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Luminous enhancement of nitride light-emitting diodes by localized surface plasmon and triangular structure

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ABSTRACT

A new type of nitride light-emitting diodes structure is proposed and investigated in this paper. The structure mainly includes n-GaN layer, multiple quantum wells layer, p-GaN layer , Ag inserts in p-GaN , TiO_2-Ag grating and TiO_2 triangular structure. The internal quantum efficiency is enhanced by the local surface plasmon and the coupling of the quantum wells, the light luminous area is increased by the triangular structure to increase the light extraction efficiency. The COMSOL software is used to simulate the LED structure in this research. The normalized radiated powers and absorbed powers under different geometric parameters and wavelength are obtained. The results reveal that the luminous intensity of the designed structure can be increased by nearly 73 times compared to the ordinary LED, which provide a foundation for the development of the high-performance LED.

1. Introduction

As display light sources, light emitting diodes (LEDs) are favored by the market because of its high brightness, low operating voltage, low energy consumption and high reliability [1–3]. However, the current luminous efficiency of LED is low, limiting its development. The luminous efficiency of LED depends mainly on the internal quantum efficiency and light extraction efficiency. Due to the light total reflection in GaN and air interface, most of the light is reflected back to the GaN to generate heat energy, which not only reduces the light extraction efficiency but also makes the LED work at a high temperature for a long time and shortens its life span. The extraction efficiency can be improved by surface roughening and photonic crystal [4–7]. The internal quantum efficiency of LED is relatively low at the normal temperature, and increasing the internal quantum efficiency depends on increasing the material quality of the GaN, but this method is costly [8,9]. The localized surface plasmon (LSP) on the metal surface can improve the light extraction efficiency, the light extraction efficiency and the light luminous characteristics of LED. In 2004, K. Okamoto et al. used surface plasmon (SP) to improve the luminous efficiency of LED. When the resonant frequency of LSP was equal to the luminous frequency of quantum wells (QWs), the energy coupled is significantly increased [10]. In 2012 , B. Gil et al. developed a non-local dielectric response theory and proposed that tuning the plasmon frequency could control the efficiency of exciton emission of light [11]. In order to make the resonant frequency of LSP coincide with the luminous peak frequency of LED and obtain a larger internal quantum efficiency, several kinds of metal nanostructures are investigated, including metal nanoparticles, nano-array structure and nano-grating. Sung et al. proposed that the electroluminescent intensity of GaN-based LED coupled with a gold nanoparticles can be

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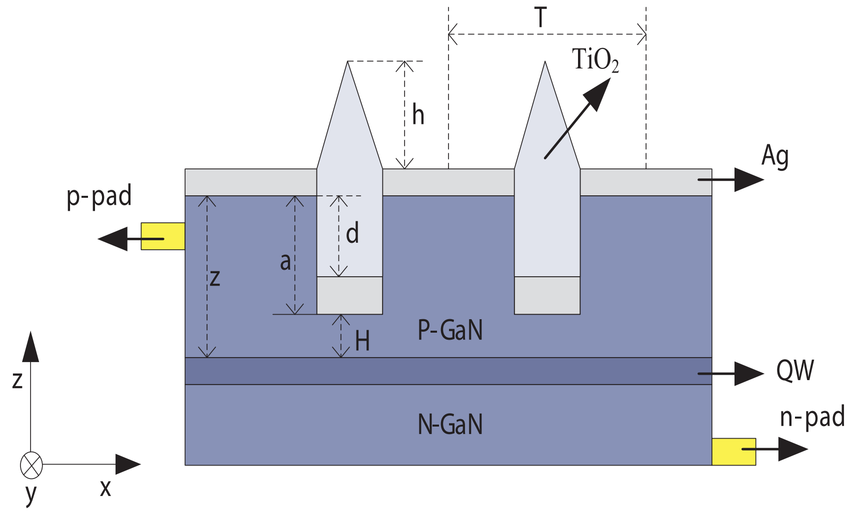

Fig. 1. The schematic diagram of the LED structure.

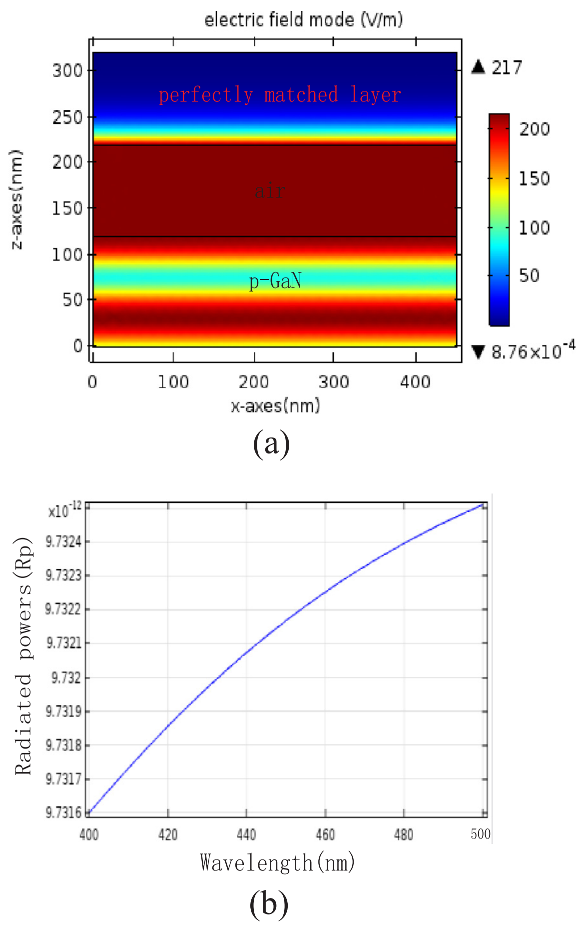

Fig. 2. (**a**) The distribution of the electric field intensity and (**b**) the radiated powers of the ordinary LED.

enhanced by 1.8 times [12]. G. Lozano et al. studied a solid-state light source based on LSP of the nano-array structure, which enhanced the luminous efficiency of the light [13]. Some studies have indicated that the light extraction efficiency of the LSP wave can be effectively improved by the micro-nano grating structure. Kamoto et al. engraved sub-wavelength metal grating on the metal surface to converted the LSP energy into light energy more efficiently [14–16]. However, the contact interface between Ag and GaN