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MOCVD Growth of GaN-Based LEDs With Naturally Formed Nano-pyramids

C.E. Lee, C.H. Chiu, M.H. Lo, H.W. Huang, T.C. Lu, H.C. Kuo, S.C. Wang

Department of Photonics & Institute of Electro-Optical Engineering,
National Chiao Tung University, Hsinchu 300, Taiwan, R.O.C

1. Introduction

Wide bangap light-emitting diodes (LEDs), which are III-Nitride, ranging from ultraviolet to the short-wavelength part of the visible spectrum have been intensely developed in the past ten years. Recently, as the brightness of GaN-based LEDs has increased, applications such as traffic signals, backlight for cell phone and short-haul communications have become possible. However, as for the replacement of conventional fluorescent lighting source with solid-state lighting, it still needs a great effort for improving the light extraction efficiency as well as internal quantum efficiency of LEDs. Research into improving the light extraction efficiency (external quantum efficiency) and brightness in the LEDs has been intense. In this research, we fabricated the GaN-based LEDs with naturally formed nano-pyramids on the top surface to enhance the light extraction efficiency.

2. Experiment and Discussion

The GaN-based LED samples were grown by metal–organic chemical vapor deposition (MOCVD) with a rotating-disc reactor (Emcore D75TM) on a *c*-axis sapphire (0001) substrate. CP_2Mg and disilane (Si_2H_6) were used as the p- and n-type doping sources, respectively. The LED structure consists of a 30-nm-thick GaN nucleation layer grown at 520 ℃ on sapphire, a 4 μm-thick Si-doped n-GaN layer grown at 1040 C, a 5-pair of InGaN/GaN multiple quantum well (MQW) structure grown at 760 C, a 50-nm-thick Mg-doped p-AlGaN electron blocking layer grown at 1040 C, and a 0.15 μm-thick Mg-doped p-GaN cladding layer also grown at 1050 C. After the growth of these layers, a growth-interruption step, stopping the TMGa flow while maintaining CP_2Mg flow, the process was called "Mg treatment".[1] Two different Mg treatment time were performed in this study. Sample A and B were treated 5 min and 10 min respectively. A second p-GaN contact layer was then grown again after this Mg-treatment process. Finally, a heavily Si doped short-period superlattice (SPS) was grown on the p-GaN contact layer to improve the Ohmic contact of the p-electrode. Afterwards, the conventional LED, sample A and B with a nano-pyramids surface, was fabricated using the standard process (four mask steps) with a mesa area of 300×300 μm^2.

Fig. 1 shows the scanning electron microscope (SEM) and atomic force microscope (AFM) images of the LED surfaces. Fig. 1(a)(b) shows the surface of the conventional LED, without Mg treatment, and there were no pyramid structure observed. The root mean square (RMS) roughness of the conventional LED was about 0.3 nm. Fig. 1(c)(d) shows

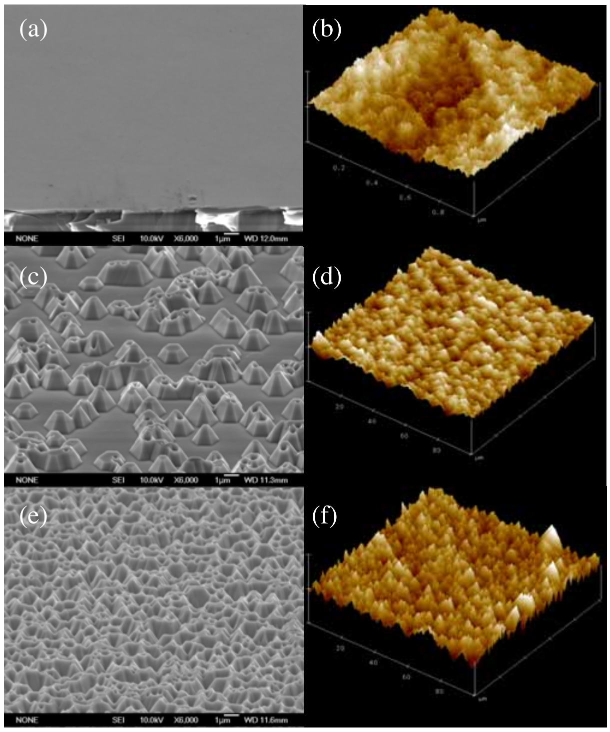

Fig. 1. The SEM and AFM pictures of conventional, sample A and sample B surfaces.

the SEM and AFM images of sample A and Fig. 1(e)(f) shows that of sample B. We can see as the treatment time increased, the density of the pyramids increased but the RMS roughness decreased, from 187.5 to 41.9 nm, the base line was gradually filled up.

The *I–V* characteristics of the conventional, sample A and B LEDs were measured. Fig. 2 plots the *I–V* characteristics of conventional, sample A and sample B LEDs. The forward voltages of the conventional, sample A and B LEDs were 3.3, 3.34 and 3.52 V at a driving current of 20 mA, respectively. The slightly higher forward voltage of LEDs with nano-pyramids was probably due to the nano-roughened process.

Fig. 3 shows the electroluminescence (EL) light output power versus driving current (*L–I* curve) of sample A, sample B and conventional LEDs. Sample B, the LED with 10 min Mg treatment, and sample A, the LED with 5 min Mg treatment, produced much higher light output as compared with that of conventional LEDs under all our measurement condition. For instance, the light output powers at 20 mA of sample A, sample B, and conventional

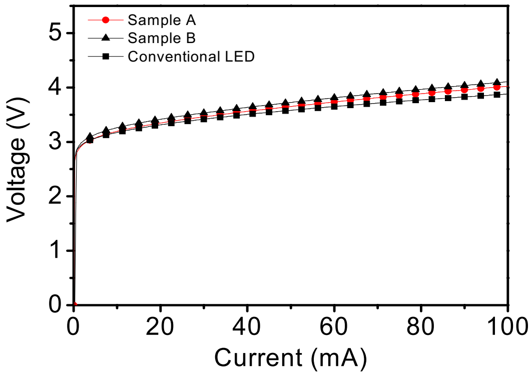

Fig. 2. The *I-V* forward curve of sample A, sample B and conventional LEDs fabricated in this investigation.

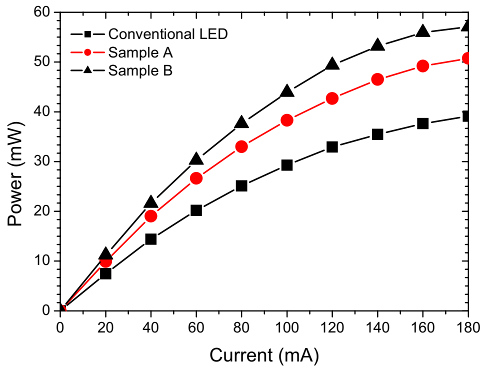

Fig. 3. Output power of sample A, sample B, and conventional LEDs measured by an integral-sphere as a function of a forward dc current.

LEDs are 7.6, 9.7, and 11.3 mW, respectively. Each measurement result was the average of 20 devices. The measured peak wavelengths of three LEDs were all at 465 nm. Therefore, the light output at 20 mA of the sample B increases by 48% as compared with that of conventional LED and increases by 16% as compared with that of sample A.

Fig. 4 shows light output patterns of sample A, sample B and conventional LED at 20 mA. It is clear from the results that the EL intensities of sample B were larger than those of sample A and conventional LEDs. According to this figure, view angles (half-center brightness or 50% of the full luminosity) of sample A and sample B are almost the same, i.e., 140˚; however, the overall integrated area of EL intensities of sample B is still larger than that of sample A. Besides, although the view angles of conventional LEDs were larger than that of sample A and sample B, i.e., 150; the enhancement of EL intensity by naturally formed nano-pyramids surfaces scheme is obvious.

3. Conclusions

We successfully fabricated the GaN-based LEDs with naturally nano-pyramids on p-GaN surface to enhance the

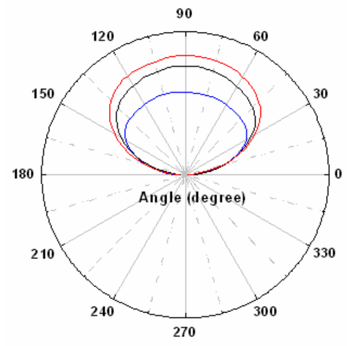

Fig. 4. Light output patterns of sample A, sample B, and conventional LEDs.

light extraction by MOVCD. The naturally formed nano-pyramids surface, with 10 min Mg treatment, improved the escape probability of light output inside the LED structure, increasing by 48% the light output of the GaN LED at 20 mA.

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