Modulation of Uniform Light Pattern with Light Extraction Enhancement by GaN Microlens Arrays of LEDs

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Abstract: The uniform light pattern with light extraction enhancement 250% of LEDs with GaN microlens arrays are demonstrated numerically and experimentally. It makes LED light source as a device of spatial-intensity uniformity integrated with GaN-LEDs structure.

OCIS codes: (230.0230) Optical devices; (230.3670) Light-emitting diodes

1. Introduction

Various LED array configurations designed to achieve the uniform illumination on a target plane by optimizing LED-to-LED spacing [1] and arranging the LED array on a spherical surface [2] have been proposed. As considering compact lighting systems, directly modulating the emitting light pattern of a LED chip by adjusting its geometric parameters is important in applications such as projection TV light engines and direct flat panel display illumination. Several light-pattern modulation schemes have been reported, including theoretical demonstrations of etching photonic crystals [3] and photonic quasi-crystals [4] into the top emitting surfaces of LEDs or the experimental demonstration of monolithically integrated microlenses into sapphire substrates of LEDs [5]. Among these approaches, the ordered surface patterning of photonic (quasi-)crystals can be applied to design various azimuthally anisotropic irradiances from LEDs [3, 4]. The GaN micro-LEDs with monolithically integrated microlenses on the sapphire rear face can improve the directionality of the light emitted [5]. Unfortunately, the scheme of tailoring geometric parameters of LED chips to demonstrate azimuthally isotropic irradiances is not yet realized. In this paper, the local modulation of photons within a micro-scaled region of MOWs just beneath the GaN microlens is proposed. We present the first experimental demonstration of the azimuthally isotropic irradiance from GaN-based LEDs. The azimuthally isotropic light emission with an intensity variation less than 10% is observed within the emitting angles of ±50° by using the angular-resolved photoluminescence.

2. Numerical Simulation of GaN-Based LEDs with Microlens Arrays

The proposed structure of LED grown on a sapphire substrate, as illustrated in Fig. 1. The microlenses fabricated on the p-GaN layer plays a role to modulate the emitting photons just beneath the microlenses. As illustrated in this figure, the structure parameters given in the numerical analysis include period of microlens array Λ = 1.6 μm and filling factor of microlens f = 0 - 1. The finite-difference time-domain (FDTD) analysis is used to study the irradiance behaviour of the proposed LED with microlens arrays. In order to describe the random propagation of unpolarized photons trapped within or escaping from LEDs, multiple TE and TM-polarized point sources with the wavelength of 460 nm are arranged within the MQWs region with an interval of 100 nm.

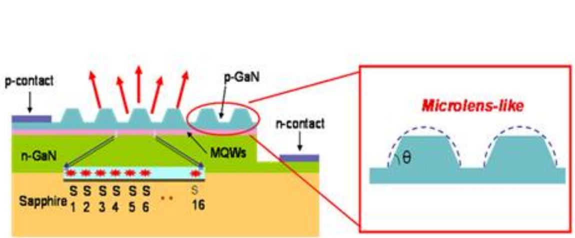

Fig. 1 Schematic diagram of proposed structure

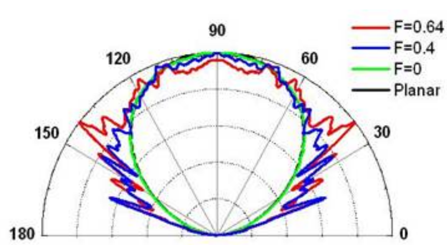

Fig. 2 Angular radiation patterns of F=0, 0.4, 0.64 and 1

Fig. 2 shows the simulated angular radiation patterns emitting from the proposed LEDs with microlens arrays of various filling factors, including F = 0, 0.4, 0.64, and 1. The four emission patterns are normalized to unity intensity at their maximum values. Among these four cases, the filling factor of 1 is the planar type with the p-GaN layer thickness of 0.3 μm. The filling factor of 0 means the p-GaN layer of the planar type is etched down to 0.115

μm. Two different filling factors F = 0.4 and 0.64 are applied to demonstrate the modulation effect of microlens with different size. As shown in this figure, a Lambertian light pattern emitting from the planar LED is agree with the theoretical prediction. The angular radiation patterns are varied with the filling factors of microlenses. As indicated in this figure, the umiform light emission with an intensity variation less than 10% is observed within the emitting angles of ±50° for the case of F = 0.64.

3. Experimental Results

The microlens array is constructed on the p-GaN layer to investigate the feasibility of modulating the emitting light patterns of LEDs. Initially, intended microlens profile with a period of 1600 nm is defined in PMMA by e-beam lithography. Finally, a following inductive-coupled plasma (ICP) dry etching process is used to transfer the patterned structure to the p-GaN layer. Figs. 3 shows pictures of fabricated microlens array observed by scanning electron microscope (SEM). The microlens is observed with an average period close to 1.6 μm. The filling factor *f* corresponding to the average period is around 0.64. The irradiance measurement of proposed LED is carried out by using an angular-resolved photoluminescence (PL) configuration, as illustrated in Fig. 4. Fig. 5 shows the measured angular radiation patterns emitting from the proposed LED and the planar LED. For comparison, the simulated angular radiation patterns emitting from both types of LEDs are illustrated in this figure. As shown in this figure, the theoretical model can be used to precisely predict the irradiance of both LEDs. An azimuthally isotropic light emission with an intensity variation less than 10% within the emitting angles of ±50° is observed. It also means that a great amount of photons with higher spatial frequencies emit from the proposed LED as compared with the planar one. With the assistance of the microlens array, more photons induced in GaN-based LED can be effectively coupled into the air. The deviation between the experimental and simulated results may result from the spatial resolution of angular PL system. However, the main feature of the uniform light pattern still agrees with the results obtained in the simulation. As compared with the planar one, the improvement of light extraction from proposed LEDs is about 250%.

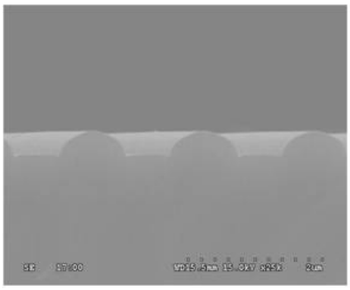

Fig. 3 SEM image of microlens structure

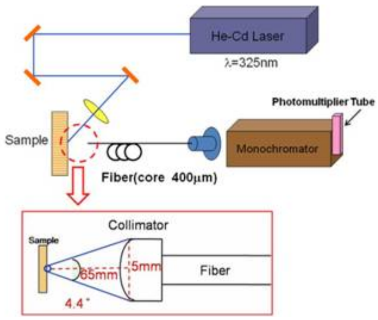

Fig. 4 Angular-resolved photoluminescence setup

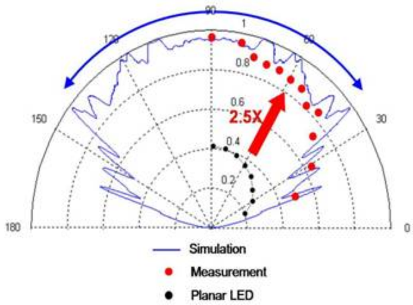

Fig. 5 Angular radiation patterns of F=0.64 & 1

4. CONCLUSION

The microlens array has been applied to a p-GaN surface of LED for purpose of modulating the light pattern uniformly within a cone of 100°. 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.

5. REFERENCES

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