Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.714-715

P7-4

Light-output Enhanced of GaN-based Light-emitting Diodes by Photoelectro-chemical oxidation in H_2O

Fang-I Lai, W. Y. Chen, C. C. Kao, H. C. Kuo, and S. C. Wang*

Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University
1001 Ta Hsueh Road, Hsinchu, Taiwan 300, ROC
*Phone: +886-3-571-2121x56320 E-mail: scwang@cc.nctu.edu.tw

1. Introduction

Wide bandgap semiconductors of III-nitride based materials have recently attracted considerable interest because of their wide applications for optoelectronic devices such as detectors, light-emitting diodes (LEDs) and laser diodes (LDs) in green-blue-UV spectrum range.

In recent years, high efficiency GaN-based LEDs have been attracted a great interest because of the wide applications such as traffic light, full color display, optical storage, and lighting [1]. However, the total output light from these LEDs is still rather low. Therefore, how to enhance the efficiency of GaN-based LEDs is an area of active study. Particularly, many studies of improvements are in the external quantum efficiency (η_{ext}) because of a significant gap between the internal efficiency of LEDs and their external efficiency. The external quantum efficiency of the nitride-based LEDs is often low due to the large refractive index difference between the nitride epitaxial layer and the air. It has been reported that the refractive indexes of GaN and the air are 2.5 and 1, respectively. Thus the critical angle [$\theta_c = \sin^{-1}(n_{air}\text{-}n_{GaN})$] for the light generated in the InGaN-GaN active region to escape is about 23° [2, 3]. Hence, for a conventional GaN-based LED, just a small fraction of light generated in the active region of the LED can escape to the surrounding air. The light extraction efficiency enhancement method was discussed in many papers [4-8].

In this article, we report on the improved light output of GaN-based LEDs using photoelectrochemical (PEC) oxidation method via H_2O on the p-GaN surface. The light output efficiency of a LED structure with an oxide film on top surface was significantly increased compared to that of a conventional LED structure. The oxide film on the top surface of the LED would also provide an efficient surface passivation effect for the devices [8].

2. Experimet

GaN LED samples were grown on a c-face sapphire (0001) substrate by MOCVD. The LED structure consists of a 30-nm-thick GaN low temperature buffer layer, a 2.0-μm-thick undoped GaN layer, a 1.5-μm-thick highly conductive n-type GaN layer, a multiple quantum wells (MQWs) region consisting of 2/5-nm-thick InGaN/GaN five periods multiple quantum wells, and a 0.3-μm-thick p-type GaN. The LED sample was firstly divided into two parts, one is for PEC oxidation; another is for comparable without PEC oxidation. Both the samples were performed regular LED process. The previous one for PEC oxidation is following performed PEC oxidation process using PEC oxidation method in water with 15V bias-assisted under 300mW/cm^2 illumination during 30 and 45 minutes. Then, the oxide film Ga_2O_3 was grown on the surface of p-GaN. In particularly, we chose water not commonly used KOH or H_3PO_4 for the solution of PEC oxidation process to ensure that the oxide film won't be etched after it formed [9]. The size of LED devices is 300×300 μm^2 and the *p*-, *n*-contact are Ni/Au (20/200 nm) and Ti/Al/Ni/Au (20/150/20/200 nm), respectively. A mesh p-contact was used to improve current spreading without transparent contact.

3. Results and discussions

The conventional LEDs, PEC-oxide LED by 30min and 45min PEC process were both preformed output light intensity-current-voltage (L-I-V) measurement. The comparison of L-I characteristic of conventional LED and PEC-oxide LED are shown in Fig. 1. The figure shows that the light output of the PEC-oxide LED was much higher than the conventional LED (about 2.5 mW) under 20 mA current injection. The light output of the oxided LEDs during 30min and 45 min PEC process were increased about 16% and 37% respectively compared with the conventional LED drived at 20 mA. The increased light output of the LED with PEC-oxide surface is directly proportional with the PEC-oxidation time and might result form the roughness of the interface between oxide film and the top of the LED surface. Additionally, the intermediate oxide layer can enhance the probability of photons escaping from the LED in the in-plane directions. By the way, the IV characteristics of all the samples reveal that the dynamic resistance (R=dV/dI) of LEDs after PEC oxidation process are almost the same with the conventional LEDs, and the PEC oxidation process would not degrade the I-V characteristic of LEDs.

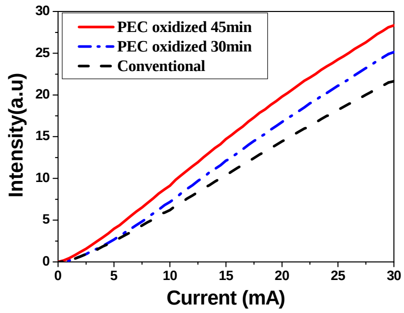

Fig. 1 L-I characteristics of conventional and PEC oxided LEDs

In order to confirm the effects of the roughened surface on the enhancement of light output, the atomic force microscope (AFM) measurement was performed after the oxide film was removed to expose the interface. Figure 2(a) shows the AFM images of the top surface of conventional LED and Fig. 2(b)-(c) show the exposed interface of oxide film and the top of the LED surface. The RMS of p-GaN surface roughness was around 2 nm as showed in Fig. 2(a). Figure 2(b) and 2(c) exhibit that the RMS of p-GaN surface roughness during 30min. and 45 min oxidation process are about 9.4nm and 18.6nm respectively. The AFM images suggest that the roughness of the interface between oxide film and GaN increases with oxidation time and might enhance the light extraction efficiency.

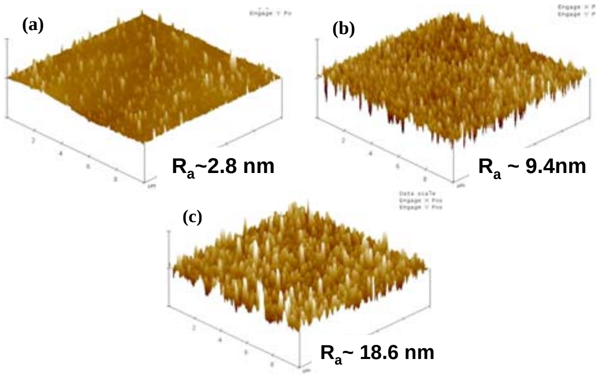

Fig. 2 AFM images of (a) the top surface of conventional LED and the exposed interface by during (b) 30min, (c) 45min PEC oxided processing.

4. Conclusions

In summary, we report on improved light output of GaN-based LEDs using photoelectrochemical (PEC) oxidation method via H_2O on the p-GaN surface. The light output of the oxided LEDs during 30min and 45 min PEC process were increased about 16% and 37% respectively compared with the conventional LED drived at 20 mA. The AFM data show that the roughness of the interface between oxide film and GaN increases with oxidation time and might enhance the light extraction efficiency.

Acknowledgments

This work was supported in part by National Science Council of Republic of China (ROC) in Taiwan under contract No. NSC 93-2215-E-009-063, part by the Extend Academic Excellence Program of the ROC under the contract No. NSC. 93-2752-E-009-008-PAE, and part by MediaTek Fellowship .

References

[1] S. Nakamura and G. Fasol, The Blue Laser Diode, 1st ed. Berlin, Germany: Springer-Verlag, (1997).
[2] C. Huh, K. S. Lee, E. J. Kang, and S. J. Park, J. Appl. Phys., **93** (2003) 9383.
[3] C. S. Chang, S. J. Chang, Y. K. Su, C. T. Lee, Y. C. Lee, Y. C. Lin, W. C. Lai. S. C. Shei, J. C. Ke and H. M. Lo, IEEE photo. Tech. Lett., **16** (2004) 750.
[4] S. X. Jin, J. Li, J. Y. Lin, and H. X. Jiang, Appl. Phys. Lett., **77** (2000) 3236.
[5] Chul Huh, K.-S. Lee, E.-J. Kang, and S.-J Park, Journal of Appl. Phys., **93** (2003) 9383.
[6] R. Windisch, B. Dutta, M. Kuijk, A. Knobloch, S. Meinlschmidt, S. Schoberth, P. Kiesel, G. Borghs, G. H. Döhler, and P. Heremans, IEEE Transactions on Electron Devices, **47** (2000) 1492.
[7] K. Nakahara, K. Tamura, M. Sakai, D. Nakagawa, N. Ito, M. Sonobe, H. Takasu, H. Tampo, P. Fons, K. Matsubara, K. Iwata, A. Yamada and S. Niki, J. Journal of Appl. Phys., **43**, No. 2A (2004) L180.
[8] L.-H. Peng, C.-H. Liao, Y.-C. Hsu, C.-S. Jong, C.-N. Hiang, J.-K. Ho, C.-C. Chiu, and C.-Y. Chen, Appl. Phys. Lett., **76** (2000) 511,.
[9] J. W. Seo, C. S. Oh, H. S. Jeong, J. W. Yang, K. Y. Lim, C. J. Yoon, and H. J. Lee, Appl. Phys. Lett., **81** (2002) 1029-1031.