Investigations on recombination mechanisms in InGaN/AlGaN multiple quantum wells

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Abstract

InGaN alloy system is attracting much attention because of its importance in both scientific and technological aspects. The wavelength emitted from InGaN can be tuned from visible red to ultraviolet by changing the alloy composition. The emission mechanism that occurs in the InGaN-based structures arises primarily from localized exciton emission. The localization of radiative electron-hole recombination is namely in a band-tail. These band-tail states are believed to be formed in local potential minima resembling quantum dots due to composition fluctuations, high density of impurity states and/or inhomogeneous lattice deformations. In addition, the quantum-confined Stark effect due to the presence of a large piezoelectric field in the quantum well is also considered to act as an important role in the emission mechanisms. The quantum-confined Stark effect (QCSE) arises from the presence of a large piezoelectric field in the quantum well. It has been discussed that the strain-induced piezoelectric polarization field plays an important role in carrier recombination in III-nitride quantum structures.

In this paper, we investigate the temperature and excitation intensity dependences of the photoluminescence (PL) spectra of InGaN/AlGaN multiple-quantum-well (MQW) heterostructures with different indium and aluminum content in the well and barrier layers. Three InGaN/AlGaN MQW samples used in this study were grown by metal-organic chemical vapor deposition system. Four pairs of InGaN/AlGaN MQWs were used as the active region and then 200-nm-thick p-GaN capping layer was grown above MQW region. During the growth of InGaN well layers and AlGaN barrier layers, the samples were grown under different trimethylindium (TMIn) and trimethylaluminum (TMAl) flow rates. The TMIn flow rates for sample A, sample B, and sample C

were 128, 112, and 112 sccm, respectively; and the corresponding TMAl flow rates were 3, 3, and 6 sccm, respectively. The temperature dependent PL spectra were measured using a continuous wave He-Cd laser with a wavelength of 325 nm as the exciting source. The temperature and incident-power dependent PL spectra were measured using a He-Cd laser with a wavelength of 325 nm and the average excitation intensity was in the range from 1 to 30 mW. The samples were mounted in a closed-cycle He cryostat where the temperature was varied from 10 to 300 K. The luminescence was dispersed by a monochrometer and detected by photomultiplier using a standard lock-in technique.

Figure 1 shows the PL spectra of the InGaN/AlGaN MQW samples recorded at temperature 10 K with an incident power 30 mW. We observed InGaN-related main emissions with peak energies of 2.46, 2.47, and 2.42 eV for sample A, sample B, and sample C, respectively. Compare sample A and sample B with the same TMAl flow rate during the growth of MQW barriers, because the radiative recombination of InGaN-based MQWs is mainly due to excitons localized at deep traps originating from indium-rich regions in the wells, the slightly smaller PL peak energy of sample A is due to the more and deeper localized states in the well layers, resulting from its higher indium content. The indium content of sample C is lower than sample A; however, it exhibits the smallest PL peak energy among the samples. We attribute the result to the large piezoelectric field and the induced QCSE in it, resulting from its highest aluminum content in the MQW barrier layers. The strain-induced polarization field tilts the potential profile, spatially separates between the electron and hole wave functions and significantly reduces the overlap integral between the electron and hole wave functions, which results in a redshift of the emission energy.

The emission energy as a function of temperature for the samples is shown in Fig. 2. With increasing temperatures, the PL peak energy of all the samples does not follow the Varshni law. The “S-shaped” temperature dependence of the PL peak energy is a fingerprint of the existence of the localization effect. It is strongly affected by the change in carrier dynamics with increasing temperature, and attributed to band-tail states in the density of states. The evident ‘S-shaped’ behavior observed for the temperature dependent PL peak energy of sample A implies that the carrier-localization effect is the dominant mechanism in this sample, mainly due to the higher indium content and the broadening band-tail states.

Figure 3 depicts the emission energy as a function of the incident power for the samples measured at 300 K, which is used to investigate the QCSE. When the samples are driven with an incident power, the piezoelectric fields in the strained well layer are screened by the injected carriers, thus weakening the QCSE. With the increasing incident power, because of the further weakened QCSE, the blueshift of peak energy occurs. We can judge the strain effect of these samples from the magnitude of the blueshift. Observing the measured results shown in Fig. 3, the blueshifts of the peak energy for sample A, sample B, and sample C are 10.2, 13, and 27.2 meV, respectively. It implies a stronger QCSE in sample C. Consequently, the inference obtained from the analysis of Fig. 1 for sample C is confirmed by the measurements of incident-power dependent PL spectra.

In this study, we investigate the emission mechanisms in the InGaN/AlGaN MQWs heterostructures with different indium and aluminum contents. Based on the measurements of temperature and incident-power dependent PL spectra from the samples, the exciton-localization effect and the QCSE are discussed. The 'S-shaped' variation of PL peak energy with temperature is enhanced for sample with higher indium content in the well layers, consistent with the band-tail states model. For sample with higher aluminum content in the barrier layer, the QCSE acts as an important role in the emission mechanisms.

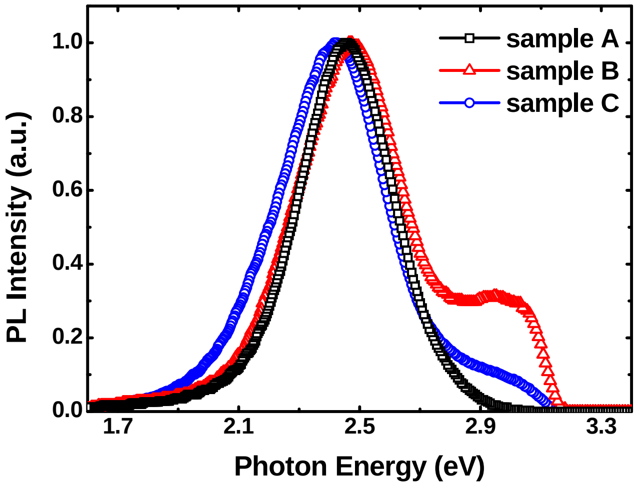

Fig. 1 Normalized PL spectra for sample A, sample B, and sample C at 10 K. The incident power is 30 mW.

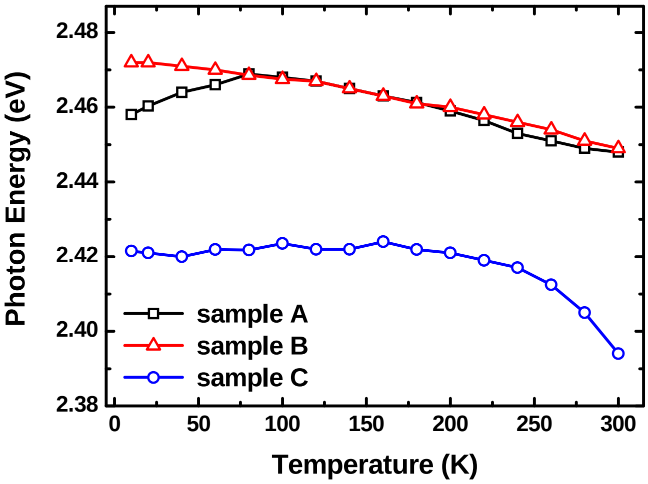

Fig. 2 Temperature dependence of peak position of luminescence spectra from sample A, sample B, and sample C at an incident power of 30 mW.

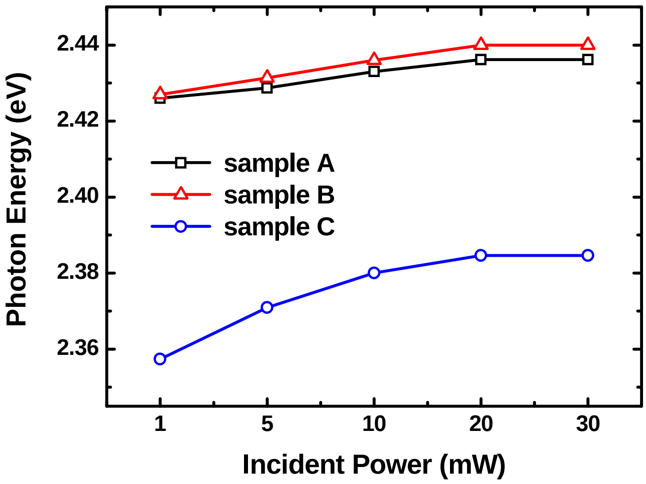

Fig. 3 Dependence of the spectral peak position on the incident power of the sample A, sample B, and sample C at 300 K.