Photoluminescence from high-quality InGaN Multiple Quantum Wells Grown by Metal Organic Chemical Vapor Deposition

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InGaN/GaN multiple quantum wells (MQWs) are attracting much interest currently due to their successful application as the active material in high brightness III-Nitride light emitting diode (LED) and cw blue laser diode (LD) devices [1]. The MQW structures in these devices possess advantages such as lowering the threshold current density for LDs and reducing the device sensitivity to temperature [2]. However, there exist difficulties in growth of high-quality InGaN MQWs. They are related to many fundamental scientific and technological issues, for example, the fundamental recombination mechanisms in InGaN MQWs and related strucutres. For InGaN QWs, the recombination of localized excitons has been proposed as an important emission mechanism [3] and the quntum dot (QD) – like structure is suggested to form from the In composition fluctuation and phase separation in the InGaN regions, leading to deep traps where excitons are localized [4]. The localized states can trap a significant amount of carriers to enhance the efficiency of spontaneous recombination light emissions. Meanwhile, the recombination originating from band-filled localized states has also been examined [5]. In additions, photoluminescence (PL) and other studies have revealed the presence of strong piezoelectric field in InGaN QWs, induced by strains in the layers due to the large lattice mismatch. This can result in a spatial separation of electrons and holes in QWs, leading to an intrinsic quantum-confined Stark effect (QCSE) which causes a red shift of the transition energy and a decrease of the transition probability [6]. Lively discussions and investigation from different points of view are hotly carrying on.

In this study, high quality InGaN MQWs were grown on sapphire substrates by metal organic chemical vapor deposition (MOCVD). Four experimental samples are involved with structures, from bottom to top: (0001) sapphire, 30 nm low temperature (520^{o}C) grown GaN, 1000 nm thick high temperature (HT) (1020^{o}C) grown GaN, 3-well InGaN MQWs grown at 800^{o}C, and 20 nm HT-grown GaN cap. The barrier material in MQW structure is InGaN alloy with a low In composition of 0.03 and a thickness of 50 Å for all samples. The well in MQW is InGaN of x(In) = 0.13 with thickness of 25, 30, 45 and 60 Å, for four samples, respectively. High resolution (HR) X-ray diffraction (XRD) using a Philips MRD including a five-crystal monochromator and a Renishaw micro-PL system equipped with a 325 nm He-Cd laser were employed for the materials characterazation. All the measurements were performed at room temperature (RT).

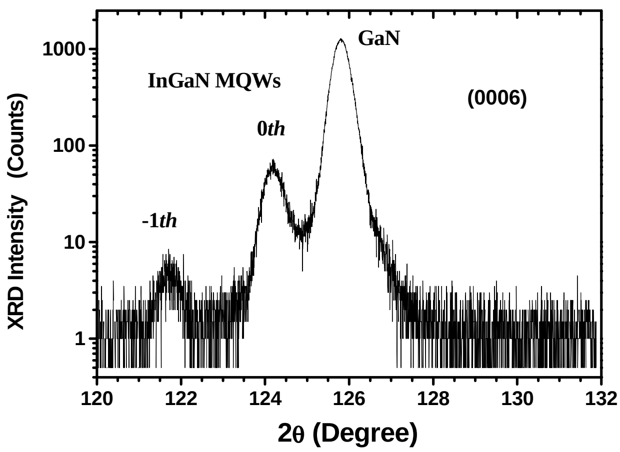

Figure 1. High resolution X-ray diffraction, (0006), of an InGaN MQW, d(well) = 25 Å and d(barrier) = 50 Å.

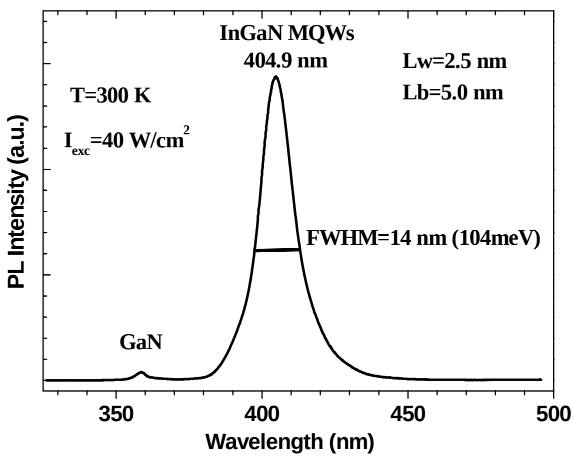

Figure 2. RT Photoluminescence of an InGaN MQW, d(well) = 25 Å and d(barrier) = 50 Å.

Figure 1 shows a HR-XRD (0006) scan for an InGaN MQW sample with well thickness of 25 Å and barrier thickness of 50 Å. Satellite peak from MQW structure can be observed even though only 3 periods were grown, showing high quality of MQW interfaces. The full width at half maximum (FWHM) value of the InGaN

0th peak is 9.1 arc-minutes, among the best results reported ever. All other samples possess similar HR-XRD patterns (not shown here).

Figure 2 shows a corresponding RT PL spectrum for this InGaN MQW sample with well thickness of 25 Å and barrier thickness of 50 Å. Room temperature PL was measured on these 4 samples. The result for the sample of 25 Å well thickness was shown typically here. A strong emission was observed at 409 nm, which came from the InGaN MQW structure. The intensity is much stronger compared to that from the underlying GaN layer. The FWHM value of this major emission band is 104 meV only. These results indicated the high quality of the sample.

RT excitation-intensity variable PL measurements were performed on two samples with the narrowest 25 Å and widest 60 Å well thickness, respectively. Their peak positions are plotted as a function of the excitation power density in Figures 3 and 4, respectively. Two samples show similar trends: At first, the PL peak is blue-shifted as the excitation power density is increased; after reaching a maximum, the PL peak is converted to shift towards red as the excitation power density is increased further. This interesting phenomenon is observed, for the first time, in the literature, to our knowledge. It is worthy to explore the physics behind this phenomenon.

A primary qualitative explanation can be given as follows. The InGaN MQWs are subject to strain due to a lattice mismatch with GaN. This causes a piezoelectric field existing in the wells, inducing the so-called quantum confined Stark effect (QCSE). When the laser excited the MQWs, photo-generated carriers will screen this electric field, and causes the blue shift of the PL peaks. The blue-shift magnitude of the wide-well sample is much larger than that of the narrow-well sample. This also indicates the screened QCSE. When the excitation power is strong enough, the piezoelectric field might be screened completely, causing the flatness of the energy level in the well. In this case, the PL peak will not blue-shift any more as the excitation is increased further. However, as the photo-generated carriers are accumulated in the well, a many body interaction may take effect, leading to the shrinkage of the band gap, i.e. the band renormalization [7]. This may explain the red shift behaviour at higher excitation levels. It is also noted that the red-shift magnitude of the narrow-well sample is larger than that of the wide-well sample. This is because the density of states of narrow well is smaller and the many body effect is more significant, compared to the case of wide well. Further penetrating investigation on this interesting effect is under way.

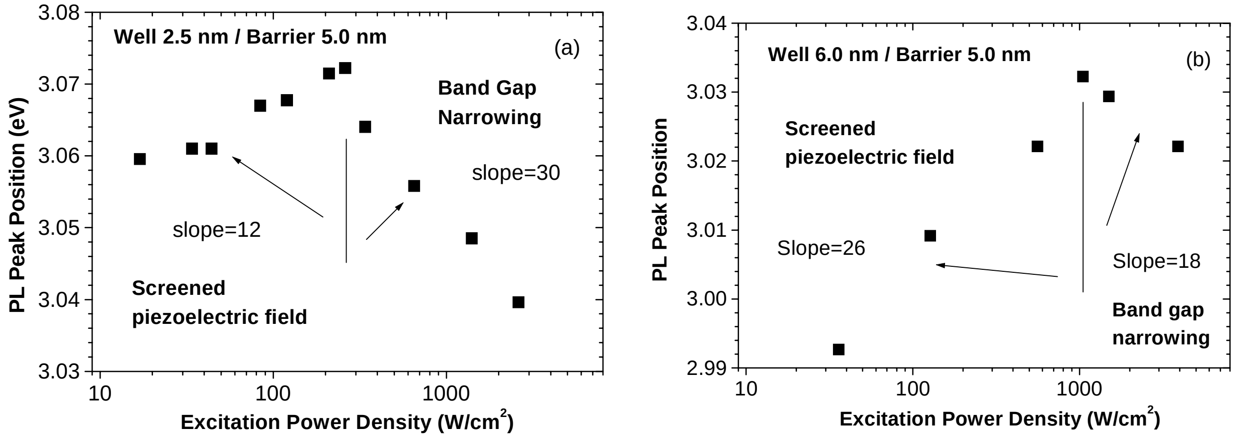

Figure 3. Dependence of PL peak position on PL excitation power density for InGaN MQWs of (a) d(well) = 25 Å and d(barrier) = 50 Å, and (b) d(well) = 60 Å and d(barrier) = 50 Å.

Reference

1. S. Nakamura and G. Fasol, *The Blue Laser Diode* (Springer, Berlin, 1997).
2. M. Koike, S. Yamasaki, S. Nagai, N. Koide, S. Asami, H. Amano and I. Akasaki, *Appl. Phys. Lett.*, **68**, 1403 (1996).
3. S. Chichbu, T. Azuhata, T. Sota and S. Nakamura, *Appl. Phys. Lett.*, **69**, 4188 (1996).
4. Y. Narukawa, Y. Kawakami, M. Funato, Sz. Fujita, Sg. Fujita and S. Nakamura, *Appl. Phys. Lett.*, **70**, 981 (1997).
5. Y.-H. Cho, J. J. Song, S. Keller, U. K. Mishra and S. P. DenBaars, *Appl. Phys. Lett.*, **73**, 3181 (1998).
6. T. Takeuchi, H. Amano and I. Akasaki, *Jpn. J. Appl. Phys.*, **39**, 413 (2000); and references there in.
7. X. Zhang, S. J. Chua, W. Liu and K. B. Chong, *Appl. Phys. Lett.*, **72**, 1890 (1998).