High extraction efficiency of photonic crystal microcavity GaN based light emitting diode

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Abstract

We have demonstrated that the light extraction efficiency of GaN based light emitting diodes (LEDs) can be significantly enhanced by using photonic crystal and microcavity (PCMC) effects. It was found that the extraction efficiency of the PCMC-LEDs is 9.5 times larger than that of the normal LEDs.

1. Introduction

Recently, GaN based light emitting diodes (LEDs) have been applied to various applications, including traffic signals, outdoor full color displays, backlight units in liquid crystal displays and so on. However, the extraction efficiency of GaN LEDs is still limited because the photon generated in multiple quantum well is trapped in a GaN LED by the total internal reflection at the GaN/air interface, and a significant portion of the photons is coupled into the guided modes of the lateral air/GaN/sapphire waveguide, to be dissipated due to the material loss. In order to obtain the high extraction efficiency, various approaches have been proposed using photonic crystal (PC) [1,2] and microcavity (MC) effects [3,4].

In this talk we report on the results of GaN-based PCMC-LEDs which utilize both PC and MC effects. Using the finite difference time domain (FDTD) method, we have calculated the extraction efficiencies of the PCMC-LEDs and three types of conventional LEDs. It was found that the PCMC LEDs have much larger extraction efficiency than the conventional LEDs.

2. Simulation

We have calculated the extraction efficiencies of normal LEDs, PC-LEDs, MC-LEDs, and PCMC-LEDs. Each LED was optimized for a given structure in terms of the layer thicknesses, the quantum well positions and so on. The calculation was performed by using Lumerical FDTD Solutions, a commercial software. A single dipole source was placed in each LED structure with the periodic and perfect matched layer boundary conditions. The center wavelength and the bandwidth of the dipole source were 450 nm and 70 nm, respectively. The material loss of GaN was 300 cm^{-1}, and for MC-LEDs and PCMC-LEDs highly reflective silver p-metals were used. The normal LEDs and the PC-LEDs had thick sapphire substrates.

3. Results

The calculated extraction efficiencies of the four LEDs are shown in Figure 1. The extraction efficiencies of the PC LEDs and the MC LEDs are 3.5 and 4.5 times larger than that of the normal LED, respectively. As reported by other groups, the PC and MC effects can significantly enhance the extraction efficiency. The extraction efficiency of the PC MC LED structure is 9.5 times larger than that of the normal LED. To the best of our knowledge, this is the highest extraction efficiency ever reported for GaN-based LEDs, showing that the extraction efficiency can be maximized by using both PC and MC effects.

4. Summary

We have shown that GaN-based LEDs can have an extremely high light extraction efficiency by simply combining the PC and MC effects which have been

proven theoretically and experimentally. We believe that the PCMC structures would lead to a new class of highly efficient bright LEDs, and can be applied to other solid state light sources and also organic LEDs.

5. References

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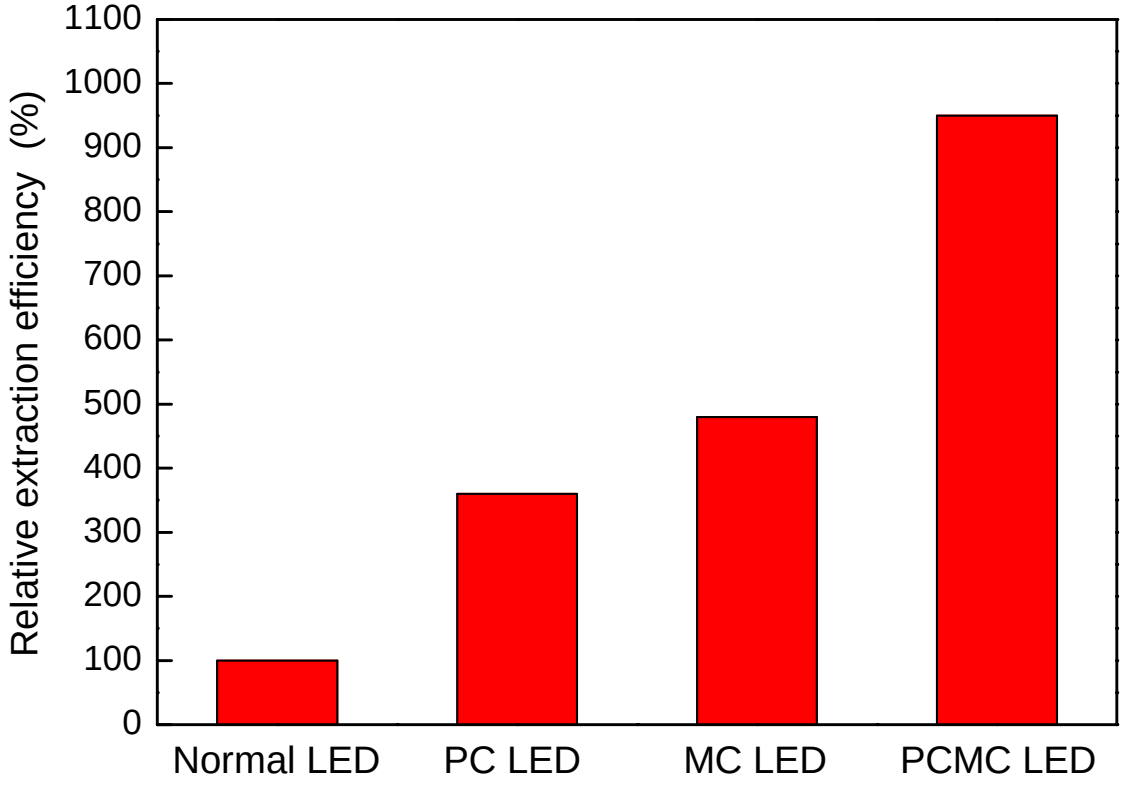

Fig. 1. Relative extraction efficiency according to GaN LED structures.