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High Brightness InGaN/GaN LEDs with ESD Protection

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1. Introduction

Nitride-based indium-tin-oxide (ITO) light emitting diodes (LEDs) with Electrostatic discharge protection were successfully fabricated. LED structure having electrostatic discharge (ESD) protection function in which an ESD diode is connected in parallel to the LED with an inverse voltage compared to the normal LED. Therefore, the LED can be protected from the damage due to electrostatic discharge. It was found that the electrostatic discharge capability of the LED with ESD protection could be greatly improved from several hundred to 2000 V in human body model (HBM).

2. Experiment

The InGaN/GaN epitaxial layers were all grown by MOCVD system on sapphire (0001) substrates [1-3]. The LED structure consists of a 50-nm-thick GaN nucleation layer grown at 550^{o}C, a 3-um-thick Si-doped n-GaN buffer layer grown at 1050^{o}C, an unintentionally doped InGaN/GaN multiquantum well (MQW) active region grown at 770^{o}C, a 50-nm-thick Mg-doped p-$Al_{0.15}Ga_{0.85}N$ layer, a 0.25-um-thick Mg-doped p-GaN layer and an InGaN/GaN n^{+}-SPS tunnel contact structure. By growing such SPS structure on top of the p-GaN cap layers, one could achieve a good "ohmic" contact through tunneling when the n^{+}(InGaN/GaN)-p(GaN) junction was properly reverse biased [4-5]. A 230-nm-thick ITO layer was subsequently evaporated onto the sample to serve as the transparent contact layer. Surfaces of the samples were then partially etched until the n-type GaN layers were exposed. LED and ESD diode were also separated by ICP dry etching until the sapphire substrate was exposed. Prior to deposition Cr/Pt/Au (300-100-25um) by e-beam evaporator to serve as the p-electrode, n-electrode and the interconnection, 1-um-thick PECVD SiO_2 films were then deposited over all chips to serve as the passivation for the electric insulation between the p-n junctions. The current-voltage characteristics of these two LEDs was measured by the HP-4155B semiconductor parameter analyzer and the ESD characteristics were tested by the Electrostatic Discharge Simulator-Model 910 which consists of a variable high voltage power supply, a high voltage switch and an R/C discharge network to simulate a specific electrostatic discharge of the human body (Mil Std. 883E) [6].

3. Results and discussion

Figure 1 shows the schematic of the normal LED (LED-I) and the LED with ESD diode (LED-II) bare chip. The chip size were also 300 um ×400 um. Figure 2 shows the intensity - current (L-I) characteristics of these two LEDs. It can be seen again that EL intensity of the LED with ITO on n^{+}-SPS upper contact was larger than that of LED with Ni/Au on n^{+}-SPS upper contact. The output power of lamped LEDs with ITO p-contact was about 8.4mW and 20mA wall plug efficiency was about 13.9% which was much larger than normal Ni/Au LEDs (i.e. 4.1mW and 6.9%). Such a significant enhancement in EL intensity could be attributed to the more transparent nature of ITO as compared to Ni/Au.

Figure 3 is an equivalent circuit diagram schematically illustrating a LED structure having a conventional electrostatic discharge (ESD) protection diode. In order to avoid the damage of LED from the electrostatic discharge during operation, the LED and an ESD diode are connected in parallel and in reverse. The current-voltage characteristics of the LED-I and the LED-II were shown in Figure 4. Due to the LED and the ESD diode are connected in parallel and in reverse, the I-V curve of the reverse region is quite different between the LED-I and the LED-II. The reverse breakdown voltage of the LED-II is much smaller than that of the LED-I. Therefore, the abnormal negative voltage or electrostatic charge could be well passed through the ESD diode without damaging the LED chip. Due to the characteristics of the p-n junction diode, the forward ESD ability of LEDs (i.e. forward ESD of GaN LEDs is over 7000V) is larger than the reverse ones of LEDs (i.e. reverse ESD of GaN LEDs is about 100~300V). Therefore, when an abnormal negative voltage or electrostatic charge is generated, the over level high voltage is discharged by the ESD diode that operates in the forward region. LED diode is well protected from the damage and the irreversible damage to the LED could be avoided.

4.Conclusion

We could obtain a 8.4 mW larger output power and 13.9% wall plug efficiency (W.P.E) by using such an ITO films as transparent p-contact layer.

Moreover, LEDs with Electrostatic discharge protection were successfully fabricated. LED structure having electrostatic discharge (ESD) protection function in which an ESD diode is connected in parallel to the LED with an inverse voltage compared to the normal LED. Therefore, the LED can be protected from the damage due to electrostatic discharge. It was found that the electrostatic discharge capability of the LED with ESD protection could be greatly improved from several hundred to 2000 V in human body model (HBM).

KEYWORDS: InGaN/GaN, LED, ESD

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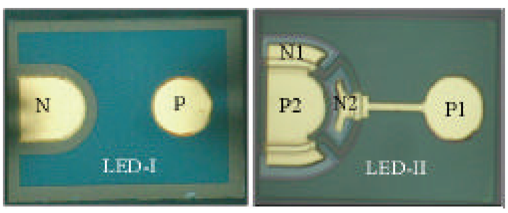

Fig 1

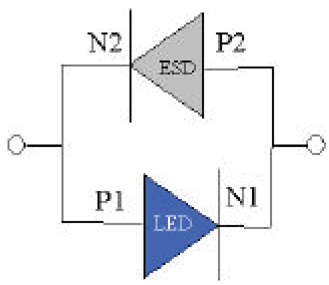

Fig 3

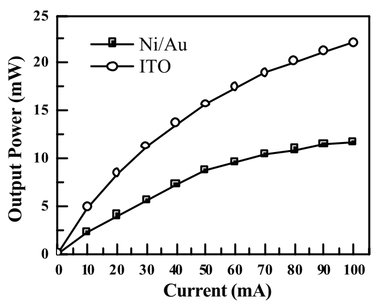

Fig 2

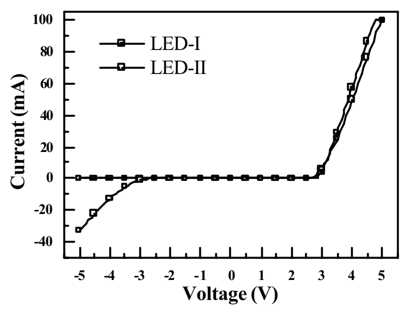

Fig 4