SECTION: MATERIAL SCIENCES

Study of material aspects of strained InAsP/InP MQW structures for application to 1.3 μm laser devices *

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ABSTRACT

Strained layer InAsP MQW structures have been grown on InP substrates by MOVPE. The quality of the structure was judged using photoluminescence and high resolution x-ray diffraction. The MQW structure luminesces strongly even at room temperature. The PL peak position of single QW InP-InAsP-InP was used to estimate the arsenic composition and well width. The strain in the superlattice structure was evaluated to ascertain the strain relaxation in the samples. The dynamic simulation of the x-ray diffraction profiles fitted well with the experimental results and the strain relaxation was consistent with the computed critical thickness. In order to produce device quality material for operation in the 1.3 μm regime, the structure was optimised with respect to well thickness, composition and strain.

INTRODUCTION

Lasers operating at 1.06 and 1.3 μm are of immense technological importance for modulator as well as communication applications. Various types of devices have been proposed and fabricated to achieve this end which include quaternary InGaAsP/InP [1,2] as well as InGaAlAs/InP [3] based systems. To extend the choice of material usability, concepts incorporating strain rather than lattice matched systems have been proposed [4]. In the recent past, material systems such as InGaAs/GaAs [5] and InAsP/InP [6] incorporating these concepts of strained-layer quantum well (SL-QW) have been researched. Strain in the layers modifies certain electronic and band properties of the material and can be used advantageously in device fabrication. In this work, we describe results of our experiments with strained QW system InP-InAsP-InP.

EXPERIMENTAL

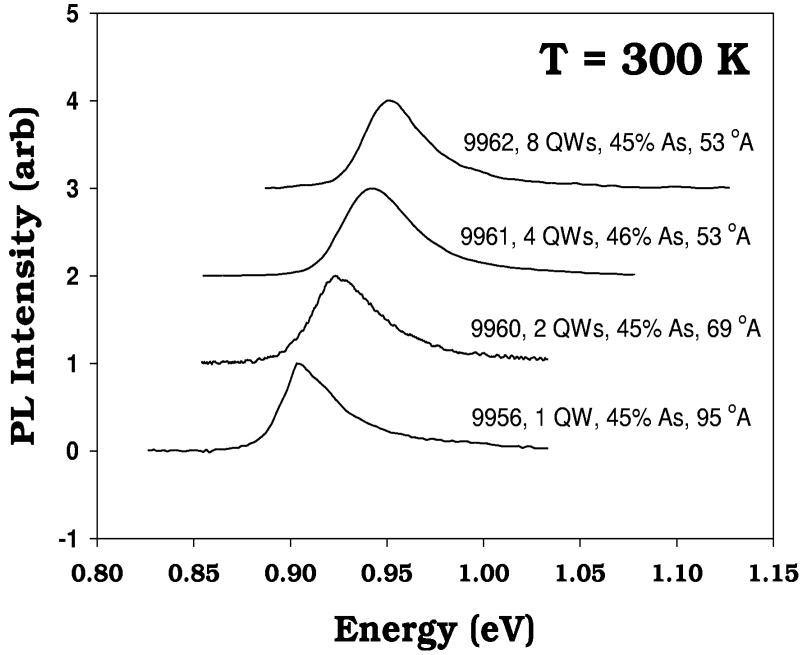
The InAsP quantum wells were grown by metal organic vapour phase epitaxy (MOVPE) at a reactor pressure of 100 Torr and at a growth temperature of 550 ^{o}C using tri-methyl indium (TMI), arsine (AsH_3) and phosphine (PH_3). The structure consisted of a 0.5 μm InP buffer layer on a (100) InP substrate followed by the InAsP QW layer and a 0.1 μm InP cap layer. In case of MQW, a 200 ^{o}A InP barrier layer was grown between the InAsP wells. Growth was interrupted in changing from the growth of InP to the InAsP layer, while a pause followed by a phosphine preflow was

found necessary in transiting from the InAsP to the InP layer to reduce any arsenic contamination in the barrier layer. A set of five samples containing 1, 2, 4,. 8 and 12 QWs were grown as a part of this study. The AsH_3 flow in the gas stream (P_{ars}) given by AsH_3/ (AsH_3+ PH_3) was kept constant in all the growth experiments. P_{ars} as well as the growth temperature were previously optimised in a separate set of experiments, the results of which are reported elsewhere [7].

RESULTS AND DISCUSSIONS

1. Photoluminescence and Energy Level Calculations

The grown samples were at first characterised using photoluminescence (PL), recorded at room temperature with excitation from a 10 mW Ar^+ ion laser as shown in figure alongside. The position and width of the PL peaks for the various samples are presented in the table I. It is seen that the PL peak widths at room temperature for all the samples lie between 30 to 45 meV. The MQW structure #9962 containing eight QWs gave strong PL at 0.951 eV (1.3 μm) and has considerably narrow peak width that is comparable to other reports on similar device material [8,9]. Alongside, the positions of the expected e1-hh1 and the e1-lh1 transitions were also calculated for InAsP/InP QWs of varying arsenic composition and well widths. The effect of the strain in the InAsP layers on the band gap as well as the splitting of the degenerate HH and LH bands were accounted for by using



E_{hh}= E_g + [2a((c_{11}-c_{12})/c_{11})-b((c_{11}+2c_{12})/c_{11})]ε and

E_{lh} = E_g + [2a((c_{11}-c_{12})/c_{11})+b((c_{11}+2c_{12})/c_{11})]ε [9]

where E_g (=0.356 + (0.675 (1-y)) + (0.32 $(1-y)^2$)) [10] is the unstrained bandgap of $InAs_yP_{1-y}$, ε is the strain, c_{11} and c_{12} are the elastic stiffness constants for InAsP [9]. Also the effects of localisation were added to this to calculate the transition energies. The coincidence of the calculated e1-hh1 transition and the PL positions were used to infer the arsenic mole fraction (y_{InAsP}) and the well width (d_{InAsP}) in all the QW samples. The parameters thus estimated are also presented in table I. Although, all samples were grown at the same arsenic flux, the arsenic composition in the sample 9961 was found to be higher (by about 1% than in other samples). This is further evidenced by the peak width also being the highest in this case. The higher incorporation of arsenic in this growth run could only be attributed to unintended fluctuation. It was seen that all SMQW samples showed intense PL emission except #

9966, containing 12 wells. The absence of luminescence from #9966, may be attributed to strain relaxation through creation of misfit dislocations, thus killing the luminescence.

Table I

Sample #	PL peak e1-hh1 (eV)	PL peak width (meV)	As fraction y_{InAsP}	Width (in ^{o}A) d_{InAsP}
9956, 1QW	0.903	33.4	0.45	95
9960, 2QW	0.925	30.4	0.45	69
9961, 4QW	0.942	45.0	0.46	53
9962, 8QW	0.951	39.0	0.45	53
9966,12QW	No PL	---	---	---

2. Calculation of Critical Thickness

The strain in the well layers being rather large, it is necessary to compute the critical thickness of the layer that can stand this strain without relaxing. For the calculation of critical thickness in a MQW structure, an equivalent single layer [11] is constructed with an equivalent arsenic composition y_{eq} and thickness d_{eq}, given by $d_{eq}= N(d_{InAsP}+d_{InP})$ and $y_{eq}= y_{InAsP}d_{InAsP}/(d_{InAsP}+d_{InP})$ where N is the number of periods in the superlattice, d_{InP} is the InP barrier thickness, y_{InAsP} and d_{InAsP} are the arsenic composition and thickness of the InAsP layer. The maximum thickness that can be grown (h_{max}~$2h_c$) [11,12] for this equivalent layer is computed using $h_c/[1+\ln(h_c/b)]=[b(1-(\nu/4))]/[2\pi(1+\nu)\varepsilon]$ [13] where $\varepsilon = 0.014$, $b= 4.2$ ^{o}A and $\nu=0.3$. For the nominal composition of 45% for the samples studied here, the equivalent composition was found to be 9% which leads to a value of 2028 ^{o}A for h_{max}. While the equivalent layer thickness of the MQW samples containing upto 8 wells is below h_{max}, this is exceeded for the sample containing 12 wells. It is thus likely that in #9966 (containing 12 MQW) strain relaxation has taken place.

3. High Resolution X-ray Diffraction

To structurally characterise the samples, high resolution x-ray diffraction patterns for a large number of symmetric and asymmetric reflections were recorded using a Philips X'PERT^{TM} material research diffractometer. The (004) reflection for #9962 is shown in figure alongside. The presence of strong satellite peaks (up to 4 orders) in the diffraction pattern highlights the coherence in the structure and the abrupt nature of the InAsP/InP interface. The same was true for other MQW samples containing 1,2 and 4 wells. The identification of the zeroth satellite peak was done through fixing the average lattice mismatch, which is independent of the reflection (hkl). The diffraction profiles were also simulated using dynamic simulation software, Philips Epitaxy^{TM}

and fitted to experimental reflection profiles. Simulations were carried out for all the samples, modeled on the basis of composition and layer thickness indicated in table I. As can be seen from figure above, a representative case of (004) reflection for #9962, the simulation and the experimental diffraction profile coincide. This match of simulation and experiment confirms the composition and well width inferred from the PL results. Besides this, the well thickness inferred independently by PL (table I) and HR XRD (table II) are in agreement.

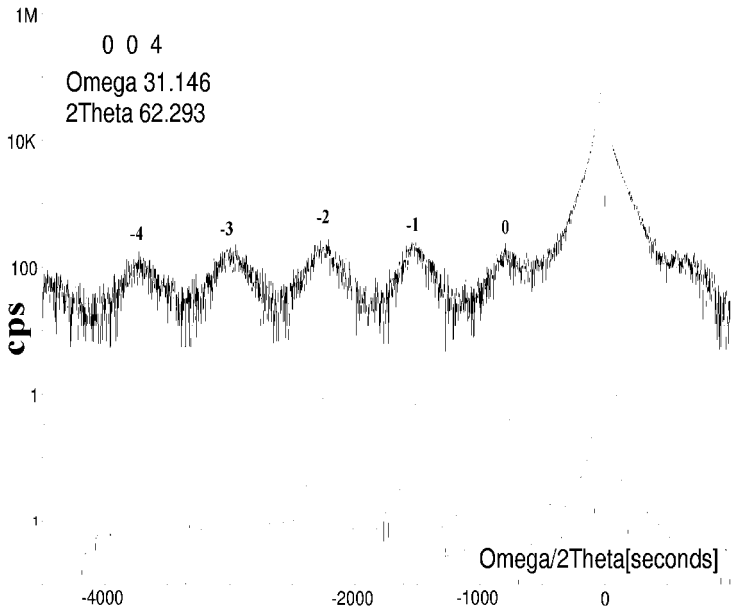


Table II

Sample	$\varepsilon_{\perp}$ (ppm)	$\varepsilon_{\parallel}$ (ppm)	$R=\varepsilon_{\parallel}/\varepsilon_{\perp}$ (%)	d_{InAsP} (in ^{o}A)
9961, 4QW	7162	513	7.1 %	53
9962, 8QW	6148	431	7.0 %	53
9966, 12QW	6054	4290	70.0 %	56

To add credence to the argument of strain relaxation in the 12 MQW sample, the MQW samples were extensively studied using asymmetric reflections to determine the extent of relaxation in these samples. The in-plane strain ($\varepsilon_{\parallel}$) as well as the out of plane strain ($\varepsilon_{\perp}$) were calculated from the angle distance of the zeroth peak and the InP substrate peak ($\Delta\omega$) using the relations $\Delta\omega=k_1\varepsilon_{\perp}+k_2\varepsilon_{\parallel}$, where $k_1 = \cos^2\phi \tan\theta_B \pm 1/2 \sin2\phi$, and $k_2 = \sin^2\phi \tan\theta_B \pm 1/2 \sin2\phi$ [14], where ϕ is the angle between the Bragg plane and the substrate plane, θ_B is the Bragg angle for the reflection, and positive sign in k_1 and k_2 is taken for the Lo (θ_B-ϕ) reflections and negative sign is taken for the Hi (θ_B+ϕ) reflections. The results presented in table II, show that the relaxation, $R = \varepsilon_{\parallel}/\varepsilon_{\perp}$, is about 70 % for #9966 as against 7 % for other samples, proving that the 12 MQW has relaxed as inferred earlier by PL and critical thickness calculation.

CONCLUSION

In this work, it has been possible through feedback from photoluminescence and x-ray studies, to grow high quality strained MQW structures of InAsP on (001) InP substrates prepared using MOCVD. The number of wells that could be accommodated within the strain relaxation limit has been determined. The HRXRD, together with the results from PL, have been used to fix the composition and well width. This has been used for designing the material structure for operation at 1.3 μm. In spite of the large strain in the individual layers, the quality of the material reveals promise of its inclusion into laser structures to yield devices that could operate efficiently.

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