

Resonant Raman Study of Strain and Composition in InGaN Multiquantum Wells

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Abstract. Resonant Raman scattering measurements on In_{0.15}Ga_{0.85}N/GaN multiquantum wells are reported. Depending on their width, the multiquantum wells are either fully strained or relaxed, as shown by the Raman frequency of the A₁(LO) phonon. In the strained sample, the A₁(LO) frequency shows no significant deviation from the GaN value, as the effects of In concentration and strain compensate almost exactly each other. In contrast, the relaxed sample shows a marked decrease of the Raman frequency. Resonant Raman profiles measured at room temperature are significantly blue-shifted with respect to the photoluminescence emission as a result of the inhomogeneous In distribution. In the relaxed multiquantum well the average In concentration and its variation range are independently determined from the Raman shift of the A₁(LO) mode and from the maximum of its resonant Raman profile. Both measurements give similar results.

INTRODUCTION

In this communication we report Resonant Raman scattering (RRS) measurements at room temperature for both pseudomorphic and relaxed InGaN/GaN multiquantum wells (MQWs). From the variation of the A₁(LO) phonon frequency with excitation energy and the RRS profile, we were able to determine the In concentration and its fluctuation range. The two samples used in our experiments contain five InGaN QWs separated by GaN barriers. They have been grown by molecular beam epitaxy (MBE) on a 300 nm thick GaN template deposited on a sapphire substrate and oriented in the (0001) direction [1]. The growth temperature (570°C) and the Ga flux were kept constant during the growth. The values for the In content, barrier and well widths (shown in Table 1) have been estimated from X-ray diffraction.

TABLE 1. Thickness of the Well and Barrier Layers and In Concentration of the Studied Samples.

Sample	Well Thickness (nm)	Barrier Thickness (nm)	In Concentration (X-ray)
576	5.0	6.0	0.16
578	2.5	5.5	0.14

Raman scattering in the backscattering configuration

was excited in the 2.0-3.0 eV excitation range with Rhodamine 110 and Stilbene 3 (UV pumped) dye lasers and an Ar-ion laser. The scattered light was dispersed with a double spectrometer and detected with a cooled charge coupled device camera. The resulting Raman peaks were normalized to the intensity of the E₂ GaN phonon and fit to a Lorentzian in order to determine their intensity and frequency.

RESULTS AND DISCUSSIONS

The A₁(LO) InGaN mode (around 710 cm⁻¹) of sample 576 changes both in frequency and intensity with increasing excitation energy, as shown in Fig. 1a. The dashed lines indicate the A₁(LO) phonon of GaN (735 cm⁻¹) and a substrate mode (750 cm⁻¹). The frequency change is due to the relative resonant excitation of sample regions with different In content. In contrast, the A₁(LO) InGaN phonon of sample 578 (Fig. 1b) is blue-shifted with respect to sample 576 and its frequency does not depend on the excitation energy. This is understood assuming that sample 578 is pseudomorphic with the substrate, whereas sample 576 is fully relaxed. The composition induced change of the phonon frequency in relaxed In_xGa_{1-x}N layers [2] is $\Delta\Omega_x = -149x$ cm⁻¹. For sample 576 this gives $\Delta\Omega_x = -22$

cm^{-1} , in agreement with Fig. 1a. This change is almost compensated by the effect of biaxial strain in the pseudomorphic sample, which is given by $\Delta\Omega_s=119x \text{ cm}^{-1}$ as estimated from the standard elastic constants and the phonon deformation potentials [3]. For sample 578 we have $\Delta\Omega_s+\Delta\Omega_x=-4.5 \text{ cm}^{-1}$, in agreement with Fig. 1b. The strain relaxation in sample 576 could be due to the growth conditions, which favour the appearance of defects in the barriers as the widths of the layers increase.

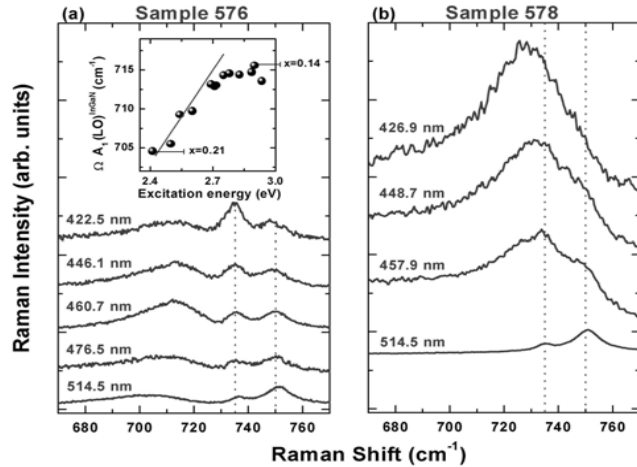


FIGURE 1. Raman spectra of samples 576 (a) and 578 (b) for different excitation energies.

The inset in Fig. 1a shows the frequency change of the $A_1(\text{LO})$ InGaN phonon in sample 576 as a function of excitation energy. The decrease of the $A_1(\text{LO})$ phonon frequency with decreasing excitation energy indicates an inhomogeneous In distribution. The slope of the solid line ($40 \text{ cm}^{-1}/\text{eV}$) was determined from the change of the phonon frequency and the gap energy with In concentration. Comparing with the results of Correia et al. [2] we obtained an In concentration ranging from $x=0.17$ to $x=0.21$. Figure 2 shows the dependence of the $A_1(\text{LO})$ phonon intensity on excitation energy (RRS profile) and the photoluminescence (PL) emission spectra of samples 576 and 578. The blue-shift of the RRS with respect to the PL, is another consequence of the inhomogeneous In distribution [4]. As expected, the PL emission energy of the strained sample 578 is blue-shifted with respect to the relaxed sample 576 due to both the quantum confinement effect in the narrower QW and the strain effect. The maximum of the RRS profile in sample 576 (Fig. 2b) corresponds to $x=0.17$, and coincides with the average In concentration obtained from the phonon frequency.

In contrast to PL, Resonant Raman spectroscopy gives information on the average properties of the sample. In our experiment, the average In concentration and its variation range in the relaxed MQW were independently determined from the Raman shift of the $A_1(\text{LO})$ mode and from the maximum of its RRS profile. Both measurements give similar results, thus confirming that Raman spectroscopy is an adequate method to investigate structural properties in semiconductor nitride structures.

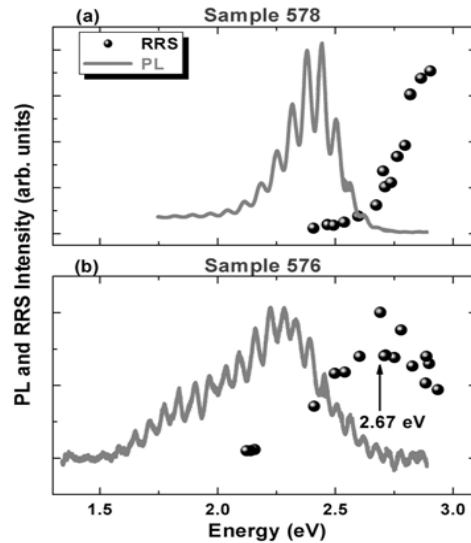


FIGURE 2. RRS profiles (points) and PL emission spectra (line) of samples 578 (a) and 576 (b).

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