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RESEARCH ARTICLE

Luminescence properties of blue and green dual wavelength InGaN/GaN multi-quantum well light-emitting diode

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Abstract Blue and green dual wavelength InGaN/GaN multi-quantum well (MQW) light-emitting diode (LED) has wide applications in full color display, monolithic white LED and solid state lighting, etc. Blue and green dual wavelength LEDs, which consist of InGaN strain-reduction layer, green InGaN/GaN MQW and blue InGaN/GaN MQW, were grown by metal-organic chemical vapor deposition (MOCVD), and the luminescence properties of dual wavelength LEDs with different well arrangements were studied by photoluminescence and electroluminescence. The experimental results indicated that well position played an important role on the luminescence evolvement from photoluminescence to electroluminescence.

Keywords multi-quantum well (MQW), luminescence, dual-wavelength, metal-organic chemical vapor deposition (MOCVD)

1 Introduction

GaN based materials cover a wide bandgap from 0.6 eV (InN) to 6.2 eV (AlN) and are capable of emitting light with wavelength ranging from ultraviolet to visible and even to infrared. With the technological breakthrough in material epitaxy and chip fabrication process, GaN-based blue light-emitting diode (LED), green LED and near ultraviolet LED have been commercially available and extensively used. Compared with single color LEDs, multi-wavelength GaN based LEDs have progressed slowly, in spite of their importance in full color display, monolithic white light-emitting diode and solid state lighting, etc. [1–4]. For example, blue and green dual wavelength LED can provide blue light and green light, which are two of the three primary colors. Also, the color tunablity make dual wavelength LED a good candidate in full-color display.

In this paper, we grew blue and green dual wavelength LEDs by metal-organic chemical vapor deposition (MOCVD), the luminescence properties of dual wavelength LEDs with different well arrangements were analyzed by photoluminescence (PL) and electroluminescence (EL).

2 Experiments

The samples were grown on c-plane sapphire substrate by Thomas Swan close-coupled-showerhead low-pressure MOCVD system. Trimethylindium (TMIn), trimethylgallium (TMGa), trimethylaluminium (TMAl) and NH_3 were used as In, Ga, Al, N precursors, respectively. H_2 and N_2 were used as the carrier gas. SiH_4 and biscyclopentadienyl magnesium (CP_2Mg) were used as N-type and P-type doping sources, respectively.

The epitaxial growth of green LED is difficult, because high Indium (In) content InGaN is difficult to grow due to the large strain between InGaN and GaN [5], and the low miscibility of InN in GaN [6]. Therefore, we introduced a low In content InGaN layer to serve as strain reduction layer [7], thus enhancing In incorporation in the following-grown green InGaN multi-quantum well (MQW) and extending its emission wavelength to a longer wavelength.

We grew four kinds of samples. The schematic structures of sample A and sample B are shown in Figs. 1(a) and 1(b), respectively, and the structure of sample C and sample D are shown in Figs. 2(a) and 2(b), respectively. Sample A is green InGaN/GaN MQW, which consists of 25 nm-thick GaN nucleation layer grown at 525°C, followed by undoped GaN buffer layer grown at 1050°C, then 5 periods of $In_{0.15}Ga_{0.85}N$ (3 nm)/GaN (14 nm) MQWs as active region; the growing temperature

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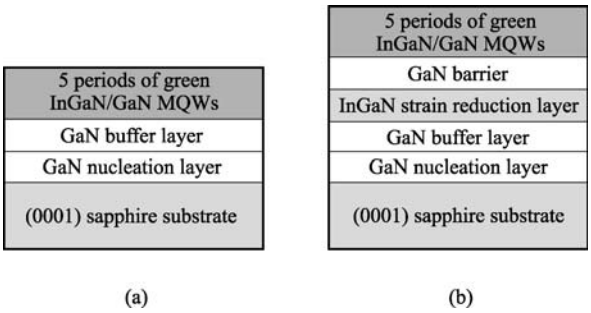

Fig. 1 Schematic structure. (a) Sample A; (b) sample B

for InGaN well and GaN barrier were 680°C and 910°C, respectively. Sample B was grown to investigate the effect of strain reduction layer on enhancing In incorporation and lengthening the emission wavelength of green InGaN/GaN MQW. Therefore, different from sample A, sample B has another low In content $In_{0.04}Ga_{0.96}N$ strain-reduction layer underneath the five green InGaN/GaN MQWs.

Sample C and sample D are blue and green dual wavelength LEDs with different well arrangements. As shown in Fig. 2(a), sample C consists of GaN nucleation layer, undoped GaN buffer layer, N-type GaN, $In_{0.04}Ga_{0.96}N$ strain reduction layer, 4 periods of green $In_{0.15}Ga_{0.85}N$ (3 nm)/GaN (14 nm) MQWs and 2 periods of blue $In_{0.12}Ga_{0.88}N$ (3 nm)/GaN (15 nm) MQWs, P-type AlGaN, and P-type GaN contact layer. Different from sample C, sample D had a different well arrangement as shown in Fig. 2(b), the blue MQWs are located at the bottom of the active region, i.e., they were grown below the $In_{0.04}Ga_{0.96}N$ strain reduction layer and the green MQWs. Apart from the well arrangement difference, sample C and sample D share the same structure and growth parameters.

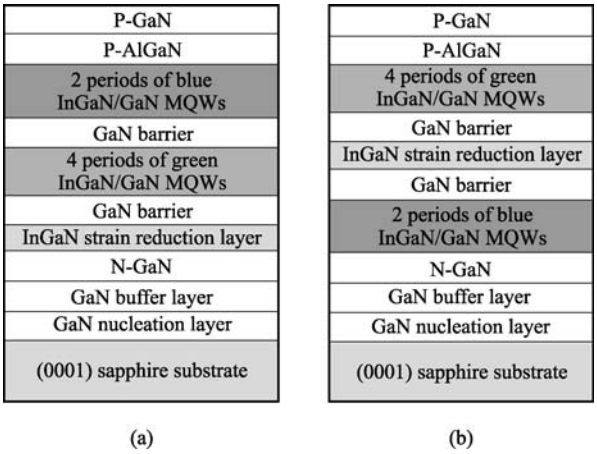

Fig. 2 Schematic structure. (a) Sample C; (b) sample D

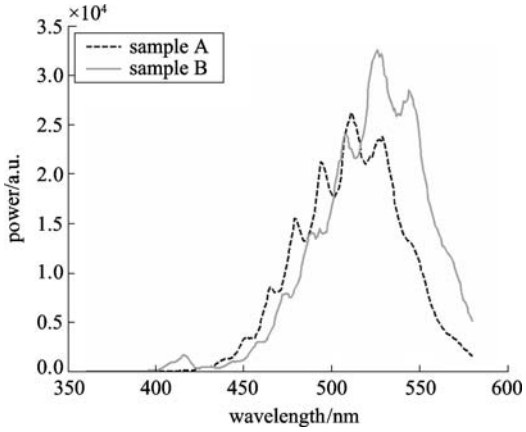

Fig. 3 PL spectra for sample A and sample B

3 Testing and discussion

Room temperature PL and EL were used to analyze the luminescence properties, and He-Cd laser operated at 325 nm was used as the excited source for PL measurement.

Figure 3 demonstrates the PL spectra for sample A and sample B, respectively. The periodic spectrum modulation observed in Fig. 3 was due to Fabry-Perot effect because of the high refractive index contrast between epitaxial layers and sapphire substrate. The emission spectrum can be fitted by Gaussian function to find its peaks [8]. By using Gaussian fitting, we find the peak-wavelength of sample A is 512 nm. Compared to sample A without strain reduction layer, sample B with strain reduction layer has stronger emission intensity and longer emission wavelength. The peak-wavelength of sample B is 530 nm, red-shift about 18 nm compared to sample A. The 416 nm peak of sample B originated from $In_{0.04}Ga_{0.96}N$ strain-reduction layer. Because $In_{0.04}Ga_{0.96}N$ has lower In composition, the strain between $In_{0.04}Ga_{0.96}N$ and GaN is smaller, and it is easy to get high crystal quality. Furthermore, the $In_{0.04}Ga_{0.96}N$ strain-reduction layer makes the following-grown GaN barrier undergo tensile-strain, thus having larger lattice parameter. Then, it is beneficial for the following-grown green MQWs to reduce strain between the InGaN well and GaN barrier; therefore, it helps the green InGaN wells to get higher In content and emit longer wavelength photons.

We made high resolution X-ray diffraction measurements by using a PHILIPS X'Pert MRD system, and then we simulated the composition and thickness of the InGaN/GaN MQW structure by using the Philips X'pert Epitaxy and Smooth software. The simulation results revealed that In content for the five green InGaN wells in sample A was 0.12; while the mean In content for the five green InGaN wells in sample B was 0.20. This further proved In incorporation enhancement by the introduction of $In_{0.04}Ga_{0.96}N$ strain-reduction layer, so the emission wavelength of sample B red-shifts with respect to that of sample A.

Figure 4(a) shows PL spectrum of sample C, in which

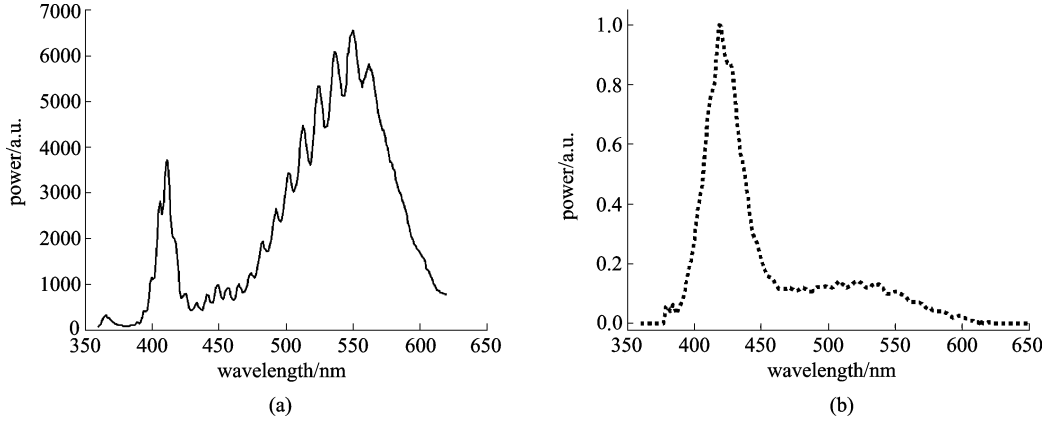

Fig. 4 Spectrum of sample C. (a) PL spectrum; (b) EL spectrum

two blue MQWs are on the top of the active region, and four green MQWs are below the blue MQWs. The PL spectrum has a very weak GaN peak at 365 nm, a relatively stronger $In_{0.04}Ga_{0.96}N$ strain-reduction layer peak at 410 nm, a weak blue MQWs peak at 461 nm, and a very strong green MQWs peak at 546 nm.

Figure 4(b) gives EL spectrum for sample C. The EL spectrum is quite different from PL spectrum. Not only does the GaN peak and strain-reduction layer peak disappear in EL spectrum, but also the blue MQWs peak becomes much stronger than the green MQWs peak. This phenomenon is due to carrier non-uniform distribution and well arrangement. Because of slower mobility and heavier effective mass of holes, and the interaction of electrons and holes, more carriers distribute in the QWs closer to P-type side [2,9]. As a result, the top blue MQWs has the strongest emission and the emission spectrum blue-shifts due to quantum-confined Stark effect and band-filling effect, while the green MQWs luminescence becomes weak due to smaller carrier density. GaN peak and strain reduction layer peak disappear in the EL spectrum due to photon re-absorption effect and less carrier distribution.

Figures 5(a) and 5(b) present the PL spectrum and EL spectrum of sample D, respectively. Compared with PL spectrum, the EL spectrum has a dominating green MQW emission peak and relatively weak blue MQW emission peak. As shown in Fig. 5(b), the solid line is the simulated blue MQW peak by Gaussian curves fitting.

Furthermore, comparing Fig. 4 with Fig. 5, it is found that sample C and sample D have different luminescence evolvement from PL to EL, which is due to their different well arrangement. Sample C has blue MQWs on the top of the active region, nearer to P-type side; whereas sample D has blue MQWs at the bottom of the active region, a bigger distance from the P-type side. Therefore, less carrier distribution and photon re-absorption effect make blue MQWs in sample D emit weakly. In contrast, the green MQWs in sample D are closer to P-type side, so more carriers contribute in the stronger emission of green light.

4 Conclusion

In this paper, we introduced a low In content InGaN layer to enhance In incorporation and lengthen the emission wavelength of green InGaN/GaN MQW. We grew blue and

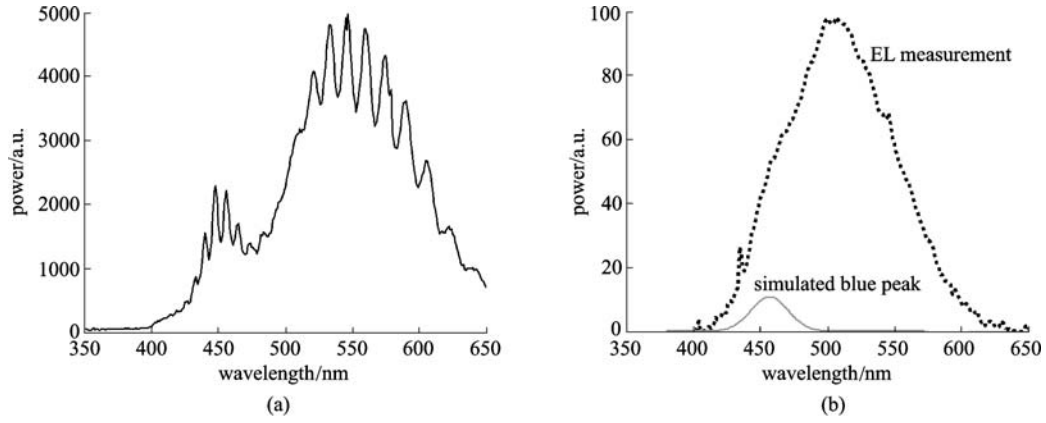

Fig. 5 Spectrum of sample D. (a) PL spectrum; (b) EL spectrum

green dual wavelength LEDs with different well sequence by MOCVD. The photoluminescence and electroluminescence results indicated that different luminescence evolvement from photoluminescence to electroluminescence is due to well arrangement and non-uniform carrier distribution.

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References

1. Ozden I, Makarona E, Nurmikko A V, Takeuchi T, Krames M. A dual-wavelength indium gallium nitride quantum well light emitting diode. Applied Physics Letters, 2001, 79(16): 2532–2534
2. Li Y-L, Gessmann Th, Schubert E F, Sheu J K. Carrier dynamics in nitride-based light-emitting p-n junction diodes with two active regions emitting at different wavelengths. Journal of Applied Physics, 2003, 94(4): 2167–2172
3. Yamada M, Narukawa Y, Mukai T. Phosphor free high-luminous-efficiency white light-emitting diodes composed of InGaN multi-quantum well. Japanese Journal of Applied Physics, 2002, 41: L246–L248
4. Damilano B, Grandjean N, Pernot C, Massies J. Monolithic white light emitting diodes based on InGaN/GaN multiple-quantum wells. Japanese Journal of Applied Physics, 2001, 40: L918–L920
5. Xiao D, Kim K W, Bedair S M, Zavada J M. Design of white light-emitting diodes using InGaN/AlInGaN quantum-well structures. Applied Physics Letters, 2004, 84(5): 672–674
6. Ho I-H, Stringfellow G B. Solid phase immiscibility in GaInN. Applied Physics Letters, 1996, 69(18): 2701–2703
7. Huang C-F, Tang T-Y, Huang J-J, Shiao W-Y, Yang C C, Hsu C-W, Chen L C. Prestrained effect on the emission properties of InGaN/GaN quantum-well structures. Applied Physics Letters, 2006, 89(5): 051913
8. Li S F, Schörmann J, Pawlis A, As D J, Lischka K. Cubic InGaN/GaN multi-quantum wells and AlGaN/GaN distributed Bragg reflectors for application in resonant cavity LEDs. Microelectronics Journal, 2005, 36(11): 963–968
9. Kuo Y-K, Chang Y-A. Effects of electronic current overflow and inhomogeneous carrier distribution on InGaN quantum-well laser performance. IEEE Journal of Quantum Electronics, 2004, 40(5): 437–444