Simulation for light power distribution of 3D InGaN/GaN MQW LED with textured surface

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***Abstract*—In this paper, we introduce a full 3D simulation for light power distribution of an InGaN/GaN MQW LED with textured surface. Device simulation was performed by APSYS software to get power distribution of light source inside the LED. Based on this, ray tracing simulation was carried out to get light power distribution outside the LED. During the process of ray tracing, the textured surface was treated as a special boundary which means its reflectivity, transmittance and refraction angle are not calculated according to Fresnel equations, but obtained from data extracted from Finite-difference time-domain(FDTD) method. By comparing ray tracing result with and without textured surface, we found that textured surface not only smoothed transmitted power distribution, but also greatly improved power extraction efficiency which can be further improved by changing texture geometry.**

I. INTRODUCTION

Nowadays, study on light emitting diodes (LED) attracts more and more interests due to its wide applications in many areas [1]. Extraction efficiency and out-device distribution of emitted light power are both crucial qualities for LED devices people are trying to improve[2]. It is important that details of light extraction for these devices be verified and understood so that further improvement or optimization may be achieved. Especially, if a LED device has textured surface with textured unit comparable to wavelength of the emitted light, wave behavior of lights must be considered on this surface.

In this paper, a full solution is proposed to simulate ray transmitting in LED device with textured surface. Firstly, 3D structure of a MQW LED with star-shaped contact is built up by Csuprem software which is a processing TCAD tool for silicon devices[3] but now can build complicated 3D structure with much convenience. Then, APSYS software [4] performs 3D photoelectric simulations on this LED. The advanced software self-consistently combines carrier transport and self-heating. Various mechanisms critical for LED analysis, such as self-consistent quantum well based spontaneous emission, non radiative recombination and injection current overflow have been included in the software.

3D ray-tracing(RT) module in APSYS software is applied to simulate light extraction, this module is based on calculating Fresnel equations on material interface and power change when ray travels in media. It proves to be especially useful for tracing ray paths[5]. Textured surface of this LED was considered as a special boundary in 3D RT and its properties were calculated by APSYS's MEEP package (finite-difference time-domain (FDTD) method[6]) .

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II. DEVICE STRUCTURE

Structure of the InGaN/GaN MQW LED under study is shown schematically in Fig. 1. The star-shaped metal colored blue is n contact. This structure is designed according to conventional LED structural configuration. The material plane has a size of 1000∗1000μm. The layer structure consists of 3.0μm n-doped GaN, a five-period InGaN/GaN MQW, topped with a 0.25μm p-doped GaN epi-layer. Indium composition in the well is 20 percent with a well thickness of 20 percent with a well thickness of 3nm in order to produce peak emission wavelength at around 480nm.

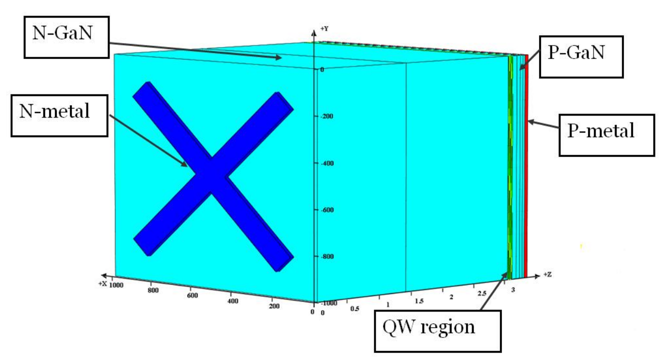

Fig. 1.3D LED with star-shaped n contact and assume N-type GaN surface is textured.

III. RESULTS AND DISCUSSIONS

In Fig.1, n GaN surface is assumed to be textured. Here, we build a 2D texture formed by equilateral triangles each of which has height of 0.5μm and bottom edge length of 1μm. Fig. 2 illuminates how FDTD calculation is applied on the texture. Point source is put at the corner and each textured unit includes three triangles. We set the bottom of triangle as reflection plane, and the top as transmission plane. Then, each unit has an incident angle α as shown in Fig. 2. By extracting data after FDTD calculation, reflection (R) and transmission (T) rate at different α will be obtained. By averaging transmitted optical energy, exit angle β for each unit is also obtained. As an illustrating work, we only consider 10

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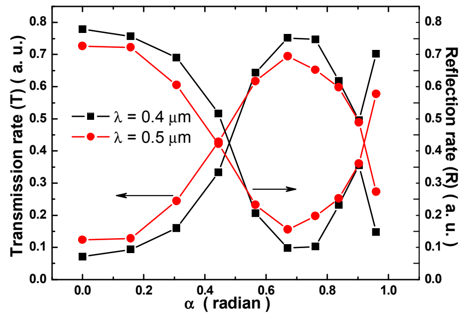
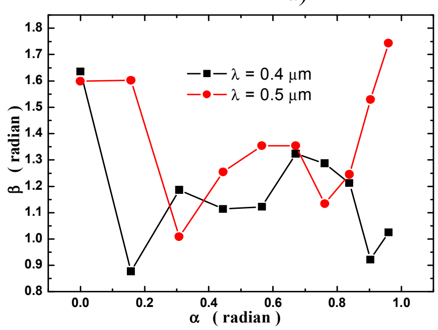
textured units to save computing time. Each time of FDTD calculation gets T, R and β for the textured GaN surface at one certain ray wavelength emitted by the point source.10 sets of data are extracted from FDTD calculations at 10 different wavelengths ranged from 0.3 to 1.3 µm. Fig.3 show 2 sets of them.



a)



b)

Fig. 3. a)T, R and b)β dependent on α for the textured GaN surface at different wavelength.

Finally, 3D ray-tracing simulation is applied. When ray reached the textured surface, the extracted optical data calculated by FDTD is used. As a compare, 3D ray-tracing simulation without textured surface is also processed. Fig.4 shows that textured surface greatly increased transmitted power.

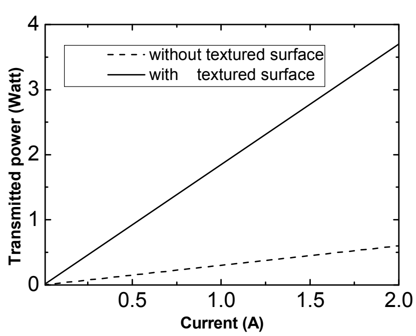
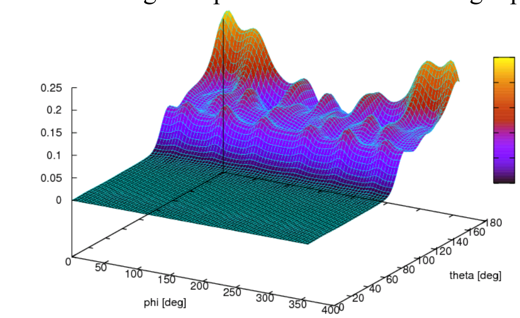
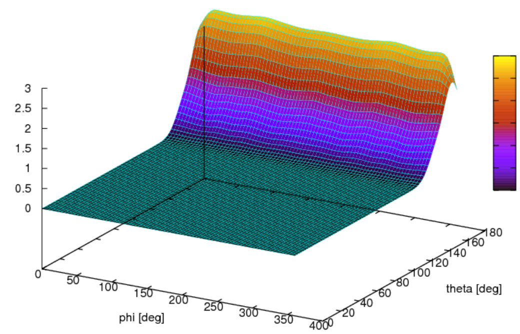


Fig. 4. Transmitted light power versus current

We also plot the angular dependence of the emitted power as a function of two angular variables phi and theta, where phi and theta are the two angles in a spherical coordinate system with +z direction same as that in the Cartesian coordinates used by APSYS and CSUPREM. Fig.5 shows 3D angular distribution of transmitted ray power. We can see that power is mainly transmitted through -z direction where theta=180^{o} and n contact stands. Fig5.a) indicates that n contact has strong influence on power distribution if there's no textured surface while Fig5.b) shows that textured surface strongly smoothes angle dispersion of transmitted light power.



a)



b)

Fig. 5. Transmitted light power distribution. a) without textured surface; b) with textured surface

Through Fig.3 a), we can get that at wavelength of 480nm the LED emitted, peak rate of power transmission is only about 0.7, which means that if we change geometry of the texture unit, we will have a big chance to improve power transmission rate that we should study in future research.

IV. CONCLUSIONS

For the first time we have conducted a 3D simulation for light power distribution of a InGaN/GaN MQW LED with textured surface. By comparing ray-tracing results with and without textured surface, we got notable difference of extraction efficiency and power distribution. In the other words, textured surface greatly improved quality of LED devices. By changing texture geometry, we will have a chance to improve transmission rate.

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