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High Reliable Nitride Based LEDs with Internal ESD Protection

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I. Introduction

Nitride-based light emitting diodes (LEDs) with internal electrostatic discharge (ESD) protection diodes were proposed and realized. A negative ESD threshold could be significantly increased from 300~400 V to 2000 V. On the other hand, we managed to bring down the 20mA operation voltage to 3.29V using the n-metal finger, which entails a good current spreading under operation as the result of reduced current crowding effect. Since a good current spreading beneficially alleviate the thermal effect under long-term operation, an effective pattern layout design clearly would also prolong the lifetime of proposed LEDs.

II. Experiments

The samples 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]. Indium-tin-oxide (ITO) was evaporated onto the sample surface (i.e. Si-doped n^+-SPS) to serve as the transparent contact layer Then, an inductively coupled plasma (ICP) etching was used to define trench isolation. The etching depth was about 4 μm, which was about the thickness of entire LED structure. Our mask was designed in a fashion that one chip can be divided into two zones. One is the primary LED while the other is the slave ESD protection diode. Notice that the dimension of primary LED is much larger than that of slave ESD protection diode. We then partially etched the sample again until the n-type GaN layer was exposed. Prior to deposition Cr/Pt/Au (300-100-25um) to serve as the p-electrode, n-electrode and the interconnection, 1-um-thick SiO_2 films were deposited to serve as the passivation for the electric insulation between the p-n junctions.

III. Results and discussion

Figure 1(a) shows the cross-sectional diagram and 1(b) the equivalent circuit of the fabricated devices. We can electrically connect p-contact of the major LED (Pm) to n-contact of the slave ESD protection diode (Ns), while connecting n-contact of the major LED (Nm) to p-contact of the slave ESD protection diode (Ps). Under normal forward bias operation, the current flows across the major LED from Pm to Nm, functioning as a normal LED. On the other hand, a reverse biased ESD-induced electrical pulse would trigger the ESD-induced current to flow across the slave ESD protection diode from Ps to Ns, by providing a passage for the ESD current to release.Figure 2 shows top views of the conventional LED (i.e. LED-I) and the LEDs with ESD protection diodes (i.e. LED-II, LED-III and LED-IV) fabricated with three different sets of layouts. Figure 3 shows forward I-V characteristics of the four fabricated LEDs, and the reverse I-V characteristics were shown in the inset. With 20 mA forward current injection, the voltage of the LED-I was 3.32V. In contrast, the voltages of LED-II and LED-III were determined to be 3.38 and 3.58V. As shown in figure 2, LED-IV is a LED with slave ESD protection diode and n-metal fingers. It can be seen that 20 mA forward voltage of LED-IV was only 3.29 V. Figure 5 shows measured intensity-current (L-I) characteristics of the four fabricated LEDs. It was determined that the 20mA output powers were 8.03, 7.73, 7.18 and 7.45 mW for LED-I, LED-II, LED-III and LED-IV, respectively. During ESD stressing, we applied negative ESD pulses onto the samples, 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) [5]. As shown in figure 6, LED-II, LED-III and LED-IV endure negative ESD stress voltages all the way up to 800, 1600, and 2000 V, respectively. In contrast, LED-I endure negative ESD surge only up to 300~400 V. Figure 7 shows life test of relative luminous intensity measured from four different kinds of LEDs, normalized to their respective initial readings. During the life test, all four LEDs were driven by 30 mA current injection at room temperature. It was found that the EL intensity decayed by only 18% after 1000 hours for LED-IV. The slightly better lifetime observed from LED-IV could be explained by the enhanced current spreading of the better pattern layout design.

IV. Conclusions

With the ESD protection diodes design, another current path can be established to channel the ESD-induced pulse current away from going through the primary LED, which will prevent the leakage because of the damage on the epitaxial structure. Therefore, an improvement on the reliability of the LEDs is effectively demonstrated.

V. Reference

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[5] ESD Association Standard Test Method for electrostatic discharge sensitivity testing－ Human Body Model (HBM) Component Level (ANSI/ESD5.1-2001).

	Chip dimension (μm^2)	Slave ESD protection diode dimension(μm^2)
LED-I	120000	0
LED-II	125400	4200
LED-III	120000	10800
LED-IV	120000	11500

Table I Total chip dimensions and the dimensions of the slave ESD protection diodes of the four LEDs fabricated in this study.

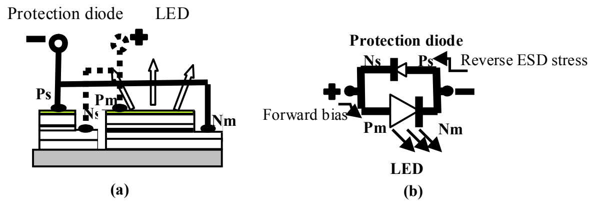

Figure 1 (a) Cross-sectional diagram and (b) equivalent circuit of the fabricated devices.

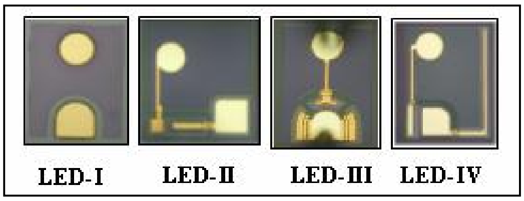

Figure 2 Top views of the LEDs fabricated in this study.

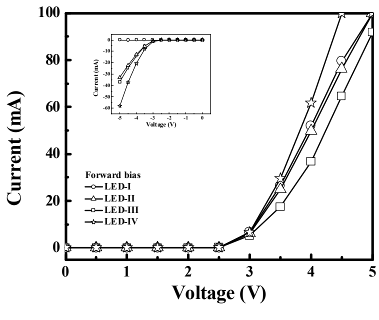

Figure 3 Forward and reverse (inset) I-V characteristics of the fabricated LEDs.

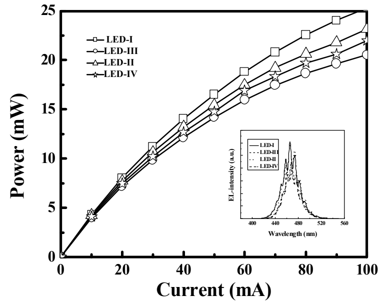

Figure 4 Measured L-I characteristics of the fabricated LEDs. Inset shows the Room temperature on-wafer EL spectra of the four LEDs with 20 mA DC current injection.

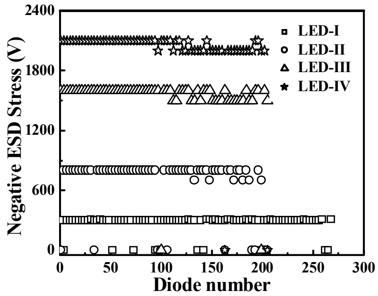

Figure 5 Reverse ESD stressing voltage distributions for the LED-I, LED-II, LED-III and LED-IV chips.

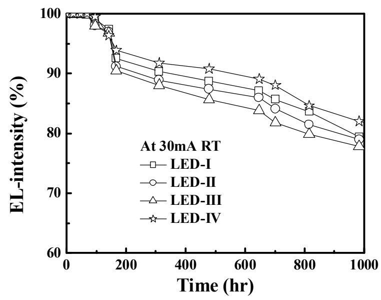

Figure 6 Life test of relative luminous intensity measured from these four different kinds of LEDs, normalized to there respective initial readings.