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Ion beam modification of strained InGaAs/InP characterized by HRXRD, PL and AFM

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Abstract

Highly tensile strained InGaAs/InP multi quantum wells have been grown by the LP-MOVPE technique. Such samples were subjected to irradiation with 100 MeV Au^{8+} ions. These were studied as a function of fluence, then the irradiated samples were annealed by rapid thermal annealing at 700 °C for 60 s in nitrogen atmosphere. We used high resolution X-ray diffraction (HRXRD), photoluminescence (PL) and atomic force microscopy (AFM) characterization techniques to study the interfacial induced changes, band gap modifications and surface morphology. Multi quantum wells were then studied before and after irradiation.

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Keywords: Quantum wells; HRXRD; AFM; Photoluminescence; Irradiation

1. Introduction

InGaAs/InP multi quantum wells (MQW) have numerous optoelectronic applications including semiconductor photodiodes. These heterostructures are also model systems for understanding semiconductor growth processes where mixed groups of III–V interfaces are involved. Quantum well interdiffusion technology has become increasingly important in the drive towards fabrication of photonic integrated circuits due to its versatile band gap tuning process. Metal organic chemical vapour deposition (MOCVD) grown InGaAs/InP structures have been studied using various characterization techniques to understand the mismatch strain on the band gap [1]. Cornet et al. [2] studied interfacial properties of InGaAs/InP lattice-matched MQWs using HRXRD. Tuning of the band gap and interface mixing of InGaAs/InP in lattice-matched heterostructures using swift heavy ion irradiation has been studied by Dhamodaran et al. [3]. Growth of heterostructures on lattice-mismatched substrates with uniform strain in the overlayer results in additional advantages. Such strain lifts the degeneracy of light holes and heavy holes at the valence band maxima [4,5]. Lattice-mismatched heterostructures are also useful in tuning the band gap [6,7]. In strained heterostructures the critical layer thickness is important since beyond this thickness the strain relaxes and misfit defects are generated which degrade device performance. Such studies of tensile strain relief beyond the critical thickness have been carried out by many researchers [8,9]. To achieve spatial tuning of the band gap, swift

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heavy ion (SHI) beam irradiation technique has been used. SHI irradiation deposits energy via electronic energy loss creates defects into the quantum well active region, which allows atomic diffusion to take place between the quantum well and barrier materials. Ryu et al. [10] studied the diffusion coefficient of cations and anions in InGaAs/InP MQWs due to rapid thermal annealing (RTA). Mixing of InGaAs/InP due to high temperature annealing has also been studied [11]. Thermal stability of InGaAs/InP quantum wells has been studied by Peyre et al. [12]. The variation in thermal effects due to cap layers of InGaAs and InP during implantation has also been studied by Carmondy et al. [13]. Compositional ingredients in InGaAs/InP structures using HRXRD was discussed [14,15]. Interface mixing of as-grown samples has also been studied by HRXRD with reasonable accuracy [16,17]. Recently we demonstrated strain modification in lattice-matched heterostructures using SHI and extensively strain-relaxed MQWs have also been explained [18,19]. Here we present new results concerning high energy irradiation and annealing affects on InGaAs/InP MQWs characterized by HRXRD.

2. Experimental details

InGaAs/InP MQWs were grown on semi-insulating InP substrates at IEMT, Poland in a computer-controlled horizontal LP-MOVPE Axitron, model 200R&D, on 2 inch InP (1 0 0) oriented substrates. Trymethylgallium (TMGa), trymethylindium (TMIn) and 100% arsine (AsH_3) and phosphine (PH_3) were used as source gases. The operating pressure in the reactor was maintained at 100 mbar, the III/V ratio at 200 and substrate temperature was 650–700 °C. Irradiation was performed at room temperature with 100 MeV Au^{8+} ions at fluences from 5×10^{12} ions/cm^2 to 1×10^{13} ions/cm^2 by scanning over 1 cm × 1 cm area using the IUAC 15 MV Pelletron accelerator. During irradiation precautions were taken to avoid heating of sample and channeling of ions into the sample by adjusting to low beam currents and orienting the sample at an angle of about 5° with respect to the beam axis. The irradiated samples were then subjected to RTA in order to anneal out the irradiation induced damage. Annealing was done at 700 °C for 60 s in a nitrogen atmosphere with a flow rate of 1000 SCCM using RXV6 rapid thermal processor (RTP) system [20]. The surface of these samples were capped with a layer of silicon nitride (Si_3N_4), deposited by plasma enhanced chemical vapour deposition (PECVD). The Si_3N_4 layer was subsequently removed using a buffered HF solution after annealing. Pristine, irradiated and annealed samples were studied by HRXRD, PL and AFM characterization techniques. The HRXRD experiments were performed using Philip X'pert system with Cu Kα radiation. Profiles of (0 0 4) symmetric scans were recorded in $\omega{-}2\theta$ scan by optimizing the tilt and azimuthal angles. Photoluminescence studies were carried out at room temperature (295 K) as well as at low temperature (18 K). PL was excited with a YAG laser (532 nm) and detected with a LN_2 cooled InAs detector after dispersing with 2/3 m McPherson monochromator. The surface morphology of the samples was characterized by AFM (in dynamic force microscopy mode) using SPA 400, Seiko Instruments Inc.

3. Results and discussion

The difference in the lattice parameter between the $In_{0.23}Ga_{0.77}As$ and InP layers results in a tensile strain in the InGaAs layer. The tensile strain was calculated from

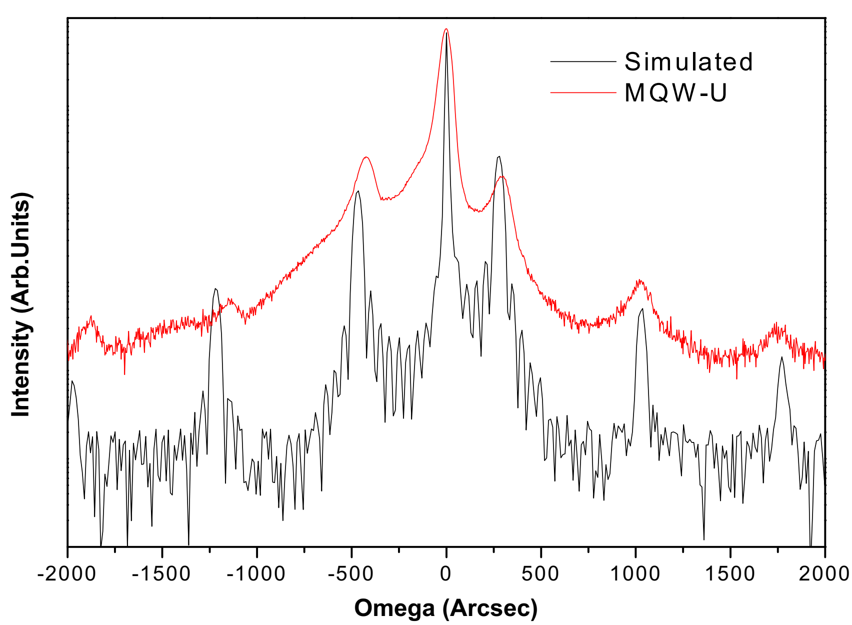

Fig. 1. HRXRD (0 0 4) scans of MQW-U and simulation fit.