

Optical Characterization for Indium Aggregation Studies in InGaN/GaN Quantum Wells

Shih-Wei Feng, Chi-Chih Liao, C. C. Yang

Department of Electrical Engineering and Graduate Institute of Electro-Optical Engineering,
National Taiwan University, 1, Roosevelt Road, Sec. 4, Taipei, Taiwan, R.O.C.

(phone) 886-2-23657624 (fax) 886-2-23652637 (E-mail) ccy@cc.ee.ntu.edu.tw

Yen-Sheng Lin, Kung-Jen Ma

Department of Mechanical Engineering, Chung Cheng Institute of Technology, Tashi, Taoyuan,
Taiwan, R.O.C.

Chang-Cheng Chuo, Chia-Ming Lee, and Jen-Inn Chyi

Department of Electrical Engineering, National Central University, Chung-Li, Taiwan, R.O.C.

Because of the large lattice mismatch between GaN and InN, indium aggregation and phase separation occur in growing InGaN. In an aggregation, a higher indium composition leads to lower energy states. Because such quantum-dot-like energy states confine carriers from free motion, they are called the localized states. Outside the aggregations, the carriers are supposed to be free in the dimensions of quantum well layer. Therefore, they can be called the free-carrier states. It was claimed that photo-luminescence (PL), i.e., spontaneous emission, came from the recombination of localized excitons. In this paper, we report the results of optical characterization for studying indium aggregation and phase separation in InGaN/GaN quantum well structures.

The samples were grown in a low-pressure metal-organic chemical vapor deposition reactor. The InGaN/GaN multiple quantum well (QW) structures consisted of five periods of silicon doped InGaN well with 3 nm in thickness. The designated indium composition was from 15 to 25 %. The silicon doping concentration was 10^{18} cm^{-3} . The barrier was 7-nm GaN. The QW layers were sandwiched with a 1.5- μm GaN buffer layer on a sapphire substrate and a 50-nm capping GaN layer. The growth temperatures were 1050 and 740 °C for GaN and InGaN, respectively.

Fig. 1 shows the S-shape PL peak variations with temperature of three samples (indium contents: 15, 20, and 25 %). The turning point from red shift to blue shift (around 100, 100, and 140 K for indium contents 15, 20, and 25 %, respectively) corresponds to a characteristic thermal energy for carriers to escape from localized states. As temperature increases, the phonon effect dominates. Fig. 2 shows stimulated emission (SE) spectral variation versus temperature in sample 1 (indium content 25%). The alternating solid and dashed curves represent the SE results with temperature varied from 13 K to room temperature (RT). The pumping fluence was fixed at 32 mJ/cm^2 . For comparison, the normalized PL spectra at 13 K (dash-dotted) and RT (dash-dotted-dotted) are also plotted. Peak A is supposed to come from recombination of localized states. Peaks B and C originate from free carrier recombination.

The four curves in Fig. 3 show the spectral positions (left ordinate) of peak A (filled squares) and peak B (filled diamonds) and the peak intensity (right ordinate) of peak A (empty squares) and peak B (empty diamonds), corresponding to the results of Fig. 2. The red shifts of peak B with rising temperature are expected due to band-gap shrinkage. However, peak A moves little with temperature. Although the global band-gap of the material shrinks with temperature, the weaker strain at a higher temperature in the QW structure, which leads to a blue shift of band-gap, may cancel the band-gap shrinkage. Meanwhile, one can see the decreasing and increasing trends of peaks A and B intensities, respectively, with temperature. As temperature rises, carriers are thermally excited to move away from the localized states and may occupy free-carrier states. Therefore localized-state recombination decreases and free-carrier recombination increases.

Fig. 4 shows the SE spectra of sample 1 with various 266 nm pump fluences at 13 K. The alternating solid and dashed curves stand for different pump fluences with the curve of the highest peak B for the highest pump fluence at 80 mJ/cm^2 and that of the lowest peak B for the lowest pump fluence at 36 mJ/cm^2 . For comparison, the LT PL spectrum is also plotted as the dashed-dotted curve in Fig. 4. The four curves in Fig. 5 show the variations of spectral positions and intensities of peaks A and B with pump fluence of Fig. 4. The red shift of peak B with increasing pump level is due to band gap re-normalization. The almost unchanged spectral position of peak A can be attributed to the mutual cancellation between the blue shift, which is due to filling-up of the low band-gap regions and the shielding of piezoelectric field (by strain) with increasing carrier density, and the red-shift, which is due to band-gap re-normalization. The small change of

peak A intensity reflects the filling-up of the localized states. The increasing peak B intensity results from the overflow of carriers from localized states as the pump level increases.

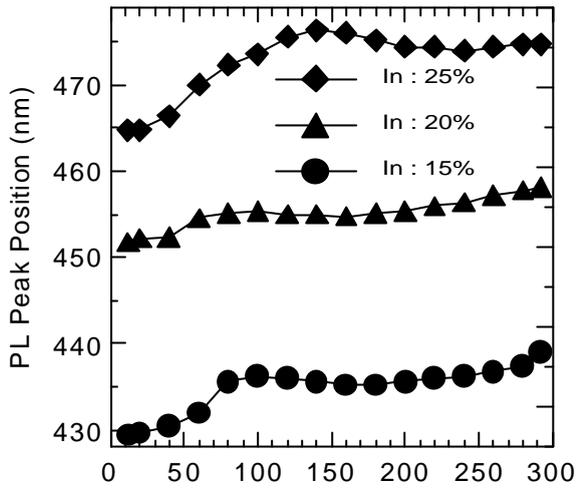


Fig. 1 PL peak wavelength versus temperature.

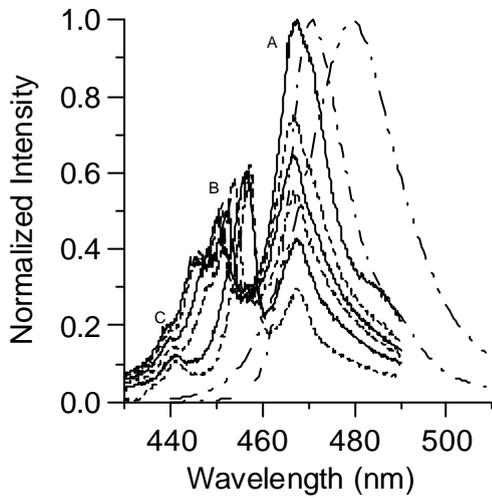


Fig. 2 SE spectra (solid and dashed curves) at various temperatures.

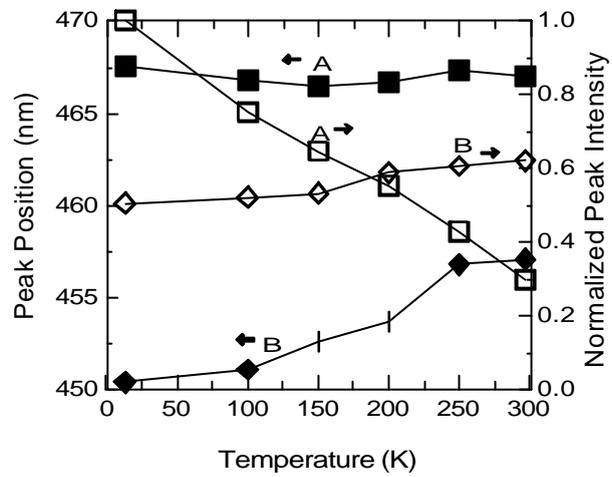


Fig. 3 Spectral positions (left ordinate) and peak Intensities (right ordinate).

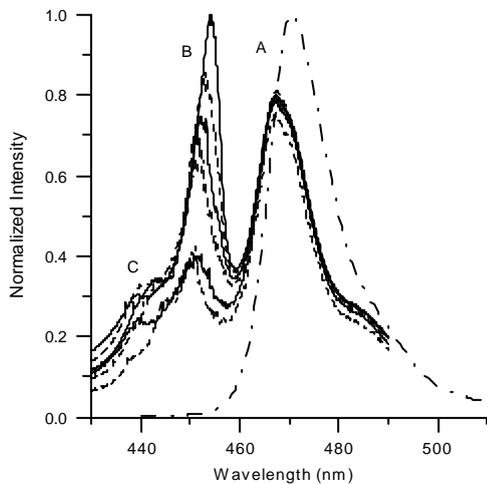


Fig. 4 SE spectra (solid and dashed curves) at various pump fluences.

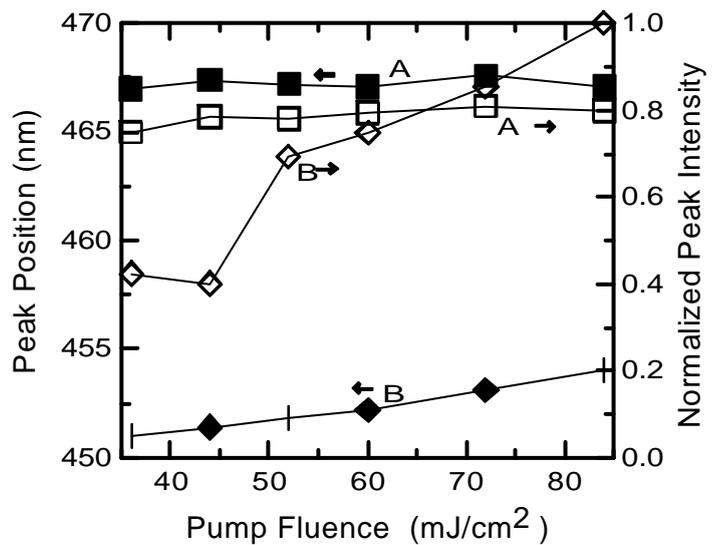


Fig. 5 Spectral positions (left ordinate) and Intensities (right ordinate).