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Polarized Gan-Based Light-Emitting Diode with a Silver Sub Wavelength Grating and Dielectric Layer

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Abstract: The effect of silver/ dielectric sub-wavelength gratings and silicon dioxide transition layer, when embedded onto InGaN/GaN -LED system, has been studied for enhancement of the polarized light. The SiO_2 transition layer is placed between InGaN/GaN -LED and the grating section. The effect of the gratings geometric parameters on the transmission of transverse magnetic (TTM) and electric mode (TTE) and polarization extinction ratio (ER) were calculated numerically by using the rigorous coupled-wave analysis (RCWA). The results show that the proposed structure embedded onto InGaN/GaN-LED system has enhanced the transmission and extinction ratio by the presence of the SiO_2 transition, due to the interference in the Ag sub-wavelength gratings and SiO_2 transition layer. The optimum parameters of the proposed structure are: grating period and $\Lambda = 100nm, f = 0.5$. TTM >80% and ER >15*dB*have been obtained over the whole range of θ with the SiO_2 transition layer. The performance of this LED system has proved to be superior to that with single-layer metallic gratings. The optimum parameters of the proposed structure are $\Lambda = 100nm, d_1 = 100nm, d_2 = 200nm$ and *f*= 0.5 which are results TTM >80% and ER >15*dB*. The performance of this LED system proved to be superior to that with single-layer metallic gratings.

Key words: Sub-wavelength grating · Rigorous Coupled-Wave Analysis (RCWA) · Light emitting diodes · Polarization.

INTRODUCTION

Light-emitting diodes (LEDs) are semiconductor solid-state lighting components which convert electrical energy into electromagnetic radiation; most of the radiation is visible to the human eye. LEDs have superior characters, compared to the traditional light sources, such as having low-cost, smaller size, long-terms stability, high efficiency, strong brightness, long lifetime and environmentally-friendly [1-3]. LEDs have been commonly used in various fields such as traffic signals, automobile lighting, full-color displays, liquid crystals and optical interconnects [3-7]. The external quantum efficiency of LEDs (EQE) is mainly dependent on the internal quantum efficiency (IQE) and light extraction efficiency (LEE). It is an important criterion for estimating the performance of LEDs. The EQE can be increased by increasing the IQE and/or enlarging the LEE [1, 8]. Very high values (approaching100%) of IQE have already been demonstrated by the epitaxial growth and device fabrication technologies [1, 9]. The LEE is very low compared to the IQE, because it is limited by the total internal reflection (TIR) at the interface between the light-emitting material and the outside of the LED [4, 10].

Several methods have been proposed to increase the efficiency of LEDs. It has been shown that light extraction efficiency LEE can be sufficiently improved, using proper micro/nanostructures, such as hemispherical source LEDs [11], funnel shaped LEDs [12], truncated-inverted-pyramid LEDs [13], surface textured LEDs [14], photonic crystal or grating assisted LEDs [15-16] and metal assisted LEDs [17].

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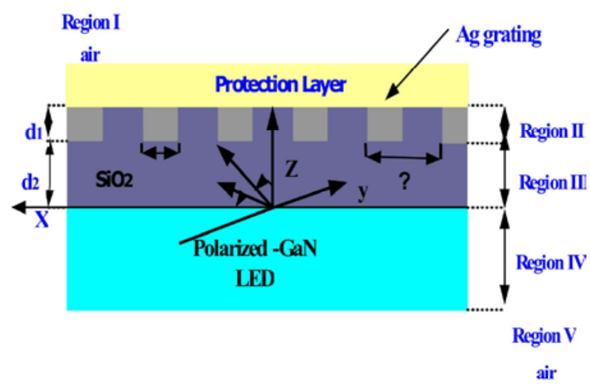

Fig. 1: Schematic of the proposed structure consisting of Ag sub-wavelength gratings and dielectric layer SiO_2

Polarization properties of sub-wavelength gratings LEDs depend on the wavelength (λ) of incident light, the grating period (Λ) and grating width (*w*) [6]. Zhang *et al* [18] used a surface emitting linearly polarized InGaN/GaN LED with a sub-wavelength metallic nano-grating to obtain a large polarization ratio. The diffraction efficiency and transmission are very sensitive to the choice of grating structure. For example, if the period of the grating is close to λ, diffraction would be influenced by Wood's anomaly. The Polarization properties from LEDs such as the emission are desired for imaging and backlighting of flat panels.

In this paper, we propose a structure consisting of Ag sub-wavelength grating structures and SiO_2 as a dielectric layer which is embedded onto LED system. The influence of gratings geometric parameters, of the proposed structure, on the transmission properties (TTE, TTM) and extinction ratio (ER=10log (TTM/TTE)) will be investigated. We will also investigate the optimum grating parameters which would lead to low fabrication of polarized LEDs. All numerical results are obtained by using the rigorous coupled-wave analysis (RCWA) method [19- 20].

Grating Simulations: Figure 1. displays the schematic of the proposed structure which is composed of silver sub-wavelength grating and SiO_2 dielectric layer, embedded onto the polarized GaN LED system through the methods of vacuum evaporation and electron-beam lithography. The polarized InGaN/GaN LED consists of GaN buffer layer, grown on sapphire substrate by metal-organic chemical vapor deposition (MOCVD). The InGaN/GaN is a quantum-well (QW) with 150 nm GaN cap layer. The thickness of the QW with GaN buffer layer is about of 5nm. A protection layer was deposited on top of the system to avoid grating oxidation. The z axis is the light propagation direction, the x and y lies in the direction of p-polarization (TM) and s-polarization (TE), respectively. θ and ϕ represents the polar angle and the azimuthal angle, respectively.

MATERIALS AND METHODS

Rigorous coupled-wave analysis (RCWA), formulated in the 1980s by Moharam and Gaylord, is used for analyzing the diffraction of electromagnetic waves by periodic gratings. RCWA analyzes the diffraction problem by solving Maxwell's equations accurately in each of the three regions (input, grating and output), based on Fourier expansion.The accuracy of the solution computed depends solely upon the number of terms retained in space harmonic expansion of electromagnetic fields, which corresponds to the diffraction order. The incident wave and the transmitted waves are located in region I and V, respectively. The relative dielectric function in grating region II can be expanded as a Fourier series and expressed as

$$\varepsilon(x,z) = \varepsilon(x+\Lambda,z) = \sum_j \varepsilon_j(Z)\exp(jPk_x) \quad (1)$$

Where Λ is the grating period, ε_p is the Fourier component of the grating permittivity, K is the magnitude of the grating vector and $j=\sqrt{-1}$. The normalized total electric field in (E_t) can be expressed as

$$E_t(x,z) = \sum_j E_{tj}\exp(ik_{xj}x - ik_{zj}^t z) \quad (2)$$

Where k_{xj} and k_{zj} are the j[th] order wave vector in the x and z direction respectively. E_{tj} is the normalized amplitude of the j[th] order transmitted wave. The transmission (Ti) of the j[th] order transmitted wave can be calculated by

$$T_j = \left|E_{tj}\right|^2 \quad (3)$$

RCWA accurately describes diffraction from an Ag sub-wavelength grating with and without dielectric layer.

RESULTS AND DISCUSSION

Effect of the Dielectric Layer Thickness: TTM, TTE and ER when $\Lambda = 100nm, f = \frac{w}{\Lambda} = 0.5, d_1 = 120nm$ and different dielectric layer thickness d_2 (from 0 to 300) nm, at normal incidence, are shown in Figure 2. The results show that

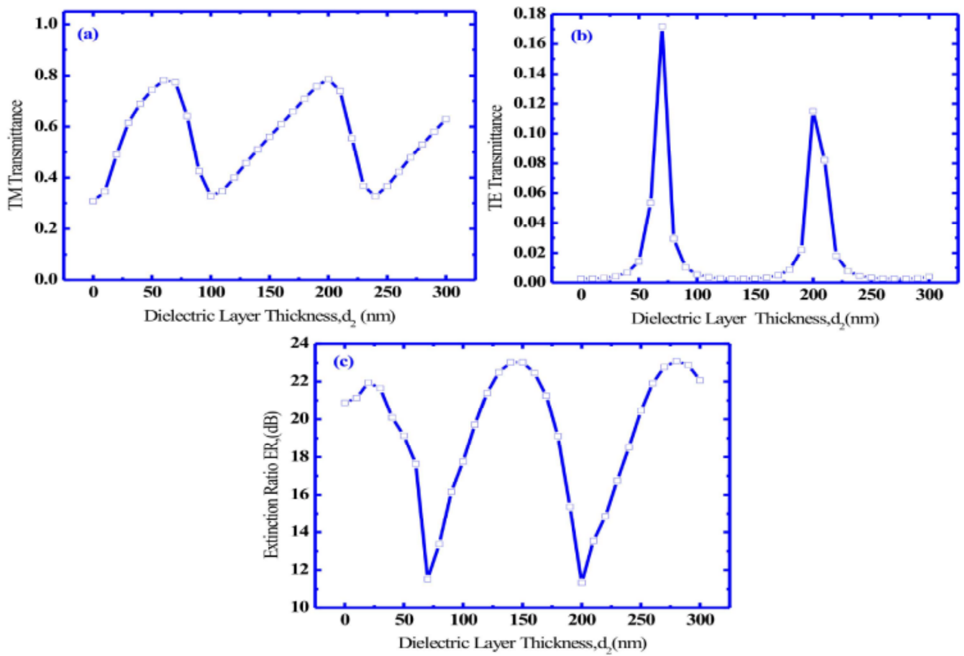

Fig. 2: The simulated transmission spectra for TM and TE and extinction ratio, with different dielectric layer thickness (a) TTM (b) TTE (c) ER

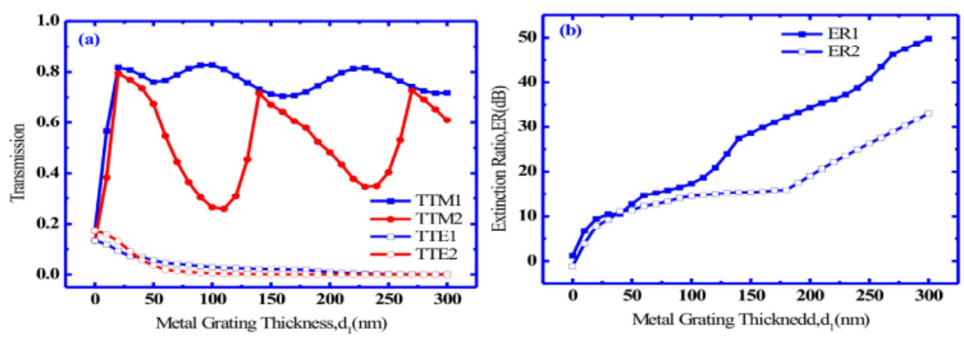

Fig. 3: The simulated transmission spectra and ER, with different metal grating thickness (a) TTM and TTE (b) ER.TTM1, TTE1 and ER1 refer to the grating with SiO_2 layer, TTM2, TTE2 and ER2 are for grating without SiO_2 layer, $d_2 = 0nm$

the proposed structure embedded onto LED system has two TTM, TTE peaks and two ER troughs at $d_2 = 60nm$ and 200*nm*. ER is also high at about 23 dB (low TTE) at $d_2 = 15nm$ and 280*nm*.The oscillatory behavior of TTM, TTE and ER is caused by the interference effect for a three-layer structure. It can be seen that the insertion of SiO_2 transition layer into the grating lead to enhancement of the transmission and polarization extinction ratio \compared to that without SiO_2 transition layer ($d_2 = 0nm$). It can be concluded that the enhancement of the transmission and extinction ratio can be tuned by different thicknesses of the dielectric layer depending on the specific requirement of the polarized LEDs system.

Effect of the Metal Grating Thickness: The effect of the metal grating thickness d_1 on the transmission and extinction ratio is studied with different d_1 (from 0 to 300) nm, $\Lambda = 100nm, f = 0.5$ and $d_2 = 200nm$, at normal incidence. The results in Figure 3 (a) show the proposed structure embedded onto InGaN/GaN LED system. The TTM > 70% at $d_1 \geq 20nm$ with SiO_2 layer. It can be seen that the values of TTM are low for grating without the SiO_2 transition layer.TTE is zero at $d_1 \geq 50nm$ with and without the SiO_2 layer, which is the region where the polarization ratio (TTM-TTE)/TTE approaches infinity. In our area of interest, we notice a high TTM1(with SiO_2) value at d_1= 100*nm*.The maximum value of the ER is about 50dB for

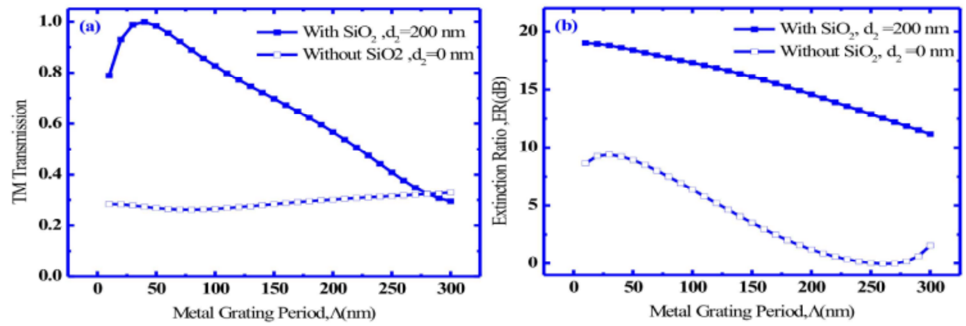

Fig. 4: The simulated TTM and ER, with different metal grating period (a) TTM (b) ER. For grating with and without SiO_2 layer ($d_2 = 0nm$)

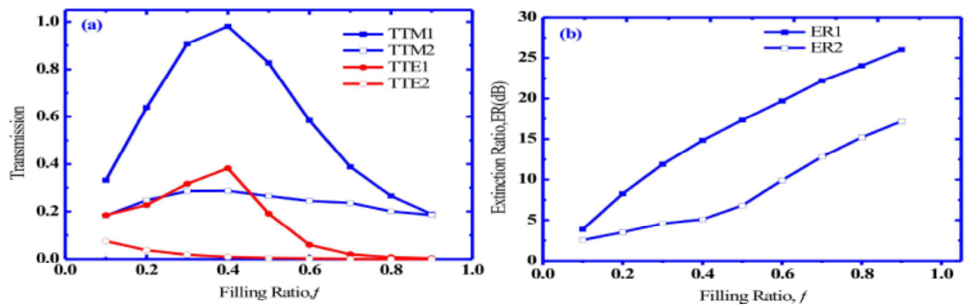

Fig. 5: The simulated TTM and ER, with different filling ratio (a) TTM (b) ER. TTM1, TTE1 and ER1 refer to the grating with SiO_2 layer; TTM2, TTE2 and ER2 are for grating without SiO_2 layer $d_2 = 0nm$

grating with SiO_2 transition layer. It has to be noticed that the insertion of SiO_2 layer to the grating has enhanced the transmission.

Effect of the Metal Grating Period: Figure 4.shows the TTM and ER of the proposed structure embedded onto GaN LED system with, d_1= 100*nm*, d_2= 200*nm* and f =0.5, for different metal grating period (Λ) (from 0 to 300) *nm*, at normal incidence angle. The results show that the system has a high value of TTM and ER for grating with SiO_2 transition layer. TTM >80% and ER >15dB when the grating period is in the range 10*nm* < Λ 110*nm* . It is clear that without the SiO_2 transition layer, TTM and ER values are much lower than those with the SiO_2 transition layer. The optimum metal grating period which is used in our study is Λ = 100*nm* for high TTM and ER value.

Effect of the Filling Ratio: The effect of the filling ratio (f) on the transmission and extinction ratio of the proposed structure (embedded onto InGaN/GaN LED system) with and without SiO_2 transition layer, is studied with different filling ratio (f) (from 0.1 to 0.9), Λ = 100*nm*, d_1 = 100*nm* and d_2 = 200*nm* at normal incidence. It can be noted that, Figure 5, the transmission has increased due to the presence of the SiO_2 layer. TTM1 (with SiO_2 transition layer) is above 80%, TTE1 >20% and $8 < ER < 20dB$ when $0.2 < f < 0.6$. Without SiO_2 transition layer, the transmission and extinction ratio are very low compared to that with SiO_2 transition layer. The results show the dependences of the transmission and extinction ratio on the filling ratio. The optimum filling ratio is about $f = 0.5$.

Effect of the Wavelength of Light: The polarized transmission by varying the wavelength of light is also studied (all the above simulations were done for λ=400 nm). Figure 6 shows TTM, TTE and ER at λ (from 400 to 500) nm with grating parameters of Λ = 100*nm*, , d_1 = 100*nm* and d_2 = 200*nm* and f = 0.5 for normal incidence. It can be seen that TTE is zero, which results in high values for ER. The results indicating that the transition layer has the largest effects in the UV/blue spectral region.

Effect of the Plane of Incidence: The effect of the plane of incidence on the TTM, TTE and ER of the proposed structure embedded onto InGaN/GaN - LED system is studied with grating parameters of Λ = 100*nm*, d_1 = 100*nm* d_2 = 200*nm* and f = 0.5 for different polar angles at and $-90° \leq \theta \leq 90°$, $\phi = 0°$. Figure 7 shows that TTM > 80% and ER > 15*dB* over the whole range of θ with the SiO_2

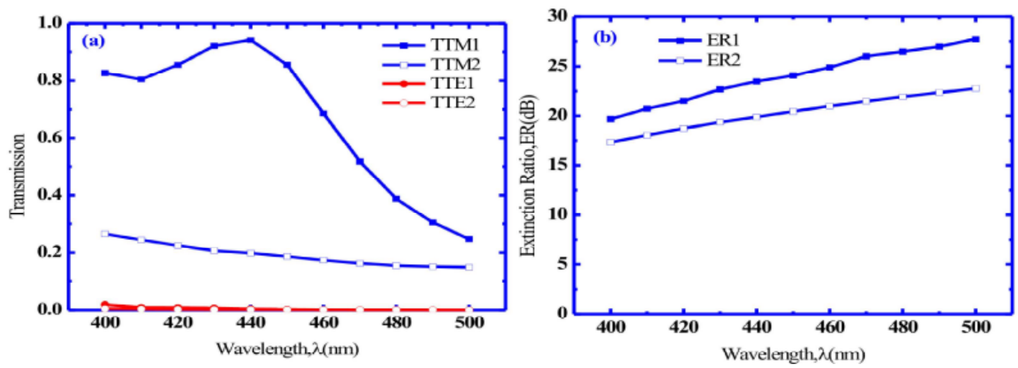

Fig. 6: The simulated TTM and ER with different wavelength (a) TTM (b) ER. TTM1, TTE1 and ER1 refer to the grating with SiO_2 transition layer; TTM2, TTE2 and ER2 are for grating without SiO_2 layer $d_2 = 0nm$

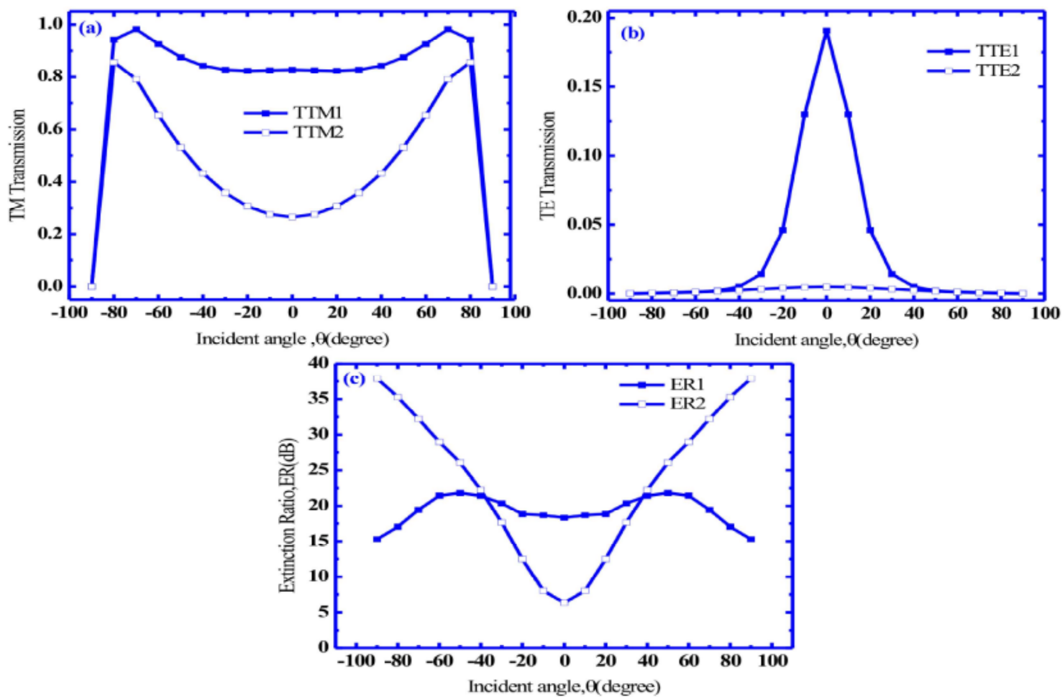

Fig. 7: The simulated TTM, TTE and ER with different θ, $\phi = 0°$ (a) TTM (b) TTE (c) ER. TTM1, TTE1 and ER1 refer to the gratings with SiO_2 transition layer; TTM2, TTE2 and ER2 are for grating without SiO_2 transition layer $d_2 = 0nm$

transition layer. It is clear that the TTM has been greatly increased by inserting the sub-wavelength Ag/ dielectric grating into the system.

The proposed structure which consists of the Ag sub-wavelength gratings and SiO_2 transition dielectric layer integrated onto InGaN/GaN-LED system has exhibited enhanced polarization performance. It has yielded high TTM and ER with the following grating parameters values: $\Lambda = 100nm$, $d_1 = 100nm$ $d_2 = 200nm$ and $f = 0.5$.

CONCLUSION

In order to enhance LED transmission and extinction ratio we embedded Ag sub-wavelength gratings and SiO_2 transition dielectric layer onto InGaN/GaN LED system. The influence of gratings geometric parameters on the transmission and extinction ratio were studied by using the rigorous coupled-wave analysis (RCWA). The results showed that the transmission and extinction ratio are affected by the gratings geometrical parameters.

The optimum parameters are Λ = 100*nm*, d_1 = 100*nm* d_2 = 200*nm* and *f* = 0.5. We have shown that TTM and ER performance could be significantly enhanced by inserting SiO_2 dielectric layer into the grating section. This can be explained by the interference in the Ag sub-wavelength gratings and SiO_2 transition layer. TTM > 80% and ER > 15*dB* were obtained over the whole range of θ with the SiO_2 transition layer.

REFERENCES

1. Gou, Y., Y. Xuan, Y. Han and Q. Li, 2011. Enhancement of light-emitting efficiency using combined plasmonic Ag grating and dielectric grating. Luminescence, 131: 2382-2386.
2. Lee, Y.S., K. II. Park, C. Huh, M. Koo, G.H. Yoo, S. Kim, S.C. Ah, Y.G. Sung and J.K. Lee, 2012. Water-resistant flexible GaN LED on a liquid crystal polymer substrate for implantable biomedical applications. Nano Energy, 1: 145-151.
3. Rao, J., R. Winfield and L. Keeney, 2010. Moth-eye-structured light-emitting diodes. Optics Communications, 283: 2446-2450.
4. Jing, X., S. Jin, Y. Tian, P. Liang, Q. Dong and L. Wang, Analysis of the sinusoidal nanopatterning grating structure, 2013. Optics & Laser Technology, 48: 160-166.
5. Du, X., H. Chen, G. Zhong, X. Dong, W. Chen, X. Lei and X. Liu, 2012. Improvement of light extraction efficiency of GaN-based flip-chip light-emitting diodes by patterning the double sides of sapphire. LED and Display Technologies II.
6. Delbeke, D., P. Bienstman, R. Bockstaele and R. Beats, 2002. Rigorous electromagnetic analysis of dipole emission in periodically corrugated layers: the grating-assisted resonant-cavity light-emitting diode, Opt. Soc. Am, 19: 871-880.
7. Zhang, G., B. Cao, C. Wang, Q. Han, C. Peng, J. Wang, K. Xu, Y. Hui and M. Pessa, 2011. Polarized GaN-based light-emitting diode with an embedded metallic/dielectric subwavelength grating. Thin Solid Film, 520: 419-423.
8. Trieu, S., X. Jin, A. Ellaboudy, B. Zhang, X.N. Kang, G. Yi. Zhang, X. Chang, W. Wei, S.Y. Jian and X.F. Xing, 2011. Top Transmission Grating GaN LED Simulations for Light Extraction Improvement, Proc. of SPIE, 7933: 79331-79341.
9. Cho, J.Y., K.J. Byeon and H. Lee, 2011. Forming the graded-refractive-index antireflection layers on light-emitting diodes to enhance the light extraction, Optics Express Letters, 36(16): 3203-3205.
10. Kitagawa, H., M. Fujita, T. Suto, T. Asano and S. Noda, 2011. Green Gain photonic-crystal light-emitting diodes with small surface recombination effect, Journal of Applied Physics Letters, 98: 181104.
11. Carr, W.N. and G.E. Pittman, 1963. One watt GaAs p-n junction infrared source, Journal of Applied Physics Letters, 3: 173-175.
12. Franklin, A.R. and R. Newman, 1964. Shaped electroluminescent GaAs diodes. Journal of Applied Physics, 35: 1153-1155.
13. Krames, M.R., M.O. Holcomb, G.E. Höfler, C.C. Coman, E.I. Chen, I.H. Tan, P. Grillot, N.F. Gardner, H.C. Chui, J.W. Huang, S.A. Stockman, F.A. Kish, M.G. Craford, T.S. Tan, C.P. Kocot, M. Hueschen, J. Posselt, B. Loh, G. Sasser and D. Collins, 1999. High-power truncated-inverted-pyramid $(Al_xGa_{1-x})_{0.5}In_{0.5}P/GaP$ light-emitting diodes exhibiting >50% external quantum efficiency. Applied Physics Letters, 75: 2365-2367.
14. Schnitzer, I., E. Yablonovitch, C. Caneau, J.T. Gmitter and A. Scherer, 1993. 30% external quantum efficiency from surface textured, thin film light emitting diodes,Applied Physics Letters, 63: 2174.
15. Liu, C., V. Kamaev and V.Z. Vardeny, 2005. Efficiency enhancement of an organic light- emitting diode with a cathode forming two-dimensional periodic hole array, Applied Physics Letters, 86: 143501.
16. Wiesmann, C., K. Bergenek, N. Linder and U.T. Schwarz, 2009. Photonic crystal LEDs-designing light extraction,Journal of Laser Photon. Rev., 3: 262-286.
17. Sung, J.H., B.S. Kim, C.H. Choi, M.W. Lee, S.G. Lee, S.G. Park, E.H. Lee and O.B. Hoan, 2009. Enhanced luminescence of GaN-based light-emitting diode with alocalized surface Plasmon resonance, Microelectron. Eng., 86: 1120-1123.
18. Zhang, L., J.H. Teng, S.J. Chua and E.A. Fitzgerald, 2009. Linearly polarized light emission from InGaN light emitting diode with subwavelength metallic nanograting,Applied Physics Letters, 95: 261110.
19. Moharam, M.G. and T.K. Gaylord, 1986. Rigorous coupled-wave analysis of metallic surface-relief gratings, Opt. Soc. Am. A, 3: 1780-1787.
20. Astilean, S., P.H. Lalanne and M. Palamaru, 2000. Light transmission through metallic channels much smaller than the wavelength, Journal of Optics Communication, 175: 265-273.