Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 532-533

P-7-6

Improved light-output of thin-GaN light-emitting diode with micro-reflector and roughened surface

Bo-Siao Cheng, Ching-Hua Chiu, Hao-Chung Kuo, Tien-Chang Lu and Shing-Chung Wang

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

1. Introduction

Recently, light emitting diodes (LEDs) with thin-GaN structure attract serious attention because of their excellent thermal dissipation [1]-[2]. The main feature of the thin-GaN LED structure is that grown on GaN LED epi-layer is stripped off and laser lift-off (LLO) techniques [3]. Heat generated from the active layer region can then be more effectively dissipated by transference to the Si substrate. However, it still needs a great effort for improving the light extraction efficiency and the heat dissipation as well as internal quantum efficiency. Research into improving the light extraction efficiency (external quantum efficiency) and the heat dissipation in the LED has been intense. Several methods such as surface roughening [4], inclined side wall [5], and diffused mirror techniques [6] have been investigated to improve their light extraction efficiency.

In this research, we fabricated the thin-GaN LEDs with naturally formed nano- pyramids on the p-GaN surface and micro-roughness on the n-GaN surface. The nano-pyramids formed by the Mg-treatment, a growth-interruption step and a surface treatment using biscyclopentadienyl magnesium (CP_2Mg), could make the surface rough as the micro-reflector. The rough surface of n-GaN could enhance the light extraction efficiency by photoelectrochemical (PEC) etching. The conventional LED (p-side up) and the LEDs with and without micro-reflector were fabricated and comparison of these fabricated LEDs will be discussed in this letter.

2. Experiment

The LED samples were grown on a c-plane sapphire substrate by means of a metal-organic chemical vapor deposition (MOCVD) with a rotating-disc reactor (Emcore D75TM). The LED structure with a size of 350 μm × 350 μm 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 ℃, 5-pair of InGaN/GaN multiple quantum well (MQW) active layers grown at 760 ℃, a 50-nm-thick Mg-doped p-AlGaN electron blocking layer grown at 1040 ℃, and a 0.15-μm-thick Mg-doped p-GaN cladding layer also grown at 1050 ℃. After the growth of these layers, a growth-interruption step, stopping the TMGa flow while maintaining CP_2Mg flow, was applied on the p-GaN surface. The details of the growth-interruption step which denoted as "Mg treatment" could be described elsewhere [7].

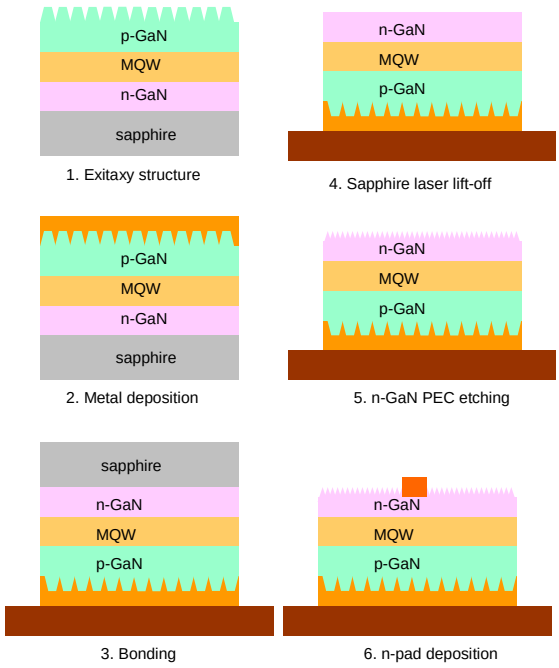
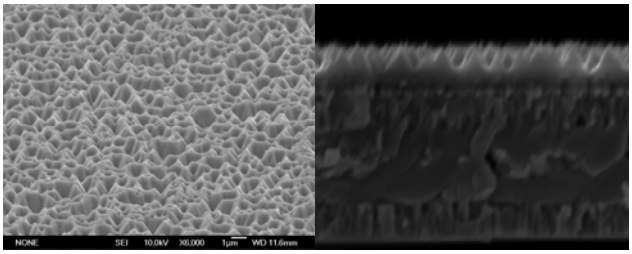


Figure 1. Schematic diagram of a thin-GaN LED structure with micro-reflector.

Nanosize pyramids with treated 10 min were formed on the surface of the p-GaN layer. For comparison, the LEDs with and without Mg treatment were fabricated. Then, typical Ni–Au metal p-contact was deposited on top of the p-GaN surface. Then, a 300-nm Ag was deposited as the micro-reflector. Then, LED chips were bonded to the Si wafer. After the bonding process of the LED, a 248-nm KrF excimer laser was employed to strip the original sapphire substrate off. The n-GaN surfaces of the LEDs with and without Mg treatment were roughed in KOH solution by PEC etching and the Cr(50 nm)/Au(300 nm) bilayer was deposited on it for serving as the n-contact metal pad. Fig. 1 illustrates the schematic diagram of the thin-GaN LED structure with micro-reflector

3. Result and Discussion

Fig. 2 shows the scanning electron microscope (SEM) images of the p-GaN surfaces (a) and the cross section of the LED structure after PEC etching (b). Notice that Mg-treatment p-face GaN surfaces show pyramid features, which is distinct from the Mg-treatment Ga-face GaN surfaces.



(a) (b)

Figure 2. The SEM micrographs of the LED (a) p-GaN surface by Mg-treatment method (b) the cross section image of the structure after PEC etching.

Fig. 3 shows the characteristic of the light output power versus the injection current. The light output powers at 20 mA of the conventional LED, and the thin-GaN LEDs with and without micro-reflector are 13.2, 21.8 and 18.0 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 power at 20 mA of the thin-GaN LED without micro-reflector shows 36% enhanced when compared to the conventional LED. The thin-GaN LED with micro-reflector increases by 65% as compared with that of the conventional LED and increases by 21% as compared with the thin-GaN LED without micro-reflector in light output power. The modified surface structure improved the probability of photons to escape from the LED, resulting in an increase in the light extraction efficiency of the thin-GaN LED due to the angular randomization of photons inside the LED structure.

The forward voltages at a driving current of 20 mA of the conventional LED, and the thin-GaN LEDs with and without micro-reflector were 3.2, 3.25 and 3.2 V, respectively. The result indicates that the electric characteristic of the thin-GaN LED compared to the conventional LED was not affected by Mg treatment and PEC etching.

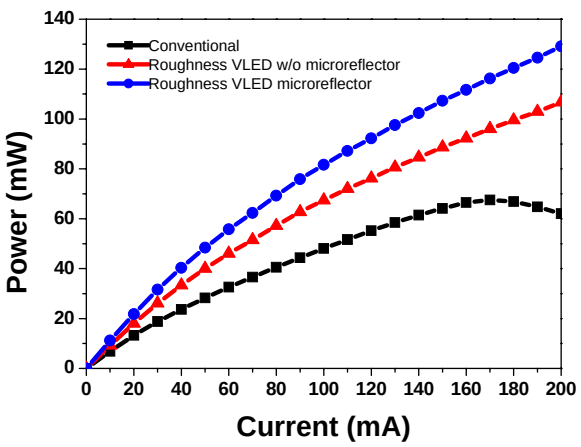


Figure 3. Output power of the conventional LED and the LEDs with and without micro-reflector measured by an integral-sphere as a function of a forward dc current.

The light output power of the conventional LED on sapphire increased with increasing current up to about 170 mA, saturated at around 170 mA, and gradually degraded. On the other hand, the light output power of the thin-GaN LED on Si was still operational up to 200 mA; suggesting superior heat dissipation with the Si substrate and also allowing higher current operation with higher light output.

4. Conclusion

In summary, we report a thin-GaN LED with micro-reflector on the p-GaN and roughened surface on the n-GaN. The nano-pyramids on the p-GaN were formed by the Mg-treatment and the roughened surface on the n-GaN was etched by PEC. Enhancement of light extraction efficiency, about 65%, could be achieved by the LED with micro-reflector and n-GaN roughness. The thin-GaN LED with superior heat dissipation on the Si substrate allowed higher current operation with higher light output. It is notable that the Mg treatment mentioned in this paper is simple and does not require complicated processes.

5. Acknowledgments

This work is supported by the National Science Council of Republic of China (ROC) in Taiwan under contract NSC 96-2120-M-009-006 and NSC 96-2628-E-009-017-MY3.

6. Reference

[1] D. S. Wuu, S. C. Hsu, S. H. Huang, and R. H. Horng, Phys. Stat. Sol., **202** (2006) 2699

[2] S. C. Hsu and C. Y. Liu, Electrochem. Solid-State Lett., **9** (2006) G171–G173

[3] W. S. Wang, M. Kneissl, P. Mei, D. W. Treat, M. Treep, and N. M. Johnson, Appl. Phys. Lett., **78** (2001) 1198–1200

[4] H. W. Huang, H. C. Kuo, C. F. Lai, C. E. Lee, C. W. Chiu, T. C. Lu, S. C. Wang, C. H. Lin, and K. M. Leung: IEEE Photonics Technol. Lett. **19** (2007) 565.

[5] D. Eisert and V. Harle: present at *Int. Conf. Numerical Simulation of Semiconductor Optoelectronic Devices*, 2002, Session 3.

[6] J. K. Kim, H. Luo, Y. Xi, J. M. Shah, T. Gessmann, and E. F. Schubert: J. Electrochem. Soc. **153** (2006) G105.

[7] C. S. Chang, S. J. Chang, Y. K. Su, C. H. Kuo, W. C. Lai, Y. C. Lin, Y. P. Hsu, S. C. Shei, J. M. Tsai, H. M. Lo, J. C. Ke, and J. K. Sheu: IEEE Trans. Electron Devices **50** (2003) 2208.