WC1-3

Spontaneous polarization effects on the optical properties of AlGaN/InGaN/GaN quantum wells

L. -H. Peng, K. -T. Hsu, and C. -W. Shih
Institute of Electro-Optical Engineering, National Taiwan University, Taipei, 106 Taiwan, R.O.C.
Tel: 886-2-2363-5251 x 408; Fax: 886-2-2367-7467; peng@cc.ee.ntu.edu.tw

C. -C. Chuo and J. -I. Chyi
Department of Electrical Engineering, National Central University, Chungli, 320 Taiwan, R.O.C.
Tel: 886-3-4222-7151 x 4470; email: chyi@ee.ncu.edu.tw

Abstract: Large spectral red shifting (~ 140 meV) and reduced radiative recombination efficiency are observed on the high excitation luminescence spectra of InGaN/GaN quantum wells capped with a AlGaN top barrier compared with that of a GaN cap layer. These observations are ascribed to the additive internal field effect due to the spontaneous polarization induced volume charge at the AlGaN/InGaN interface.

Recent development in the epitaxial growth, doping control, and device processing on the group III-nitride has brought in a plethora of activities on the material research and device application. However, there still exist concerns regarding the emission mechanism of the InGaN quantum wells (QWs). In particular, due to the inhomogeneity issues of material growth, it has been suggested the dominant mechanism of the radiative recombination in the InGaN QW emitter be the localized carrier effects [1]. Others suggest the large piezoelectric polarization (P_{pz}) field on the order of 1 MV/cm arisen from the strained layer growth in the QW active region is responsible to the optical properties of InGaN/GaN emitters [2].

More recently,. it is noted that a macroscopic spontaneous polarization (P_{sp}), characteristic to crystals of low point group symmetry, can even exist in nitride without being subject to strain. Discontinuity of P_{sp} across a nitride heterostructure can further induce 2D-electron or hole gas at the interface [3]. The theory has further predicted that the P_{sp} effect would be more pronounced in the GaN/AlGaNsystem; whereas the P_{pz} would be more effective in changing the electronic and optical properties of the InGaN/GaN QWs [4]. However, there are disputes regarding whether the P_{sp} would play a dominant role over P_{pz} in shaping the optical properties of GaN/AlGaN QWs [5]-[6]. Regarding the widely used InGaN QW emitter structure, it is desirable to design an optical study not only immune from the localization effects but also able to distinguish the contributions from P_{sp} and P_{pz}.

In this work, high-excitation spectroscopy is conducted to study the optical properties of strained InGaN/GaN QWs. By engineering the P_{sp} induced charge to have opposite sign via a top barrier designed in the symmetric GaN/InGaN/GaN and asymmetric GaN/InGaN/AlGaN QWs, we are able to resolve a large spectral shifting (~ 140 meV) and reduction of emission efficiency in the latter. These observations are ascribed to the additive internal field effect due to the spontaneous polarization induced volume charge at the top AlGaN/InGaN interface.

Two sets of InGaN/GaN QW samples were grown on a ~ 1.5 μm undoped GaN buffer layer on the (0001) sapphire substrate in an AIX 200/4 low-pressure MOCVD system [7]. The first set of samples contains a Si doped (~ 10^{18} cm^{-3}) 2.5 nm $In_{0.12}Ga_{0.88}N$/GaN SQW capped with a 50 nm GaN or $Al_{0.1}Ga_{0.9}N$ as the top barrier layer. The second set of samples contains 5 pairs of 3.0 nm $In_{0.15}Ga_{0.85}N$/GaN MQWs on sapphire substrates with the growth parameters of the buffer and cap layer identical to those in the first set. The design of a (Al)GaN cap layer is to ensure a (positive) negative volume charge distribution via $-\nabla \cdot P_{sp}$ at the top interface of (Al)GaN/InGaN. With the active InGaN well region compressively strained to the GaN buffer layer, the P_{pz} and P_{sp} field would add up at the InGaN/AlGaN top barrier side whereas they tend to compensate with each other at the InGaN/GaN top interface. This action would result in a change of the electronic structure and modification of the optical properties of the InGaN QW emitter.

To ensure a complete filling of the localized states, the optical study reported in this work was conducted with a KrF excimer laser excitation (TuiLaser ExciStar 2000) with a pulse width of 10 ns, repetition rate of 10 Hz, and maximum pulse energy of 14 mJ. The experiments were taken in a surface emission configuration to minimize the reabsorption effect on the photo-luminescence (PL) spectra. The PL data were recorded by a spectrometer equipped with a CCD array detector.

Shown in Fig. 1 are the room-temperature time-integrated room-temperature PL spectra of the 2.5 nm $In_{0.12}Ga_{0.88}N$/GaN (a)symmetric SQW capped with a 50nm top (Al)GaN barrier. A spectral red shifting ~ 40 meV and 25% reduction in the emission intensity can be clearly revealed in the asymmetric SQW case. This example illustrates the importance of considering the P_{sp} effect in modifying the optical properties of InGaN QW emitters.

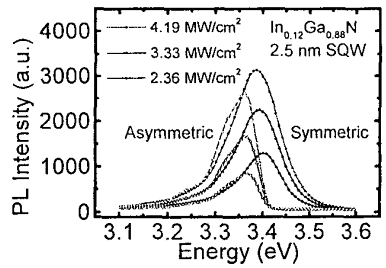

Fig. 1 PL spectra of symmetric and asymmetric 2.5 nm InGaN SQW.

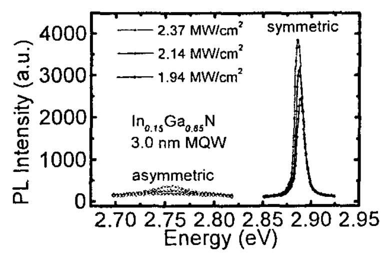

Fig. 2 PL spectra of symmetric and asymmetric 3.0 nm InGaN MQW.

We further illustrate in Fig. 2 the PL spectra from the wider 3.0 nm $In_{0.15}Ga_{0.75}N$ MQWs which are subject to a stronger P_{pz} field in the active region. An even larger spectral red shifting ~ 140 meV and 10 fold reduction in the PL intensity are now resolved on the asymmetric InGaN MQWs. In order to elucidate the polarization field effects of P_{pz} and P_{sp} on the electronic structure and optical properties of InGaN QW, a self-consistent analysis taken into account the many-body, charge screening, P_{pz} and P_{sp} effects [8] is shown in Fig. 3. It is noted that the addition of the P_{pz} and P_{sp} induced electric field in the asymmetric InGaN QW has not only resulted in a spectral red shifting but also reduction in the overlap between the subband wave function and hence the emission intensity. The dramatic PL peak energy shifting from 3.4 eV in the 2.5 nm $In_{0.12}Ga_{0.88}N$ QWs of Fig. 1 to that of 2.88 eV in Fig. 2 is attributed to the enhanced P_{pz} effect in the strained, wider 3.0 nm $In_{0.15}Ga_{0.85}N$ well.

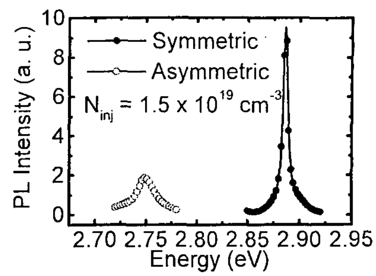

Fig. 2. Calculated PL spectra of the 3.0 nm $In_{0.15}Ga_{0.85}N$ MQWs.

In summary, we show the additive effect of the P_{sp} and P_{pz} induced electric field at the InGaN/AlGaN interface can lead to substantial decrease in the interband optical transition energy and emission intensity in the InGaN QW. This research was sponsored by the NSC Grant No. 89-2215-E-002-041 and 047.

[1] S. F. Chichibu, T. Azuhata, T. Sota, T. Mukai and S. Nakamura, "Localized quantum well excitons in InGaN single quantum well amber light-emitting diodes," J. Appl. Phys. **88**, 5153-5157 (2000).

[2] C. Wetzel, T. Takeuchi, H. Amano, and I. Akasaki, "Electric-field strength, polarization dipole, and multi-interface band offset in piezoelectric GaInN/GaN quantum well structures," Phys. Rev. B **61**, 2159-2163 (2000).

[3] O. Ambacher, B. Foultz, J. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Murphy, A. J. Sierakowski, W. J. Schaff, L. F. Eastman, R. Dimitrov, A. Mitchell, and M. Stutzmann, "Two dimensional electron gases induced by spontaneous and piezoelectric polarization in undoped and doped AlGaN/GaN heterostructures," J. Appl. Phys. **87**, 334-344 (2000).

[4] V. Fiorentini, F. Bernardini, F. D. Sala, A. D. Carlo, and P. Lugli, "Effects of macroscopic polarization in III-V nitride multiple quantum wells," Phys. Rev. B **60**, 8849-8858 (1999).

[5] S. -H. Park and S. -L. Chuang, "Spontaneous polarization effects in wurtzite GaN/AlGaN quantum wells and comparison with experiment ," Appl. Phys. Lett. 76, 1981-1983 (2000).

[6]. R. A. Hogg, C. E. Norman, A. J. Shields, M. Pepper, and N. Iizuka, "Comparison of spontaneous and piezoelectric polarization in GaN/AlGaN multi-quantum-well structures," Appl. Phys. Lett. **76**, 1428-1430 (2000).

[7] C. -C. Chuo, C. -M. Lee, T. -E. Nee, and J. -I. Chyi, "Effects of thermal annealing on the luminescence and structural properties of high indium-content InGaN/GaN quantum wells," Appl. Phys. Lett. **76**, 3902-3904 (2000).

[8] L.-H. Peng, C. -W. Chuang, and L. -H. Lou, "Piezoelectric effects in the optical properties of strained InGaN quantum wells," Appl. Phys. Lett. **74**, 795-797 (1999).