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High Power GaN-Based LEDs with Transparent Indium-Zinc-Oxide Films

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1. Introduction

Recently, GaN-based light emitting diodes (LEDs) have attracted considerable attention because of their potential applications in optoelectronic area such as full-color display, traffic signal, and high-efficiency lamps [1]. However, it is necessary to further enhance the LED output intensity for high power applications on flash lamp and solid-state lighting. One feasible approach for increasing output optical power of LEDs comes obviously by enlarging the chip size. Algora [2] has reported the fabrication of large-area infrared-emitting diodes (about 200 times larger than standard ones). Recently, Wierer *et al*. [3] have presented the performance of large-size (about 1 mm×1 mm) high-power GaN-based LEDs operated under higher injection current. Another practical way to increase LED output power is to enhance the effect of current spreading of low-resistance transparent conduction layer (TCL). In general, to obtain the largest possible benefit from using a TCL, high transparency, low contact resistance, thick enough, and easy fabrication of the TCL are required. Nevertheless, the transparency of conventional oxidized-Ni/Au layer with total thickness of 15 nm only reaches a range of 60-75% in blue light spectral range [4]. As increasing the film thickness for reducing the sheet resistance to further maximize the current spreading effect, the contact reliability could become a serious issue.

In our previous work [5], we reported the use of RF sputter-deposited indium-zinc-oxide (IZO) film as a thick TCL for nitride-based LEDs (300 μm ×300 μm). Essentially, IZO has a wide-bandgap (3.2-3.5 eV), a low resistivity ($2\text{-}4\times10^{-4}$ Ω-cm), and a high transmittance (> 80% in visible light region) [6]. Under an injection current in the 10-50 mA range, as compared to the case without IZO film, about 35-28% improvement in light output has been obtained. In this study, we report on the fabrication and characteristics of large-area high power GaN-based LEDs with Ni/Au/IZO as the TCL. The effectiveness of IZO TCL for high power LEDs with different sizes was investigated.

2. Experiments

The LEDs used in this study were grown on a c-plane sapphire substrate by metalorganic chemical vapor deposition (MOCVD). The InGaN/GaN LED structure comprised an undoped GaN buffer layer, a Si-doped n-GaN layer (2-3 μm), an undoped 5-period GaN/InGaN multiple quantum well (MQW), and an Mg-doped p-GaN layer (0.15-0.2 μm). The as-grown samples were then furnace-annealed at 750 ^{o}C in nitrogen ambient to activate the p-type dopant [1]. Typical values of the p-type and n-type concentration obtained from Hall measurement are around 2.0×10^{17} cm^{-3} and 4.1×10^{18} cm^{-3}, respectively. The n-type mesa was defined by an inductively coupled plasma (ICP) etching system. Subsequently, Ni(2.5 nm)/Au(4.5 nm) and IZO films were deposited in sequence onto the p-GaN layer, and bonding pads were formed on the TCL and n-type GaN. The IZO film was deposited by RF sputtering using an IZO target with 90%wt In_2O_3 and 10%wt ZnO in Ar ambient. During IZO deposition, the argon flow rate, applied RF power, and the deposition pressure were maintained at 20 sccm, 120 W, and 3×10^{-3} Torr, respectively. The size of all fabricated LEDs are 1.5 mm ×1.5 mm, 1 mm ×1 mm, and 0.6 mm ×0.6 mm, referred to as sample A, B, and C, respectively. Figure 1 shows the top-view of fabricated power LED chip under 350 mA. It is noted that the geometry of electrodes was designed to maximize the current spreading.

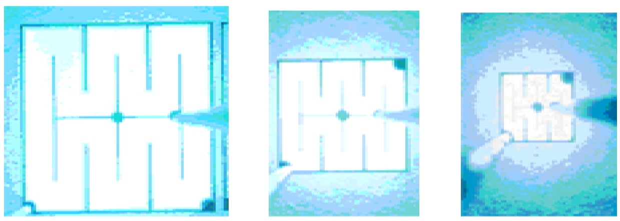

Fig. 1 Light emission from the fabricated LEDs under an injection current of 350 mA. (a) sample A, (b) sample B, and (c) sample C.

3. Results and Discussion

Figure 2 shows the dependence of the measured transparency of the IZO film deposited on glass substrates on the annealing temperature in N_2 ambient for 20min. An average transparency of around 88% in blue light spectral range for the as-deposited IZO films has been achieved. The as-deposited IZO films is with a sheet resistance of around 10 Ω/□ and a resistivity is in the range of $1.9\text{-}4.3\times10^{-4}$ Ω-cm.

Figure 3 compares the I-V characteristics of LEDs with and without IZO film. Under an injection current of 350 mA, the measured forward voltage drop (V_f) for sample A, B and C, without IZO layer, is 3.78, 3.91, and 4.18 V, respectively. With a 300nm-thick IZO overlay, the value of V_f is seen increasing to 3.89, 4.10, and 4.51 V for sample A, B and C, respectively. The increase in V_f is attributed to the finite series resistance introduced by the IZO film.

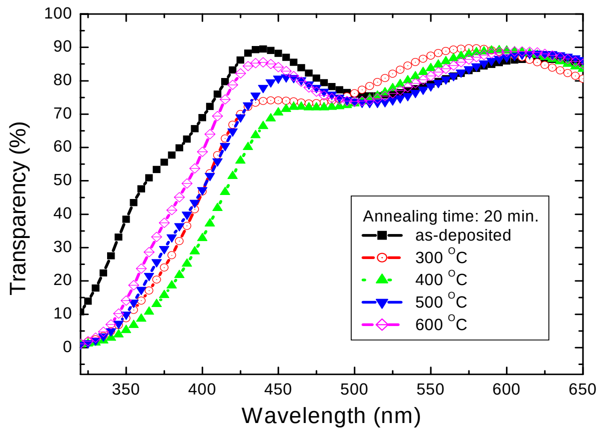

Fig. 2 The measured transparency of the sputter-deposited IZO films. The thermal annealing was conducted in N_2 ambient.

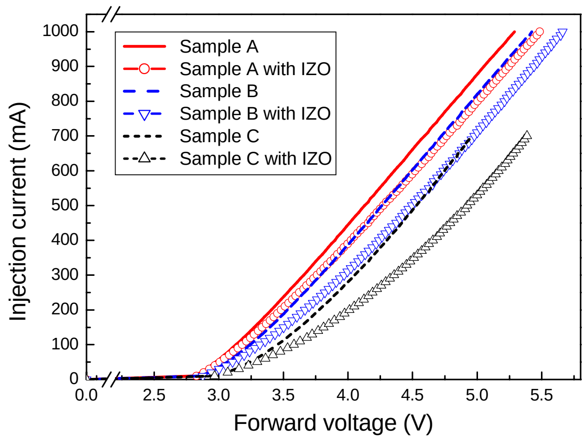

Fig. 3 The measured I-V characteristics of LEDs with and without IZO film.

Figure 4 compares the measured Lop-I characteristics of the fabricated LEDs with and without IZO film. It is observed that the use of IZO strongly enhances the current spreading of injection current; as a result, it leads to considerable increase in Lop. Our results show that sample A gains the largest degree of improvement in Lop among the three LEDs with different sizes, indicating that the thermal effect might play an important role in device performance.

Figure 5 shows the dependence of the percentage improvement in Lop (i.e., ΔLop/Lop) on the injection current with chip size as a parameter. As compared to the case without IZO layer, under an injection current of 350 mA, there is about 62.1% improvement in ΔLop/Lop for the sample A. Furthermore, it shows that ΔLop/Lop increase with the increasing chip size, which suggests that the larger the chips size is, the more effective the IZO layer in improving current spreading is. Under an injection current in the range of 100~700 mA, the average ΔLop/Lop for sample A, B, and C is about 61.59%, 40.03%, and 17.78%, respectively. However, the decrease in ΔLop/Lop with increasing the injection current reveals that thermal effect might occur in the fabricated LEDs.

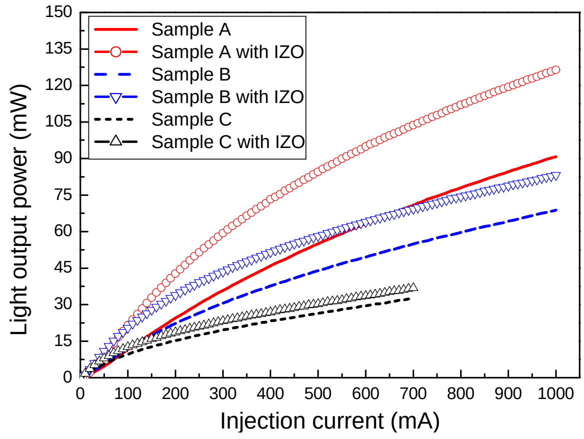

Fig. 4 The measured Lop-I characteristics of the LEDs with and without IZO film.

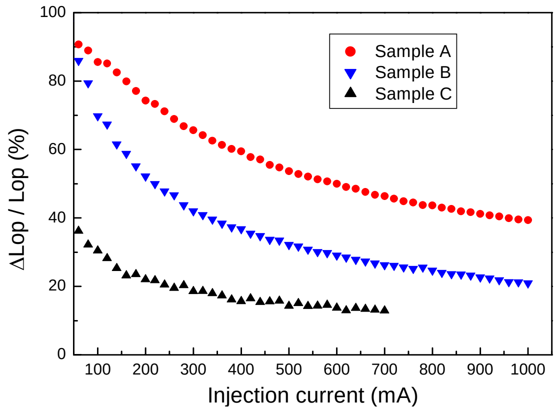

Fig. 5 The dependence of ΔLop/Lop on the injection current for LEDs with an IZO TCL.

4. Conclusion

In summary, electrical and optical characteristics of large area high power GaN-based LEDs with an IZO overlay have been presented and compared. It has been shown that the larger device size, the more effective in improving the light output of LEDs. For the LEDs with oxidized-Ni(2.5 nm)/Au(4.5 nm) contact to p-GaN under an injection current of 350 mA, the use of a 300-nm-thick IZO layer resulting in about 62.1% improvement in Lop has been achieved.

Acknowledgements

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