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Special Issue

Improvement of current blocking for III-nitride based LEDs by treatments of Ar plasma on p-GaN surface

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***Abstract*-- We successfully demonstrated that the Ar plasma-damaged p-GaN surface increased the resistance of ITO/P-GaN contact serving as injection current deflection layer under the electrode pad. It was found that both of the Vf at 20mA were approximately 3.3V. Under a 20 mA current injection, it was found that output powers were 9.8 and 11.08 mW for conventional LEDs and LEDs with Ar plasma damaged p-GaN surfaces respectively. We can increase the LED output power by 13% by inserting the p-GaN surface damaged by Ar plasma under the electrode pad. It was also found that after testing 72 hours, the half lifetimes of conventional LEDs and LEDs with Ar plasma damaged p-GaN surface were about 49% and 55% of the initial intensity, respectively.**

***Index Terms*-- Ar plasma damaged; p-GaN surface; output powers.**

I. INTRODUCTION

Nitride-based materials have recently emerged as important semiconductor materials, leading to the realization of high performance light emitters from ultraviolet (UV) to blue and green spectral regions [1, 2]. For example, GaN-based blue and green light-emitting diodes (LEDs) have already been extensively used in full-color displays and as high-efficient light sources for traffic-light lamps. High efficiency nitride-based LEDs are also potentially useful for solid state lighting. To approach solid state lighting, however, one needs to further improve the output efficiency of these LEDs. There are several parameters that affect the output efficiency of the LEDs, such as light extraction efficiency, internal quantum efficiency, and current distribution of LEDs. It has been demonstrated that several methods can be used to improve output efficiency of GaN-based LEDs by enhancing the light extraction efficiency, such as textured surfaces [3-5], a highly transparent p-contact layer [6], a proper substrate design [7], and flip-chip packaging [8]. Moreover, the crystal quality, device band engineering structure design, and doping profile would affect the internal quantum efficiency of LEDs. Besides these factors, current distributed throughout the LEDs also plays one of the key roles in the efficiency of the LEDs as well. In other words, current distributed throughout the LEDs determines the real light-emitting area of the devices, and light output power is proportional to the light-emitting area. Current distribution had been wildly studied in the GaAs-based LEDs [9-12] to increase output power. Current blocking is one of the ways to change current distribution in the LEDs. The current injected by the top contact enters the active region predominantly under the top contact. The extraction of the light generated in the active region is thus strongly hindered by the opaque metal contact. The current block layer would block the entering current from top contact to the active region. The light extraction efficiency of LEDs is improved because the current is deflected away from the top contact. In this study, we would perform the different methods of current-blocking layer formation on the InGaN/GaN multiple quantum wells (MQWs) LEDs. We would also compare the electrical and optical characteristics of those different current blocking layers.

II. EXPERIMENTAL

Samples used in this study were all grown on 2-inch (0001) sapphire substrate by vertical metal organic chemical vapor deposition (MOCVD). The detailed layers and growth procedures have been described in a previous publication [13]. The thicknesses of the p-AlGaN and p-GaN layers were 50nm and 150nm, respectively. After growing the samples, post annealing was needed to activate the top p-GaN layer of InGaN/GaN MQWs LED at 700℃ 20min. The partial p-GaN and active layers were removed to expose the n-GaN layer for the n-electrode Ohmic contact by using the Inductive Coupled Plasma (ICP) etcher. The current blocking layer was formed right before the deposition of the indium-tin-oxide (ITO) transparent contact layer (TCL). A partial etched p-GaN surface was introduced underneath the p-electrode pad to form the current-blocking layer in this study. Then, the ITO TCL was deposited on the p-GaN surface to cover the current blocking layer. The Cr/Au (50/200nm) bi-layer metal contact was deposited on the ITO TCL and exposed n+-GaN layers to form the p-type electrode (anode) and the n-type electrode (cathode), respectively, at the same time. The chip size of the LEDs in our study was 8x10 mil2. The current-voltage (I-V) characteristics of the current blocking layer and experimental LEDs were measured by using the HP-4156C semiconductor parameter analyzer, and the output powers of the LEDs were measured by using calibrated integrating sphere.

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III. RESULTS AND DISCUSSION

Figure 1 indicated the I-V characteristics of the ITO/p-GaN contact with and without Ar plasma treatment p-GaN surface. It was found that the resistance of ITO/p-GaN contact increased after the Ar plasma treated the p-GaN surface. The resistance of the ITO/p-GaN contact with Ar plasma treatment p-GaN surface was 1.25 times higher than that of ITO/p-GaN contact without the treatment. The increase of the resistance of the ITO/p-GaN contact on Ar plasma treatment p-GaN surface should be attributed to the Ar plasma damage result in decreasing the carrier concentration on the p-GaN surface. It should be noted that high contact resistance of the Ar plasma damaged p-GaN surface could be served as the current deflection resistance right under the electrode pads.

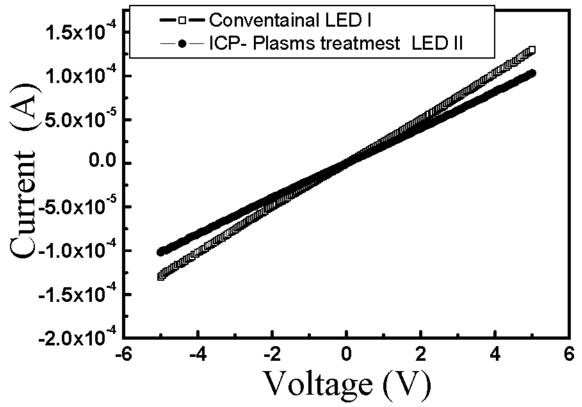


Fig 1. The resistance of the ITO/p-GaN contact with Ar plasma treatment p-GaN surface was 1.25 times higher than that of ITO/p-GaN contact without the treatment

Figure 2 indicated the intensity-current-voltage (L-I-V) curve of LEDs with and without (i.e. ICP-plsma treatmest LED II and Conventional LED I , respectively) Ar plasma treatment under the electrode pad. It was found that both of the forward voltage (Vf) were approximately 3.3V at 20mA. The 20mA-Vf results indicated that the electrical characteristics of LEDs were not obviously degraded by the Ar plasma treatment under the electrode pad processes. Furthermore, it was found that output powers of these two LEDs were increased as we increased the injection current. Under the same injection current, it was found that output power observed from ICP-plsma treatmest LED II was always larger than the conventional LED I. Under 20 mA current injections, Figure 3 showed the output powers were 9.8 and 11.08 mW for conventional LED I and ICP-plsma treatment LED II, respectively. In other words, we can increase the LED output power by 13% by inserting the Ar plasma-damaged p-GaN surface under the electrode pad. The enhancement of output power observed from ICP-plsma treatment LED II should be attributed to the improved current spreading of LEDs by high contact resistance of the ITO/p-GaN under electrode pad.

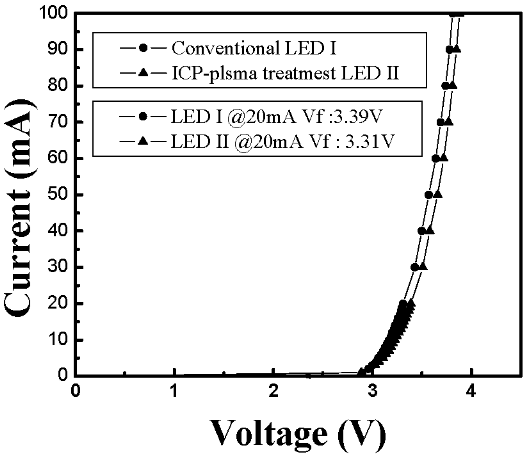


Figure 2 indicated the intensity-current-voltage (L-I-V) curve of LEDs with and without (i.e. ICP-plsma treatmest LED II and Conventional LED I , respectively) Ar plasma treatment right under the electrode pad

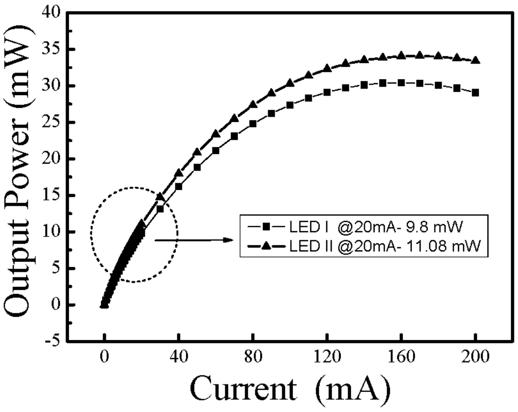
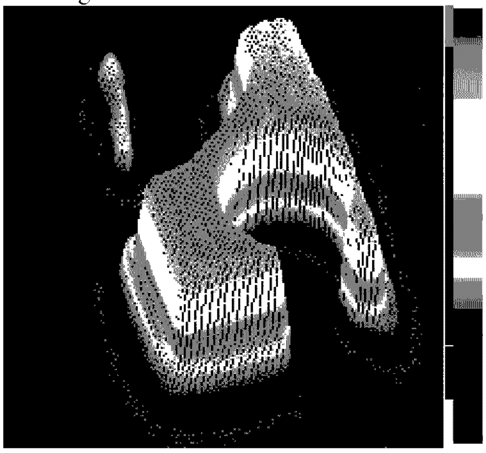
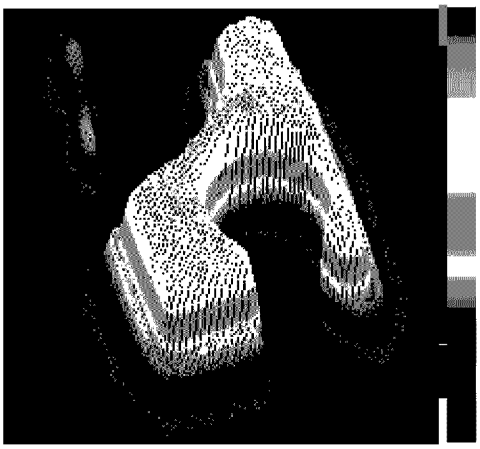


Figure 3 show the output powers were 9.8 and 11.08 mW for conventional LED I and ICP-plsma treatmest LED II, respectively.

To further investigating the effects of current distribution, we measured near field optical images of the LEDs. Figure 4 show the 3D images measured from the LEDs with/without Ar plasma-damaged p-GaN surface under the electrode pad, as we injected 20 mA DC current into the devices. It can be seen clearly that the output light was emitted uniformly across the chips since current spread uniformly in LED II. In contrast, it was found that light output distribution is non-uniform for the conventional LED I. The better current spreading of LED II should be attributed to the high ITO/p-GaN contact resistance under the electrode pad deflect the injection current away from pad and then increasing the emission area of devices. In other words, the LED I without high resistive Ar plasma-damaged p-GaN surface under electrode pad would lead the most of injection current to go into devices under the electrode pad. However, the light emitted under the pad would be absorbed by the opaque metal pad and then reducing the output power of LED. Therefore, the output power and near field intensity image of LED II is about 13% larger than that of LED I. Besides, the non-uniform current distribution near the electrode pad might enhance the current crowding while driving at high current. Therefore, it was found that the injection current to reaching the highest output power of Conventional LED I is less than that of ICP-plsma treatment LED II in Fig. 2.



(a) with Ar plasma



(b) without Ar plasma

Figure 4 (a)(b) show the 3D images measured from the LEDs with/without Ar plasma damaged p-GaN surface under the electrode pad.

Figure 5 shows the reliability test of the LED I and II injection with 50mA at 80oC. It was found that the decayed intensity of LED I and LED II were about 49% and 55% of the initial intensity, respectively, after aging 72 hour. It should also be attributed to the better current spreading of the LED II with high ITO/p-GaN contact resistance under the electrode pad. The better current spreading could reduce the current crowding under the pad at high current injection. As a result, the intensity degradation of the LED II during the high temperature high injection current aging is less than that of LED I.

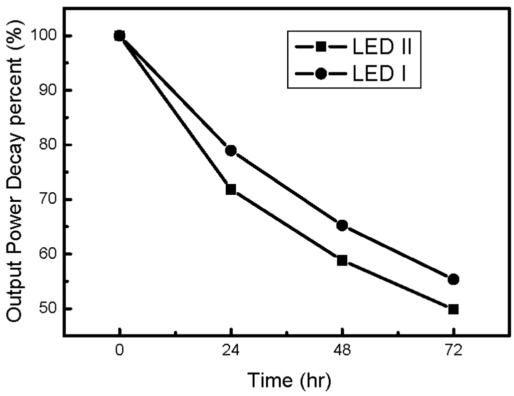


Figure 5 shows the reliability test of the LED I and II injection with 50mA at 80oC

IV. SUMMARY

In summary, we successfully demonstrated that the Ar plasma-damaged p-GaN surface increased the resistance of ITO/P-GaN contact serving as injection current deflection layer under the electrode pad. It was found that the Vf of both LEDs at 20mA were approximately 3.3V. It was found that output powers were 9.8 and 11.08 mW for LED I and LED II at 20 mA, respectively. In other words, we can increase the LED output power by 13% by inserting the Ar plasma-damaged p-GaN surface under the electrode pad. It was also found that the decayed intensity of LED I and LED II were about 49% and 55% of the initial intensity, respectively, after aging 72 hour. It was believed that high resistance ITO/P-GaN contact with Ar plasma-damaged p-GaN surface under pad would improve the injection current spreading to whole device. And better current spreading could lead to improve the photoelectrical characteristics of LEDs.

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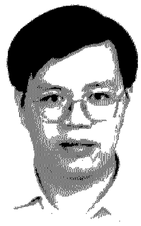
BIOGRAPHIES



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