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High-Brightness Non-Polar A-plane GaN Light Emitting Diodes Grown on R-plane Sapphire Substrates

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1. Introduction

Recently, there have been extensive research activities on non-polar and semi-polar GaN LEDs because of their potential to eliminate the influence of spontaneous and piezo-electric fields, which are reported to have detrimental influence on LED efficiency and efficiency-droop [1,2,3]. However, crystal quality as well as light output power of non-polar GaN LEDs on sapphire substrates has not been competitive to c-plane based LEDs despite the various efforts to enhance the epitaxial growth conditions. The inherent inferior material quality is reported to result from the presence of high density of threading dislocations (TDs) and basal plane stacking faults (SFs), which prevents the LED performance from reaching the level of practical application. Only the LEDs fabricated on GaN substrates have shown competitive results to conventional LEDs, so far [4].

In this work, we report the first demonstration of high-brightness a-plane GaN LEDs grown on sapphire substrate with light output powers reaching above 5 mW at a forward current of 20 mA.

2. Experimental Procedure

The LED structures were grown by conventional metal organic chemical vapor deposition (MOCVD) on 2-inch r-plane sapphire substrates.

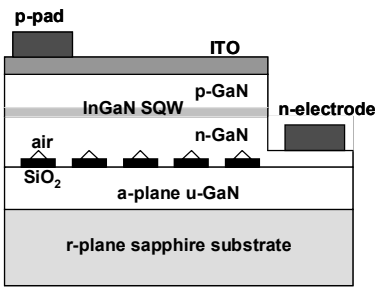

Fig 1. Schematic diagram of the a-plane InGaN/GaN LED

Typical device structure contained a GaN template, which consists of a 4 μm undoped-GaN and a 2 μm Si-doped GaN, followed by an active region having a 10 nm InGaN layer. A 150 nm p-type GaN layer was grown over the active region to complete the LED structure. To improve the crystalline quality of GaN templates, a patterned-epitaxial-lateral-overgrowth (PLOG) layer, having hexagon shaped SiO_2 layers as selective masks, was employed. Mirror-like coalescence of GaN layer was achieved by optimizing the selective lateral growth conditions.

3. Results and Discussion

To investigate the optical quality of PLOG a-plane GaN, we measured its 362 nm room temperature cathode-luminescence (CL) characteristics. Significantly higher CL intensity and fewer dark spots, which are attributed to threading dislocations, were observed in the areas above the SiO_2 layer. The full width at half maximum (FWHM) values of the (11-20) GaN X-ray rocking curves (XRCs) along c-axis and m-axis are 414 and 317 aresec, respectively. These values are better than those of our planar templates not containing PLOG structure, which have typical XRC FWHM values of 450 and 455 arcsec, respectively.

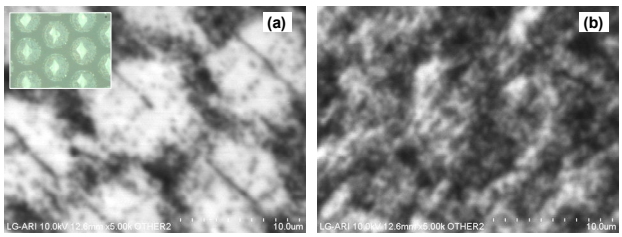

Fig 2. CL images of (a) PLOG and (b) planar template structure (Inset shows the optical microscope image for PLOG structure)

These results indicate that defect density is effectively reduced by the PLOG structure. The light-output and operating voltage versus current (L-I and V-I) characteristics were measured for a typical a-plane GaN LED. All measurements were carried out under direct-current (DC) conditions at room temperature. Indium tin oxide (ITO) was used as the transparent p-electrode and the chip size was 300×600 μm^2. At 20 and 100 mA of forward currents, the output powers were 5.1 and 19.6 mW, respectively. The forward voltage was 3.86 V at 20 mA.

The peak wavelength shift was less than 2 nm in the current range of 5~100 mA.

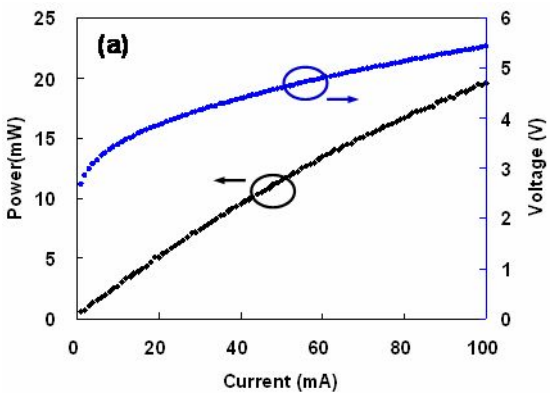

Fig 3. Light power and voltage characteristics as a function of applied current of a-plane InGaN/GaN LED

4. Summary

In summary, we have successfully fabricated high power a-plane GaN LED grown on r-plane sapphire by improving the crystalline quality using PLOG structure. It is expected that with the application of various light extraction technologies such as patterned sapphire substrate and p-GaN surface roughening, the performance of our non-polar LEDs on sapphire substrate could be comparable to that of conventional c-plane LEDs in near future.

References

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