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High Brightness Green Light Emitting Diode with Charge Asymmetric Resonance Tunneling Structure

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1. Introduction

Recently, major developments in wide band-gap III-V nitride compound semiconductors have led to the commercial production of high brightness green light emitting diodes (LEDs) [1-3], which can be used in full-color displays and light sources for traffic light lamps with high efficiency, high reliability and high speed. Conventional LEDs use single or multiple quantum wells as the active light emitting layers [4]. In order to improve the light emitting efficiency, one should maximize the number of carriers recombine inside the active layers and minimize the number of carriers recombine outside the active layers. Thus, one should increase the carrier capture rates of the active layer. However, the capture rate depends on carrier masses and the quantum well parameters, such as well and barrier layer thickness and the number of quantum wells [5-6]. For example, although a narrow quantum well can provide a larger carrier confinement, lots of carriers will still recombine outside the active layer since the capture rate of the narrow quantum well is low. As a result, the efficiency of the LED will still be low [7]. Here, we propose a new LED structure with one electron emitter well and one MQW active layers. The so call charge asymmetric resonance tunneling (CART) structure can significantly increase the number of electrons captured into the MQW active layer [8].

The samples were grown by an EMCORE D-180 MOCVD system. Fig. 1(a) shows the schematic structure of the CART LED, which consists of a 300 Å-thick GaN nucleation layer, a 2 μm-thick Si-doped GaN, a 500 Å-thick $In_{0.1}Ga_{0.9}N$ electron emitter layer, a 10 Å-thick GaN tunneling barrier layer, a 9-period InGaN/GaN MQW structure consisting of 30 Å-thick $In_{0.49}Ga_{0.51}N$ well layers and 70 Å-thick GaN barrier layers, and a 0.3 μm-thick Mg-doped GaN cap layer. Fig. 1(b) shows that band diagram of the CART LED. The Mg-doped GaN cap layer also serves as the hole emitter which can supply holes freely into the active layer. On the other hand, we designed our CART structure so that the electrons can easily tunnel from the electron emitter layer through the tunneling barrier layer and into the MQW active layer. Such a barrier design uses the CART phenomenon which allows electrons to tunnel freely. At the same time, it can also block holes effectively. Fig. 2 shows the I-V characteristics of the CART LED. We can observe an abrupt turn-on between 3 and 4 V, and the forward voltage is 3.2 V at I = 20 mA. Fig. 3 shows the room temperature EL spectra of the CART LED with different amount of injection current. For the CART LED, we found that the emission peak wavelength of the EL spectra is 525 nm with a 33.6 nm FWHM. The energy difference between the strained-free band-edge emission peak of $In_{0.49}Ga_{0.51}N$ layer and the peak wavelength of our EL spectrum is about 160 meV. This difference is due to the band gap narrowing effect as proposed by Nakamura et. al.. The dependences of the integrated EL intensity and the dominated wavelength on the injection current are shown in Fig. 4. At 20 mA, the luminescence intensity, output power, and external quantum efficiency of the

CART LED are about 100 mcd, 4 mW, and 25 %, respectively.

In summary, the LED with charge asymmetric resonance tunneling has been proposed. The higher efficiency, high brightness, and the lower forward voltage can be obtained by using CART structure in green LED. The results have shown that CART structures are promising for future efficient green LED devices. Further studies on LED testing data of device such as reliability and lifetime are now under way.

Acknowledgements

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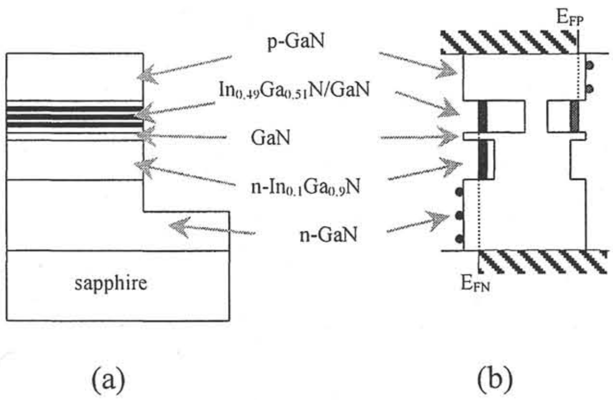

Fig. 1 (a) the schematic structure of the CART LED and (b) the general scheme of a CART LED under applied forward bias voltage.

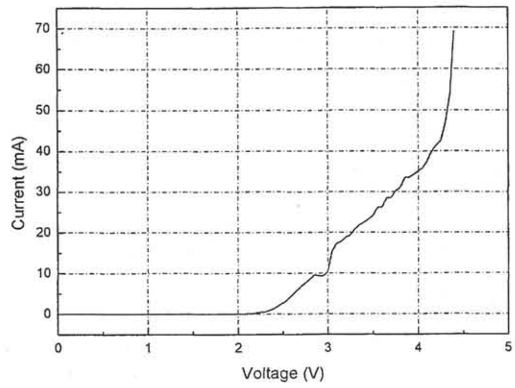

Fig. 2 the I-V characteristics of the CART LED.

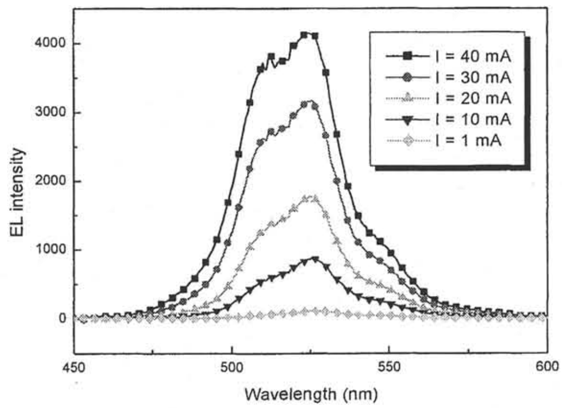

Fig. 3 the spectral distribution of the CART LED emission at room temperature.

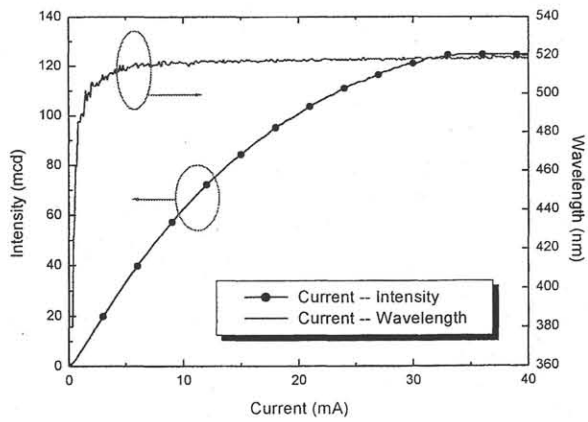

Fig. 4 The dependence of the total luminescence intensity and the dominated wavelength on the inject current.