Improvement the Light Extraction Efficiencies with patterned sapphire substrates by wet and ICP etching

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Abstract—In this study, Sapphire substrates patterned by a selective chemical wet and an inductively coupled plasma (ICP) etching technique was proposed to improve the performance of GaN-based light-emitting diodes (LEDs). The light output powers of LED on ICP-etching patterned substrates was better than the LED on Wet-etching patterned substrates that improvement 17%.

I. INTRODUCTION

The low extraction efficiency is primarily due to the large difference in the refractive indices between III-nitride materials and air so that the light extraction efficiency is limited by the internal reflection [1]. To solve these problems, patterned substrates were demonstrated could improved the light extraction. Some articles reported the sapphire substrates patterned by dry etching with periodic grooves or holes [2,3]. In this study, we prepared the sapphire substrate with columned patterns etched by wet etching and ICP etching. For comparison, we fabricated the same InGaN/GaN LEDs epitaxial condition on wet and ICP etching patterned sapphire substrates. The optoelectronic properties of the fabricated LEDs will be discussed.

II. EXPERIMENTS

The sapphire substrates used in this study were 2 in. For wet etching, A 300 nm SiO₂ was deposited on sapphire substrate by plasma enhanced chemical vapor deposition (PECVD). The circular photoresist array with a 2.5 μm diameter and 2.5 μm spacing was defined by the standard photolithography process on SiO₂ film. Then SiO₂ film was patterned in a buffered oxide etch solution using photoresist as a mask. After SiO₂ patterning, the photoresist was removed and the SiO₂ array was left to serve as the mask for the etching of sapphire substrates. The sapphire substrates with SiO₂ masks were wet-etched in a mixture of H₂SO₄ and H₃PO₄ (H₂SO₄:H₃PO₄ = 3:1). The SiO₂ mask was then removed in HF solution. For ICP etching, the photoresist array was fabricated directly on sapphire substrate by the standard photolithography process. Then the sapphire substrate was etched with BCl₃/Cl₂ in an ICP etcher using photoresist array as mask. After etching, the photoresist was removed. And then the samples used in this study were all grown on PSS by MOCVD. Details of the growth procedure could be found elsewhere[4,5].

Fig. 1 shows the epitaxial layers and the LED structures fabricated on patterned sapphire substrates. Photoluminescence (PL) was measured at room temperature using a 325-nm line of a He-Cd laser as an excitation source. The morphologies of the Wet and ICP LEDs surface were observed by a field emission scanning electron microscope(FESEM). The current-voltage(I-V) and light output power measurement was also performed at room temperature by an HP4145 semiconductor parameter analyzer.

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the room temperature (RT) photoluminescence (PL) spectra of the wet-LED and ICP-LED. It can be seen that PL spectrum of the wet-LED and ICP-LED samples show a blue emission at around 440 nm.
Fig. 3 (a)-(e) show a field-effect scanning electron microscope image of the p-GaN surface that had been grown on pattern sapphire substrate by Wet-etching and ICP etching. As shown in Fig. 3(a) and (b) that hexagonal pits with diameter of 320-384 nm, 325-420 nm and depth of 90-170 nm, 250-257 nm on Wet-etching and ICP-etching LED surface, respectively. The hexagonal pit density on the wet-etching PSS and ICP-etching PSS LEDs surface were $2.6 \times 10^8$ cm$^{-2}$ and $3.5 \times 10^8$ cm$^{-2}$, respectively. Fig. 4 shows the light output powers and forward voltages as a function of injection currents (L–I–V) characteristics for the two LEDs. This indicates that the Wet-LED and ICP-LED have similar I–V characteristics. The forward voltages of 3.814 V and 3.788 V were measured at the injection current of 20 mA for Wet-LED and ICP-LED, respectively. Under a 20 mA forward injection current, the light output powers of Wet-LED, and ICP-LED were 1.395 and 1.571, respectively. It was a clearly to found that used the wet etching method would improvement the light output power than ICP etching method about 17%.

Fig. 2. Room temperature PL spectra of the Dry-etching LED and Wet-etching LED.

Fig. 3. SEM images of the Wet and ICP LEDs surface.

IV. CONCLUSION

In conclusion, the characteristics of GaN-based LEDs grown on ICP- and wet-patterned sapphire substrates were analyzed. The light output powers of LED on ICP-etching patterned substrates was better than the LED on Wet-etching patterned substrates that improvement 17%.

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REFERENCES


