

Excitation Spectroscopy and Level Assignment in Piezoelectric $\text{Ga}_{1-x}\text{In}_x\text{N}/\text{GaN}$ Quantum Wells

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Performance of nitride light emitters is poised to take another big leap as soon as the electronic band structure and interband transition scheme has been modeled and identified. Major steps along this path have been the determination of the electronic band gap energy in GaInN thin films and the direct quantification of the piezoelectric polarization field in GaInN/GaN heterostructures and quantum wells. On the basis of those parameters the electronic band structure and interband transition schemes can be derived for two of the currently preferred models, i.e., zero-dimensional quantum dots and two-dimensional quantum wells. Here we present results of such calculations within the framework of perturbation theory and effective mass approximation for the case of two-dimensional GaInN/GaN quantum wells. The results are a detailed model of the interband transition schemes taking into full consideration the effective band gap bowing, the pseudomorphic strain condition, its associated piezoelectric polarization, as well as the full valence band non-degeneracy of heavy hole, light hole, crystal field split-off hole in their ground and excited states. The model is a more detailed expansion of the concept of a Stark-like ladder and fully accounts for the asymmetry of barrier energies and the quantum confined Stark effect of respective ground and excited states.

By means of this model we analyze results of photoluminescence excitation spectroscopy in $\text{Ga}_{1-x}\text{In}_x\text{N}/\text{GaN}$ quantum wells of variable composition. GaInN/GaN multiple quantum well structures have been grown by metal organic vapor phase epitaxy on *c*-plane sapphire. Films have been optimized for homogeneity in terms of specular reflectance, x-ray diffraction, and luminescence peak energy. Photoluminescence excitation spectroscopy was performed at low temperatures by means of a white light source and monochromator set-up. Wavelength selective detection was performed using a spectrograph and CCD.

Fig. 1.a) gives examples of photoluminescence excitation spectra in 3 nm GaInN/GaN multiple quantum well structures with variable composition. Several pronounced features are identified in the energy range between the barrier band gap energy and the luminescence detection energy. In general similar to results in the literature a pronounced absorption edge appears at lower energy. At the height of its full signal intensity several independently varying peaks as marked by ticks appear that reveal involvement of a multitude of interband transitions. In most cases the signal rolls off towards the band gap energy of the barrier. In some cases, however, an increase is observed in this direction. This indicates that varying conditions of the resonant states also strongly affect the carrier capture into the wells. A similar general shift of an interband transition in parallel with increasing x has previously been described and interpreted as the three-dimensional critical point in the joint density of states which is controlled by the polarization dipole across the polarized well. In the present case, however, the shift of the absorption edge cannot be traced back to the GaN band gap energy for vanishing InN fraction. We therefore propose quantized levels of the well to be involved in these transitions.

The calculation of the subband structure and associated interband transitions reveals levels similar to those sketched in Fig. 1.b). Along these results and further supportive information from photoluminescence spectroscopy we derive an assignment of the observed absorption edges by means of the quantized states in the highly polarized quantum wells. The direct correspondence of calculation and experiment provide important feedback on the reliability of the model. The model can therefore be extended to describe with higher accuracy the details of the electronic bandstructure within the quantum wells. By means of this enhanced insight into the electronic band structure of the two-dimensional quantum well we gain further insight into the possible radiative recombination paths. These results should also be most useful for the development of bandstructure models for zero-dimensional quantum dots. Our model therefore provides the tools to optimize device structures in two-dimensional layers for superior performance in order to take full advantage of the capabilities of the system.

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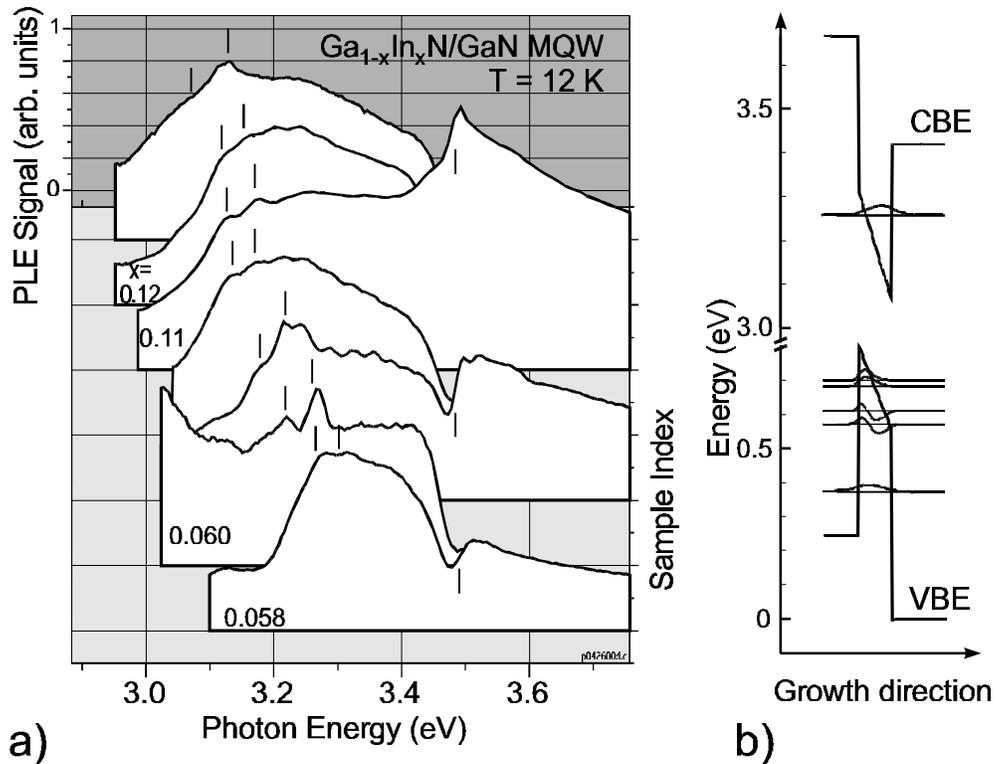


Figure 1

a) Low temperature photoluminescence excitation spectra of a set of 3 nm GaInN/GaN multiple quantum well structures with variable composition as indicated in labels for some samples. A pair of sharp absorption maxima follows a pronounced absorption edge towards lower energy with increasing InN fraction. Ticks mark the experimental transition energies. b) Schematic of the electronic subband structure in a 3 nm GaInN/GaN quantum well within a self-consistent perturbational approach accounting fully for the previously determined polarization dipole, asymmetric barrier heights, and the quantum confined Stark effect of the higher states. By means of the bandstructure model we derive an assignment of the quantized levels involved in the experiment.