Photonic Crystal Embed Light Guiding for LED

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ABSTRACT

We designed a device that is use a Fabry-Pérot structure combining the photonic crystal that we call "Photonic Crystal Embed Light Guiding". This devices was employed to lead light-emitting diode(LED) has efficacious directivity.

1. INTRODUCTION

The light-emitting diodes (LED) have been widely applied displays and backlight modules. Most of groups are committed to enhance light extraction and have highly directivity [1-7], and Photonic Crystals(PhC) [8-10] is dielectric material with periodically distributed structure in air space. PhC band gap reveals the characteristics that is light with specific wavelength cannot propagate. Some research also proved to limit the light in specific area with the characteristics of photonic crystal band gap so as to enhance the light extraction rate.

In previous works, we have developed series device with PhC to improve LED performance. With various PhC structure to change the LEDs shape of light distribution. Our team has used the PhC characteristics to lead the directivity of light more effective on the light directivity and presented a white light LED for multi-view angle display application [11-13].

In this paper we designed a new structure that can optimize the directivity of LED that is base on the PhC and combine a Fabry-Pérot structure and discuss the transmission of the light in this structure.

2. SIMULATION AND RESULTS

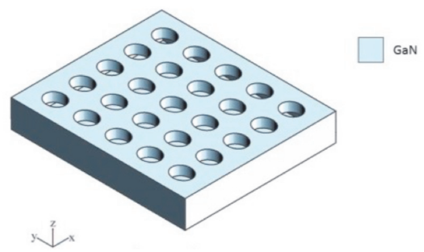
The LED light source can be considered the difference angle of incident in reality, the light source will be LEDs array. So we simulate incident difference plane wave by finite element method (FEM) and transmission is base on following equation (1).

$$\text{Transmission} = \frac{E_{out}}{E_{in}} \tag{1}$$

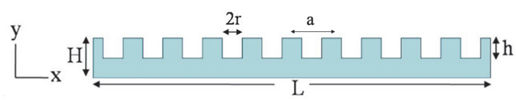
The parameter E_{in}, E_{out} is the energy of Electromagnetic wave.

Fig. 1-a shows the structure of PCs slab that is periodic air holes arrays and made by GaN in three-dimensional on LED surface and Fig. 1-b show the structure of PhC in cross section and geometrical parameters include lattice constant (a), etching depth (h), hole dimeter (r) and GaN layer (H). In simulation, we try to reduce the problems so that we used the one-dimensional unicell of PhC (Fig. 1-c) to simulation the light distribution of LED. Because on the PhC, the Electromagnetic wave propagate in PhC that no matter in x-direction or y-direction, can be considered identical.

(a)



(b)



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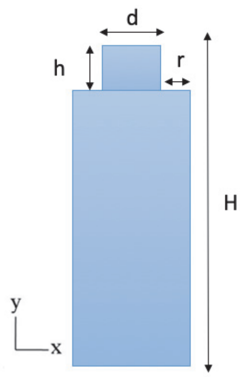

Fig. 1 Photonic crystal structures of periodic air holes array on LED surface
(a) Two-dimensional PhC slab structure diagram.(b) Cross-sectional view (h=200 nm). (c) Unicell of photonic crystals

Fig. 2 is show the simulation for transmission of LED light field base on PhC. The geometrical parameters were used in GaN layer H=350nm etching depth h=150nm lattice constant a=530nm hole dimeter r=0.25a. The result shows the transmission of LED light. we can see the max transmission is on the theta $\pm 6^{\circ}$, $\pm 15^{\circ}$, $\pm 52^{\circ}$.

The LED light was propagated in these direct but the bandwidth was too wide so that we demonstrate a device that PhC embed with Febry-Pérot structure which optimize the light directivity. With this device, we are able to guiding the light to specific direction.

Fig. 3 is the Febry-Pérot structure base on PhC structure, our team deign a structure that is used silicon to coat the silver and embed with PhC. The geometrical parameters of Febry-Pérot structure were used silver layer (f) silicon layer (b) and upper the Febry-Pérot structure is the PhC.

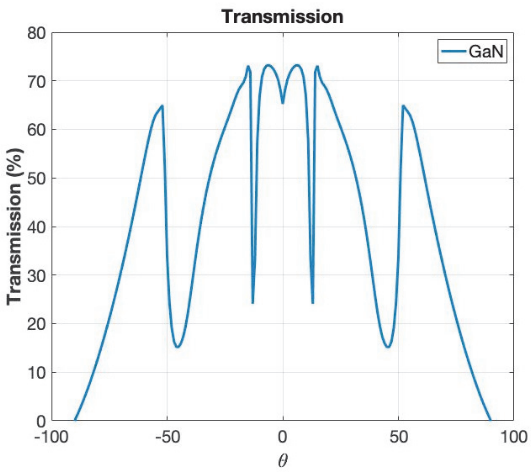

Fig. 2 Wave length λ= 532 nm, LED transmission of light.

The max of transmission is on the theta ±6°, ±16°, ±52°.

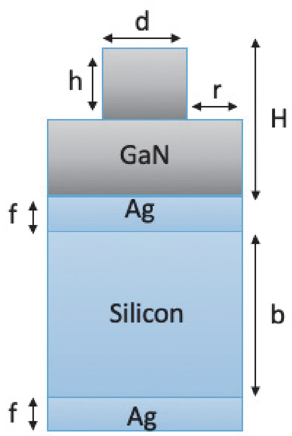

Fig. 3 Photonic Crystal Embed Light Guiding structure.

Fig. 4 is show the transmission of LED in PhC embed light guiding structure, the geometrical parameters f=50nm, b=1000nm. In this structure max of transmission is 40% at $\pm 51^{\circ}$ and the direction of LED light is almost in this angle. This result prove the LED direction will be improved by Febry-Pérot structure with PhC.

In order to optimize intensity of the transmission direction, we define the extinction ratio (Eq 2.):

$$\text{Extinction ratio(EXT)} = \frac{I_{max}}{I_{min}} \qquad (2)$$

and change thickness of the silver layer to compare the extinction ratio.

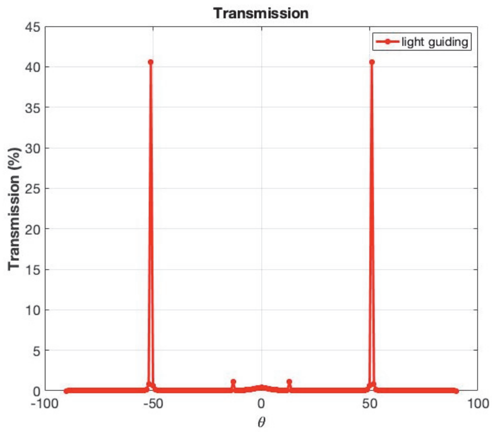

Fig. 4 LED transmission of PhC embed light guiding, max of transmission is 40% at ±51°

Fig. 5 show the transmission of the LED light, We change the thickness of silver layer from f=50nm to 110nm it is blue, orange, yellow, purple line respectively.

The result shows the highest transmission is blue line silver layer f=50nm, it has 40% at $\pm 51^{\circ}$and second one is when f=70nm, other are too low so that it can't distinguish clearly in fig. 5 because the absorption rate of silver layer is too much when the thickness increase. But thickness will NOT change the direction of LED light source no matter how thick of the silver layer.

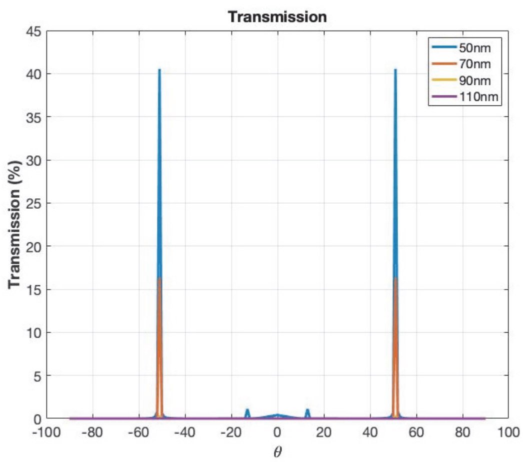

Fig. 5 Transmission of LED light with difference thickness of silver layer.

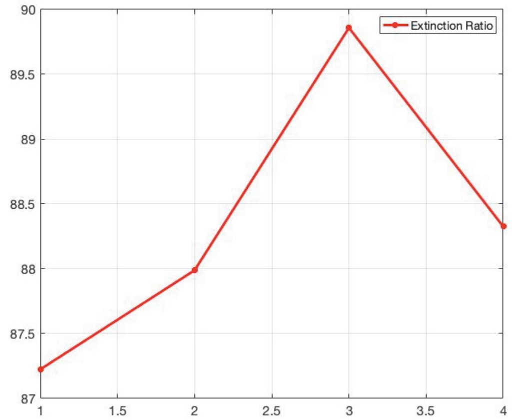

Fig. 6 The extinction ratio of difference thickness of silver layer.

Fig. 6 is the extinction ratio of difference thickness of silver layer. The simulation number 1, 2, 3, 4 is f=50nm, 70nm, 90nm, 110nm respectively.

From this result show the trend of difference thickness of silver layer. It provide the extinction ratio of difference thickness but these EXT doesn't make too much of a difference because the silver layer increase with same magnification so the max and min of transmission is increase in same times.

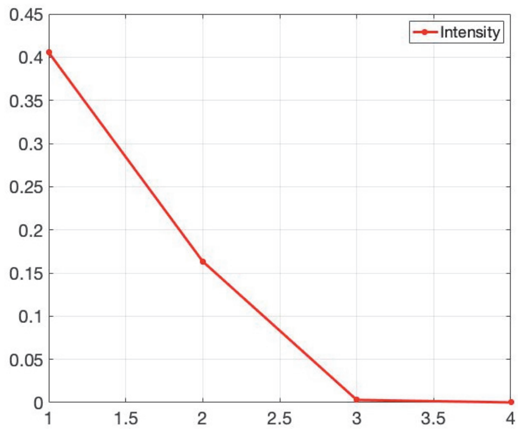

Fig. 7 The intensity of difference thickness of silver layer.

Fig. 7 is show the intensity of difference silver layer and the max intensity of thickness is 40% in silver layer f=50 nm and second is 16% in f=70 nm. From fig. 6, the extinction ratio of difference thickness of silver layer these are don't make too much of a difference but the intensity is difference between the thickness of silver.

From these result, the thickness of silver (b) choose in 50nm is the best. Because in this thickness that has highest transmission but almost same extinction ratio.

These result show that photonic crystal with Fabry-Pérot structure was employed to lead LED has efficacious directivity.

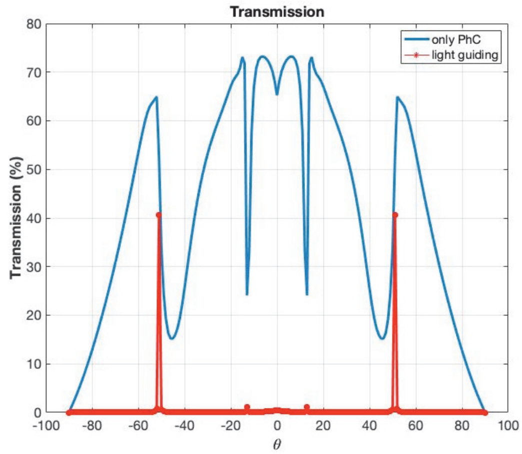

Fig. 8 The Transmission of only photonic crystal and PhC embed Light guiding structure

Fig. 8 shows the result of compare only photonic crystal and light guiding structure with photonic structure. From this fig, we can see the light guiding structure with photonic crystal structure has more directivity of LED. Although the transmission was decrease but the direction was optimized successfully. In this device, the light with wave length 532 nm only allow to propagate in $\pm 51^{\circ}$.

3. CONCLUSION

Our team found the shapes of light distribution on LED with difference types of photonic crystal structure, no matter change the structure of PhC or type of lattice, our team got the excellent result. In previous works, we design the photonic crystal slab on LED array and it's success to provide directive of LED. In this letter, in order to optimize this device, we embed the new structure upper the photonic crystal. This new structure that was Fabry-Pérot structure base on PhC. Although the transmission was decrease but the direction was optimized in a large part but we have further prove that the structure can also optimize the directivity of LED successfully.

This research aims to develop the more directivity of light device base on two-dimensional photonic crystal slab, the future will be based this study, resulting in fabricate this structure and try change difference material to more optimize the directivity.

Finally, research application in the flexible display technology of 3D.

REFERENCES

[1] B. Schmidt, V. Almedia, C. Manolatou, S. Preble and M. Lipson, "Nanocavity in a silicon waveguide for ultrasensitive nanoparticle detection," Appl. Phys. Lett., Vol. 85, No. 21, 4854 (2004).

[2] P.I. Borel, L.H. Frandsen, A. Harpth, J.B. Leon, H.Liu, M. Kristensen, W. Bogaerts, P. Dumon, R. Baets, V. Wiaux, J. Wouters and S. Beckx, “Bandwidth engineering of photonic crystal waveguide bends,” Electron. Lett, Vol. 40, No. 20, 1263 (2004).
[3] S. Mandal and D. Erickson, “Nanoscale optofluidic sensor arrays,” Opt. Express, Vol. 16, No. 3, 1623 (2008).
[4] C.-F. Lai, J.-Y. Chi, C.-C. Kuo, H.-H. Yen, C.-E. Lee, C.-H. Chao, H.-T. Hsueh and W.-Y. Yeh, “Far-field of GaN film-transferred green light-emitting diodes with two-dimensional photonic crystals,” Optics Express, Vol. 17, No. 11, 8795 (2009).
[5] C.-F. Lai, H.-C. Kuo, P. Yu, T.-C. Lu, C.-H. Chao,H.-H. Yen and W.-Y. Yeh, ” Highly-directional emission patterns based on near single guided mode extraction from GaN-based ultrathin microcavity light-emitting diodes with photonic crystals,” Applied Physics Letters, Vol. 97, No. 1, 013108 (2010).
[6] C.-F. Lai, C.-H. Chao and W.-Y. Yen, ”Optimized Microcavity and Photonic Crystal Parameters of GaN-Based Ultrathin-Film Light-Emitting Diodes for Highly Directional Beam Profiles,” IEEE Photonics Technology Letters, Vol. 22, No. 21, 1547(2010).
[7] C.-F. Lai, H.-C. Kuo, P. Yu, H.-H. Yen and W.-Y.Yeh, “Divergent Far-Field III–Nitride Ultrathin Film-Transferred Photonic Crystal Light-Emitting Diodes,” Japanese Journal of Applied Physics, Vol. 49, No. 4, 04DG08 (2010).
[8] E. Yablonovitch, “Inhibited Spontaneous Emission in Solid-State Physics and Electronics”, Phys. Rev. Lett. Vol. 58, 2059 (1987).
[9] S. John, “Strong localization of photons in certain disordered dielectric superlattices”, Phys. Rev. Lett, Vol. 58, 2486 (1987).
[10] E. Kuramochi, M. Notomi, S. Hughes, A. Shinya, T.Watanabe and L. Ramunno, “Disorder-induced scattering loss of line-defect waveguides in photonic crystal slabs,” Phys. Rev. B, Vol 72,161318 (2005).
[11] C. C. Chiu, F.-L. Hsiao, "High Directivity Light Source Based on Photonic Crystal Structure", The 22nd International Display Workshops (IDW’15), Otsu, Japan, Dec.9- 11 (2015).
[12] Y. M. Weng, C. C. Chiu, F.-L. Hsiao, “The Design of LED Backlight Structure for Multi-view Angle Display Application, ” International Conference on Optical MEMS and Nanophotonics, Singapore, Jul. 31- Aug. 4 (2016).
[13] Y. M. Weng, C. C. Chiu, F.-L. Hsiao, "The Design of White Light LED for Multi-View Angle,” The 23th International Display Workshops (IDW’16), FMCp1-4, Japan, Fukuoka, Dec. 9 (2016).