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Structural and optical study of BInGaAs/GaAs quantum wells grown by MOVPE emitting above 1.1 eV

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ABSTRACT

High resolution X-ray diffraction (HRXRD) and Photoluminescence (PL) spectroscopies have been utilized to achieve structural and optical BInGaAs/GaAs quantum well properties, grown by metal organic vapor phase epitaxy (MOVPE). A significant fraction of indium (36% and 46%) has been incorporated into BGaAs which show that a $B_xIn_yGa_{1-x-y}As$ can be grown lattice matched to GaAs. At room temperature PL energy emission is at 1.19 eV for lower indium composition and 1.14 eV for the higher. It has been revealed that the PL band shifts significantly to low energy side to 50 meV with increasing indium solid composition. This confirms that the BInGaAs semiconductor material is well suited for active cell layers in multi-junction solar emitting near 1.1 eV.

1. Introduction

The interest in BGaAs and BInGaAs materials, as candidates for applications in multi-junction solar cells, was renewed some year ago. Direct band gap B(In)GaAs alloys with boron content up to several percents have been successfully grown on GaAs by metal organic vapor phase epitaxy (MOVPE) [1–4], and molecular beam epitaxy (MBE) [5,6]. In addition $B_xGa_{1-x}As$ alloys and $B_xIn_yGa_{1-x-y}As$ layers lattice matched to GaAs have been studied because they offer new opportunities in band gap engineering, e.g., for applications in solar cells [2,7]. The incorporation of boron in binary and ternary compounds is of special interest for growing lattice-matched material on GaAs substrates and for strain compensation in quantum-well structures. Higher flexibility in strain compensation and band gap engineering could be reached with the combined incorporation of boron and nitrogen supported by the fact that in MOVPE the N and B incorporation are unaffected by each other [7–10]. Alloying of indium with GaAs reduces the band gap considerably, but lattice mismatch excludes applications in solar cell structures, where sufficiently large absorber layers are required. The $B_xIn_yGa_{1-x-y}As$ quaternary system is of particular interest for solar energy conversion devices because the incorporation of boron and indium in GaAs could potentially lead to strain-free materials with reduced band-gap values. Such absorbent materials could be incorporated into multi-junction solar cell structures with high conversion efficiency [11]. Solar cell structures with BGaInAs epilayer as a base layer have been grown and successfully tested by Leibiger et al. [7]. They have observed that the band-gap energies of $B_xGa_{1-x}In_yAs$ are only moderately red-shifted with increasing boron concentration which can be described by a linear function. Moreover, an absorption coefficient α is increased with decreasing band-gap energies.

In this paper, we have investigated HRXRD and Photoluminescence PL of $B_xIn_yGa_{1-x-y}As$ QW structures grown on GaAs by metal organic vapor phase epitaxy (MOVPE) as a base active layer in solar cell. HRXRD demonstrated that BInGaAs can potentially be used in strain free. We focused our study on the reduction of band gap energy when incorporating boron and indium into GaAs matrix. At room temperature PL band range 1.19 and 1.14 eV with increasing indium solid composition. We explained the advantage given by BInGaAs QWs in the solar cell efficiency. Therefore, it can absorb a different part of the wide energy distribution of photon in sunlight and generate enough photocurrent. BInGaAs may be the active cells in the multi-junction solar cell device.

2. Experiments procedure

BInGaAs samples have been grown by atmospheric-pressure MOVPE in a T-shape horizontal reactor. The QWs were grown on (001) GaAs substrates misoriented 1° towards [110] direction. Diborane (B_2H_6), triethylgallium (TEG), trimethylindium (TMI) and arsine (AsH_3) were used as boron, gallium, indium and arsenic sources, respectively. Hydrogen was used as carrier gas. AsH_3 flow rate was kept constant, leading, for BInGaAs layers, to V/III ratios ranging between 120 and 460. The boron composition was varied by varying V/III flux ratio [12]. High

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resolution X-ray diffraction (HRXRD) measurements were performed systematically with the copper target ($\lambda CuK\alpha_1 = 1.54056$ Å) radiation from a Discover D8 (40 kV 55 mA) high power X-ray generator. Photoluminescence measurements were carried out between 10 and 300 K while keeping the samples in a closed-cycle helium circulation cryostat. The excitation wavelength used is the 514.5 nm line of the cw Ar^+ laser. The emission was dispersed by a high-resolution spectrometer and detected by a thermoelectrically cooled InGaAs photodetector with a built-in amplifier.

3. Results and discussions

Quaternaries BInGaAs QWs have grown at varied growth temperature 580 °C and 520 °C. Boron composition incorporation in BInGaAs has been assumed that was incorporated in same ternary alloys BGaAs. We have assumption that boron solid composition is $x_B = 1\%$ for the first structure has grown at temperature $T_g = 580$ °C. The second has grown at low temperature $T_g = 520$ °C, boron composition is $x_B = 3\%$. Previously we have published the effect of low growth temperature, such as the boron composition increase with decreasing growth temperature [13]. As well, in order to optimize the indium incorporation efficiency, the influence of growth temperature has been studied by P. Rodriguez et al. [14]. They show that growing the quaternary alloy at low growth temperature seems a key point to increase both boron and indium incorporation. HRXRD is performed to estimate indium solid composition of (B)InGaAs samples. We have exploited BInGaAs/GaAs epilayers grown under the same conditions of QWs to determine exactly the In composition. Fig. 1a and b shows symmetric diffraction $\omega/2\theta$ scans using (004) plane for the BInGaAs grown at 580 °C with boron solid composition value 1%. At low growth temperature 520 °C, Fig. 2a and b shows symmetric diffraction $\omega/2\theta$ scans using (004) plane for the BInGaAs with 3% boron fraction. Using the asymmetric (115) plan diffraction reciprocal space, of (B)InGaAs epilayer grown under same condition of QWs, we can determine the perpendicular lattice mismatched ($\Delta a/a$) and strain parameter (ε), so we can deduce the In composition. From the angular difference $\Delta\theta$ between the BInGaAs and GaAs peaks we calculate lattice mismatch which is related to indium composition as follow:

$$\Delta\theta = \frac{1}{2}(\Delta\omega_+ + \Delta\omega_-) \tag{1}$$

$$\Delta\varphi = \frac{1}{2}(\Delta\omega_+ - \Delta\omega_-). \tag{2}$$

These variations are used to determine the perpendicular and parallel mismatch according to the following equations:

$$\varepsilon_\perp = \left(\frac{\Delta a}{a}\right)_\perp = \frac{a_\perp - a_s}{a_s} = \Delta\varphi \tan\varphi - \Delta\theta \operatorname{cotg}(\theta_B) \tag{3}$$

$$\varepsilon_\parallel = \left(\frac{\Delta a}{a}\right)_\parallel = \frac{a_\parallel - a_s}{a_s} = -\Delta\varphi \tan\varphi - \Delta\theta \operatorname{cotg}(\theta_B) \tag{4}$$

where $\Delta\omega\pm$ is the separation angle between (115) diffraction peak of BInGaAs and that of GaAs substrate and θB is the GaAs Bragg angle for asymmetric (115±) plan.

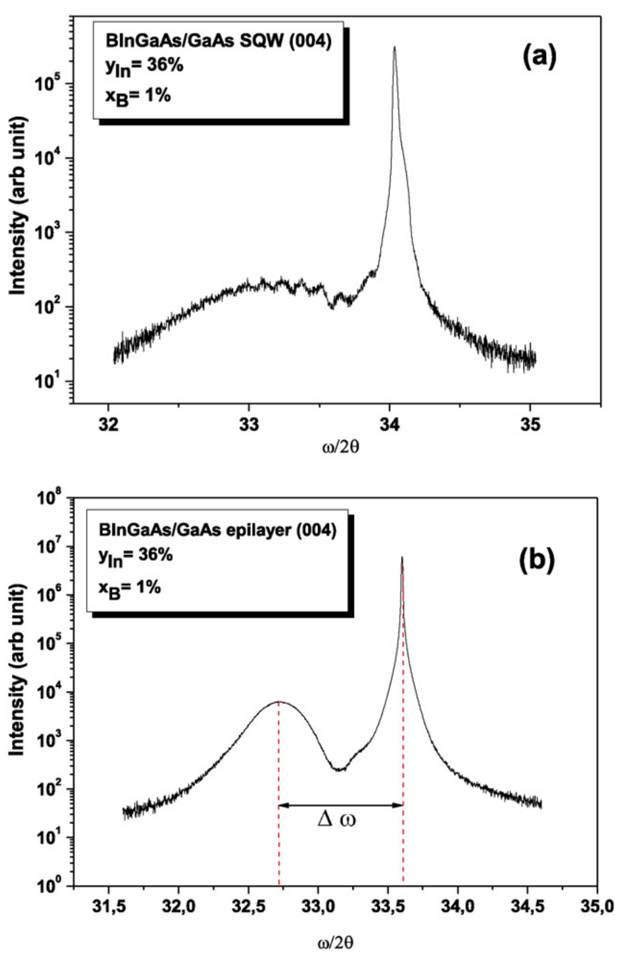

Fig. 1. High resolution X-ray diffraction $\omega/2\theta$ symmetric plan (004) spectra of $B_xIn_yGa_{1-x-y}As$/GaAs single quantum well (a) and epilayer (b) grown at $T_g = 580$ °C.

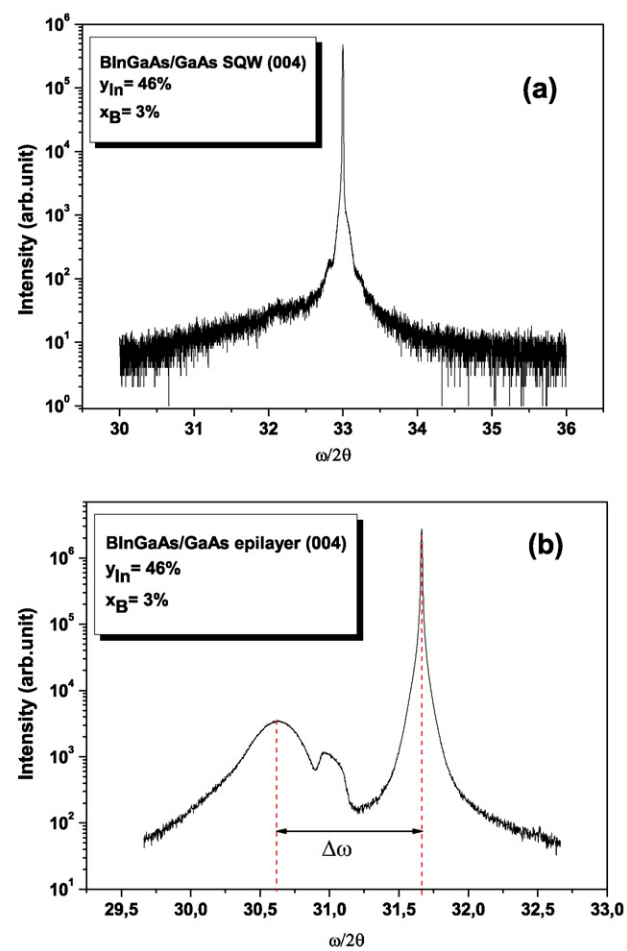

Fig. 2. High resolution X-ray diffraction $\omega/2\theta$ symmetric plan (004) spectra of $B_xIn_yGa_{1-x-y}As$/GaAs single quantum well (a) and epilayer (b) grown at $T_g = 520$ °C.