Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.836-837

P11-8

Fabrication the Nanoporous InGaN-based Light-Emitting Diodes

Chia-Feng Lin, Jing-Hui Zheng, Zhong-Jie Yang, and Jing-Jie Dai

Department of Materials Engineering, National Chung Hsing University,
250 Kuo Kuang Rd. Taichung 402, Taiwan, R.O.C.
Phone: + 886-4-22858329 E-mail: cflin@dragon.nchu.edu.tw

1. Introduction

Recently porous semiconductors have been widely studied due to their unique optical properties compared to conventional bulk materials. Porous layer can be used as a buffer layer or intermediate layer for strain management during epitaxial regrowth. This porous structure can reduce the defeat density and relief strain caused by lattice mismatch between GaN and sapphire. The nanoporous n-GaN material had been reported to improve optical quality. Fabricating the porous on p-GaN more difficult than n-GaN. Because it needs hole to accumulate at p-GaN surface to form oxidation layer in this experiment. The PEC wet oxidation process and oxide removed process was used to form the nanoporous GaN:Mg and GaN:Si structures different from the previously reports.[1],[2],[3]

2. General Instructions

The processed LED structure consisted of a 1 μm-thick unintentionally doped GaN layer, a 3 μm-thick n-type GaN:Si layer, and six-pairs of 3 nm-thick InGaN-well/7 nm-thick GaN-barrier MQW active layers, followed by a 0.1 μm-thick magnesium-doped GaN (GaN:Mg) layer. Prior to PEC wet-etching process, a mesa region was defined with a depth of about 1.5 μm by an inductively coupled plasma etcher using a Cl_2 gas. During the wet-oxidation process, the DI water solution was used as the oxidation solution without stirring. Accompanied with the illumination exposure of a 400W Hg lamp for 30 min, an external DC bias fixed at positive 20 V was applied on the n-type GaN:Si layer surface as the anode contact and using platinum as the cathode. After removed the Ga2O3 layer on the GaN surface, the porous GaN:Si of ICP etching surface and GaN:Mg mesa surface were observed on the surface. The etched surface morphologies were observed using JEOL JSM-6700F field-emission scanning electron microscopy (FE-SEM). The photoluminescence spectrum was measured at room temperature by using a 355nm YVO4 laser as the excited source.

After Figure 1 shows uniformly distributed nanoporous of GaN:Mg and GaN:Si surface were observed on the top mesa and bottom ICP etching surfaces after PEC oxidation and oxide-removed process. The oxidation layer was formed with DC-biased PEC process and then remove oxide layer by HCl or aqua-regia. The nanoporous structure on p-GaN and n-GaN layers was observed from SEM images shown in Fig. 1(a). The nanoporous GaN:Mg and GaN:Si surface in this InGaN-based LED structure has the potential to increasing the external quantum efficiency. The average pore size is about 80nm observed from the Fig. 1(b). And the mesa sidewall was also roughening during this PEC process. This porous GaN has the high crystal quality to release the lattice mismatch induced stain compared with the previously reports.

.

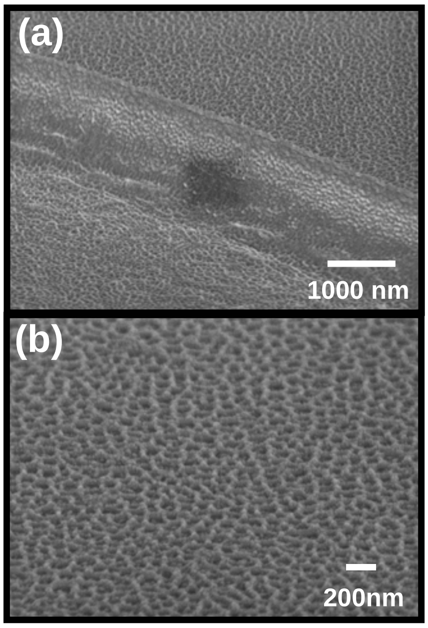

Fig. 1 SEM micrographs of porous InGaN-based LED structure under PEC process, (a)the step profile of mesa region and (b) porous of the GaN:Mg surface on the mesa region.

Figure 2 shows the PL emission spectra of standard and nanoporous LED samples in logarithm scale measured at room temperature. For the standard sample, the emission peaks of GaN bandage and InGaN/GaN MQW layers located at 371.0nm and 432.8 nm, respectively. After the PEC wet-oxidation and oxide-removed process, the GaN:Si and GaN:Mg layers were formed as the nanoporous structure. Different from the standard sample, the emissions peaks of GaN bandage, and two InGaN/GaN MQW emission peaks of the PEC treated sample were found to locate at 372.7, 408.6, and 432.8 nm respectively as shown in Fig. 2. Comparing with the PL peak position of the InGaN/GaN MQW structure at 432.8 nm (2.865 eV) for the standard sample, a strong blue shift to 408.6 nm (3.035 eV) occurred in the PEC treated sample due to the reduction in piezoelectric field as reported by Dai et al.[4]. The strain caused by the lattice mismatch between the GaN and InGaN layers was expected to partly release in the nano-porous MQW structure, and thus the reduction in the piezoelectric field caused by the partial strain relief would then induce the blue shift phenomenon of 24.2 nm (170 meV). By dividing 3 nm, the well width, the 170-meV blue shift of the PL peak position for the InGaN/GaN MQW layer corresponded to the reduction of piezoelectric field as about 0.56 MV/cm. The nanoporous enhanced the PL intensity by rough the p-GaN to increase extraction efficiency. After PEC process, the PL intensity is higher compared to sample without PEC treated caused by the roughness can scatter the light from bulk to air. Because of lattice mismatching could resulting in appearance of stress between these layers. The stress could be released was due to formation of nanoporous. The PL peak of n-GaN is tendency red shift which is attributed to release tensile stress. The PL peak of MQW structure, has the blue shift phenomenon, because of the releasing compressive stress.

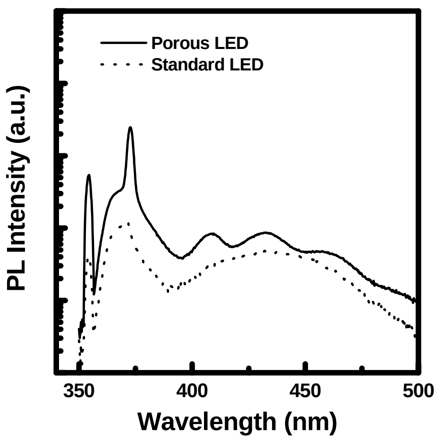

Fig. 2 Photoluminescence emission spectra of standard and porous InGaN-based LED samples measured at room temperature.

3. Conclusions

In this paper we used PEC oxidation process to form nanoporous on p-GaN and n-GaN. The average pore size is about 80nm. The nanoporous enhanced the PL intensity by rough the p-GaN to increase extraction efficiency. After PEC process, the PL intensity is higher compared to sample without PEC treated caused by the roughness can scatter the light from bulk to air. The stress could be released was due to formation of nanoporous. The PL peak of n-GaN is tendency red shift which is attributed to release tensile stress. The PL peak of MQW structure, has the blue shift phenomenon, because of the releasing compressive stress. The piezoelectric field could be reduced attributed to the strain released. Reducing piezoelectric effect can increase recombination efficiency of electrons and holes, because of the band structure is not more tilting. We can obtain that releasing stress increases the internal efficiency. From this study, the nanoporous structure was fabricated by PEC treatment to release the strain, increase the internal and extraction efficiency of the InGaN-based LEDs.

Acknowledgements

The authors gratefully acknowledge the financial supports for this research by the National Science Council of Taiwan under grant no. NSC-93-2215-E-005-010. The authors also thank Professors S.C. Wang and H.C. Kuo with National Chiao Tung University for their contributions.

References

[1] Y. D. Wang, S. J. Chua, M. S. Sander, P. Chen, S. Tripathy, and C. G. Fonstad, Appl. Phys. Lett. **85**, 816 (2004).
[2] Xiuling Li, Young-Woon Kim, Paul W. Bohn, and Ilesanmi Adesida, Appl. Phys. Lett. **80**, 980 (2002)
[3] M. Mynbaeva, A. Titkov, A. Kryganovskii, V. Ratnikov, K. Mynbaev, H. Huhtinen, R. Laiho, V. Dmitriev, Appl. Phys. Lett. **76**, 1113 (2000).
[4] K. Tachibana, T. Someya, S. Ishida, and Y. Arakawa, Appl. Phys. Lett. **76**, 3212 (2000).