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Mechanism investigation of chlorine-treated InGaN/GaN light-emitting diodes

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Abstract

The electrical and optical performances of InGaN/GaN multiple-quantum-well (MQW) light-emitting diodes can be improved by using chlorine to treat the surface of p-type GaN layer. The chlorine was produced from electrolyzing diluted $HCl_{(aq)}$. The Ga vacancies induced on the surface of chlorine-treated p-type GaN were investigated using an X-ray photoelectron spectroscopy (XPS). The specific contact resistance of 6.1×10^{-6} Ω-cm^2 was obtained for Ni/Au metal contact with the chlorine-treated p-type GaN due to the creation of more hole concentration from induced Ga vacancies. The light output power of the resultant chlorine-treated InGaN/GaN MQW light-emitting diodes increases 1.33 times compared with that without chlorination treatment. Furthermore, the reverse leakage current of the chlorine-treated InGaN/GaN MQW light-emitting diodes was also significantly improved due to the passivation function of chlorination treatment of p-type GaN layer.

I. Introduction

Recently, wide band gap Gallium nitride (GaN) compound semiconductors have been attracted for applications in visible-to-ultraviolet light emitters, near white emission light sources and high-power devices. For those devices, high-quality and reliable metal-semiconductor contact would perform a significant key issue for device performances. The ohmic performance for p-type GaN can not be easily achieved due to the difficulty in growing heavily doped p-GaN. To obtain good ohmic performance of p-type GaN and improve the resultant devices, we presented a chlorination treatment of p-type GaN layer in this work. The chlorine was produced from electrolyzing diluted $HCl_{(aq)}$. An X-ray photoelectron spectroscopy (XPS) was used to analyze the surface of chlorine-treated p-type GaN. The electrical and optical performances of the multiple-quantum-well (MQW) InGaN/GaN light-emitting diodes with and without chlorination treatment were measured and analyzed.

II. Experimental procedure

The epitaxial layers utilized were grown on c-plane sapphire substrates using a metal-organic chemical vapor deposition (MOCVD) system. This structure consists of a 50-nm-thick low-temperature GaN nucleation layer, a 2-μm-thick GaN buffer layer, a 4-μm-thick Si-doped GaN layer(3×10^{18}cm^{-3}), an undoped InGaN/GaN multiple quantum well (MQW) active layer, a 50-nm-thick Mg-doped $Al_{0.1}Ga_{0.9}N$ layer (1×10^{17}cm^{-3}), and a 300-nm-thick Mg-doped GaN layer (5×10^{17}cm^{-3}). The grown samples were then annealed for the activation of generating holes at 750^{o}C for 30 min in N_2 ambient. Dilute HCl (1 HCl+10 H_2O) chemical aqueous was used as the electrolytic solutions. The grown MQW GaN LED sample was placed underneath the Pt anodic electrode and a voltage of 20V was applied on the Pt electrode for 60 min. The mesa regions (300×300μm^2) of the blue LED were formed using BCl_3 gas in a reactive ion etching (RIE) system. The chamber pressure of the RIE system was maintained at 4×10^{-3} torr. Prior to the deposition of the ohmic metal, the GaO_x layer and native oxide layer on the MQW GaN LED samples with and without chlorination treatment were removed using a chemical solution of HNO_3 : HCl (1:3). The Ti/Al/Pt/Au (25/10/50/150 nm) ohmic metals were deposited on the Si-doped GaN layer by electron-beam evaporation. Using lift-off technique, the samples were then thermally annealed at 850^{o}C for 2 min in N_2 ambient. Ni/Au (20/100 nm) metals were deposited on the ohmic regions of the p-type GaN layer using electron-beam evaporator. Both samples treated with and without chlorine were thermally annealed at 500^{o}C for 10 min in air ambient.

III. Experimental Results and Discussion

The chlorine used for chlorination treatment was produced by electrolyzing dilute $HCl_{(aq)}$ at the Pt anodic electrode. The produced chlorine was adhered and reacted with the p-type GaN surface. The Ga dangling bonds of the Ga-face p-type GaN surface grown by MOCVD system reacted with chlorine to form $GaCl_x$. The $GaCl_x$ can easily be dissolved in the chemical solvent [1]. Therefore, Ga vacancies can be induced on the surface of the p-type GaN layer. More hole concentration can be expected from the induced Ga vacancies.

According to the XPS measurement, the ratio of Ga/N and Ga/O for the chlorine-treated p-type GaN relative to that without chlorination treatment as a function of depth is indicated in Table I. From the XPS measurement result, the depth of the chlorination treatment can thus be deduced to be about 1nm.The relative ratio of Ga/N for chlorine-treated sample was half of that of the sample without chlorination treatment. This phenomenon can be deduced from the $GaCl_x$ performed form chlorination surface treatment was dissolved to induce Ga vacancies on the p-type GaN surface. Therefore, the hole concentration on the p-type GaN surface was increased by generating the Ga vacancies on the surface. The relative ratio of Ga/O for chlorine-treated sample was 0.2 times of that without chlorination surface treatment. This phenomenon indicated that the increase of O atoms from the surface in HClO abundant environment using chlorination treatment. Therefore, it is necessary to remove GaO_x using aqua regia. The removal of GaO_x can also induce Ga vacancy [2].

Table I The (Ga/N) and (Ga/O) ratio of chlorine-treated p-type GaN compared with p-type GaN without chlorination treatment.

Depth	0nm (surface)	1nm	3nm	5nm
(Ga/N) Ratio	0.5	0.97	1	1
(Ga/O) Ratio	0.2	0.66	1	1

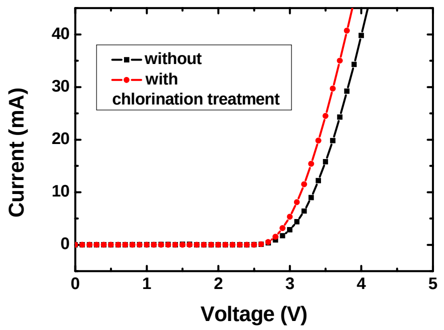

Fig.1 The current-voltage characteristics of the MQW InGaN/GaN LEDs with and without chlorination treatment.

Figure 1 shows the current-voltage (I-V) characteristics of the MQW InGaN/GaN LEDs with and without chlorination treatment. The forward voltage of the LEDs with and without chlorinated treatment is 3.4V and 3.6V for the current of 20mA, respectively. The reduced of the forward voltage for chlorine-treated MQW InGaN/GaN LEDs is attributed to the better ohmic performances due to the creation of more hole concentration from the induced Ga vacancies. The specific contact resistance of p-type GaN with and without chlorination treatment is $6.1\times10^{-6}\Omega\text{-cm}^2$ and $7.2\times10^{-4}\Omega\text{-cm}^2$, respectively.

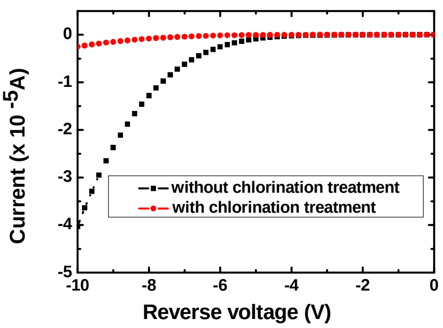

Fig. 2 The leakage current characteristics of the MQW InGaN/GaN LEDs with and without chlorination treatment.

Figure 2 shows the leakage current characteristics of the MQW InGaN/GaN LEDs with and without chlorination treatment. The reverse current of the LEDs with and without chlorination surface treatment is 2.5μA and 40μA, respectively, for the reverse bias at -10V. It is well known that the surface states act recombination centers for increasing leakage current [3]. Therefore, we could deduce that the decrease of leakage current in reverse voltage is attributed to the passivation of chlorination treatment and the reduce of surface state density.

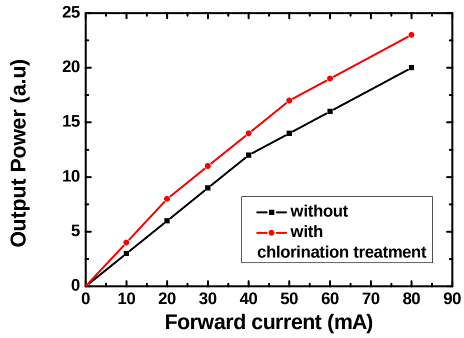

Fig.3 The light output power-current characteristics of the MQW InGaN/GaN LEDs with and without chlorination treatment.

The light output power-current (L-I) characteristics of the MQW InGaN/GaN LEDs with and without chlorinated treatment is shown in Fig. 3. The relative light-output power of the chlorinate-treated MQW InGaN/GaN LEDs was increased 1.33 times than that without chlorination treatment for the current of 20mA. The surface states density of the MQW InGaN/GaN LEDs could be decreased effectively by chlorination treatment. Therefore, the current can effectively inject into the MQW InGaN/GaN active layer due to the reduce of surface states density of the p-GaN surface. Therefore more light output power can be obtained.

CONCLUSIONS

In summary, the function and mechanism of the optical and electrical performances on the chlorine-treated MQW InGaN/GaN LEDs have been investigated. The chlorination surface treatment can be used to enhance the formation of Ga vacancies and to reduce the surface state. Therefore, the optical and electrical performances of the resultant MQW GaN LEDs can be improved.

Reference

[1] D. R. Lide and H. P. R. Frederikse, Eds. *CRC Handbook of Chemistry and Physics*, (75th ed. CRC Press, Boca Raton, FL. 1995).

[2] C. S. Lee, Y. J. Lin and C. T. Lee, Appl. Phys. Lett. **79**,3815 (2001)

[3] S. J. Pearton, J. C. Zolper, R. J. Shul, and F. Ren, J. Appl. Phys. **86**,1 (1999)