

Modulation of Uniform Light Pattern with Light Extraction Enhancement by Using Microstructure on p-GaN of LEDs

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Abstract --- The uniform light pattern with light extraction enhancement in LEDs with microlens-like structures is demonstrated numerically and experimentally. It makes LED light source as a device of spatial-intensity uniformity integrated with GaN-LEDs structure.

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Keywords: microlens-like structure, light pattern, photoluminescence (PL), LEDs, finite difference time domain (FDTD)

1. Introduction

Solid-state lighting technology has recently advanced with the development of III-nitride semiconducting optoelectronic devices and the implementation of nano/micro structure. Nowadays, several approaches have already been proposed and demonstrated to improve output efficiency of III-nitride-based LEDs, such as surface texturing [1-3], photonic crystals (PhCs) [4, 5]. The light pattern modulation also has been proposed by using photonic quasi-crystal [6] and microlens array [7]. However, the photonic quasi-crystal is not easy to put into practice with predictable results. The microlens array of LEDs can concentrate the emission into more normal direction than the planar LEDs. This characteristic is not clearly quantitative analysis and demonstration of the light pattern. In general, it is considered that the modulated light pattern of LEDs with periodic microstructures is attributable to the coupling of light from the etched sidewall surfaces and the great increase in the surface areas. However, there is a lack of clarity on the light pattern modulation of the microstructures. In our study, the concept of microstructure LEDs and light pattern modulation on p-GaN are combined into a single device. Furthermore, microlens-like structures have been integrated into the device in order to improve the intensity uniformity and to demonstrate light pattern control of the LED light emitted.

2. Numerical analysis with FDTD method

In this work, the numerical and experimental demonstrations for the modulation of light pattern in III-nitride-based LEDs with microlens-like microstructures are proposed. As shown in Fig. 1, a schematic diagram of the III-nitride-based LEDs microstructure with trapezoid shape on p-GaN are fabricated on a sapphire (Al_2O_3) substrate. The epitaxial structure consists of a 20-nm-thick GaN nucleation layer, a 4- μm -thick Si-doped GaN n-cladding layer, a six-period InGaN/GaN multiple quantum well (MQW) active region, a 50-nm-thick Mg-doped $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ p-cladding layer and a 0.3- μm -thick Mg-doped GaN layer. Multiple point sources with TE and TM polarizations in the MQW region are utilized in the finite difference time domain (FDTD) analysis to model the behaviour of LEDs. Multiple light sources are arranged similarly with the characteristics of LEDs such as non-planar wavefronts and random polarizations.

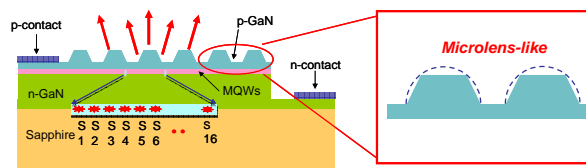


Fig. 1

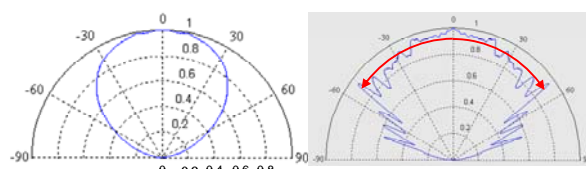


Fig. 2

Fig. 3

Fig. 2 and Fig. 3 show the angular radiation patterns of planar and microlens-like structures, respectively. The angular radiation pattern of planar structure shows the Lambertian distribution just as theory predication. And the proposed structure can make the intensity distribution uniform in $\pm 50^\circ$.

After the growth, the standard photolithography and dry etching are subsequently used to form microstructure pattern of the epitaxial structure. The GaN sample was coated with a 400-nm-thick photoresist (PR) and was processed to break out the photoresist on the sites of the pattern by electron beam nanolithography. The microlens-like patterns of grating on the PR thin film were formed for a stripe, with period of 1600 nm on $1 \times 1 \text{ mm}^2$ area in the epitaxial wafer of blue LED. The patterned photoresist layer on the GaN surface was then developed in a solution of methylisobutyl ketone and isopropyl alcohol. The RIE dry etching process was performed for 60s using the high density plasma system. The surface roughness and the depth of holes can be characterized by atomic force microscope (AFM) measurements. Figure 2 shows 3-D AFM images for the proposed structure with a period $\Lambda=1600 \text{ nm}$.

3. Numerical and experimental demonstration of uniform light pattern with light extraction enhancement in LEDs

The sample with microlens-like microstructure on p-GaN surface was measured by photoluminescence (PL) angular-resolved measurement. The measurement setup consists of a He-Ne laser (325 nm), a monochromator, a photomultiplier tube, a lock-in

amplifier, a long-pass filter, an object lens of 20X magnification, and fiber with fiber collimator, as shown in Fig. 4.

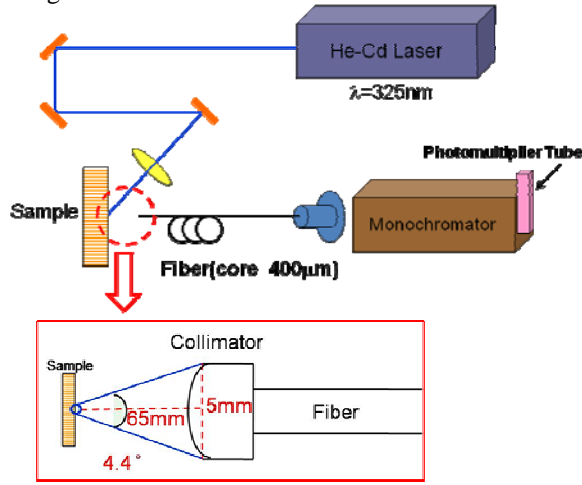


Fig. 4

Figure 5 shows the normalized light patterns of the microstructure on p-GaN. The blue solid line was the light pattern of simulation results by FDTD method. Then, the red dots show the measurement results of PL angular-resolved. Compared with the LED without structure, it can be seen clearly that output beam pattern of the LED with microlens-like structure on p-GaN is uniform. This phenomenon is the same as prediction in the simulation. It also means that a great amount of light with high-frequency components emits from the LED with proposed microstructures. Generally, LEDs are light sources with broadband spectra, non-planar wavefronts, and random polarizations. The photon behaviour cannot be controlled by the optical device sensitive to the light characteristics. This microlens-like structure provides the light pattern modulation for LED light source. And the light pattern is modulated to a uniform intensity above 80% within a cone of 100 degree.

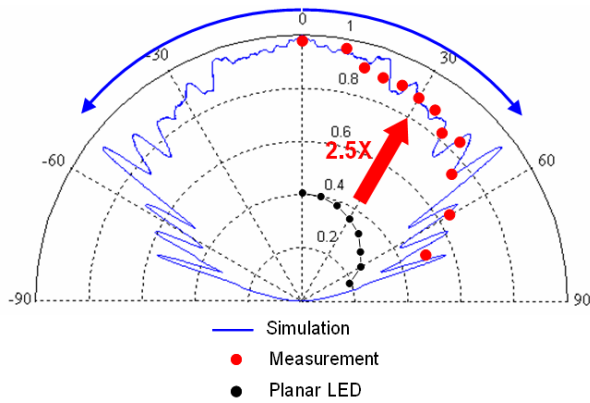


Fig. 5

4. Conclusions

The microstructure of microlens-like has been applied to a p-GaN surface of LED for purpose of modulating the light pattern uniformly within a cone of

100 degree and 2.5 times light extraction enhancement simultaneously. Through the simulation of FDTD and the measurement of PL angular-resolved, the proposed structure reveals the strong modulation effect in uniformity light pattern of LED light source. As a concluding remark, the proposed microlens-like structure provides modulation for LEDs as a spatial intensity uniformity device integrated with GaN-LEDs structure.

6. References

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