of MOS samples with and without dry etching of AlGaN surface.



(a) (b)

Fig.4 XPS spectra for (a) Ga3d and (b) N1s core levels from the GaN surfaces.

of the n-GaN layer and the low-energy ALD process. On the other hand, the sample with dry-etched GaN surface showed poor C-V behavior, i.e., a lower accumulation capacitance and a nearly plateau behavior appeared at reverse bias.

The $1/C^2$-V plots for the MOS diodes are shown in Fig. 3 (b). An excellent linear behavior was observed for the sample without dry etching process, and the donor concentration calculated is very close to that from the Schottky C-V measurement. This demonstrates good control of depletion layer by the gate bias. For the sample with dry-etched GaN surface, the slope is much gentle and the capacitance variation is strongly impeded at bias less than -3V, indicating a limited movement of the surface potential due to the existence of high-density electronic states at the Al_2O_3/n-GaN interface.

Figure 4 shows Ga3d and N1s core level spectra from the GaN surfaces before and after the dry etching process. After the dry etching, the FWHM of the Ga3d spectrum clearly increased. Moreover, a separation between the N1s and Ga Auger lines becomes vague. These results exhibited disorder of chemical bonds, including a deficiency of N atoms, at the dry-etched GaN surface. It is likely that such crystalline degradation is responsible for poor C-V behavior. A preliminary experiment showed that N_2-radical treatment and/or an annealing process is effective in improving interface properties of the MOS structure with dry-etched GaN surface.

References

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