Green and Blue Light Emitting InN/GaN Quantum Wells with Nanosize Structures Grown by Metalorganic Chemical Vapor Deposition

Je Won Kim and Kyu Han Lee

Abstract—**The structural and electrical properties of InN/GaN multiple quantum wells, which were grown by metalorganic chemical vapor deposition, were characterized by transmission electron microscopy and electroluminescence measurements. As the quantum well growth time was changed, the wavelength was varied from 451 to 531 nm. In the varied current conditions, the blue LED with the InN MQW structures did not have the wavelength shift. With this result, we can expect that the white LEDs with the InN MQW structures do not show the color temperature changes with the variations of applied currents.**

Index Terms—**Green Light Emitting, InN, GaN, Quantum Well, Nano Structure, MOCVD**

I. Introduction

GaN based materials have attracted considerable interest in relation to their potential usage in optoelectronic devices. The light-emitting diode (LED) for red color is made from the InGaAlP based materials, otherwise blue and green LEDs are made from the GaN based materials. In the three primary color LEDs, optical power efficiency of green LED has the lowest values. It is ascribed that the crystal quality of InGaN multiple-quantum wells (MQWs) is being degraded because the film stress is increased due to the large lattice mismatch with increasing the indium mole fraction of InGaN well layers to achieve the green LEDs. The other possible reason is that the radiation recombination is difficult caused of the larger electron and hole separations by the strong piezoelectric field. To achieve the certain wavelength in the GaN-based LEDs, we should control the indium mole fractions of well layers and well thicknesses.

In case of InN LEDs, the well thickness can be more reduced to make a certain wavelength. Therefore, it is very important to understand the characteristics of InN LED due to the stress control and electron-hole separations in MQW structures.

II. Experiments

Blue and green LEDs were grown by metal organic chemical deposition (MOCVD) on c-axis sapphire substrate. Trimethylgallium (TMGa), trimethylindium (TMIn), ammonia (NH_3), bis-cyclopentadienyl (Cp_2Mg), and silane (SiH_4) were used as sources of Ga, In, N, Mg, and Si. InN MQW structures have been embedded in the LED structures. To change the wavelength, the growth time of InN well layer was changed. The growth time was varied between 125 and 255 seconds. After the growth of epilayers, the conventional fabrications were performed using standard process with mesa area (300μm × 300μm).

Ocean optics spectrometer was used to measure the electro-luminescence, and Si photo-detector was used to measure the optical power of LEDs. Transmission electron microscopy (TEM) measurements were conducted to characterize the structural analysis. During TEM measurement, the exposed time was shortened as much as possible due to the damage by the electrons [1].

Manuscript received April 8, 2005; revised June 12, 2005.
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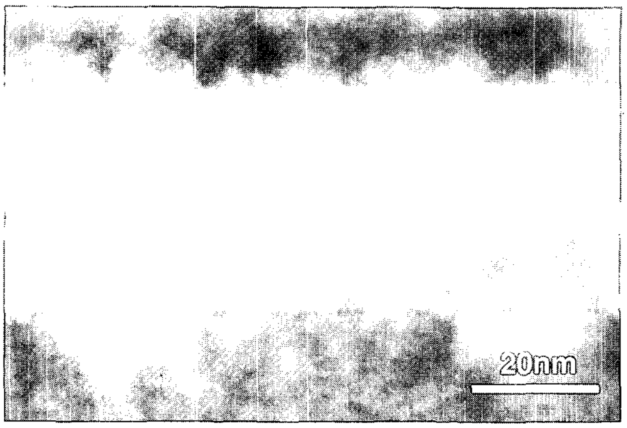
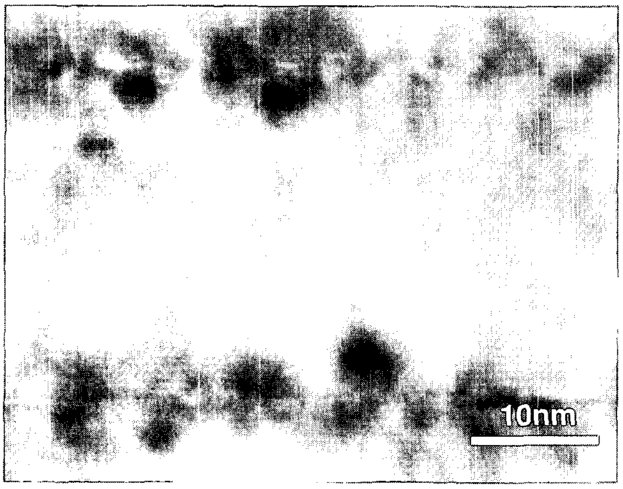
III. Results and Discussion

TEM micrographs of InN-based MQW structures are shown in Fig. 1. The growth time of the well layer is 195 seconds. Fig. 1(a) shows that MQW is well grown without any defect generation [2]. In the Fig. 1(b), it was seen that the well layer is grown like a quantum dot. The well layer is expected to be under the compressive stress because of the lattice constant difference between InN and GaN epilayers [3]. The well layer thickness is possibly presumed from the high-resolution image. The well layer thickness is ascribed to be under 1 nm. It can be expected that the nano-size structures were grown in the InN MQW layers.

The current-voltage characteristics of InN MQW LEDs were investigated. The forward and reverse voltages were 2.6 V, 3.2 V and -21V at the driving currents of 10uA, 20mA and -10uA. These measurements show the similar results with the InGaN LED's current-voltage characteristics. Table 1. shows the relationship between growth time and electroluminescence wavelength at a driving current of 20mA. With increasing the well thickness, the reduced quantum effects made a result to increase the wavelength.



(a)



(b)

Fig. 1. TEM images of InN MQW layers with the well growth time of 195 sec

In the Fig. 2, the relative optical powers of InN LED are measured with the wavelength. The data of the InGaN green LED is added to compare with the InN LED. In this measurement, the highest optical power was at the InN LED having the peak wavelength of 500 nm. Normally, in the InGaN MQW system, the optical power of InGaN LED having the wavelength of 450nm is higher than that of InGaN LED at 500 nm [4]. Otherwise, InN LEDs show the different phenomenon. This can be ascribed that the well layer thickness and the localization effect caused by quantum dot formation influence the optical power [5]. In case of green LED having InN MQW, optical power is 70% compared with the normal green LED with InGaN MQW system.

Fig. 3. shows the wavelength changes with the varied applied current conditions. In case of the blue LED with InGaN MQW, the blue shift is approximately 8 nm when the current is increased from 1 to 60 mA [6]. But the blue LED with the InN MQW did not have the wavelength shift. It is caused by the very thin well thickness. The piezoelectric field does not arise the wavelength shift in the InN MQW systems. On the contrary of InN blue LED, the wavelength changes are varied to 22 nm at the InN green LED when the current is changed from 1 to 60 mA. This result is a larger than that of the normal InGaN green LED with the wavelength shift of 14 nm. This could be explained to be the increased thickness fluctuation and the decreased epilayer quality compared with the InN blue LEDs.

Table. 1. Growth time and wavelength of InN MQWs at the condition of 20mA

Sample	Growth Time(sec)	Wavelength(nm)
S1	125	452
S2	195	500
S3	220	505
S4	255	531

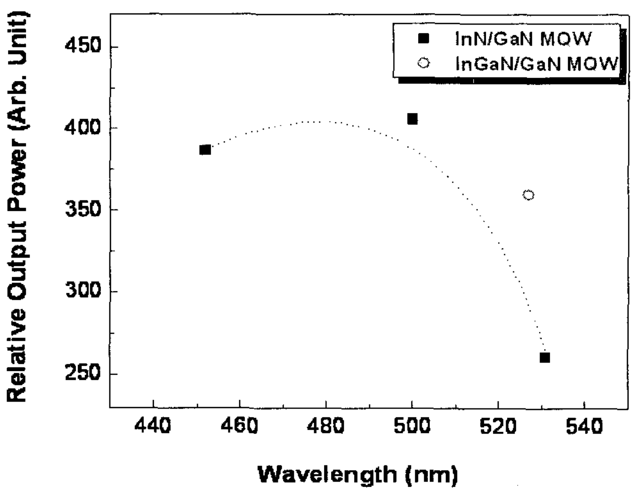


Fig. 2. The optical power of the InN/GaN MQWs compared with the InGaN/GaN MQWs

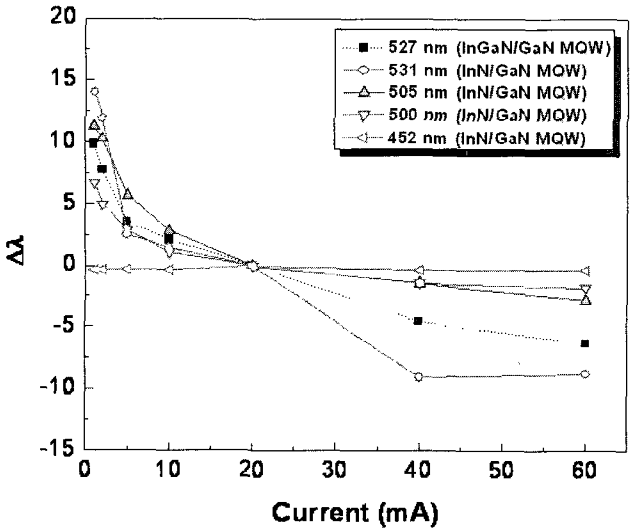


Fig. 3. Wavelength variations with the applied currents

IV. Conclusions

The InN MQW structures were grown and investigated with the electrical and optical characteristics in this study. In case of InN blue LEDs, there was no wavelength shift with increasing the applied current. It can be expected to make the white LEDs that have not the color temperature changes with the applied current. In case of InN green LED, optical power was 70% compared with the normal InGaN MQW LEDs. Accomplishing the optimization of the InN MQW structures, it could be possible to achieve the higher optical powers.

References

[1] T. M. Smeeton, M. J. Kappers, J. S. Barnard, M. E. Vickers, and C. J. Humphreys, *Appl. Phys. Lett.* **83**, 5419 (2003).

[2] S. D. Lester, M. J. Ludowise, K. P. Kileen, B. H. Perez, J. N. Miller, and S. J. Rosner, *J. Crys. Growth* **189/190**, 786 (1998).

[3] K. Tachibana, T. Someya, and Y. Arakawa, *Appl. Phys. Lett.* **74**, 383 (1999).

[4] T. Mukai, M. Yamada, and S. Nakamura, *Jpn. J. Appl. Phys.* **38**, 3976 (1999).

[5] S. Chichibu, T. Azuhata, T. Sota, and S. Nakamura, *Appl. Phys. Lett.* **69**, 4188 (1996).

[6] Y. Narukawa, I. Nikki, K. Izuno, M. Yamada, Y. Murazaki, and T. Mukai, *Jpn. J. Appl. Phys.* **41**, L371 (2002).

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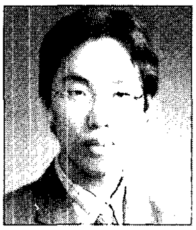

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