Enhance Infrared Light Emitting Diodes Efficiency Using Surface Plasmonic Effect and Photonic Crystals

M.Y. Li, Y.L. Jing, L.Li, H. Wang, N. Li, H.L. Zhen *
National Laboratory of Infrared Physics, Shanghai Institute of Technical Physics,
Chinese Academy of Sciences, SH 200083, P.R.China, zhenhl@mail.sitp.ac.cn

Abstract: Infrared light emitting diodes efficiency based on GaAs substrate has been limited due to light trapping and total internal reflection of GaAs materials. In this paper we introduced a new method of combining surface plasmonic effect and photonic crystal structure to enhance not only light extraction efficiency but also internal quantum efficiency. Through Finite Difference Time Domain method we found that under the condition of 400nm Au grating and 400 nm SiO2 photonic crystals, highest efficiency will be obtained.

I. INTRODUCTION

Traditional method mainly focused on how to change the reflection of material to reduce total internal reflection. Recently several study proposed using surface plasmon theory to enhance internal quantum efficiency. However, because of high index of metal, the power excited by surface plasmon can't be efficiently coupled out. So we combined surface plasmon and photonic crystal to achieve enhancement of light emitting efficiency for led through improvement of both internal quantum efficiency and light extracting efficiency.

II. SIMULATION RESULTS

We simulate three kinds of GaAs LED structures. To couple emitting power to surface plasmonic modes we attenuate GaAs material to 100nm bottom contact, 10nm active layer and 40nm top contact. On the bottom of device we coated a 200nm thickness reflection layer of Au. On the top of LED, we fabricate three kinds of structures which are 200nm height photonic crystals of SiO_2, 20nm height Au grating and a structure which combined these two structures.

Far field distribution has been calculated by FDTD method. By analysing field distribution, we calculated light extraction efficiency and internal quantum efficiency through equations below:

$$\mathrm{LEE} = \frac{\gamma_{rad}}{\gamma_{rad}+\gamma_{loss}} \quad (1)$$

$$\mathrm{IQE} = \frac{\gamma_{rad}+\gamma_{loss}}{\gamma_{rad}+\gamma_{loss}+\gamma_{unrad}} \quad (2)$$

Where γ_{rad} is the radiative decay rate, γ_{loss} is the power absorbed by material and γ_{unrad} is unradiative power.

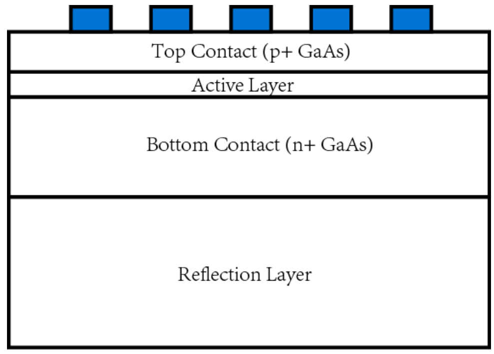

Fig. 1 Structure A: with photonic crystals

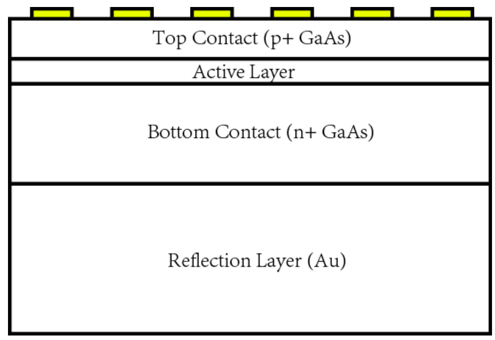

Fig. 2 Structure B: with metal gratings

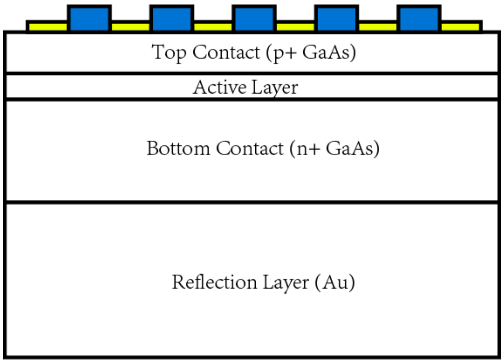

Fig. 3 Structure C: with PC and metal gratings

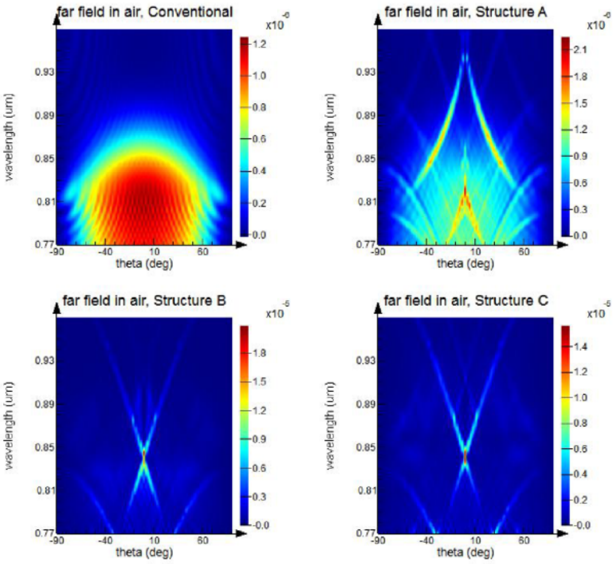

Fig. 4 Far field distribution vs theta

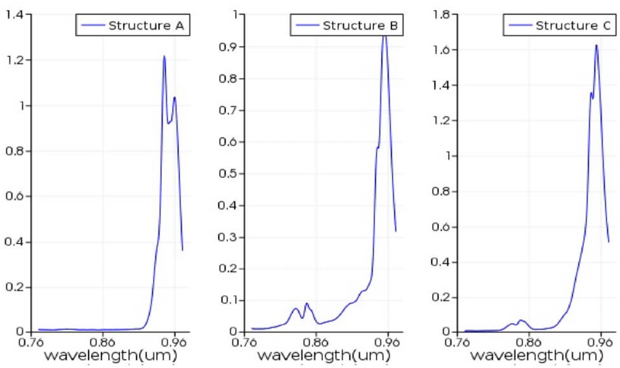

Fig. 5 Light extraction efficiency

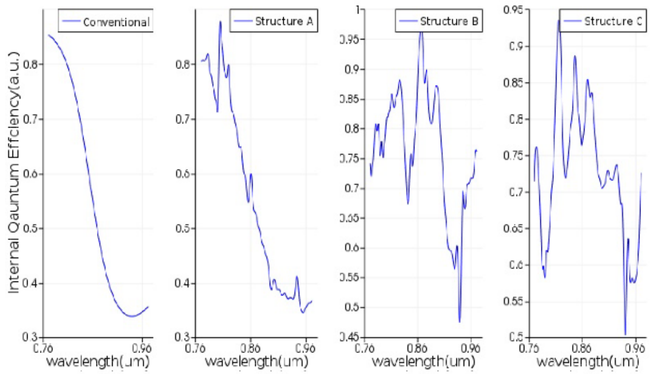

Fig. 6 Internal quantum efficiency

Fig.4 indicates that introducing of metal grating will greatly change the distribution of far field for light emitted from LED compared to conventional and photonic crystal structure. Fig.5 shows that although metal grating decrease the enhancement of light extraction efficiency compared to photonic crystal LED, but a combination of these two structures will enhance LEE. Fig.6 shows surface plasmonic effect attribute to the improving of internal quantum efficiency.

ACKNOWLEDGEMENT

This work was supported by the National High-tech R&D Program of China (863 Program): 2013AA031903.

REFERENCES

[1] Hauss J, Riedel B, Bocksrocker T, et al. Periodic Nanostructures Fabricated by Laser Interference Lithography for Guided Mode Extraction in OLEDs[C]//Solid-State and Organic Lighting. Optical Society of America, 2010: SOThB2.

[2] Zhmakin A I. Enhancement of light extraction from light emitting diodes[J]. Physics Reports, 2011, 498(4): 189-241.

[3] Lu C H, Lan C C, Lai Y L, et al. Enhancement of Green Emission from InGaN/GaN Multiple Quantum Wells via Coupling to Surface Plasmons in a Two - Dimensional Silver Array[J]. Advanced Functional Materials, 2011, 21(24): 4719-4723.

[4] Zhu J, Zhang H, Zhu Z, et al. Surface-plasmon-enhanced GaN-LED based on the multilayered rectangular nano-grating"[Optics Communications 322 (2014) 66-72][J].

[5] Cheng L W, Sheng Y, Xia C S, et al. Simulation for light power distribution of 3D InGaN/GaN MQW LED with textured surface[J]. Optical and quantum electronics, 2011, 42(11-13): 739-745.