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Characteristics of Flip-Chip InGaN LEDs on Patterned Sapphire Substrates

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1. Introduction

The high emission InGaN based light-emitting diodes (LEDs) semiconductor have become commercialized products between the ultraviolet (UV) and green spectra region, while attracted considerable application in the areas of photonic and power electronic devices [1]. It well knows that the refractive indexes of GaN and air are 2.5 and 1.0, respectively. The critical angle [$\theta_c=\sin^{-1}(n_{air}/n_{GaN})$] for the emission light generated in the InGaN-GaN active layer to escape can be calculated approximately 23° [2]. Most of the light emitted from the LED active region and remain trapped in the high refractive index of GaN due to total internal reflection at the LED-air interface. Therefore the external quantum efficiency of the conventional nitride based LED is often low. Currently, the most commonly used flip-chip technology to achieve high power LED [3]-[4]. It is no bonding pads or wires exist on top of the devices hence photons could be emitted freely from the sapphire substrate.

In this work, we propose a new approach for growing a high-quality GaN film using a patterned sapphire substrate (PSS) [5]-[6]. This technique eliminates the dislocations and increases the emitted light extraction efficiency. The proposed method can reduce the TDs via a single growth process without any interruption and deposition onto the SiO_2 mask. It also eliminates the need for a precise photolithography process to transfer a special pattern axis and prevents induced contamination.

2. Experimental

The InGaN/GaN MQW LED samples were grown using a low-pressure MOCVD method on (0001)-oriented two-inch PSS and conventional sapphire substrates. PSS was prepared using a periodic hole pattern on the (0001) sapphire with a hole depth of 1.5μm. The hole dimension (diameter: 3 μm; spacing: 3 μm) was fabricated using a standard photolithography process and inductively-coupled-plasma etching. The LED sample had a chip size of 1 nm × 1 nm, fabricated using standard photolithography and dry etch techniques. Flip chip processing is performed by the first defined a 1000-nm-think Al reflective mirror was deposition on top of the p-type GaN: Mg layer by photolithography and etching. A Ti/Al metal n contact is than defined on the exposed n-type GaN layer by photolithography and etching. Flip chip processing ends with the defined an Au-based interconnecting metallization on the both p and n contacts. Than the flip chip soldered to a Si submount via the interconnecting metallization which served to both enhance light extraction from the chip as well as improve heat sinking as shown in the cross-section in Fig. 1

3. Results and discussion

Fig. 2(a) presents the forward current-voltage (I-V) characteristics of flip chip InGaN LEDs with and without PSS at room temperature (RT). It can be seen that the forward voltages LEDs at 20 mA dc current were 3.15 and 3.11 V, respectively. This indicates that the PSS flip chip LED has similar I-V characteristics as compared with the conventional flip chip LED.

Fig. 3 shows the RT electroluminescence (EL) spectra of flip chip InGaN LEDs with and without PSS operated at 100 mA. It can be seen clearly that the EL peak positions of the both LEDs were located at 425 nm. Note that the active layers in the both of the LEDs were grown under the same growth run. The EL intensity of the flip chip PSS LED was about 43 % lager than that of the conventional one. These result indicated that the significant enhancement in EL intensity could be attributed to the increase of the extraction efficiency by scattering the emission light at the PSS/GaN interface.

Fig. 4 shows a plot of the light output power (L-I) characteristics of the flip chip InGaN LEDs with and without PSS as a function of dc injection current up to 500 mA at RT. As shown in Fig. 4 both of these LEDs L-I curves showed linear characteristics up to 350 mA than saturates with increase injection current at 400 mA, the saturates current caused by thermal heating effect. The light output was greatly increased by 37% for the flip chip LED having PSS compared to conventional flip chip LED at a forward injection current 350 mA. Considerable enhancement in the output power was observed in the flip chip LED with PSS. Such a result could be attributed to the effect of emission light scattering from the side edge of the nitride epilayer and etched sapphire interface. It is also reported by Morita et al [8]. Generally, the light extraction efficiency in the InGaN-based LED is mostly limited mainly due to the refractive index of GaN layer is higher than that of the surrounding air. In addition, a part of the propagation light is absorbed by the metal electrode. However, when raised ring pattern are formed on the n-GaN surface, the propagation emission light is scattered.

To confirm this point, the light output pattern of the PSS flip chip LED (@ 100 mA) was measured and shown in Fig. 5, where the chip was not encapsulated into epoxy. The light output pattern of the conventional flip chip LED is also depicted for comparison. It is clear from the results that the EL intensities obtained from the PSS flip chip LED were larger than those from the conventional flip chip

LED in the near vertical directions (i.e., small than ± 45°). The improvement in emitted light extraction efficiency is considered as a consequence of the light scattering by the PSS.

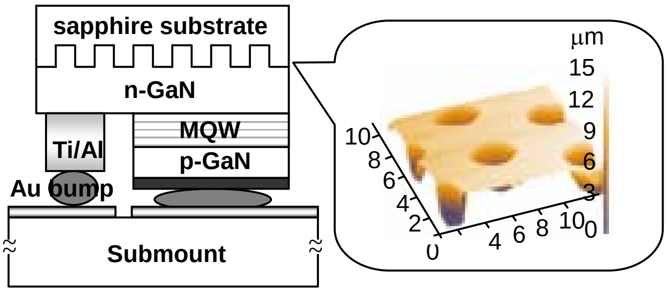

Fig.1 Schematic of flip chip InGaN LED structure grown on patterned sapphire substrate.

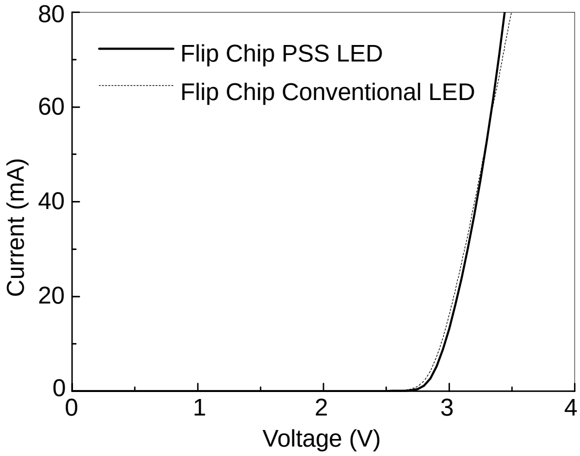

Fig. 2 I-V characteristics of the flip chip InGaN LEDs with and without PSS

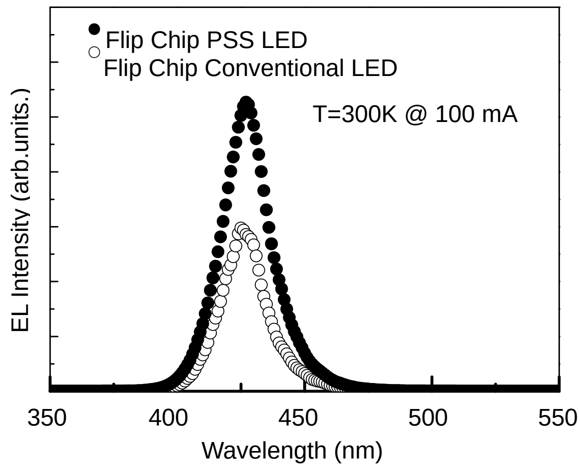

Fig. 3 Room-temperature EL spectra of flip chip PSS LED with and without PSS.

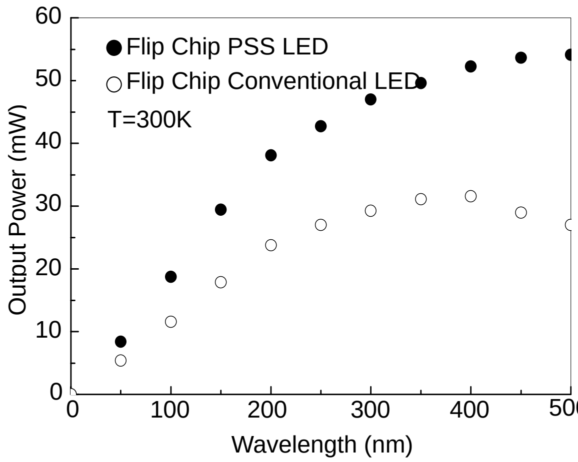

Fig. 4 L-I characteristics of flip chip InGaN LEDs with and without PSS.

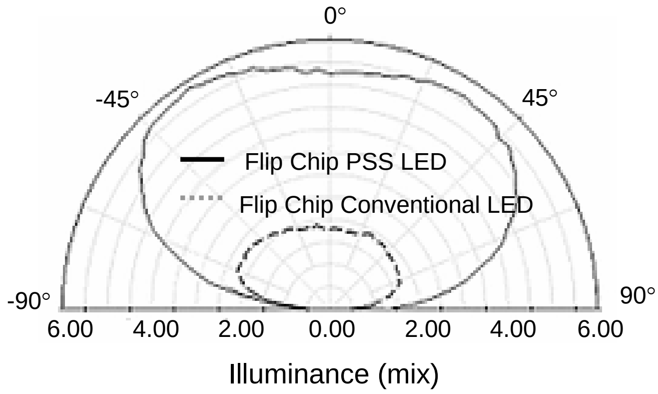

Fig. 5 Light output patterns of the flip chip PSS LED and flip chip conventional LED.

4. Conclusion

We demonstrated the characteristics of InGaN-based flip chip LEDs with PSS. As much as 43% increased light emission intensity was obtained at 20 mA forward current injection. Moreover, the output power of the PSS flip chip LED at 350 mA forward current injection was measured at 49.58 mW. The output power enhancement could be attributed to the enhancement of light extraction was the output light scattered at GaN epilayer and sapphire interface.

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