# Improvement of LED Luminance Efficiency by Sapphire Nano PSS Etching

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**Abstract:**

GaN-based blue LEDs (with 450-460 nm light emission) are generally produced by depositing a GaN film on a sapphire substrate and then fabricating them into LED devices. Patterned sapphire substrates (PSS) are fabricated and used in GaN-based LEDs in order to increase the internal quantum efficiency by reducing GaN crystal defects. They also have the benefit of improving external quantum efficiency by increasing the reflection area. Regarding electroluminescence (EL) intensity, performing PSS etching improves the luminous efficiency by about 13% compared to processing without PSS. It is well-known that luminous efficiency of LED devices increases by carrying out the PSS process (Figure 1).

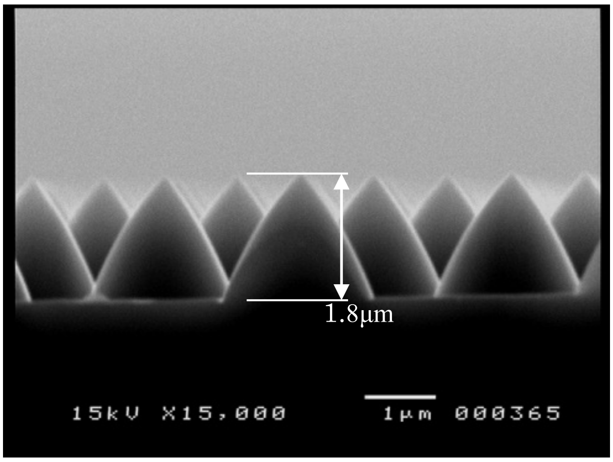



Figure 1. Typical micro-PSS etch pattern.

A dry etching process using a photoresist mask has been utilized for PSS processing because the required etching precision cannot be achieved with wet etching. However, since sapphire dry etching requires a high RF power, the wafer absorbs heat from the plasma and can reach temperatures of up to 250℃, causing photoresist burning and deterioration, and harming the etching process. Therefore, to prevent photoresist deterioration, it is necessary to keep the substrate temperature below 100℃. SAMCO has investigated 3 methods to achieve this: 1) Direct chucking of sapphire substrate; 2) Indirect chucking using tape or grease; 3) Heat resistance enhancement of the dry photoresist mask.

Method 1 – direct chucking, performs temperature control by clamping wafers to a cooled electrostatic chuck (ESC) or mechanical chuck and introducing high pressure helium on the backside of the wafer to maintains the wafer temperature below 100℃. Method 2 – indirect chucking, uses a tray and a heat conductive sheet or grease to achieve similar results. However, when using either of these methods, failure in cooling during the dry etching process can occur due to insufficient clamping of the ESC or mechanical chuck, or peeling/delamination of the heat conduction sheet from the tray. To overcome these problems, we have developed a dry etching process that uses a positive photoresist with heat resistant Novolak resin (ZPP-L100 manufactured by ZEON Japan).

In Method 3, firstly, a UV-cure was carried out using a low-pressure mercury lamp primary with active wavelengths of 185nm and 254nm in order to prevent the photoresist from softening and drooping. Then, the sample was post-baked at 250℃ to avoid degradation of the photoresist caused by the absorption of heat from plasma during the dry etching process. As a result, the sapphire dry etching process was completed without photoresist burning or drooping.

The result of this experiment shows that through the use of a heat-resistant photoresist mask, etching defects caused by insufficient direct chucking or indirect cooling can be eliminated. Thus, stable sapphire etching can be realized.

The heat resistant photoresist technology is also beneficial for nano PSS, which further improves the luminous efficiency of LEDs. We carried out etching experiments to create nano PSS, aiming to achieve a higher internal quantum efficiency than standard micro-PSS by reducing GaN crystal imperfections. In these nano PSS etching experiments, sapphire patterns of 200nm in diameter were fabricated on the sapphire wafer as shown in Figure 2. The size of the nano-PSS pattern was set to about half of the emission wavelength of 450nm. Then we grew GaN epitaxial layers on the nano-PSS, measured EL characteristics of 450~460nm, and compared the luminous efficiency (Figure 3). The results showed that the EL emission intensity of nano-PSS is 45% higher than of flat sapphire substrates. It is also 30% higher than the EL emission intensity of the conventional micro-PSS (Figure 4).

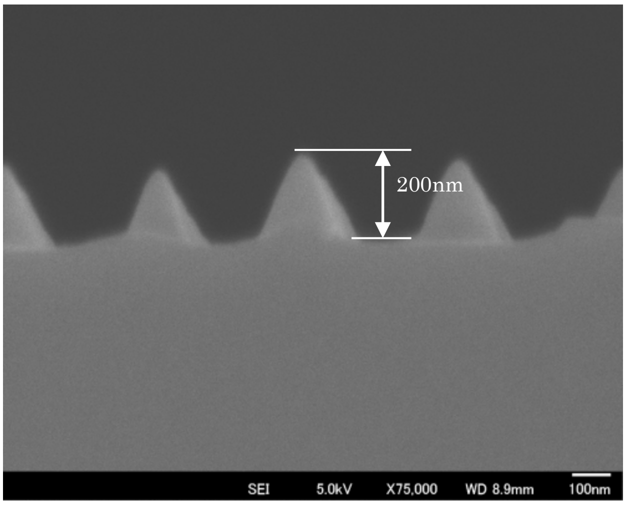



Figure 2. Nano-PSS

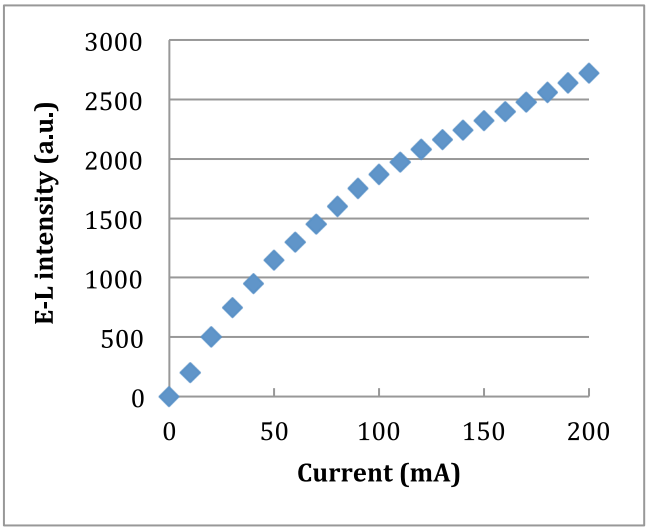
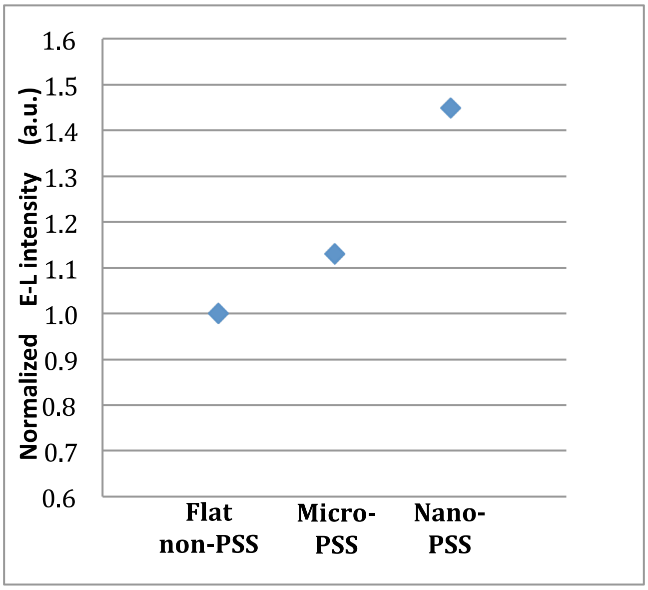



Figure 3. E-L luminous efficiency of LED with nano-PSS pattern (height 250nm) and injected current.




| | E-L intensity (a.u.) | Wavelength (nm) |
|---|---|---|
| Flat (non-PSS) | 1.00 | 450 |
| Micro PSS | 1.13 | 460 |
| Nano PSS | 1.45 | 455 |

Figure 4. Comparisons between each PSS pattern and its E-L intensity

Our aim is to optimize the nano-patterns on sapphire substrates to further improve the luminous efficiency of GaN LEDs. Meanwhile, we are also evaluating alternative applications for heat-resistant photoresist technology. For example, currently $SiO_2$, SiN and metal masks are used for plasma etching processes requiring high substrate temperatures. As we have demonstrated here, heat-resistance photoresist could significantly improve fabrication efficiency in other applications.

**Acknowledgement:**

We are grateful to Professor Ikko Tadatomo of Yamaguchi University for helpful discussion of Nano PSS Etching.