InGaN LEDs grown on patterned sapphire substrates with modified top-tip cone shapes

Hsu-Hung Hsueh[a], Sin-Liang Ou[b], Chiao-Yang Cheng[c], Dong-Sing Wuu[b,d*], and Ray-Hua Horng[a]

[a] Graduate Institute of Precision Engineering, National Chung Hsing University, Taichung 402, Taiwan
[b] Department of Materials Science and Engineering, National Chung Hsing University, Taichung 402, Taiwan
[c] Wafer Works Optronics Corporation, Taoyuan 320, Taiwan
[d] Department of Materials Science and Engineering, Da-Yeh University, Changhua 515, Taiwan

*dsw@dragon.nchu.edu.tw
Tel: +886-4-22840500 ext. 714, Fax: +886-4-22855046

Abstract

High efficiency GaN-based light-emitting diodes (LEDs) are used in a large range of potential applications such as full-color displays, traffic signals, automobiles, solid-state lighting, backlights of liquid-crystal displays, and so on. High luminescence efficiency is needed in LEDs devices used for these applications. However, it is well known that a high threading dislocation density (typically 10^9-10^{11} cm^{-2}) is inherent in the GaN epilayer on lattice-mismatched substrates consisting of sapphire and silicon carbide [1]. High dislocation density would affect the device characteristics including device lifetime, electron mobility, and the quantum efficiency of radiative recombination.

Recently, various growth techniques, such as epitaxial lateral overgrowth (ELOG), pendeo-epitaxy and facet-controlled epitaxial lateral overgrowth, have been proposed to reduce the threading dislocation density in GaN epilayer to the range of 10^6-$10^7 cm^{-2}$. Furthermore, because of its single-growth process with no interruption, patterned sapphire substrate (PSS) technique is another promising method to achieve the high quality GaN epilayers. Nevertheless, the PSS technique requires a long time to merge the epilayer grown on etched and non-etched sapphire substrate, and then reaches a smooth film surface. According to the past research [2], the InGaN/GaN film with a high quality can be obtained by metal organic chemical vapor deposition (MOCVD) on the cone-shape PSS. For the growth on cone-shape PSS, the epilayer is merely grown on the flat basal of sapphire in the first stage. In addition, there exists no preferential orientation for the epilayer growth on cone areas. This indicates the less growth time for epilayer with a smooth film surface on cone-shape PSS can be obtained than that on a conventional PSS.

In this study, the cone-shape PSSs have been fabricated for the growth of InGaN LED structures. Moreover, the modified top-tip shapes in the PSSs were formed by the wet chemical etching with various treatment times. The GaN growth modes, film quality and LED performance were investigated for growth on a series of PSSs.

The cone-shape PSSs were fabricated on (0001) sapphires by using an inductively coupled plasma reactive ion etching (ICP-RIE) system using the reactive Cl_2 gas. The diameter, interval and height of each cone-shape pattern were 2.4 μm, 0.5 μm and 1.5 μm, respectively. After the ICP-RIE process, the fabricated cone-shape PSSs were etched with a mixture of H_2SO_4:H_3PO_4 (3:1) solution at 250 °C for 3-10 min to form the various top-tip shapes. The LED structures consisted of a undoped GaN, a n-type GaN:Si, an InGaN/GaN multiple quantum well (MQW) active region and a p-type GaN:Mg layer were grown on these PSSs in sequence by MOCVD. For the device process, a mesa pattern of LED sample was defined with the size of 24 × 45 $mil.^2$.

Fig. 1 shows the scanning electron microscope (SEM) images of cone-shape PSSs with various wet etching times of 3, 5, 7 and 10 min, respectively. It was found that the top-tip shape was transformed from smooth to angular with increasing the wet etching time. Moreover, the bottom size of each cone-shape was enlarged and the interval was reduced as the wet etching time was increased, which leaded to the decrease in c-plane ratio of sapphire.

Fig. 2 demonstrates the light output power as a function of injection current for the LEDs grown on cone-shape PSSs with and without wet etching, respectively. It revealed that the light output of LED device was improved as the PSS was treated with wet etching, which resulted from the improvement in epilayer quality due to the reduction in c-plane ratio of sapphire. However, as the etching time was more than 3 min, the light output was decreased slightly. This could be attributed to the epilayer growth not only on the c-plane area but also on the angular cone region in the initial stage as the wet etching time was increased. It caused the higher dislocation density in epilayer and the deterioration in device performance.

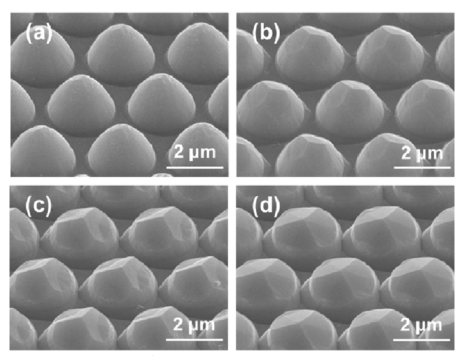

Fig. 1 SEM images of PSSs with various wet etching times of (a) 3 min, (b) 5min, (c) 7 min and (d) 10 min.

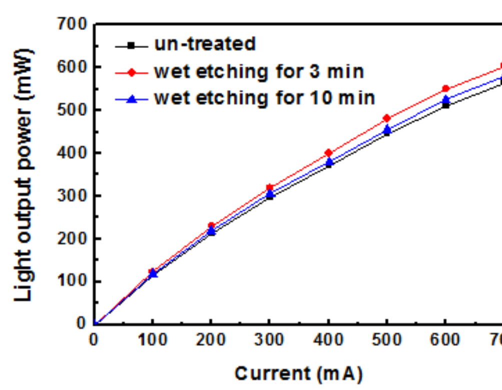

Fig. 2 Light output power as a function of injection current for the LEDs grown on cone-shape PSSs with and without wet etching.

References

1. X. A. Cao, S. F. LeBoeuf, M. P. D'Evelyn, S. D. Arthur, and J. Kretchmer, Appl Phys. Lett. 84, 4313 (2004).
2. J. H. Lee, J. T. Oh, Y. C. Kim, and J. H. Lee, IEEE Photon. Technol. Lett. 20, 1563 (2008).