# Optical Properties of AlInGaN Alloys and AlInGaN/InGaN Multiple Quantum Wells

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We recently proposed to use quaternary AlGaInN compounds for a Strain Energy Band Engineering approach to independently adjust strain and band offset in GaN/AlN/InN devices. We applied this new technique for the design and optimization of AlN/GaN/InN based field effect transistors. As the first step in applying the same approach to AlN/GaN/InN based light emitters, we now report on the comparative studies of the photoluminescence studies of AlGaInN and AlGaN epitaxial films grown on GaN buffer layers and on the comparative photoluminescence studies of AlGaInN/InGaN, GaN/InGaN, and AlGaN/InGaN Multiple Quantum Well (MQW) structures.

Fig.1 compares the photoluminescence spectra of the $AlIn_{0.015}GaN$ films with those of $Al_{0.09}Ga_{0.81}N$ films grown under identical conditions. The solid dots in Fig.1 are obtained using incident photon energies that equal the exciton energies as determined from the reflectivity spectra. The open points correspond to the measurements for the incident photon energies that are approximately 100 meV above the resonance. As can be seen from Fig. 1a, the peak position of the resonantly excited luminescence band in AlGaN is about 13 meV below the exciton energy. As shown in Fig.2, this peak blueshifts toward the exciton position with an increase in the excitation photon energy. In contrast, the peak position of the luminescence band for the AlInGaN samples (indium flows $F_{\mathrm{In}}= 5$ and $F_{\mathrm{In}} = 10$ mole/min) is close to the exciton energy independently of the excitation photon energy. The data in Fig. 2 show that the Stokes luminescence band in AlGaN monotonously shifts toward higher energies. This behavior is characteristic for disordered films. Contrarily AlGaInN films do not demonstrate significant Stokes shift in PLE spectra. Hence, we conclude that the incorporation of a few percents of indium into AlGaN improves the film crystallinity, which causes the modification of the band-edge optical properties.

Based on this conclusion we accomplished the comparative photoluminescence studies of multiple quantum well (MQW) structures with quaternary barriers. MQW structures were grown by low pressure MOCVD on $n^+$- SiC substrates following a 0.8 μ thick $n^+$ $Al_{0.1}Ga_{0.9}N$ conducting buffer layer and a 0.1 μm thick n-GaN layer. The MQW region consisted of two $In_{0.2}Ga_{0.8}N$ quantum wells surrounded by three barrier layers. The barrier layers for the three samples of our study were $Al_{0.15}In_{0.15}Ga_{0.7}N$, $Al_{0.15}Ga_{0.85}N$ and GaN. The well and barrier layer thicknesses were kept at 30Å and 40Å respectively. Room temperature PL spectra measured using a low intensity (10 mw) HeCd laser operating at ?=325 nm for these samples are included in Figure 3. As seen, the addition of Al- and In- to the GaN barrier of a GaN-$In_{0.2}Ga_{0.8}N$ multiple quantum well results in a strong blue shift of the peak wavelength of the PL- signal. It also significantly increases the intensity of the PL emission. For the $Al_{0.15}Ga_{0.85}N$ barrier sample in spite of the increased confinement we observe a strong red shift and a weaker PL emission signal. This rules out carrier confinement as the dominant mechanism for the observed PL emission enhancement and blue shift of our quaternary barrier MQW. Figure 4 shows PL emission peak shift as a function of well width together with the simulated results for different built-in filed values. Comparing these dependencies, we conclude that the enhanced PL emission for the quaternary barrier MQW results from a true quantum well emission. Contrarily, for the GaN-InGaN MQW sample the emission mechanism was determined as localized quantum dots emission.

The results of the present study clearly confirm the drastic improvement in materials quality with the introduction of indium and that the use of quaternary barriers should enable the design of much more efficient AlN/GaN/InN based solid-state light emitters.

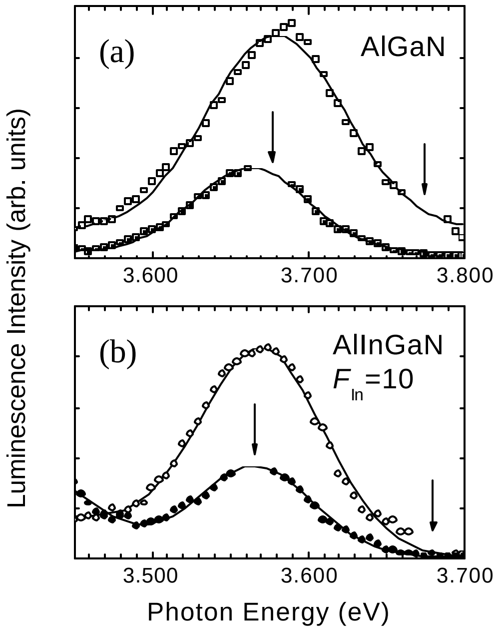


Figure 1. Room-temperature luminescence spectra of AlGaN (a) and AlInGaN (b) layers. Open points, off-resonant exitation; filled points, resonant excitation at the exciton energy (arrows indicate the incident photon energy). Solid lines, Gaussian approximation.

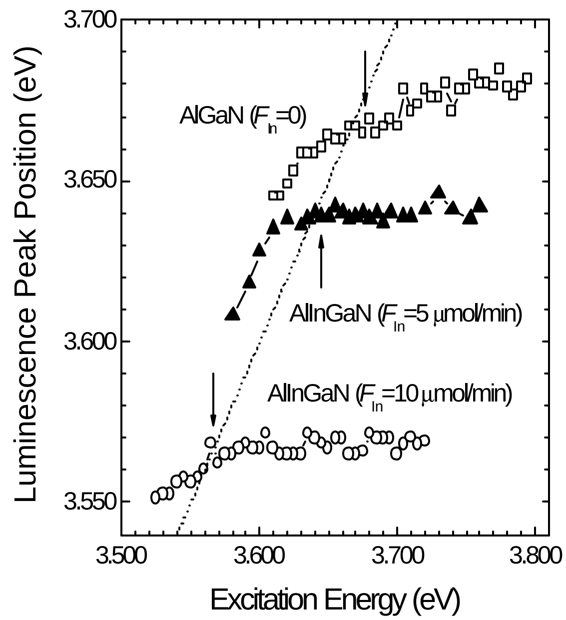


Figure 2. Dependences of the luminescence peak position on incident photon energy for AlGaN and AlInGaN layers. Dotted line separates the Stokes region (right) from the anti-Stokes region (left). Arrows indicate the exciton position.

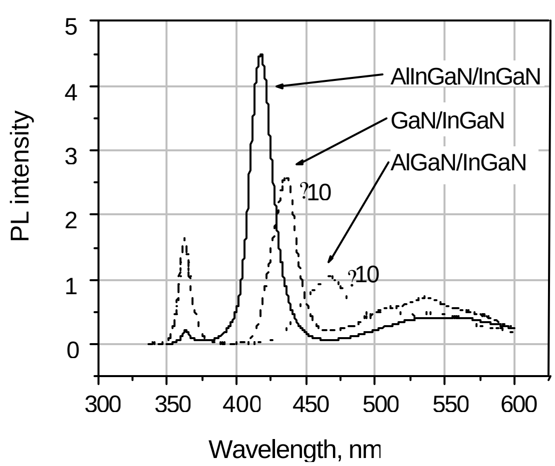


Figure 3: Room temperature PL spectra of $Al_{0.15}In_{0.15}Ga_{0.7}N$-$In_{0.2}Ga_{0.8}N$, GaN-$In_{0.2}Ga_{0.8}N$, $Al_{0.15}Ga_{0.85}N$-$In_{0.2}Ga_{0.8}N$ MQWs.

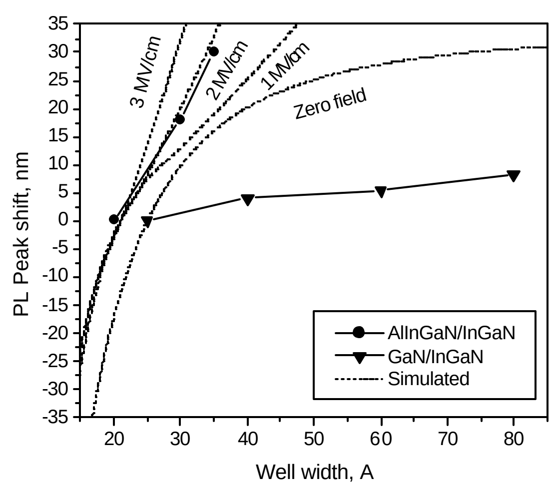


Figure 4. PL peak shift as a function of the quantum well width. Dashed lines present the results of simulations for the different values of built-in electrical field across the quantum wells.