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The universal photoluminescence behaviour of yellow light emitting (Ga,In)N/GaN heterostructures

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ABSTRACT

We have studied the time-resolved photoluminescence spectra of yellow light emitting (Ga,In)N-based quantum wells grown by metal–organic vapour phase epitaxy on C-plane sapphire substrate for indium compositions ranging up to 23%. The temperature dependent time resolved photoluminescence spectra collected through the 8–300 K range are found to exhibit behaviours very similar to what is reported in literature in samples with different designs (well width, indium composition in the well layer). However, our quantum devices always exhibit a two-mode exponential decay with a long decay time about four to five times longer than the short one, which was not reported so far. The photoluminescence decay times are wavelength-dependent as always found for indium rich quantum well, a behaviour that is interpreted in terms of carrier localisation in local potential minima. The spectral dependence of the decay time, which was fitted using sigmoidal function, gives access to an average decay time, centred at a given energy, with a phenomenological broadening constant. The average splitting between characteristic energies for long and short decay times, and the broadening constants both increase with the indium composition. The average decay time increases exponentially with the product of the well width to indium composition. This quantity is found to be an excellent indicator of the device performance.

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1. Introduction

There is currently a strong demand, for studying with great details the growth and performances of yellow light emitting quantum wells. The main motivation is to bridge the blue–green light emission range with the red one (conventional phosphide-based technology). The realization of yellow light-emitting diodes faces paramount difficulties although about 12% internal quantum efficiency was reported in 2010 [1]. There are two options: (i) using wide wells for red-shifting the emission energy thanks to the internal electric fields resulting from the wurtzite symmetry (for polar orientation); (ii) increasing the indium concentration in the well layer may be an alternate solution for reducing the bandgap of the carrier-confining material. We recall that increasing the chemical contrast between the well layer and the barrier layers increases the electric field in the well layer, and thus the quantum confined Stark effect (QCSE) [2].

The solution may thus not be intuitive and was roughly framed theoretically by Graham et al. [3]. They computed, within the context of an effective mass approach, the amount of indium required for yellow light emission in *(Ga,In)N-based* quantum wells versus well width. This also gave us the corresponding values of the overlap integral for electron and hole envelope functions, they got the evolution of the radiative decay time (an easy to measure quantity). *The calculations suggest that radiative decay times may become rapidly long, leading to a degradation of the optical properties when increasing well width* [4,5]. Utilization of the red-shift of the light emission wavelength by *growing quantum well layers wider than in the context of the conventional blue–green light emitting diodes technology is thus a lure.* The QCSE splits apart the electron and hole wave functions to the different interfaces of the well layer and the overlap of their envelope function rapidly limits to their tails near the centre of the well. This quantity decreases close to exponentially with the thickness of the quantum well, resulting in a similar exponential decay of the radiative recombination with well thickness [6]. The solution that arises from the calculation is to investigate light emitters based on *indium rich (Ga,In)N quantum wells* and to use thin well layers so that carriers are not confined in the triangular part of the quantum well. *However* as evidenced by Ho and Stringfellow [7] or Matsuoka [8] in the nineties, the relative sizes of nitrogen and indium generates huge inhomogeneous strain-fields in indium-rich regions. This favours spinodal decompositions of *(Ga,In)N* as soon as the indium composition is substantially increased. This can lead to strong chemical inhomogeneities in the quantum well layer and rough interfaces between well layers and barrier layers. Both effects will impact negatively the photoluminescence (PL) peak linewidth. Improving the light-matter coupling efficiency in the yellow seems to require to playing with both QCSE and high indium compositions.

2. Experimental

To contribute calibrating this, we have grown samples by metal–organic chemical vapour deposition (MOCVD) along the polar orientation, and we performed a detailed investigation of their PL properties. The three samples have ten periods of (Ga,In)N/GaN quantum wells whose thickness and indium composition are characterized with the following couples (2.9 nm, 0.23), (3.6 nm, 0.21), and (4.6 nm, 0.18). These couples are designed to obtain PL in the yellow range. More details on the growth conditions can be found in Ref. [9]. Time-resolved PL measurements have been performed as a function of the temperature on these samples. The 266 nm laser radiation emitted at repetition rate of 82 MHz was pulse-picked to allow measuring long decay times. The PL was recorded using a 30 cm focal length spectrometer and a 150 groove/mm grating, detected with a Hamamatsu Streak camera with detection in the 10 ps range. The cw PL spectrum is obtained here by integration through the whole collection time of instantaneous spectra.

3. Results and discussion

The cw spectra have a maximum peak in the 2.1–2.2 eV range, and are quite broad (as always found in literature). When spectra are obtained limiting the integration at long delays after the excitation