English Research Express@NCKU Volume 30 Issue 9 - September 2, 2016
[http://research.ncku.edu.tw/re/articles/e/20160902/1.html]

GaN-Based Power Flip-Chip LEDs With SILAR and Hydrothermal ZnO Nanorods

Shoou-Jinn Chang[1,*], Nan-Ming Lin[2], and Shih-Chang Shei[2]

[1] Institute of Microelectronics & Department of Electrical Engineering, National Cheng Kung University
[2] Department of Electrical Engineering, National University of Tainan

IEEE J. Sel. Top. Quantum Electron., Vol. 21, No. 4, 9100405, 2015

For practical solid-state lighting, one needs to deliver large power into large-size devices. The inputted electrical power will be partially converted into output light while the remaining power will be converted into heat. Without a good thermal property, the generated heat can easily fail the devices. Thus, it is extremely important to enhance thermal properties of high power LEDs. However, the reflective index of sapphire is higher than that of air. This will result in Fresnel reflections, most of the generated lights in the active layer are absorbed inside LEDs and then converted into heat. Rough sapphire surface is a simple technique and has been used to destroy the total internal reflection [1]. It has been reported that one can increase the light extraction efficiency of GaN-based LEDs by using SiO2, ITO, and SiNx nanopillars [2]–[4]. Recently, using ZnO nanopillars to increase the light extraction of GaN-based LEDs has been reported due to simplicity and cost effectiveness [5]–[10]. Among these, the solution approach based on soft chemical technique has attracted increasing attention in recent years. In this paper, we reported the ZnO nanorods on the top of sapphire surface to enhance light extraction. The ZnO nanorods were formed by successive ionic layer adsorption and reaction (SILAR)-based and hydrothermal method (Hm). This method is simple, low cost, with high reliability and large area growth. The detailed procedure will be reported.

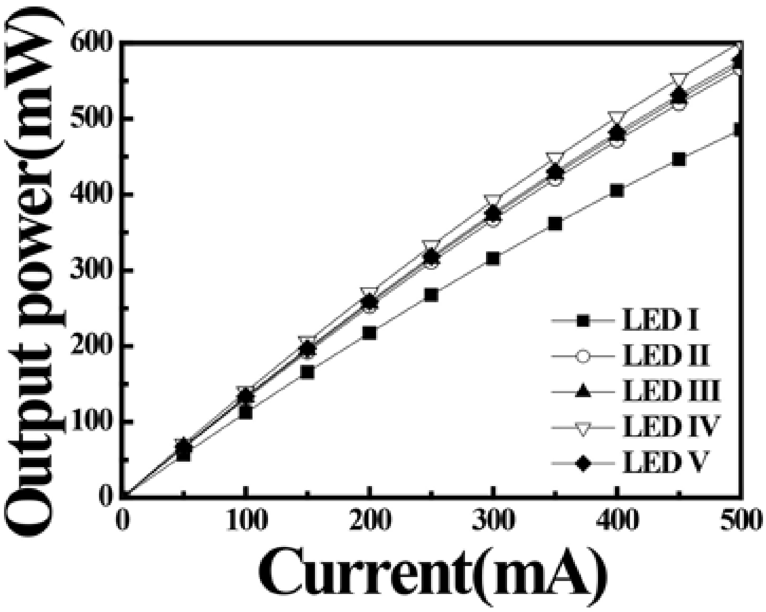

Fig. 1. Output power as a function of injection current for the five LEDs.

Fig. 1 shows the light output power–current characteristics of the five LEDs. With 350 mA current injection, it was found that the output powers were 361.7, 420.7, 426.8, 448.2, and 430.4 mW for LED I, LED II, LED III, LED IV, and LED V, respectively. It was also found that LED II, LED III, LED IV, and LED V were significantly larger than that of LED I. It was found that LED IV was also 24% larger than that of LED I. This improvement can be attributed to the fact that the ZnO nanorods on the top of sapphire can reduce Fresnel reflection, and such a result suggests that SILAR with four cycles is the best choice. Our result is similar to that of an approach [5]. According to the reference, they proposed an two-step hydrothermal method to form ZnO nanorods, The first step is to dip the substrate into zinc acetate dihydrate $[Zn(Ch_3COO)\ _2.2H_2O]$ dissolved in an ethanol solution followed by annealing at 100 °C for 3 min. After the formation of ZnO seed layers, the ZnO nanorods were formed in solution of zinc nitrate hexahydrate and hexamine dissolved in DI water at 95 °C for 3 h. Compared with our method, we used SILAR and Hm, especially, our Hm only needs 1.5 hour with SILAR four cycles. We not only can form ZnO nanorods but also can control ZnO nanorods from the loose to dense. In 2011, Dai *et al.* has demonstrated that vertical ZnO nanorods can enhance the light extraction of GaN-based LEDs by finite difference of time domain. From their simulated results, the vertical ZnO nanorods can reduce the light reflection. Once again, their simulated results agree well with our experimental results [7].

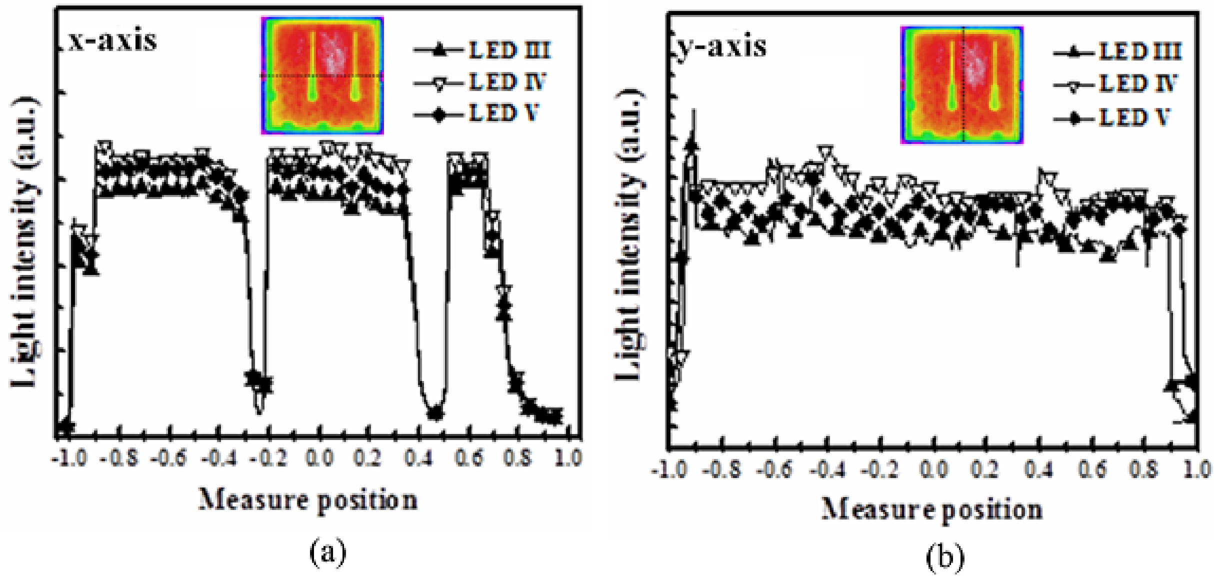

Fig. 2. Spatial profiles of light emission intensity taken from LED III, LED IV, and LED V under an injection current of 350 mA in the (a) x-direction and (b) y-direction.

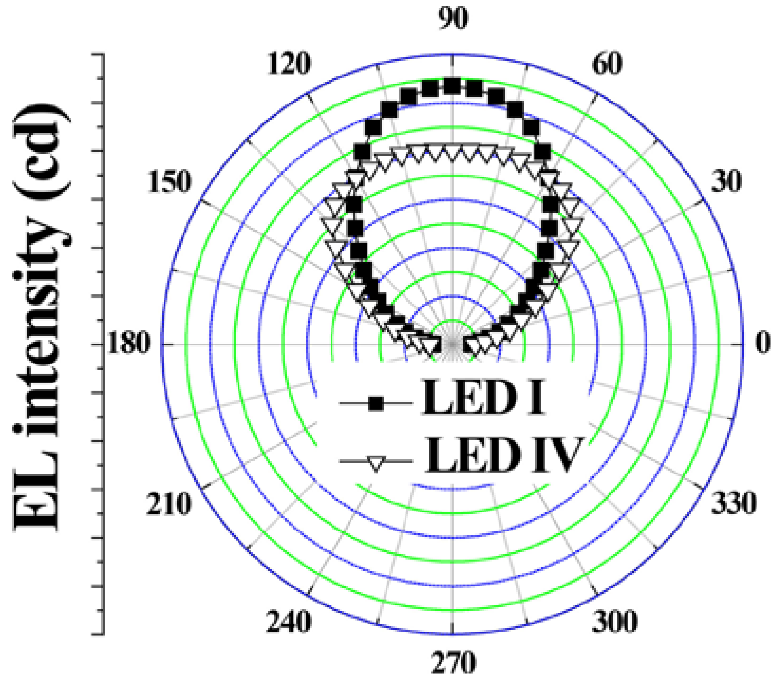

Fig. 3. Light output patterns measured from the two LEDs.

Fig. 2(a) and (b) show the spatial profiles of light emission intensity taken from LED III, LED IV, and LED V under an injection current of 350 mA, in the x-direction and y-direction, respectively. It can be seen again that the output intensity of LED IV was larger than that observed from LED III and LED V. Fig. 3 shows light output patterns measured from LED I and IV. During measurements, we injected a 350mAdc current into the two LEDs.With 350 mA current injection, it can be seen clearly that the FC LED without ZnO nanorods (i.e., LED I) was in the near horizontal direction. On the other hand, the EL intensity observed from the FC LED with the ZnO nanorods (i.e., LED IV) in the near vertical direction was larger than that observed from the FC LED without ZnO nanorods. The ZnO nanorods can effective guide internal light to escape from the sapphire.

References:

[1] S. J. Chang, W. S. Chen, S. C. Shei, C. F. Shen, T. K. Ko, J. M. Tsai, W. C. Lai, J. K. Sheu, A. J. Lin, S. C. Hung, "GaN-based power flip-chip light-emitting diodes with Cu submount," *IEEE J. Sel. Topics Quantum Electron* ., vol. 15, no. 4, pp. 1287–1291, 2009.

[2] S. C. Shei, "SILAR-based application of various nanopillars on GaNbased LED to enhance light-extraction efficiency," *J. Nanomater* ., vol. 2013, art. 653981, 2013.

[3] X. F. Zeng, S. C. Shei, and S. J. Chang, "SiO_2 nanopillars on microscale roughened surface of GaN-based light-emitting diodes by SILAR-based method," *J. Nanomater* ., vol. 2013, art. 753230, 2013.

[4] S. C. Shei, X. F. Zeng, N. M. Lin, and S. J. Chang, "SiNx nanopillars on AlGaInP-based light-emitting diodes to enhance light extraction using self-assembly ZnO nanomask coating by successive ionic layer adsorption and reaction method," *Thin Solid films*, vol. 570, pp. 230–234, 2014.

[5] Y. S. Lee, Y. I. Jung, B.Y. Noh, and I.K. Park, "Emission pattern control of GaN-based light-emitting diodes with ZnO nanostructures," *Appl. Phys. Exp*., vol. 4, pp. 112101-1– 112101-3, 2011.

[6] D. K. Hui, W. L. Shan, H. D. Xiu, S. C. Beng, and C. S. Jin, "Influence of size of ZnO nanorods on light extraction enhancement of GaN-based light-emitting diodes," *Chin. Phys. Lett*., vol. 28, pp. 098501-1–098501-4, 2011.

[7] K. Dai, C. S. Soh, S. J. Chua, L. Wang, and D. Huang, "Influence of the alignment of ZnO nanorod arrays on light extraction enhancement of GaN-based light-emitting diodes," *J. Appl. Phy*., vol. 109, pp. 083110–1– 083110-5, 2011.

[8] J. M. Lee, J. Yi, W. W. Lee, H. Y. Jeong, T. Jung, Y. Kim, and W. I. Park, "ZnO nanorods- graphene hybrid structures for enhanced current spreading and light extraction in GaN-based light emitting diodes," *Appl. Phys. Lett*., vol. 100, pp. 061107-1–061107-5, 2012.

[9] C.Y. Cho, N. Y. Kim, J. W. Kang, Y. C. Leem, S. H. Hong, W. Lim, S. T. Kim, and S. J. Park, "Improved light extraction efficiency in blue light-emitting diodes by SiO_2 -coated ZnO nanorod arrays," *Appl. Phys. Exp*., vol. 6, pp. 042102-1–042102-3, 2013.

[10] Z. Yin, X. Y. Liu, H. C. Yao, Y. Z. Wu, X. P. Hao, M. Han, and X. G. Xu, "Light extraction enhancement of GaN LEDs by hybrid ZnO micro-cylinders and nanorods array," *IEEE Photon. Technol. Lett*., vol. 25, no. 20, pp. 1989–1992, 2013.