Investigation of the effects of heat treatments on InGaN/GaN single and multiple quantum wells (SQW, MQWs) for quantum well intermixing (QWI)

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Abstract

In recent years single and multiple InGaN/GaN quantum-wells (SQW, MQWs) have received considerable attention due to their importance in solid state lighting. The most widely commercialized light emitting diodes (LEDs) are based on III-nitride low dimensional structures capable of light emission from the ultraviolet to the red [1, 2]. The external quantum efficiency (EQE) of such LEDs is usually analyzed as the product of the internal quantum efficiency (IQE) and the extraction efficiency of photons, with the IQE assessed by temperature dependent photoluminescence (PL) measurements; nowadays, for low InN content, IQE higher than 90% is commonly reported [3]. However, in the green spectral region, the IQE is much lower, mainly due to pyro- and piezo-electric fields which cause the quantum confined Stark effect, QCSE, to separate electrons from holes [4]. Additionally, due to the compositional fluctuations of the InGaN ternary alloy, an excessive broadening of the spectral emission is found to occur for even higher InN contents (e.g in the yellow/amber/red spectral regions). These drawbacks must be overcome to produce monolithic white LEDs based on the RGB approach using the InGaN/GaN MQW system [1,2].

Among several competing methods to improve efficiency in the green gap our group is pioneering an uncommon approach based on a controlled promotion of quantum well intermixing (QWI) [5]. The main aims are to use ion implantation followed by thermal annealing treatments to tune the emission of the quantum well active layer. Prior to the implementation of these studies a comprehensive investigation of the effects of heat treatments on the PL spectral shape and IQE of the InGaN/GaN SQW and MQW structures should be realized; this contribution outlines our first results.

As-grown and thermally annealed InGaN/GaN MQWs were examined by PL spectroscopy. For the as-grown MQWs the dominant emission of a set of eleven samples from a standard commercial wafer, peaked at ~440 nm at 11 K (Figure 1.a). The as-grown wafer reveals heterogeneities observed as energy shifts of the band maximum. Besides the emission from the QW active region, the GaN DAP and DX optical emission can be identified in the PL spectra.

The dependence of the 11 K luminescence on the excitation intensity for a selected as-grown sample is shown in Figure 1.b. The recombination of the QW active region was found to be sensitive to the excitation intensity as indicated by the intensity drop of the high energy line after a two decade reduction of the excitation. Furthermore, slight shifts of the band maxima are observed.

Major differences are observed upon thermal annealing treatments at different temperatures and atmospheres. The QW emission intensity decreases for samples annealed at 1100 ºC in a N_2:NH_3 or pure N_2 atmosphere. This reduction is accompanied by a relative increase of the GaN DAP luminescence and the development of a broad UV/Violet emission band (Figure 2.a)). For the samples annealed in N_2 atmosphere, further analysis was performed by varying the annealing temperature between 900 to 1100 ^{o}C. In this case, no changes in the QW PL spectra occur up to 1000 ^{o}C. However an abrupt change in the relative intensities of the active layer vs GaN PL was found to occur for 1100 ^{o}C (Figure 2.b). Under such conditions the PL spectrum is dominated by the GaN DAP and DX recombination processes. These results reveal that annealing significantly alters the optical properties of the MQWs and cannot be overlooked in the subsequent study of the QWI effect.

Acknowledgements

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Figures

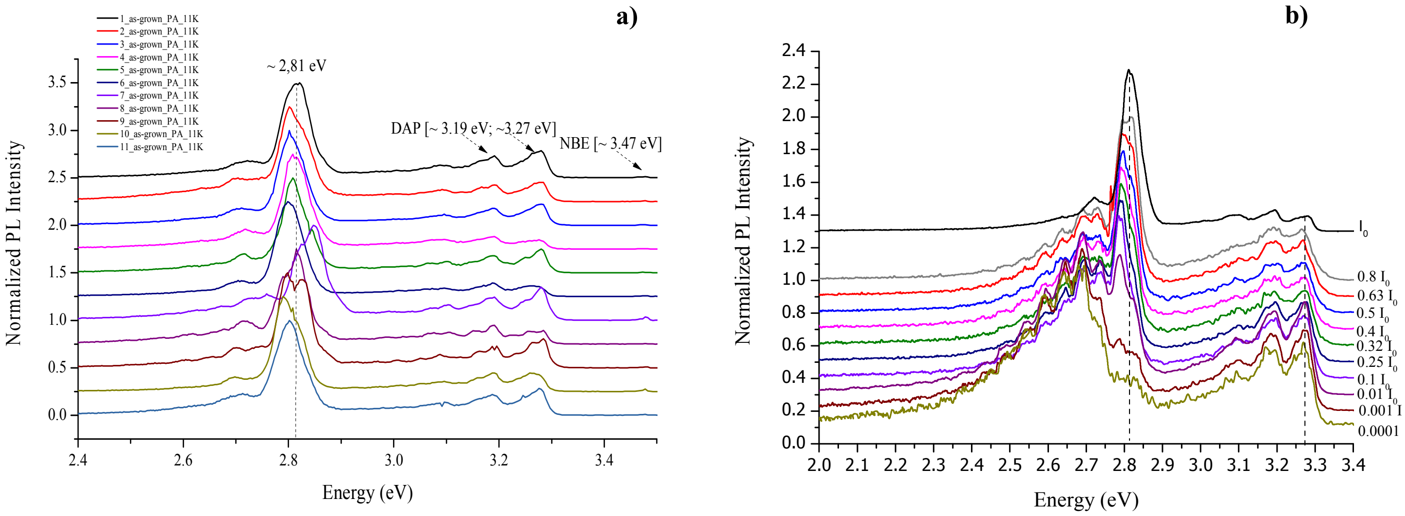

Figure.1: a) Normalized 11 K PL spectra from samples 1 to 11. **b)** 11 K excitation intensity dependence for the as-grown sample 4.

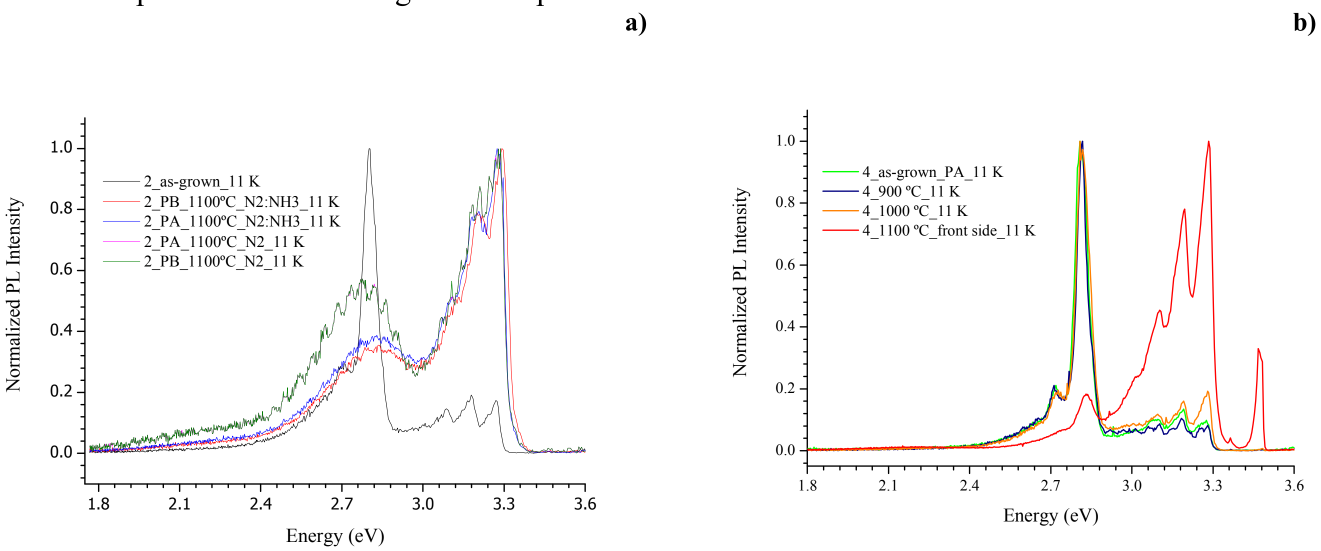

Figure.2: 11 K PL spectra for the **a)** as-grown and annealed sample 2, **b)** as-grown and annealed sample 4**.**