Hydrazine (N\textsubscript{2}H\textsubscript{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\textsubscript{2}H\textsubscript{4} treatment prior to Al\textsubscript{2}O\textsubscript{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\textsubscript{th} hysteresis, indicating that N\textsubscript{2}H\textsubscript{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\textsubscript{2}H\textsubscript{4}) treatment for improving the interface quality. The native oxide of the AlGaN/GaN surface is reduced by N\textsubscript{2}H\textsubscript{4} treatment before Al\textsubscript{2}O\textsubscript{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\textsuperscript{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\textsubscript{2} ambient. A planar device isolation process was performed by phosphorus-iron implantation. The contact resistance was measured to be 0.61-0.76 Ω·mm using transfer length method (TLM). Prior to Al\textsubscript{2}O\textsubscript{3} passivation layer deposition, samples were cleaned in organic solutions and then dipped in hydrazine monohydrate (N\textsubscript{2}H\textsubscript{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\textsubscript{2}O\textsubscript{3} layer was deposited at 150°C using TMA/O\textsubscript{2} as precursors. Then, S/D contact windows were opened by selectively etching the Al\textsubscript{2}O\textsubscript{3} by buffered oxide etchant (BOE). Finally, Ni/Au gate electrode was deposited by e-beam evaporation. AlGaN/GaN HEMT device without N\textsubscript{2}H\textsubscript{4} treatment was also prepared as control devices. The device characterization was performed on AlGaN/GaN HEMT with gate length = 4.5 μm, gate width = 100 μm, L\textsubscript{GD} = 3.5 μm, and L\textsubscript{GS} = 1 μm.

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\textsubscript{2}H\textsubscript{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\textsubscript{2}H\textsubscript{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\textsubscript{2}H\textsubscript{4}-treated sample has lower Ga-O peak intensity than the untreated sample. Similarly, Al-O peak intensity of the N\textsubscript{2}H\textsubscript{4}-treated sample is lower than that of the untreated.

![AFM images and RMS values of the untreated (a) and N\textsubscript{2}H\textsubscript{4}-treated (b) AlGaN/GaN surface.](image-url)
sample in Fig. 3 (b). This decrease indicates that N\textsubscript{2}H\textsubscript{4} effectively removes the native oxide component, which causes the trap states, due to its oxygen removing property.

![XPS spectra](image)

**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\textsubscript{2}H\textsubscript{4}-treated AlGaN/GaN HEMT. 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 \( \mu \text{A/mm} \).

A larger hysteresis (\( \Delta V_{th} \)) 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\textsubscript{2}H\textsubscript{4} treatment exhibits a small hysteresis (\( \Delta V_{th} \)) of ~0.05 V and subthreshold swing (SS) of ~105 mV/dec, indicating that trap sites could be reduced by N\textsubscript{2}H\textsubscript{4} treatment. This confirms the effectiveness of the N\textsubscript{2}H\textsubscript{4} surface treatment process prior to insulator deposition for MIS-HEMTs.

![Transfer curves](image)

**Fig. 4** Gate stress dependent transfer curves sweep of the untreated (a) and N\textsubscript{2}H\textsubscript{4}-treated (b) AlGaN/GaN HEMT.

3. Conclusions

In conclusions, for the first time, we demonstrate the N\textsubscript{2}H\textsubscript{4} surface treatment process of AlGaN/GaN HEMT. After 20 minutes N\textsubscript{2}H\textsubscript{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 (\( \Delta V_{th} \)) of ~0.05 V and subthreshold swing (SS) of ~105 mV/dec reveal that N\textsubscript{2}H\textsubscript{4} treatment was effectively reduced the trap sites at insulator/III-nitride interface.

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