Double-sided Pattern Design on Patterned Sapphire Substrate of GaN-based LEDs

Xinyu Yu, Zhen Che, Jun Zhang*, Mengyuan Xie, Jianhui Yu, Huihui Lu, Yunhan Luo, Zhe Chen
Key Laboratory of Optoelectronic Information and Sensing Technologies of Guangdong Higher Education Institutes
Department of Optoelectronic Engineering, Jinan University
Guangzhou, China
*Corresponding author: ccdbys@163.com

***Abstract*— In this paper, we established a optical model and made an analysis of GaN-based LED flip chip by double-sided PSS (patterned sapphire substrate). The result analysis shows that the small distance and large radius of micro-cylinder and micro-hemisphere for cylindrical and hemispherical PSS would be more effective to enhance LED efficacy. The hemispherical pattern is more efficient than the cylindrical for enhancement for the light extraction efficiency (LEE) of PSS-LED flip chip. The light extraction efficiency of micro-hemispherical PSS-LED chip is twice than that on the non-patterned (or normal planar) sapphire substrate (non-PSS).**

Keywords—double-sided pattern;patterned sapphire substrate; light extraction efficiency;

I. INTRODUCTION

Patterned sapphire substrate (PSS) technique have been intriguing due to its benefit to the epitaxial growth of GaN and light extraction efficiency (LEE), leading to enhancement of external quantum efficiency (EQE) for GaN-based LEDs[1-3]. Recently, the hemisphere pattern is reported as an efficient pattern to be fabricated on the sapphire substrate of GaN-based LEDs [4,5]. Many other type patterns have been also reported, such as groove, cylinder, cone [6-8]. For all these patterns, the appropriate size is vital. However, it is not reported before that the hemisphere patterns can be fabricated on double side of sapphire substrate and how is it to influence the LEE of flip chip. In this paper, the optical model of a PSS-LED flip chip is established by ASAP, and the change of LEE with different sizes of double-sided hemisphere patterns is analyzed.

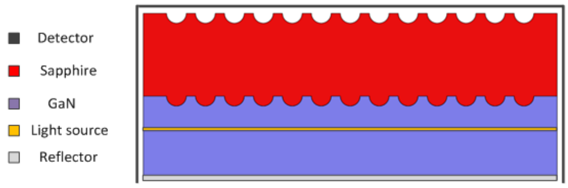

Fig. 1. Shematic of optical model of a PSS-LED flip chip with double-sided hemisphere pattern

II. OPTICAL MODEL OF PSS-LED FLIP CHIP

In this section, the optical model of a PSS-LED flip chip is established. As shown in Fig.1, this chip has a patterned sapphire substrate which hemisphere patterns were fabricated on the top and bottom surface.

According to the refraction law, the photons from active layer (light source) have greater chance to escape from the chip due to curved surface structure of hemisphere. And the light extraction efficiency of chip enhanced while the total internal reflection reduced [9].

The optical model of flip chip is composed of sapphire substrate, n-GaN layer, active layer and p-GaN layer. And their optical parameters and thickness are listed in Table 1.

Table 1. Optical parameters and thickness of the model

materials	Thickness/μm	Refractive index	Absorption coefficient/mm^{-1}
Sapphire	100	1.67	0.001
N-GaN	4	2.45	10
Active layer	0.1	2.45	10
P-GaN	0.3	2.45	10

The light extraction efficiency of PSS-LED flip chips with different micro-cylinder and micro-hemisphere are simulated. The simulation is based on the Monte Carlo ray trace method [10, 11].

III. RESULTS AND DISCUSSIONS

In the below, the cylinder and hemisphere patterns are considered as efficient structures for the enhancement of light extraction efficiency. These two type patterns were fabricated on top and bottom surfaces of the sapphire substrate. The parameters that we focus on are the periodic distance and radius of cylinder and hemisphere patterns, which influence the LEE of LEDs and the results are shown in Fig.2.

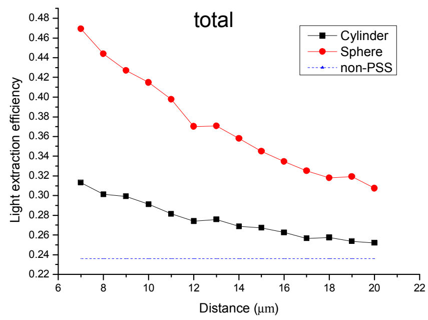

Fig. 2. LEE of PSS-LED chip as a function of distance, when the radius is 3μm

Fig.2 shows that the influence to the LEE caused by variation in the distance is opposite. When the distance increase, the LEE increase. It can be attributed to the decrease in the number of patterns when increasing distance. The more the patterns are dense, the better the LEE is. When the distance is 7μm and the radius is 3μm, the cylindrical and hemispherical LEE increase to 0.313 and 0.483, which is 32.6% and 104.7% higher than the LED chip on a normal planar sapphire substrate (non-PSS), respectively.

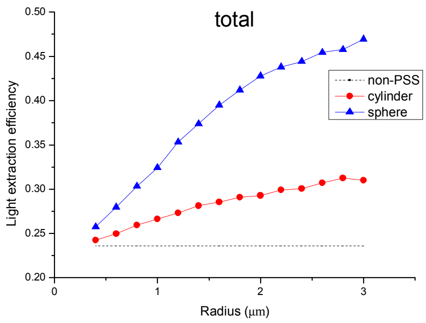

Fig. 3. LEE of PSS-LED chip as a function of radius, when the distance is 7μm

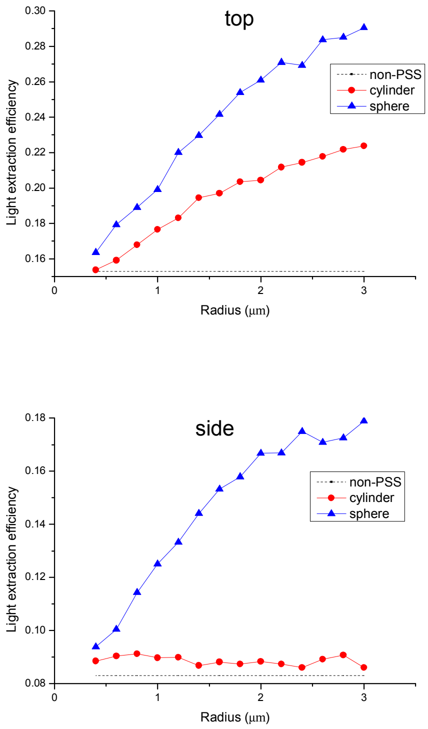

Fig. 4. LEE from top and four side facets of PSS-LED chip as a function of radius, when the distance is 7μm

More detailed analysis is given in Fig.3 and Fig.4, which represents the LEE from total, top, and sum of four side facets of the chip model as a function of the radius, respectively. It reaches its maximum when the radius is 3μm, which is 32.6% and 104.7% higher than the non-PSS LED chip, respectively. Fig.3 demonstrates that generally, a larger unit hemisphere helps to achieve larger total LEE. In Fig.4, we spot that the increasing radius is helpful to top LEE, which is similar to the total LEE. However, the side LEE of cylinder pattern stays relatively steady with the increasing radius, while the hemisphere's increases. It is informative to guide us to choose the optima parameter for some specially designed LEDs, such as side-illuminating LEDs.

The above results indicate that the small distance and large radius of cylinder and hemisphere for cylindrical and hemispherical PSS would be more effective to enhance LED efficacy. It also reveals that the hemispherical pattern is more efficient than the cylindrical for enhancement for the LEE of PSS-LED flip chip. In our works, we try to work out the optimal value of distance and radius for the micro-cylindrical and micro-hemispherical PSS.

ACKNOWLEDGMENT

This work is supported by National Nature Science Foundation of China (NSFC) (Grand Nos. 61008057, 11004086, 61177075), by Key Technology R & D Project Of Strategic Emerging Industries Of Guangdong Province, China (2012A032300016, 2012A080302004, 2011A081302002, 2012A080301002), by Fundamental Research Funds for the Central Universities, China (No. 21614313, 21613405, 21613325).

REFERENCES

[1] D. Lu, D.I. Florescu, and D.S. Lee, "Advanced characterization studies of sapphire substrate misorientation effects on GaN-based LED device development". Phys. Tec. Stat.Sol., 2003

[2] J.J. Chen, Y.K. Su, and C.L. Lin, "Enhanced Output Power of GaN-based LEDs With Nano-Patterned Sapphire Substrates". Pho. Tech. Lett.., vol. 20, pp. 1193-1195, Jul 2008

[3] S.J. Zhou, B. Cao, and S. Liu, "Improved light extraction efficiency of GaN-based LEDs with patterned sapphire substrate and patterned ITO". Opt. and Las. Tech.,vol. 44, pp. 2302-2305, Oct 2012

[4] Z.T. Lin, H. Hui, and S.Z. Zhou, "Pattern Design of an Epitaxial Growth on Patterned Sapphire Substrates for Highly Efficient GaN-based LEDs",Cry. Grow.and Desi. ,vol. 12, pp.2836-2841,Jun 2012

[5] P. Zhao, H.P.Zhao, Analysis of light extraction efficiency enhancement for thin-film-flip-chip InGaN quantum wells light-emitting diodes with GaN micro-domes", Opt. Expr., vol 20, pp. A765-A776, Sep 2012

[6] C. C. Pan, C. H. Hsieh, and C.W. Lin,"Light output improvement of InGaN ultraviolet light-emitting diodes by using wetetched stripe-patterned sapphire substrates",J. of Appl. Phys.,vol. 102,pp. 084503(1)-084503(5), 2007

[7] D.H. Jang, J.I. Shim, and K.Y. Yoo, "Patterning of sapphire/GaN substrates", J. of the Kor.Phys. Soci., vol. 54, pp. 2373-2377, Jun 2009

[8] S. Suihkonen, M. Ali, O. Svensk, "Patterning of sapphire/GaN substrates", Phys. Stat.Soli., vol. 8, pp. 1509-1512, 2011

[9] A.I, Zhmakin,"Enhancement of light extraction from light emitting diodes", Phys. Repo., vol. 498, pp. 189-241, 2011

[10] Y.K. Ee, P. Kumnorkaew, R. A. Arif, "Optimization of light extraction efficiency of Ⅲ-Nitride LEDs with self-assembled colloidal-based microlenses", J. of Sele. Topi. In Quan Elec., vol. 15, pp. 1218-1225, Jul/Aug 2009

[11] Y.K. Ee, P. Kumnorkaew, R. A. Arif, "Light extraction efficiency enhancement of InGaN quantum wells light-emitting diodes with polydimethylsiloxane concave microstructures", Opt. Expr., vol. 17, pp. 13747-13757, Aug 2009.