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The improvement of Al_2O_3/AlGaN/GaN MISHEMT performance by N_2 plasma pretreatment*

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This paper discusses the effect of N_2 plasma treatment before dielectric deposition on the electrical performance of a Al_2O_3/AlGaN/GaN metal-insulator-semiconductor high electron mobility transistor (MISHEMT), with Al_2O_3 deposited by atomic layer deposition. The results indicated that the gate leakage was decreased two orders of magnitude after the Al_2O_3/AlGaN interface was pretreated by N_2 plasma. Furthermore, effects of N_2 plasma pretreatment on the electrical properties of the AlGaN/Al_2O_3 interface were investigated by x-ray photoelectron spectroscopy measurements and the interface quality between Al_2O_3 and AlGaN film was improved.

Keywords: Al_2O_3/AlGaN/GaN MISHEMT, atomic layer deposition, N_2 plasma pretreatment
PACC: 7340N, 7340Q

1. Introduction

The gate leakage current is an important factor that limits the performance and reliability of conventional high-power AlGaN/GaN high electron mobility transistors (HEMTs).[1] Thus, a thin dielectric oxide layer is often inserted between the gate metal and AlGaN barrier layer leading to the approach of the MOS HEMT.[1−7] Among them, Al_2O_3 is considered to be one of the potential candidates because of its relatively high dielectric (high-k) constant and wide band gap.

However, due to the difficulty in preparing an atomically cleaned surface before the deposition of the dielectric layer, surface pretreatment is required. Many works have reported how to improve the interface properties using ammonia (NH_3) pretreatment before atomic layer deposition (ALD) of high-k materials on Si or Ge substrates.[8,9] However, there is no report on atomic-layer-deposited Al_2O_3 on a plasma pretreated AlGaN substrate.

In this work, the electrical performance of an Al_2O_3/AlGaN/GaN metal-insulator-semiconductor (MIS) HEMT with Al_2O_3 deposited on acid-cleaned and N_2 plasma-treated AlGaN surface is presented. Then, in this work we also take C–V measurements and an x-ray photoelectron spectroscopy (XPS) measurement to study the impact of this technological procedure on the interface quality between the AlGaN epilayer and the Al_2O_3 film.

2. Device fabrication

The schematic illustration of a cross-sectional view of the fabricated device is shown in Fig.1. The AlGaN/GaN heterojunction structure was grown on a 5 cm c-face sapphire substrate by metal-organic chemical vapour deposition (MOCVD). This layer structure consisted of a 1 μm thick undoped-GaN layer and a 25-nm $Al_{0.3}Ga_{0.7}N$ barrier layer. Its measured room-temperature Hall mobility and sheet carrier concentration, they were 1230 $cm^2/(V{\cdot}s)$ and 1.0×10^{13} cm^{-2}, respectively.

Electrical isolation was made by forming a mesa structure with inductively coupled plasma etching with chlorine gas. In order to form the source and drain ohmic electrodes, Ti/Al/Ni/Au were deposited by electron beam evaporation and annealed by rapid thermal annealing at 830 °C for 30s in nitrogen gas ambient. Prior to the Al_2O_3 deposition, one of the wafers was etched in $HF:HCl:H_2O = 1:1:8$ solution

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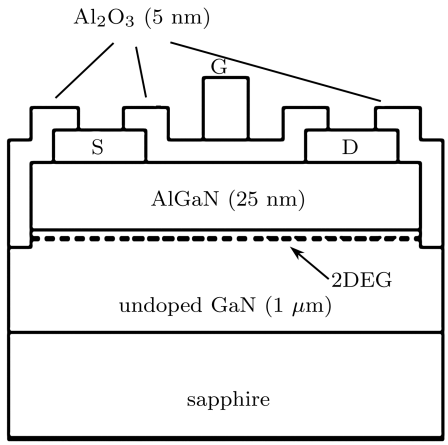


Fig.1. A schematic cross-section of AlGaN/GaN MISHEMT.

for 30s and pretreated by N_2 plasma for 3min in an inductively-coupled plasma chamber, while the other wafer was only etched in the above solution for 30 s. A 5 nm Al_2O_3 layer was deposited on two wafers at 300 °C. Ni/Au(20 nm/200 nm) was used for the gate electrode fabrication.

3. Results and discussion

Figure 2 shows the output characteristics of the AlGaN/GaN MISHEMT on each wafer with a gate length L_g of 1 μm and a gate width W_g of 120 μm. The pinch-off voltage is consistently –5 V. The drain current densities of the two devices are 790 and 815 mA/mm, the transconductance is 178 and 183 mS/mm, respectively. Biased at peak g_m, small-signal performance of MISHEMTs exhibits cut-off frequencies (f_t) of 10.26 GHz and 11.2 GHz, unilateral gain cutoff frequency (f_{max}) of 16.05 GHz and 20.1 GHz, as shown in Fig.3.

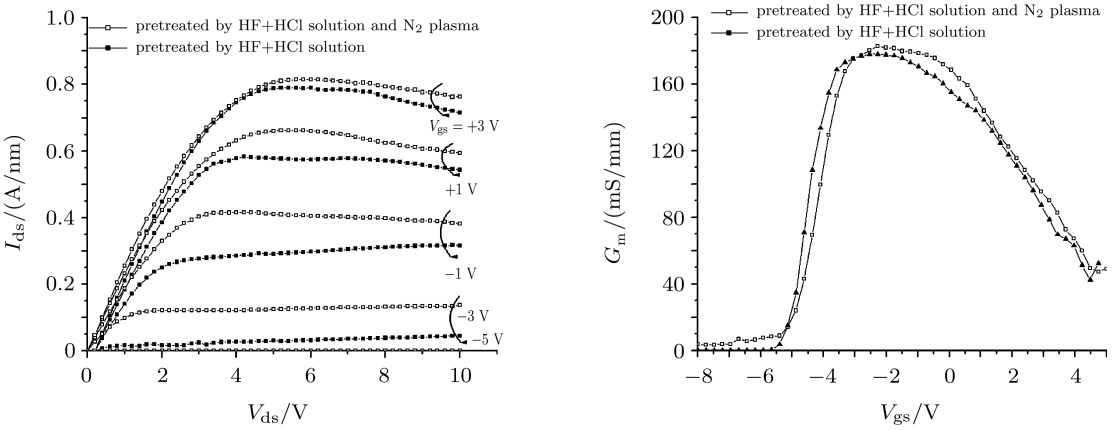


Fig.2. The output characteristics of the MISHEMT device on each wafer.

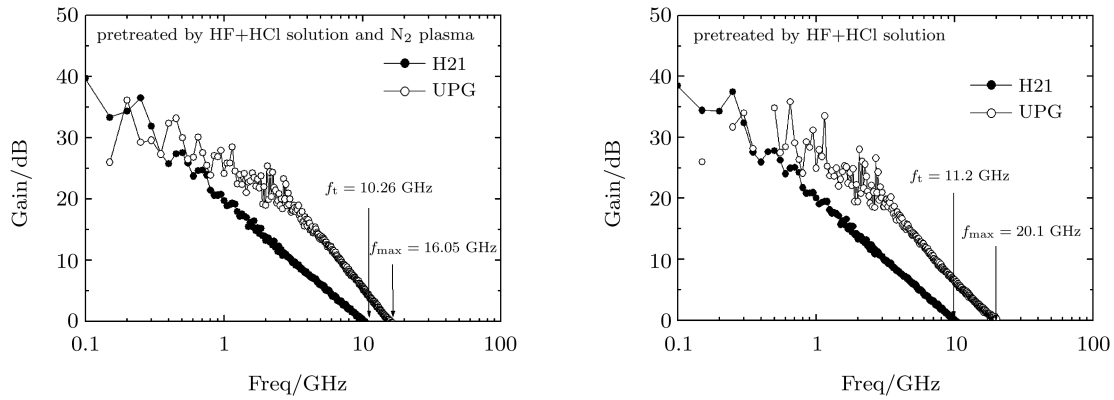


Fig.3. Small-signal results of the device.

In Fig.4, we show the gate leakage current for the devices on the two wafers. Specifically, under a negative gate bias $V_{gs} = -20$ V, the gate leakage current of the N_2 plasma-treated device before Al_2O_3 deposition is as low as 2 μA/mm, which is approximately two orders of magnitude smaller than that of the acid-solution-etched device. The gate–drain breakdown voltage of the two devices was 64 and 81.6 V at $I_g = 1$ mA/mm as shown in Fig.5, compared to the conventional AlGaN/GaN HEMT with the identical L_{gd} of 4 μm, which exhibits a breakdown voltage of 52 V.[10] This improvement in the breakdown voltage is attributed to the reduction of the gate leakage current by introducing the insulator between the AlGaN layer and the Shottky gate. Figure 6 presents the C–V characteristics measured at 1 MHz for gate capacitors of the devices on the two wafers. It is evident that a sharper rise is seen from depletion mode to accumulation mode obtained from the MOS capacitor with Al_2O_3 dielectric deposited on the acid solution etched and N_2 plasma treated AlGaN, compared to that obtained on only the (HF+HCl)-cleaned AlGaN. This indicates that the interface is much smoother and less interface shows capture and release of electrons during C–V measurements; the larger maximum capacitance in accumulation (C_{max}) ($C_{max} \sim 36.9$ pF vs 30.1 pF) shows that the dielectric permittivity is much larger. Hence the N_2 plasma pretreatment before Al_2O_3 deposition can effectively improve the interface property.

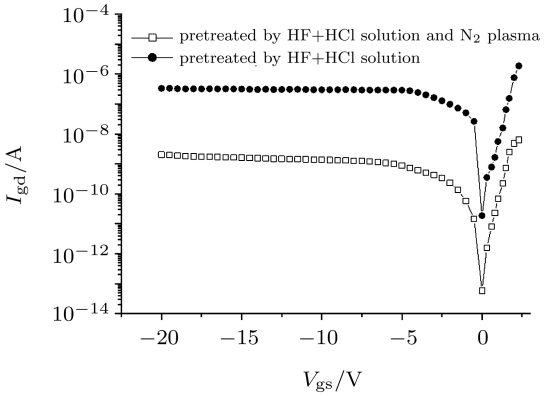


Fig.4. Gate leakage current of the MISHEMTs.

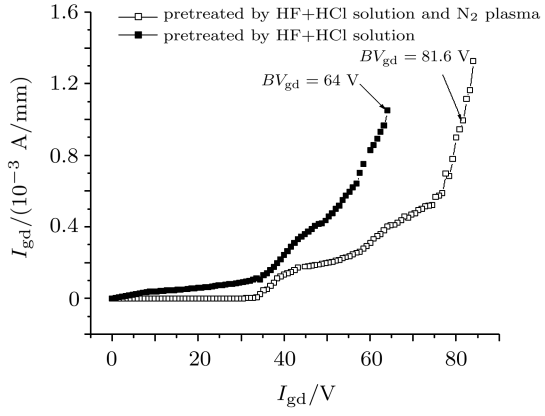


Fig.5. Gate–drain breakdown characteristics.

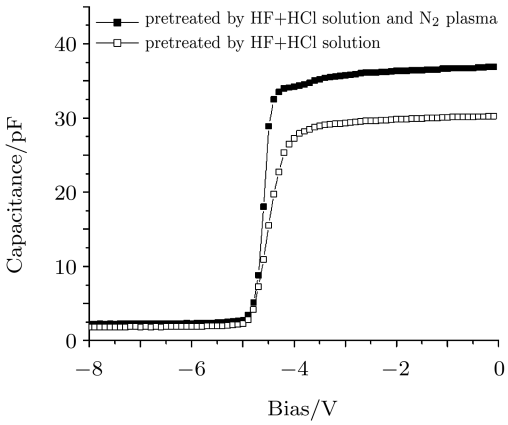
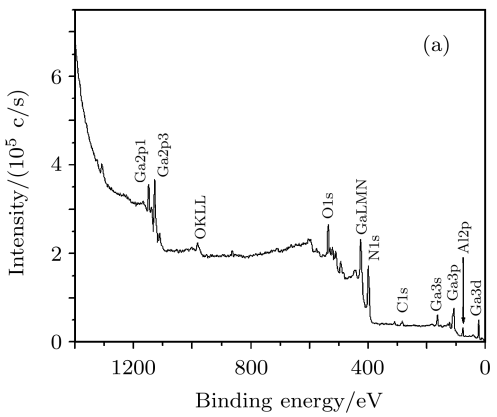


Fig.6. The 1 MHz C–V characteristics of a MOS capacitor.

In order to understand the effect of N_2 plasma pretreatment on the properties of the Al_2O_3/AlGaN interface, we take x-ray photoelectron spectroscopy (XPS) measurements on the samples. As shown in Fig.7, for the acid-cleaned AlGaN surface, the intensity of O1s is greater than that of the N_2 plasma treatment, while the intensity of Ga and Al is almost identical. The AlGaN epilayer is easily oxidized in air to form the Al–O and Ga–O compounds, during the acid treatment, the oxide of the AlGaN is partly removed, while after the N_2 plasma treatment, the oxidation of the AlGaN surface is prevented effectively.



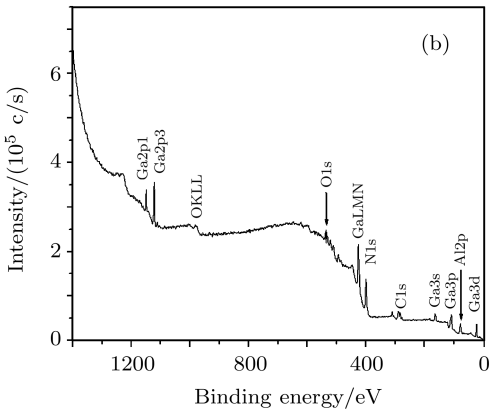


Fig.7. XPS spectra of two AlGaN/GaN samples pretreated differently. (a) pretreated by HF+HCl solution, (b) pretreated by HF+HCl solution and N_2 plasma.

4. Conclusion

We have studied the effects of N_2 plasma pretreatment and HF+HCl solution etching before Al_2O_3 deposition, on the output characteristics of Al_2O_3/AlGaN/GaN MISHEMTs. Although there are no obvious differences in the maximum output current and transconductance, the gate leakage current of the Al_2O_3/AlGaN interface after being pretreated by N_2 plasma is two orders of magnitude lower than that of the acid solution treated only. Moreover, the XPS measurements indicate that N_2 plasma pretreatment can improve the interface quality.

References

[1] Adivarahan V, Yang J, Koudymov A, Simin G and Khan M A 2005 *IEEE Electron Dev. Lett.* **26** 535

[2] Liu C, Chor E F and Tan L S 2007 *Semicond. Sci. Technol.* **22** 522

[3] Marso M, Heidelberger G, Indlekofer K M, Bernat J, Fox A, Kordos P and Luth H 2006 *IEEE Electron Dev. Lett.* **53** 1517

[4] Kordos P, Gregusova D, Stoklas R, Cico K and Novak J 2007 *Appl. Phys. Lett.* **90** 123513

[5] Dora Y, Han S, Klenov D, Hansen P J, No K, Mishra U K, Stemmer S and Speck J S 2006 *J. Vac. Sci. Technol.* B **24** 575

[6] Kuzmik J, Konstantinidis G, Harasek S, Hascfk S, Bertagnolli E, Georgakilas A and Pogany D 2004 *Semicond. Sci. Technol.* **19** 1364

[7] Khan M A, Hu X, Tarakji A, Simin G, Yang J and Gaska R 2000 *Appl. Phys. Lett.* **77** 1339

[8] Ye P D, Wilk G D, Yang B, Kwo J, Gossmann H J, Frei L M, Mannaerts J P, Sergent M, Hong M and Ng K K 2004 *J. Electron. Mater.* **33** 912

[9] Brewer R T, Ho M T, Zhang K Z, Goncharova L V, Starodub D G, Gustafsson T, Chabal Y J and Moumen N 2004 *Appl. Phys. Lett.* **85** 3830

[10] Guo L L, Feng Q, Hao Y and Yang Y 2007 *Acta Phys. Sin.* **56** 2895 (in Chinese)