Available online at www.sciencedirect.com
ScienceDirect
Journal of Crystal Growth 301–302 (2007) 84–87
JOURNAL OF CRYSTAL GROWTH
www.elsevier.com/locate/jcrysgro

P-cracker cell temperature effects on the optical properties of AlGaInP:Be layers grown by SSMBE

C. Soubervielle-Montalvo[a], I.C. Hernández[b], M. Sheldon[b], A.Yu. Gorbatchev[a], A.G. Rodríguez[a], F. de Anda[a], L. Zamora-Peredo[a], V.H. Méndez-García[a,*]

[a]*Optical Communication Research Institute (IICO) and Facultad de Ingeniería, Universidad Autónoma de San Luis Potosí, Av. Karakorum 1470, Lomas 4a Sección, 78210 San Luis Potosí, SLP, Mexico*
[b]*Lasertel Inc., 7775 N. Casa Grande Hwy, Tucson, AZ 85743, USA*

Available online 20 December 2006

Abstract

The optical properties of Be-doped $Al_{0.2}Ga_{0.3}In_{0.5}P$ layers grown on GaAs by solid source molecular beam epitaxy have been studied. In particular, we investigated a set of heavy doped samples grown at different phosphorous cracking temperatures (PCT). The analysis of the 15 K-PL spectra showed three strong transitions below the AlGaInP band edge associated to Be acceptor levels (A^0, X), shallow impurities (A, X) and a broad signal related with oxygen deep levels (O, DL). The Photoluminescence (PL) spectra from samples dramatically change as the PCT is increased, in such a way that in the spectrum from the sample grown at the highest P-cracking zone temperature, the (O, DL) intensity is visibly dominant. Besides, we found that despite that the Be cell temperature being maintained at 1015 °C for all the samples, the Be-doping concentration is reduced as the PCT is increased. Therefore, as PCT increases, the active Be-concentration decreases as a consequence of Be-compensation with O. This phenomena is reflected in the PL properties of the samples as a reduction of the (A^0, X) intensity. The rocking curves of the (0 0 4) planes obtained by high resolution X-ray diffraction (HRXRD) justify the inclusion of impurities and the reduction of the crystal quality of the sample grown at the highest PCT. This work shows that the incorporation of defects during the growth of the AlGaInP:Be films due to O contamination can be reduced using low PCT.

PACS: 78.55.−m; 68.35.Fx; 81.15; 78.20.−e; 68.35.Dv; 78.55.Cr

Keywords: A1. Photoluminescence; A1. Shallow impurities; A3. Molecular beam epitaxy; B1. Cracker-cell; B2. Optical properties; B2. III–V semiconductors

1. Introduction

The unique properties that the $Al_xGa_yIn_{1-x-y}P$ quaternary alloy possesses, like high crystalline quality and large direct band gap material lattice matched to a III–V substrate, have been of a great deal of importance for the synthesis of optoelectronic devices such as light emitting diodes and semiconductor lasers, widely used in information processing systems and optical fiber communication systems [1].

Despite the success of the mass production and device coupling of the AlGaInP-based semiconductor lasers, issues that have not been thoroughly examined are the optical properties from samples when the incorporation of oxygen occurs during the solid source molecular beam epitaxial growth (SSMBE). The development of valved crackers for elemental phosphorous has enabled the growth of bulk phosphide films and heterostructures, and it is known that the P-valved cracker cell is a native source of oxygen [2,3]. However, the details concerning the mechanism of its introduction, the creation of disorder effects and nonradiative recombination centers have not been in detail investigated.

In this work, we studied the optical properties of Be-doped $Al_{0.2}Ga_{0.3}In_{0.5}P$ layers grown on GaAs by SSMBE.

*Corresponding author. Tel.: +52 444 8250183; fax: +52 444 8250198.
E-mail address: vmendez@cactus.iico.uaslp.mx (V.H. Méndez-García).

0022-0248/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jcrysgro.2006.11.293

During the growth of the quaternary alloy, the Be-cell temperature was maintained at the same value for all the samples, while the P-cracking zone temperature was varied. Despite that the doping concentration being similar for the samples, oxygen related photoluminescence (PL) peaks gained intensity with increase the PCT. The samples changes introduced when high PCT is used also modify the structural properties of the samples, as observed by the rocking curves of the (0 0 4) planes obtained by high-resolution X-ray diffraction (HRXRD).

2. Experimental procedure

The samples were grown in a Veeco-Applied Epi GenIII MBE system. First, 0.1-μm-thick GaAs buffer layers (BL) were grown on semi-insulating GaAs(1 0 0) substrates at the temperature of 605 °C. Then, the substrates temperature was set at 505 °C, where Be-doped 0.5 μ-thick $Al_{0.2}Ga_{0.3}In_{0.5}P$ films were deposited. The Be-cell temperature (BeCT) was 1015 °C for all samples, which nominally results on carriers concentration around $\sim 2\times10^{18}\,cm^{-3}$, but slight Be-doping differences were observed among the samples and will be discussed afterward. The growth rate for GaAs was 1 μm/h while for the AlGaInP layers was 2 μm/h. We have used an Applied-Epi phosphorous-cracker cell with the cracking zone at several temperatures. Samples 1MBE, 2MBE and 3MBE were grown at PCT 800, 900 and 1000 °C, respectively. Another sample, 4MBE, was grown at PCT 900 °C using an additional vacuum pump in order to improve the MBE growth chamber background pressure.

PL spectroscopy as a function of temperature was utilized to investigate the optical properties of samples employing an He–Cd laser (325 nm) chopped to 200 Hz as the excitation source. The crystal quality of the samples was evaluated with HRXRD rocking curves performed in a Phillips double crystal spectrometer. Finally, the carrier concentration was investigated with electrochemical capacitance voltage (ECV) measurements.

3. Results and discussion

Fig. 1 shows 15 K-PL spectra close to the AlGaInP band gap energy from samples grown at 800, 900 and 1000 °C. Broad peaks are observed typically from highly doped semiconductor materials. As it is known, heavy doping shifts the conduction and valence bands in such a way that the band gap decreases, broadening the single particle states, and the random distribution of dopants also induces band tailing [4]. Nevertheless, note that the gradual broadening of the PL lineshape from sample 1MBE to 3MBE, is not a consequence from multiple doping levels of the samples. Instead, the broadening has been solely prompted by changes of the PCT, as will be discussed later. Carefully analyzing the PL spectra, we found reasonably good fits to three Gaussian lines located at 2.170, 2.152 and 2.104 eV, marked with dashed lines in

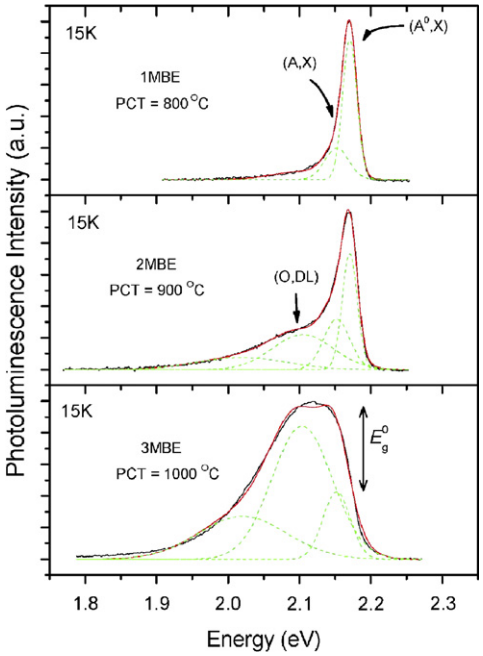

Fig. 1. PL spectra from AlGaInP films grown at different PCT. Three transitions (A, X), (A^0, X) and (O, DL) were identified and are indicated on the spectra. E_g^0 indicates the (B, B) transition as discussed in the text.

Fig. 1. Utilizing the method reported by Vurgaftman for quaternary alloys [5], we found that the unperturbed band-to-band (B,B) transition E_g^0 is situated close to 2.189 eV at 15 K, therefore none of the former transitions can be identified as (B,B). In order to further verify the position of the (B,B) transition, PL measurements as a function of temperature were performed for 1MBE. The energy of the PL lines is plotted in Fig. 2. The highest energy transition is presumably the (B,B) line that appears at temperatures not less than 77 K in Fig. 2, in good agreement with former observations [6]. By employing the empirical Varshni equation frequently used to fit the energy gaps of semiconductor materials [7],

$$E_g(T) = E_g(T=0) - \frac{\alpha T^2}{T+\beta}, \tag{1}$$

where α and β are adjustable (Varshni) parameters and $E_g(T=0)$ is the energy gap at 0 K, we found a reasonable good fit of the experimental data as observed in Fig. 2. Besides, the unperturbed E_g^0 transition energy resulting from the fitting procedure is quite close to the value obtained from the Vurgaftman method.

The former experiments, performed as a function of temperature, lead us to propose that the transitions observed in Fig. 1, located at 2.170, 2.152 and 2.104 eV, could be associated with Be acceptor levels (A^0, X), shallow impurities (A, X) and oxygen deep levels (O, DL), respectively. These transitions have been previously identified in heavy doped AlGaInP samples [6].

Fig. 3 shows the behavior of the PL-transitions intensity as a function of PCT. In the same graph is plotted the Be