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Evolution of the optical transitions in $Al_xGa_{1-x}As$/GaAs quantum well structures grown on GaAs buffers with different surface treatments by molecular beam epitaxy

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ABSTRACT

$Al_{0.3}Ga_{0.7}As$/GaAs Quantum Well structures were grown by molecular beam epitaxy (MBE) on a 500 nm thick GaAs buffer layer subjected to the following surface processes: a) in-situ Cl_2 etching at 70 °C and 200 °C, b) air-exposure for 30 min. The characteristics of these samples were compared to those of a continuously grown sample with no processing (control sample). We obtained the quantum wells energy transitions using photoreflectance spectroscopy as a function of the temperature (8–300 K), in the range of 1.2 to 2.1 eV. The sample etched at 200 °C shows a larger intensity of the quantum well peaks in comparison to the others samples. We studied the temperature dependence of the excitonic energies in the quantum wells (QWs) as well as in GaAs using three different models; the first one proposed by Varshni [4], the second one by Viña et al. [5], and the third one by Pässler and Oelgart [6]. The Pässler model presents the best fitting to the experimental data.

1. Introduction

Photoreflectance spectroscopy (PR) has been used extensively as an optical characterization technique in the study of bulk materials, AlGaAs/GaAs thin films, quantum wells (QWs), modulation-doped heterojunctions, heterojunction bipolar transistor structures or pseudomorphic high electron mobility transistors [1]. Because of its low cost and simplicity, PR is used extensively in a wide range of experimental conditions. At room temperature, we can obtain a rich and sharp spectrum in comparison with Photoluminescence (PL) technique. However, sometimes the spectra obtained by PR are not as easy to analyze as PL spectra. This is the reason for which PR is used for qualitative analysis. In this work, we report an analysis of the experimental PR data obtained for a series of samples that in principle do not have straightforward spectra.

In recent years, many semiconductor microstructures have been grown with the use of molecular beam epitaxy (MBE) technique. One of this kind of semiconductor heterostructures is $Al_xGa_{1-x}As$/GaAs Quantum Well (QW) with $0<x<0.45$ [2]. The popularity of these heterostructures is due to their physical simplicity. For $x<0.45$, the coupling in the lattice parameter between AlGaAs and GaAs is free of stress, and it is possible to obtain a wide range of emitted energies. In this work, we present the PR analysis of a series of four samples grown by MBE in which three QWs were grown on GaAs buffers with different treatments. Two of these samples were overgrown on in-situ Cl_2 etched GaAs buffers with different Cl_2 etching conditions. One sample was prepared on air-exposed GaAs buffer, and the last one, as a control sample, was grown without any process. The aim of this work is to compare PR spectra with those obtained by PL technique [3]. The PR spectra show a better sensitivity than photoluminescence spectroscopy to analyze optical properties of $Al_{0.3}Ga_{0.7}As$/GaAs Quantum Well structures. Also, we studied the evolution of the energy gap and excitonic energy transitions in these QWs as a function of the PR temperature using the models proposed by: Varshni [4], Viña et al. [5], and Pässler and Oelgart [6]. The Pässler model presents the best fitting to the experimental data for low temperature values.

2. Experimental details

The experimental arrangement for the preparation of the samples by MBE technique has been described in detail in Ref. [7]. A set of four $Al_xGa_{1-x}As$/GaAs QW samples with $x=0.3$ and with different treatments for the 500 nm thick GaAs buffer layer was studied. In each sample the QW structures were grown with nominal widths of 7, 5, and 3 nm located at 20, 67, and 112 nm measured from the etched surface, respectively. The nominal thickness of the layers was obtained by measuring the oscillation period of the specular spot of reflection high energy electron diffraction (RHEED) patterns. The different treatments for the samples were: a) continuous MBE growth with no interruption (sample 1, control sample), b) growth interruption and exposure to air by 30 min after growing the GaAs buffer layer (sample 2, air-exposed), c) in-situ etching of the GaAs buffer with Cl_2 gas at $T=200$ °C (sample 3),

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Table 1
Growth parameters of the samples.

Sample	Process
1	Continuous growth (control sample)
2	Ex-situ processed (exposed 30 min to air)
3	In-situ etched with Cl_2 gas at $T = 200$ °C
4	In-situ etched with Cl_2 gas at $T = 70$ °C

and 70 °C (sample 4). PR measurements were performed using a Triax-320-Jobin Yvon monochromator, a chopped pump He–Ne laser ($\lambda = 6328$ Å, 1.959 eV) at the frequency of $f = 151$ Hz, a quartz tungsten-halogen lamp, a Si-detector, and a SR-810 lock-in detection system. The monochromatic beam was focused on the modulated area of the sample and the reflected beam was recorded by a Si-detector, the reflectivity ΔR at the frequency f is extracted using a lock-in amplifier. For calibration purposes, a Hg lamp was used. The sample was attached to the cold finger of a He closed-cycle refrigeration system, thus varying the sample temperature between 8 and 300 K. Table 1 summarizes the growth parameters for each of the studied samples.

3. Results

Fig. 1 shows a comparison between (a) photoluminescence at 9 and 300 K, and (b) photoreflectance spectra at 8 and 300 K for sample 3. The PL spectrum at 9 K shows, besides the signal from GaAs bulk at 1.52 eV, three intense peaks at 1.57, 1.61 and 1.68 eV. These peaks correspond to the ground transition from the first level of electrons to the first level of heavy holes in the three QWs. The energy location of these peaks corroborates that the three QWs were effectively grown with the nominal thickness. As can be seen, PL emission was not observed in the sample at room temperature. In sharp contrast, in Fig. 1(b) we observe that photoreflectance signals at room temperature are better resolved than photoluminescence signals. This is one of the reasons for which we are interested in studying PR spectra.

Fig. 2 shows a comparison between photoreflectance spectra at 8 K for all the samples. As can be noted from this figure, in sample 1, there are four features localized at 1.51, 1.58, 1.62, and 1.71 eV. The first peak at 1.51 eV is associated with the band gap energy for GaAs reported at 1.5194 eV [8]. The first peak shows a complex structure which was analyzed with Franz–Keldish Oscillations (FKO) through a Fast Fourier Transformation (FFT) in order to eliminate interferences. The second, third and fourth peaks correspond to the ground transition in the first, second and third quantum wells, respectively.

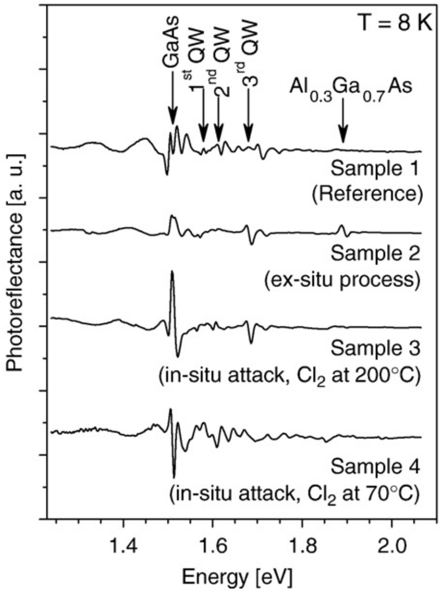

Fig. 2. Photoreflectance spectra at 8 K for samples 1–4.

The line shape of the PR spectra was fitted to a third derivative function according to the theory of modulated electroreflectance in the low-field limit [9]

$$\Delta R/R = A\mathrm{Re}(e^{i\theta}(E - E_g + i\Gamma)^{-n}) \tag{1}$$

where A is the amplitude, θ is the phase angle, E is the incident phonon energy, E_g is the band gap energy, Γ is the broadening parameter and n depends on the critical point. For an excitonic transition, the PR spectrum is first-derivative like so $n = 2$. To fit a nonexcitonic band to band transition $n = 2.5$ is required [10,11]. We used $n = 2.5$ and $n = 2$

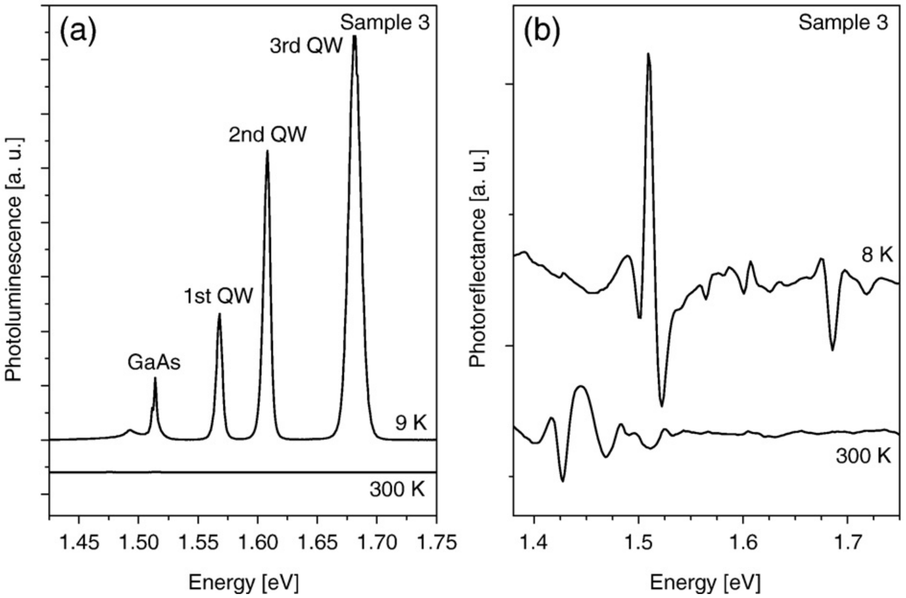

Fig. 1. (a) PL spectra for sample 3 at 9 and 300 K. (b) PR spectra for sample 3 at 8 and 300 K.