Impact of UV/ozone surface treatment on AlGaN/GaN HEMTs

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Abstract: Surface treatment plays an important role in the process of making high performance AlGaN/GaN HEMTs. A clean surface is critical for enhancing device performance and long-term reliability. By experimenting with different surface treatment methods, we find that using UV/ozone treatment significantly influences the electrical properties of Ohmic contacts and Schottky contacts. According to these experimental phenomena and X-ray photoelectron spectroscopy surface analysis results, the effect of the UV/ozone treatment and the reason that it influences the Ohmic/Schottky contact characteristics of AlGaN/GaN HEMTs is investigated.

Key words: AlGaN/GaN HEMT; surface treatment; UV/ozone treatment; Ohmic/Schottky contact
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1. Introduction

AlGaN/GaN HEMTs have drawn a great deal of attention during the last few years because of their excellent output power ability, good power added efficiency and their high-frequency, high-temperature application potential. Great progress in material growth and device technologies has made these devices achieve excellent performance. Wu *et al.*[1] reported a saturated power density of 40 W/mm at 4 GHz, a peak PAE of 60%. Palacios *et al.*[2] boosted the power density up to 10 W/mm at 40 GHz. Recently, the devices reported by Kumar *et al.*[3] exhibited f_T of 82 GHz and f_{max} of 103 GHz.

The process of making AlGaN/GaN HEMTs requires multiple photolithography steps, metal deposition steps and dry/wet etching steps. During the process, the wafer may be polluted by metallic impurities, particulates, oxides and organic contaminants[4]. In order to fabricate a device with high performance and good reliability, it is crucial to remove these contaminants before each step by appropriate surface treatment. In this paper, we present some experimental phenomena to demonstrate that UV/ozone treatment can influence the electrical properties of Ohmic contacts and Schottky contacts. Meanwhile, we present a detailed analysis of the effect of UV/ozone treatment on AlGaN/GaN HEMTs. The experimental results show that UV/ozone treatment has two major effects on the HEMTs. First, the treatment can effectively remove the carbon (C) and organic contaminants which are often inevitably induced by residual photoresist from the GaN or AlGaN surface, to provide a clean surface for metal deposition and other processing steps. Second, UV/ozone treatment can significantly influence the electrical characteristics of Ohmic/Schottky contacts, which can be attributed to the formation of a thin oxide on the GaN or AlGaN surface acting as a passivation layer after UV/ozone treatment.

2. Experiment and discussion

2.1. Impact on Ohmic contact

The AlGaN/GaN HEMT material structure employed in this paper is provided by the Institute of Semiconductors, Chinese Academy of Sciences. In this sample, AlGaN/GaN epilayers were grown on sapphire substrate, and the AlGaN barrier had a thickness of 250 Å with an Al content of 25%. AlGaN/GaN HEMTs were fabricated by first depositing a Ti/Al/Ni/Au metal stack for the Ohmic contacts followed by annealing at 890 °C for 50 s in N_2 atmosphere, and nitrogen ion implantation was used for isolation. Two samples, A and B, which were diced from the same wafer were used in this experiment. The devices with 60 μm × 1 gate width were measured; in sample A we found that the current between drain and source was 0.56 A/mm and unsymmetrical under −10 to 10 V test voltage in steps of 100 mV. Then this sample was put in the ultraviolet/ozone cleaning system for 30 min; through point to point testing the current change was found to be symmetrical and was increased by about 20%, as shown in Fig. 1.

We believe that the improvement in Ohmic contact characteristics is mainly due to two factors. First, UV/ozone treatment can effectively remove the C induced during the fabrication process, which can prevent the introduction of deep level acceptors into the AlGaN/GaN structure, and thus prevent the reduction of electron density, therefore improving the current. This has been demonstrated by X-ray photoelectron spectroscopy (XPS) surface analysis in the Analysis Center of Tsinghua University. Table 1 gives the atomic concentration ratios of C/N and O/N based on XPS surface analysis. Based on the XPS results, the surface of sample A which underwent UV/ozone treatment contained less C than sample B which did not undergo UV/ozone treatment, as shown in Fig. 2(a) and Table 1. Second, UV/ozone treatment can create a thin oxide on the GaN or AlGaN surface, which also can be seen from the

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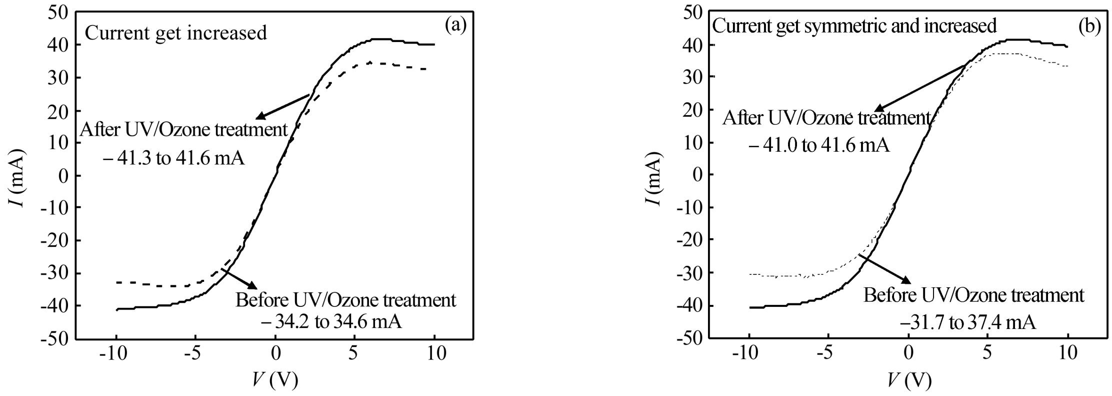

Fig. 1. Measured DC I–V characteristics of Ohmic contact with and without UV/ozone treatment from −10 to 10 V test voltage in steps of 100 mV, tested by an Agilent HP 4155A semiconductor parameter analyzer. (a) Current is increased after UV/ozone treatment; (b) Current is symmetric and increased after UV/ozone treatment.

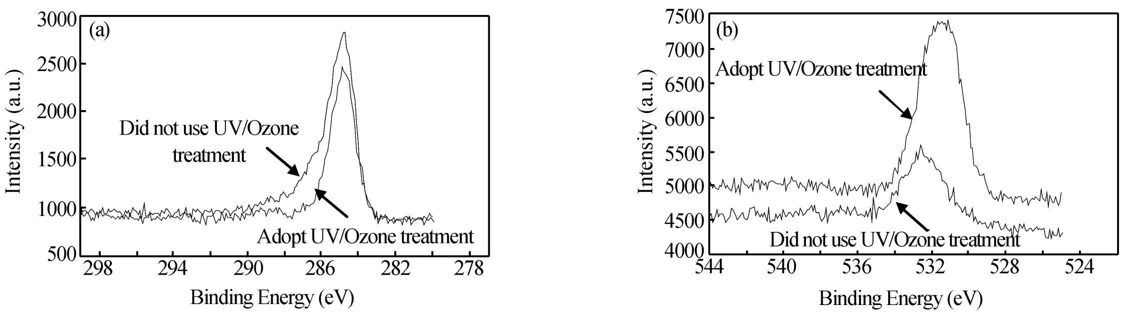

Fig. 2. XPS spectra of sample A which underwent UV/ozone treatment and sample B which did not undergo UV/ozone treatment: (a) XPS spectra of carbon comparison between samples A and B; (b) XPS spectra of O comparison between samples A and B.

Table 1. XPS atomic concentration ratios before UV/ozone treatment and after UV/ozone treatment.

	C/N	O/N
Before UV/ozone treatment	1.520	0.391
After UV/ozone treatment	0.736	0.867

XPS results; the surface of sample A contains more element O than sample B, as shown in Fig. 2(b) and Table 1. The thin oxide layer acts as a passivation layer due to the strong oxidizability of ozone, which can reduce the density of surface traps and increase the drain current.

2.2. Impact on Schottky contact

Based on the above experiment, the impact of UV/ozone treatment on the Schottky contact characteristics of AlGaN/GaN HEMTs was investigated at the same time. A recessed-gate was used in this experiment which was realized using inductively-coupled plasma (ICP) reactive ion etching. The gate length was 0.8 μm. A Ni/Au metal stack was used for the Schottky contacts. A total of two samples sawed from the same wafer used in experiment I were run during this experiment in order to reduce the effect of wafer nonuniformity. For one sample, sample C, we used only dilute HCl (1HCl : $3H_2O$) for 20 s as a surface treatment prior to gate metal deposition, which removes the native oxide and surface contaminants. For the other sample, sample D, UV/ozone treatment for 30 min was used after the dilute HCl treatment, to remove the C and organic contaminants. We also considered that the gate leakage could be reduced related to the formation of a thin insulation layer at the interface between the gate metal and AlGaN, caused by the strong oxidizability of ozone.

To investigate the impact of UV/ozone treatment on the electrical characteristics of Schottky contacts, I–V measurements at different test temperatures from 150 to 360 K were performed using a 2 inch LAKESHORE TTP4 prober. The devices with 60 μm × 1 gate width were tested under a voltage from –20 to 2 V applied between gate and drain. Figures 3 and 4 show that the Schottky contact characteristics of these two samples show the same trend as the temperature varies; the ideality factor and gate leakage current increase with increasing temperature. The fact that the ideality factor of sample D is higher than sample C is mainly because UV/ozone treatment can create a thin interlayer at the metal-AlGaN interface. As the temperature changes, the slope of the I–V curves of sample C changes less than that of sample D; the slope of ln$I$–V is inversely proportional to the ideality factor n, as Figures 3(b) and 4(b) show. That is to say, the slope of the ln$I$ versus V curves of sample D is more dependent on temperature. It has been demonstrated in Ref. [5] that the slope of ln$I$ versus V curves is independent of temperature; this means that there is an increasing contribution of the tunneling component mainly due to defect-assisted tunneling in forward current flow of the Schottky contact. Therefore the experimental results indicate that UV/ozone treatment can reduce the tunneling current due to the formation of a thin insulation layer at the interface between the gate metal and AlGaN which is induced by

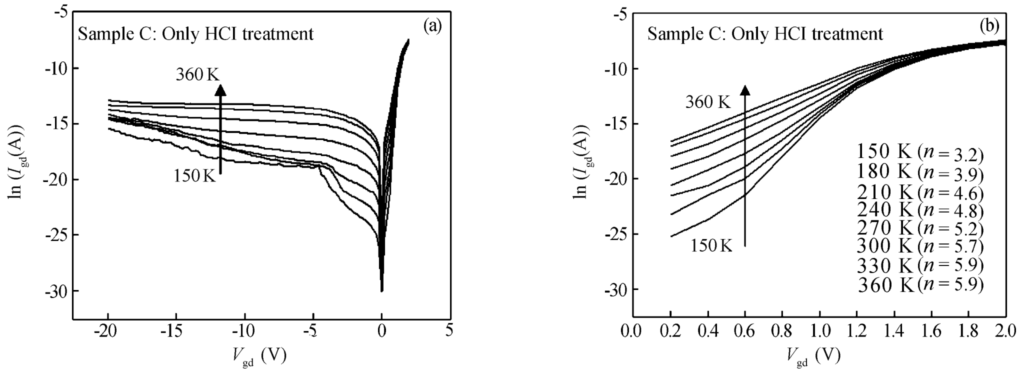

Fig. 3. (a) Measured DC I–V–T characteristics of Schottky contact at V_{gd} from –20 to 2 V. Test temperature varies from 150 to 360 K in steps of 30 K. Only dilute HCl treatment is used before gate metal deposition. Tested by a Desert Cryogenics LAKESHORE TTP4 prober. (b) Forward DC I–V–T characteristics of Schottky contact.

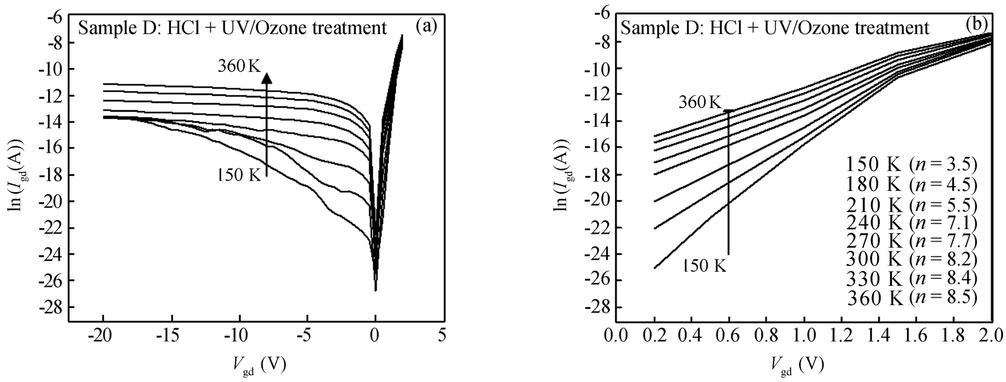

Fig. 4. (a) Measured DC I–V–T characteristics of Schottky contact at V_{gd} from −20 to 2 V. Test temperature varies from 150 to 360 K in steps of 30 K. UV/ozone treatment is used after dilute HCl treatment prior to gate metal deposition. (b) Forward DC I–V–T characteristics of Schottky contact.

the strong oxidizability of ozone. However, according to the results there is one point for which we can find no appropriate explanation: compared to sample C the gate leakage is not reduced by the thin insulation layer as expected in sample D, so further experiments are needed to explain this.

3. Conclusion

In conclusion, this paper investigates the impact of UV/ozone treatment on the performance of AlGaN/GaN HEMTs, especially the Ohmic/Schottky contact characteristics. The improvement of Ohmic contact characteristics is mainly because UV/ozone treatment after ion implantation isolation can effectively remove the C from the GaN or AlGaN surface, preventing the introduction of deep level acceptors into the AlGaN/GaN structure, and it can also create a thin oxide on the GaN or AlGaN surface, which acts as a passivation layer due to the strong oxidizability of ozone, reducing the density of surface traps. Both of them can increase the electron density, and then increase the drain current. Using UV/ozone treatment before gate metal deposition reduces the tunneling current of Schottky contacts related to the formation of the thin insulating layer at the interface between the gate metal and AlGaN. However, it is not observed that the gate leakage current is suppressed by the thin insulation layer; the reason for this phenomenon is not absolutely certain and needs further experiments to explain it.

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