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Hydrazine (N_2H_4)-Based Surface Treatment Method for AlGaN/GaN MIS-HEMTs with A High Quality Interface

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Abstract

This letter reports a AlGaN/GaN high electron mobility transistors (HEMTs) with a high quality insulator/III-nitride interface using N_2H_4 treatment prior to Al_2O_3 deposition. A decomposition of native oxide is revealed by X-ray photoelectron spectroscopy (XPS), and a good AlGaN/GaN surface roughness is observed by atomic force microscopy (AFM). A gate stress dependent transfer curve sweep exhibits the improved V_{th} hysteresis, indicating that N_2H_4 treatment effectively improves the AlGaN/GaN surface.

1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are regarded as one of the promising candidates for high power and high frequency applications, because of its high breakdown breakdown voltage (BV) and high saturation velocity. In order to obtain larger BV devices, metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) are preferred over the Schottky-gate HEMTs, owing to the suppressed gate leakage current and enlarged gate swing [1]. However, the gate insulator causes the trap states at the insulator/III-nitride interface, which leads to threshold voltage instability in MIS-HEMTs [2]. Up to present, various studies, such as surface cleaning and treatment, are conducted to improve the interface quality, by reducing surface contaminant and native oxide [3-5]. Although many researches have been investigated, surface treatment prior to insulator deposition, has not been intensively studied. In addition, no standard process is used for surface treatment.

In this paper, for the first time, we propose a surface treatment process on AlGaN/GaN HEMT using hydrazine (N_2H_4) treatment for improving the interface quality. The native oxide of the AlGaN/GaN surface is reduced by N_2H_4 treatment before Al_2O_3 deposition, and finally a high quality interface is obtained.

2. Device Fabrication

The AlGaN/GaN heterostructure was grown by metal-organic chemical vapor deposition (MOCVD) on sapphire substrate. The device structure consists of a 2 μm undoped GaN buffer layer, a 1 nm AlN interlayer, and a 25 nm AlGaN buffer layer. The sheet resistance and electron mobility were 1900 cm^2/Vs and 434 ohm/sq., respectively, by Hall measurement. Ti/Al/Ni/Au ohmic contact was formed by thermal evaporation and lift-off, followed by rapid thermal annealing at 900°C for 50 seconds in N_2 ambient. A planar device isolation process was performed by phosphorus-ion implantion. The contact resistance was measured to be 0.61-0.76 Ω·mm using transfer length method (TLM). Prior to Al_2O_3 passivation layer deposition, samples were cleaned in organic solutions and then dipped in hydrazine monohydrate (N_2H_4) for 20 minutes at room temperature for surface treatment. The sample was rinsed with deionized (DI) water and dried before loaded into atomic layer deposition (ALD) chamber. A 10 nm Al_2O_3 layer was deposited at 150°C using TMA/O_2 as precursors. Then, S/D contact windows were opened by selectively etching the Al_2O_3 by buffered oxide etchant (BOE). Finally, Ni/Au gate electrode was deposited by e-beam evaporation. AlGaN/GaN HEMT device without N_2H_4 treatment was also prepared as control devices. The device characterization was performed on AlGaN/GaN HEMTs with gate length = 4.5 μm, gate width = 100 μm, L_{GD} = 3.5 μm, and L_{GS} = 1 μm.

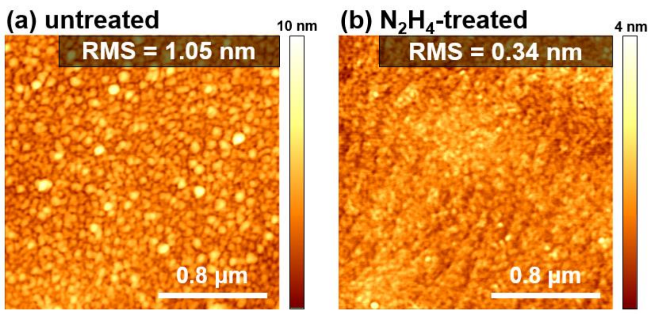

Fig. 1 AFM images and RMS values of the untreated (a) and N_2H_4-treated (b) AlGaN/GaN surface.

3. Results and Discussion

Fig. 1 shows the atomic force microscope (AFM) images and root mean square (RMS) values of the untreated (a) and N_2H_4-treated (b) AlGaN/GaN surface. After 20 minutes treatment, RMS value is reduced from 1.05 nm to 0.34 nm. To investigate this decrease in detail, X-ray photoelectron spectroscopy (XPS) analysis was performed on AlGaN/GaN surface after N_2H_4 treatment. Fig. 3 displays the Ga 3d and Al 2p core-level spectra of the AlGaN/GaN surface. As seen in Fig. 3 (a), the N_2H_4-treated sample has lower Ga-O peak intensity than the untreated sample. Similarly, Al-O peak intensity of the N_2H_4-treated sample is lower than that of the untreated sample in Fig. 3 (b). This decrease indicates that N_2H_4 effectively removes the native oxide component, which causes the trap states, due to its oxygen removing property.

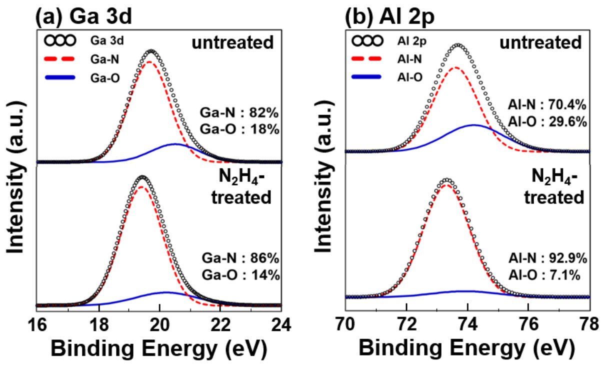

Fig. 3 Core-level Ga 3d (a) and Al 2p (b) XPS spectra of the AlGaN/GaN surface.

Fig. 4 shows the gate stress dependent transfer curves sweep of the untreated (a) and N_2H_4-treated AlGaN/GaN HEMT (b). Gate stress condition was i) V_{GS} up-sweep from -5 V to 1 V held at -5 V during 5 seconds, and ii) V_{GS} down-sweep from 1 V to -5 V held at 1 V during 5 seconds, respectively. V_{DS} was kept at 0.5 V to minimize the source-drain lateral electric field. V_{th} is defined as the gate bias at the drain current of 1 μA/mm.

A larger hysteresis (ΔV_{th}) of ~0.4 V and subthreshold swing (SS) of ~119 mV/dec are observed at untreated AlGaN/GaN HEMT in Fig. 4(a), which is believed to be caused by electron trapping at insulator/III-nitride interface. By contrast, AlGaN/GaN HEMT with N_2H_4 treatment exhibits a small hysteresis (ΔV_{th}) of ~0.05 V and subthreshold swing (SS) of ~105 mV/dec, indicating that trap sites could be reduced by N_2H_4 treatment. This confirms the effectiveness of the N_2H_4 surface treatment process prior to insulator deposition for MIS-HEMTs.

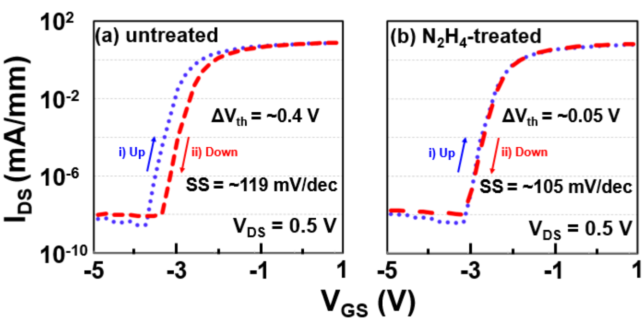

Fig. 4 Gate stress dependent transfer curves sweep of the untreated (a) and N_2H_4-treated (b) AlGaN/GaN HEMT.

3. Conclusions

In conclusions, for the first time, we demonstrate the N_2H_4 surface treatment process of AlGaN/GaN HEMT. After 20 minutes N_2H_4 treatment, the reduction of native oxide component (Ga-O/Al-O) was revealed by XPS and AFM analyses. To investigate the impact of this decrease on V_{th} hysteresis of AlGaN/GaN HEMT, gate stress dependent transfer curves was measured. A small hysteresis (ΔV_{th}) of ~0.05 V and subthreshold swing (SS) of ~105 mV/dec reveal that N_2H_4 treatment was effectively reduced the trap sites at insulator/III-nitride interface.

Acknowledgements

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