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InGaN–GaN Multiquantum-Well Blue and Green Light-Emitting Diodes

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THE III–V NITRIDE semiconductor materials have a wurtzite crystal structure and a direct energy bandgap. At room temperature, the bandgap energy of AlInGaN varies from 1.95 to 6.2 eV depends on its composition ratio. Therefore, III–V nitride semiconductors are useful for light-emitting device in the short wavelength region. Indeed, III–V nitride-based blue and green light-emitting diodes (LEDs) are now commercially available. Currently, these blue and green LEDs have already been extensively used in traffic light source and full color display. The active region of a typical III–V nitride-based blue and green LED consists an unintentionally doped InGaN–GaN multiquantum-well (MQW) structure sandwiched in between the (Al)GaN n-type and p-type cladding layers. However, due to the lattice mismatch between InGaN and GaN, relaxation might occur as the number of quantum well (QW) increases. Furthermore, piezoelectric field-induced quantum confined Stark effect (QCSE) might also influence the luminescence properties of these III–V nitride-based blue and green LEDs. In this work, we report the study of the InGaN–GaN MQW blue and green LEDs with different numbers of QW pairs. The relaxation induced effects of these LEDs will be discussed in detail.

Samples used in this study were all grown on (0001) sapphire (Al_2O_3) substrates in a vertical low-pressure organometallic vapor phase epitaxy (OMVPE) reactor with a high-speed rotation disk. The gallium, indium, aluminum and nitrogen sources were trimethylgallium (TMGa), trimethylindium (TMI), trimethylaluminum (TMA), and ammonia (NH_3), respectively. Bicyclopentadienyl magnesium (Cp_2Mg) and silane (SiH_4) were used as the p-type and n-type doping sources, respectively. Fig. 1 shows the DCXRD spectra of the blue MQW LEDs with different numbers of InGaN–GaN MQW pairs. Fig. 2(a) and (b) show, respectively, the room-temperature PL spectra and PL FWHM of the blue MQW LEDs. Fig. 3(a) and (b) show the room-temperature EL spectra and external quantum efficiencies of the blue MQW LEDs, respectively. Fig. 4(a) and (b) show the forward current–voltage (I–V) characteristics and V_f for blue MQW LEDs with different pairs of QWs, where the forward voltage V_f is defined as the operation voltage with a 20-mA injection current. Fig. 5(a) and (b) show the EL spectra of the 11-pair and 16-pair blue MQW LEDs with different amount of injection currents.

Fig.6 shows the DCXRD spectra of the green-LED samples with different numbers of InGaN–GaN MQW pairs. Fig.7 shows the room-temperature PL spectra of the green MQW LEDs. Fig.8 shows the room-temperature EL spectra of the green MQW LEDs under the same 20-mA injection current. We found that the EL peak position was 495.7, 504.2, 506, and 519.2 nm for eight-, six-, four-, and two-pair green MQW LEDs, respectively. With the same In composition ratio in the InGaN well layers, we again observed a blue shift in EL spectra when the number of QW increases. Fig. 9 shows a comparison in normalized EL spectra for blue MQW LED and green MQW LED. It can be seen that the EL FWHM of green MQW LED (i.e., 35 nm) was much larger than that of the blue MQW LED (i.e., 26 nm). Fig. 10(a) and (b) show the forward I–V characteristics, and V_f for green MQW LEDs with different pairs of QWs. Fig. 11(a) and (b) show the EL spectra of the six-pair and two-pair green MQW LEDs with different amount of injection currents.

In summary, InGaN–GaN MQW blue and green LEDs were prepared by MOVPE, and the properties of these LEDs were evaluated by PL, DCXRD, and EL measurements. It was found that there were only small shifts observed in PL and EL peak positions of the blue MQW LEDs when the number of QW increased. However, significant shifts in PL and EL peak positions were observed in green MQW LEDs when the number of QW increased. It was also found that there was a large blue shift in EL peak position under high current injection in blue MQW LEDs. However, the blue shift in green MQW LEDs was negligibly small when the injection current was large. These observations could all be attributed to the rapid relaxation in green MQW LEDs since the In composition ratio in the InGaN well was high for the green MQW LEDs. The forward voltage of green MQW LEDs was also found to be larger than that of blue MQW LEDs due to the same reason.

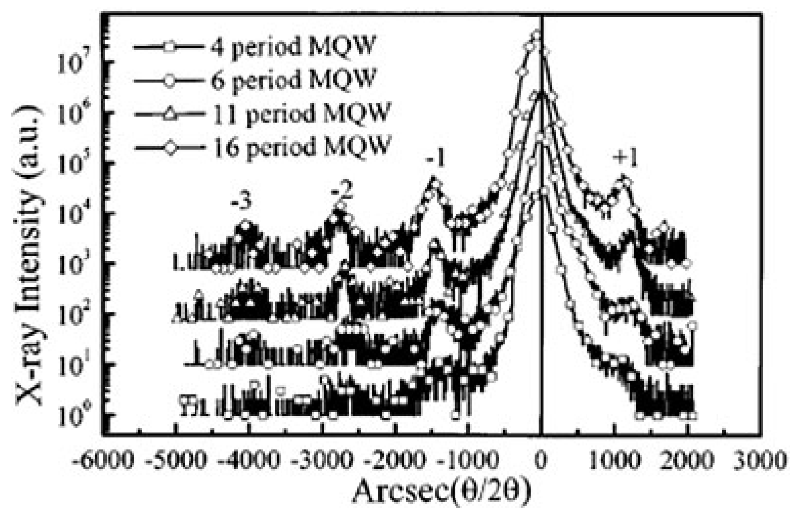
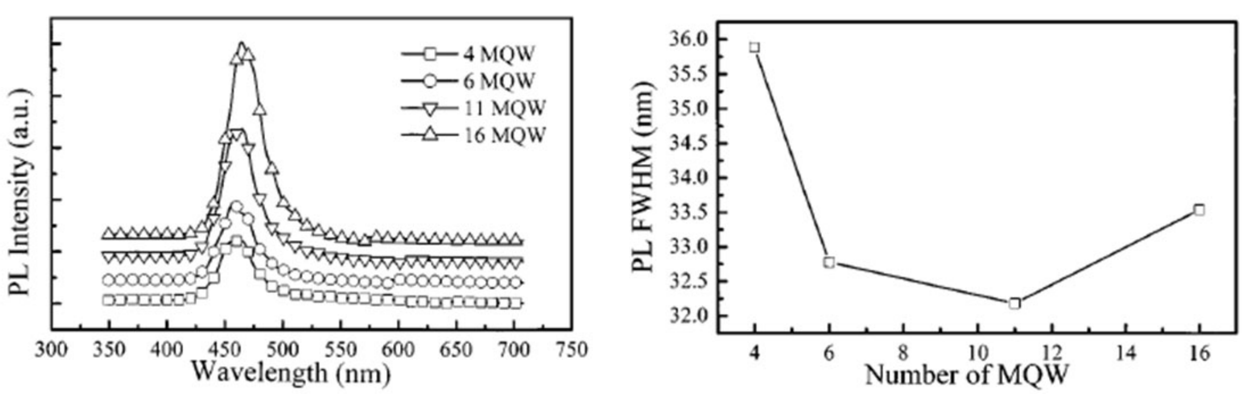


Fig. 1. The DCXRD spectra of the blue MQW LEDs with different numbers of InGaN-GaN MQW pairs.



(a) (b)

Fig. 2. The room-temperature (a) PL spectra and (b) PL FWHM of the blue MQW LEDs with different pairs of QWs

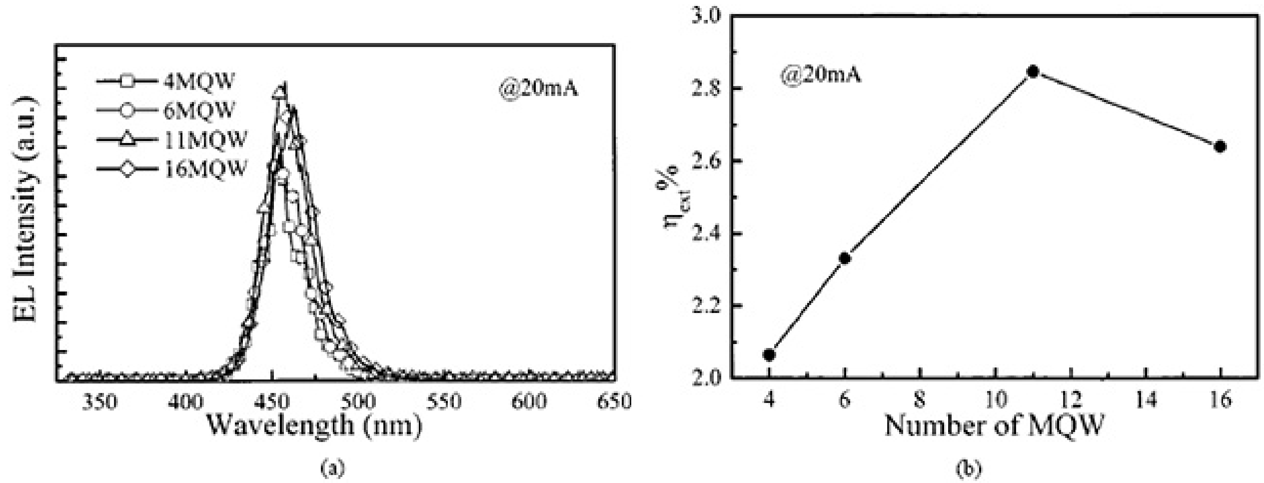


Fig. 3. The room-temperature (a) EL spectra and (b) external quantum efficiencies of the blue MQW LEDs with different pairs of QWs.

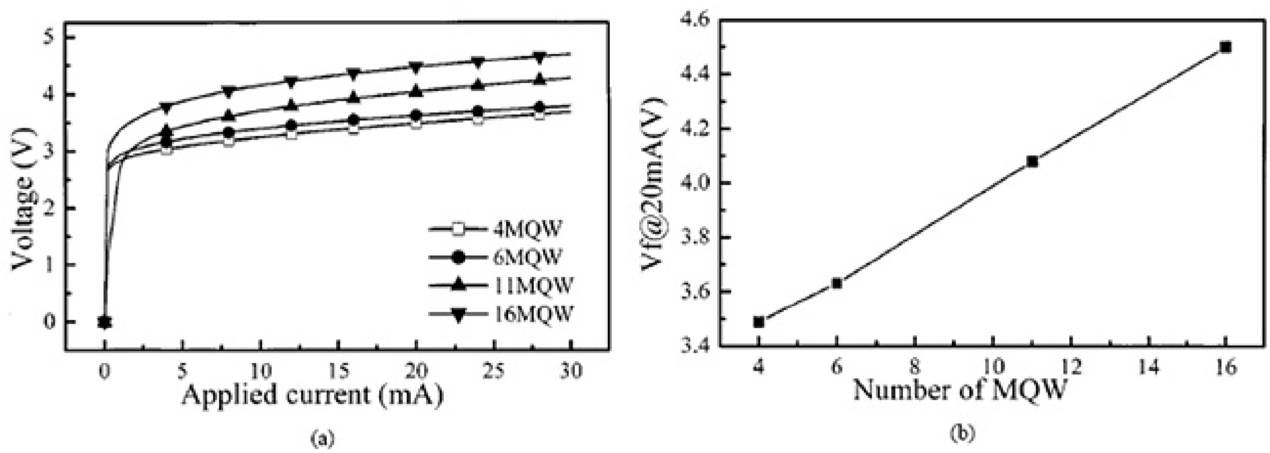


Fig. 4. The (a) forward I–V characteristics and (b) V_f for blue MQW LEDs with different pairs of QWs.

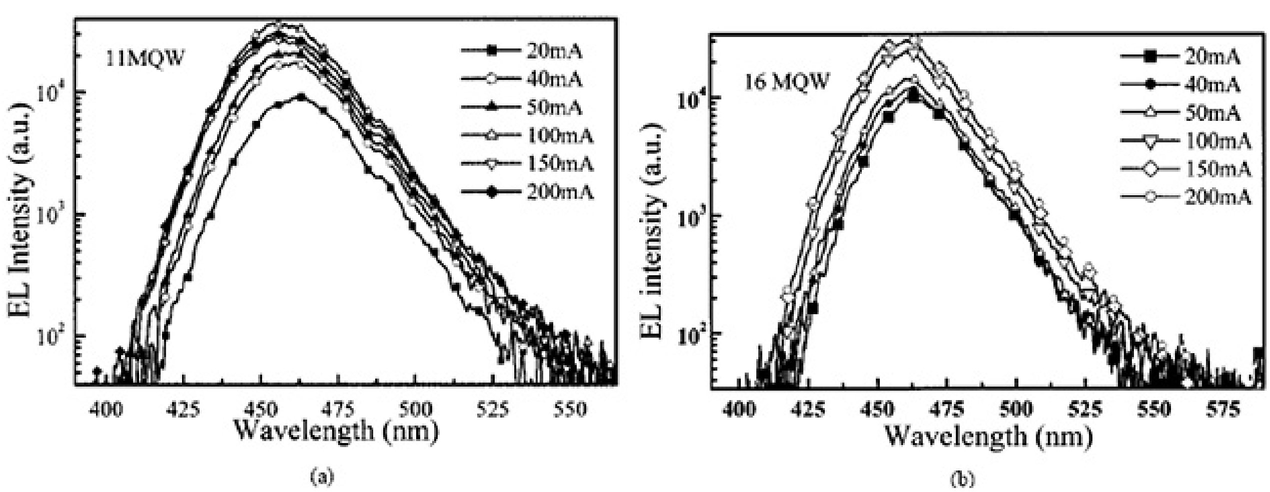


Fig. 5. The EL spectra of (a) the 11-pair blue MQW LED and (b) 16-pair blue MQW LED with different amount of injection current.

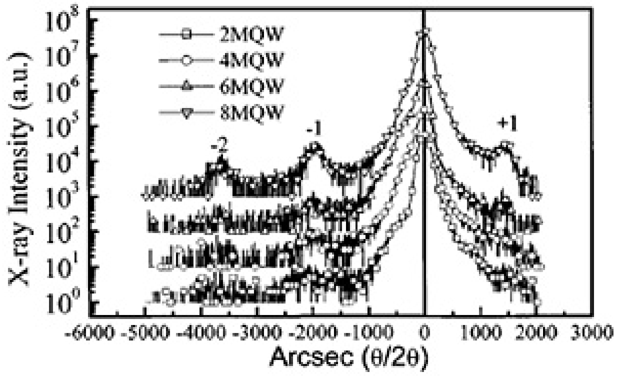


Fig. 6. The DCXRD spectra of the green MQW LEDs with different pairs of QWs.

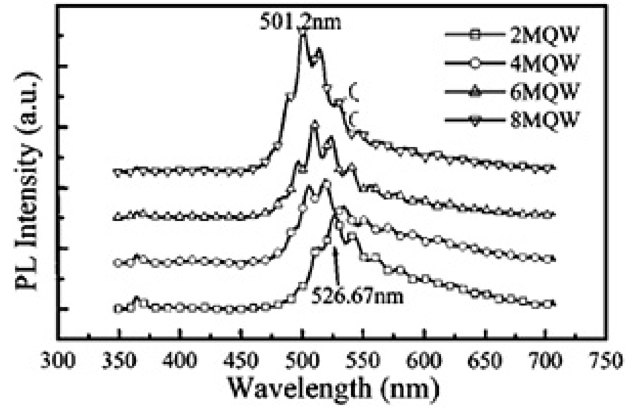


Fig. 7. The room-temperature PL spectra of the green MQW LEDs with different pairs of QWs.

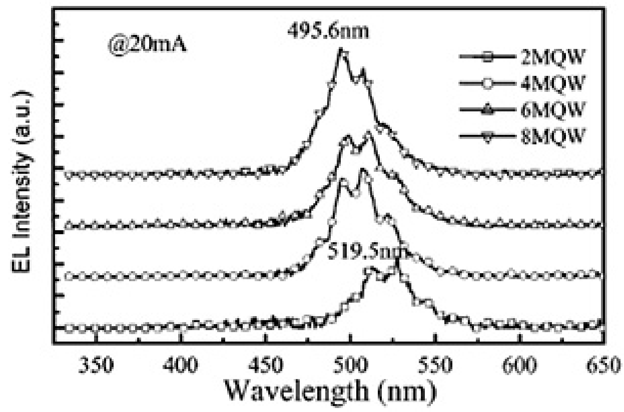


Fig. 8. The room-temperature EL spectra of the green MQW LEDs under the same 20-mA injection current.

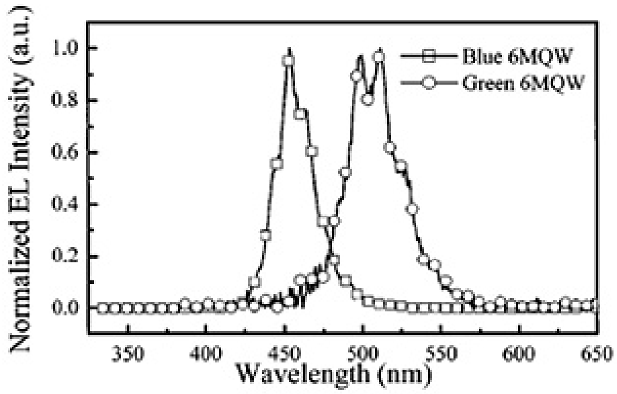


Fig. 9. The comparison in normalized EL spectra for blue MQW LED and green MQW

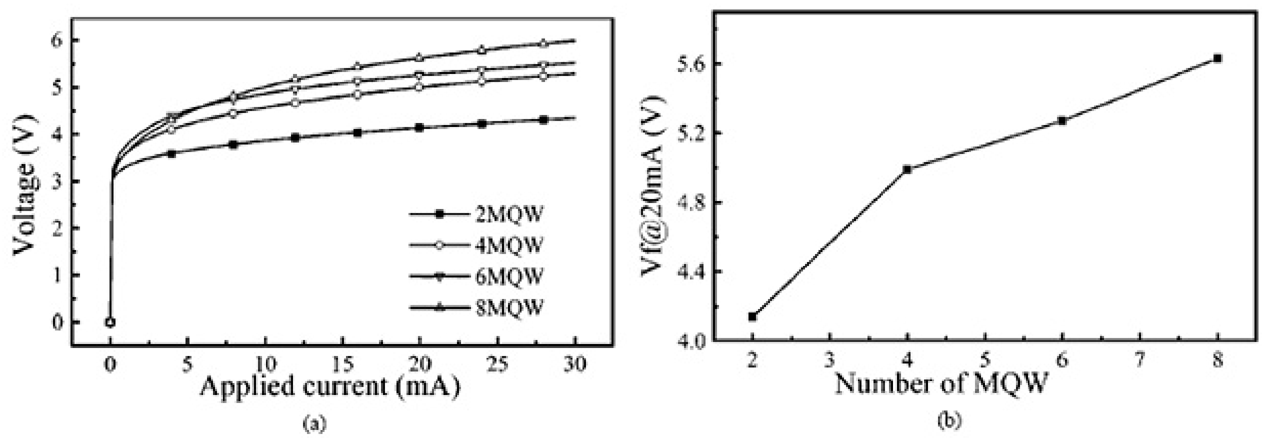


Fig. 10. The (a) forward I–V characteristics and (b) V_f for green MQW LEDs with different pairs of QWs.

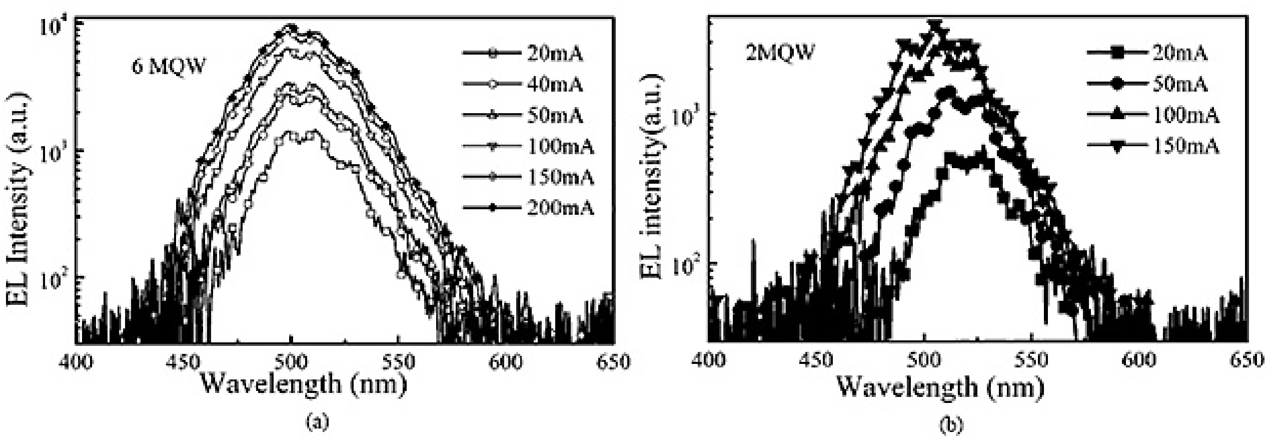


Fig. 11. The EL spectra of the (a) six-pair greenMQWLED (b) two-pair green MQW LED with different amount of injection current.

TABLE I MEASURED EL PEAK POSITIONS WITH DIFFERENT AMOUNT OF INJECTION CURRENTS FOR THE 4 BLUE LEDS.

	4 MQW	6 MQW	11 MQW	16 MQW
20mA	455.2nm	455.8nm	458.8nm	462.4nm
50mA	451.5nm	452.6nm	454.6nm	461.6nm
100mA	449.6nm	450.8nm	453.2nm	460.4nm
150mA	448nm	449.6nm	452.7nm	459.8nm
200mA	447.7nm	449.1nm	451.2nm	459.8nm

TABLE II MEASURED EL PEAK POSITIONS WITH DIFFERENT AMOUNT OF INJECTION CURRENTS FOR THE FOUR GREEN LEDS.

	2 MQW	4 MQW	6 MQW	8 MQW
20mA	519.2 nm	506 nm	504.2nm	495.7nm
50mA	515.2 nm	504.2 nm	504 nm	495.4nm
100mA	508.1 nm	503 nm	503.7nm	495.5nm
150mA	506.4 nm	502.3 nm	503.7nm	495.3nm
200mA		500.8 nm	503.5nm	495.9nm

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