# MOLECULAR BEAM EPITAXY GROWN STRAINED HETEROSTRUCTURES FOR ACTIVE REGION OF LASER DIODE WITH EMISSION WAVELENGTH 1520-1580 NM

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**Abstract.** We describe strained semiconductor heterostructures InGaAlAs/InGaAs/InP fabricated by molecular beam epitaxy and designed for active region of laser diode with emission wavelength 1520-1580 nm. Structural and optical properties of the strained semiconductor heterostructures InGaAlAs/InGaAs/InP were studied by X-ray diffraction and photoluminescence analysis. We confirm the possibility to use strained semiconductor heterostructures InGaAlAs/InGaAs/InP for active region of laser diode with 1.6 % lattice mismatch between InGaAs quantum wells and InP substrate.

## 1. Introduction

Traditional semiconductor materials for active regions of laser diodes (LD) with emission wavelength 1520-1580 nm are quaternary solid solutions InGaAsP and binary compounds InP. Heterostructures based on InGaAsP/InP are usually grown by vapor phase epitaxy (VPE) [1]. An alternative approach for formation of LD active regions is a use of strained semiconductor heterostructures (SSH) based on triple and quaternary solid solutions InGaAs or InAlGaAs. Quantum-dimensional heterostructures with strong localization of electrons in the quantum well (QW) can be formed by this approach, and as the result one can fabricate LDs with high temperature stability of lasing threshold current. InGaAs and InAlGaAs material systems are suitable for growing high-strained heterostructures with the lattice mismatch parameter between QW material and substrate material about 1-2 %. The point is that such substantial mismatch will increase the differential gain of LDs [2-5]. If we use the SSH InAlGaAs/InGaAs/InP there appears an offset of conduction band at the heterointerface. The ratio of the offset magnitude to the change of band gap $\Delta Ec/\Delta Eg$ for the SSH InAlGaAs/InGaAs/InP can reach 0.7, while the ratio for heterostructure InGaAsP/InP is only 0.4. There is high contrast of refractive index at the heterointerfaces when one uses the SSH InAlGaAs/InGaAs/InP instead InGaAsP/InP heterostructures [6-8]. Larger differential gain, larger quantum efficiency and lower temperature sensitivity of the SSH InAlGaAs/InGaAs/InP are the main advantages in comparison to InGaAsP/InP heterostructures [9, 10]. Also molecular-beam epitaxy (MBE) provides an opportunity to fabricate the SSH InAlGaAs/InGaAs/InP with a large lattice mismatch parameter between quantum-dimensional layers and with a greater number of QWs in comparison to VPE method without degeneration of a structural quality.

## 2. Experimental

SSH InGaAlAs/InGaAs/InP on the substrate InP (100) were fabricated by MBE on the Riber MBE49 growth system at the company "Connector Optics". We fabricated samples with lattice mismatch parameter $f$ that is defined as:

$$f = \frac{a_2 - a_1}{a_1},$$            (1)

where $a_1$ is the lattice parameter of InP substrate and $a_2$ is the lattice parameter of InGaAs QW. Each sample consisted of 5 pairs of alternating narrow-gap InGaAs QWs and wide-gap InGaAlAs barriers. All SSH contained the same $In_{0.53}Al_{0.20}Ga_{0.27}As$ barrier layers, but composition and thickness of QWs were changed to get different lattice mismatch parameters $f$ and photoluminescence (PL) peak wavelength ~ 1520 nm. We fabricated the SSH samples with mismatch parameter $f$ InGaAs/InP: 1.0, 1.3 and 1.6 %. Composition, thickness, lattice mismatch and PL peak wavelength of the barriers and QWs are given in Table 1.

Table 1. Properties of heterostructure InGaAlAs/InGaAs/InP.

| № | Barrier material | QW material | Thickness of barrier/QW, nm | Mismatch, % | PL peak wavelength, nm |
|---|---|---|---|---|---|
| C327 | $In_{0.53}Al_{0.20}Ga_{0.27}As$ | $In_{0.67}Ga_{0.33}As$ | 10.0/3.2 | 1.0 | 1519 |
| C328 | $In_{0.53}Al_{0.20}Ga_{0.27}As$ | $In_{0.72}Ga_{0.28}As$ | 10.0/2.7 | 1.3 | 1521 |
| C331 | $In_{0.53}Al_{0.20}Ga_{0.27}As$ | $In_{0.76}Ga_{0.24}As$ | 10.0/2.5 | 1.6 | 1524 |

Structural properties of the samples were characterized by X-ray diffractometer produced by PANanalytical Company. PL spectra of the samples were detected using PM2000, VerteX, Nanometrics with InGaAs photodetector.

## 3. Results and discussion

Diffraction curves of the samples with mismatch $f$ InGaAs/InP 1.0 %, 1.3 % and 1.6 % are shown in the Fig. 1a, Fig. 1b, and Fig. 1c, respectively. X-ray diffraction analysis (XRDA) was performed in the angular range $2\theta = 31-32.5º$ and in a parallel geometry of X-ray beam. The X-ray power source of 1.8 kW was a tube with copper anode ($\lambda = 0.154187$ nm). Thickness and composition of the SSH were defined by the data of XRDA.

XRDA of the samples confirmed agreement between measured and predetermined values of elemental composition and thickness of the SSH. Region of diffraction curve corresponding to the diffraction from the QW (wide maxima) moved to the left with increase of mismatch $f$, while the peak corresponding to the diffraction from the InP substrate stayed in the same position. Larger mismatch $f$ did not lead to degeneration of the SSH structural quality, that was confirmed by common type of diffraction curves with big number of narrow diffraction peaks in the angular range of detection.

Optical properties of the SSH were studied by PL using a laser beam with emission wavelength of 532 nm. PL spectra measured at room temperature with pump power of 4 and 43 mW are shown in Fig. 2.

Intense PL with peak wavelength 1521±3 nm was observed for all samples. When we changed pump power up to 43 mW we observed slight shift of the PL peak to shorter wavelengths due to the reduction of QW thickness. PL was observed approximately with the same intensity for all samples independently from mismatch $f$, and there was a linear change in the intensity of the PL signal with increase of pump power. Saturation of the PL signal was not observed with the change of pump power.
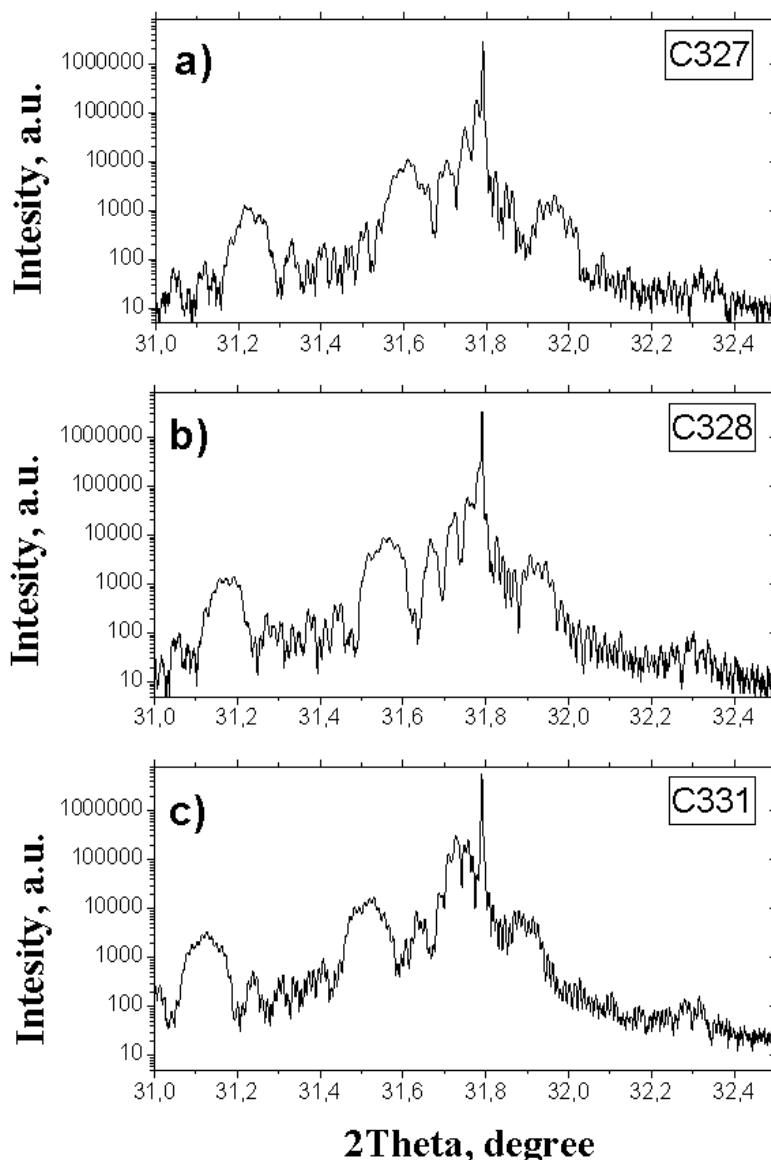
**Fig. 1.** Diffraction curves recorded in the angular range $2\theta = 31-32.5°$ for SSH InGaAlAs/InGaAs/InP with mismatch $f$: a) 1 %; b) 1.3 %; c) 1.6%.

Results of the study of optical properties were confirmed the possibility of using SSH InGaAlAs/InGaAs/InP with the mismatch $f$ 1.6 % for fabrication of LD active region. Larger mole fraction of In in $In_xGa_{x-1}As$ QW and therefore larger mismatch $f$ increase differential gain of active region and improve the frequency characteristics of LD [3].

### 4. Conclusion

We grew the strained semiconductor heterostructure (SSH) InGaAlAs/InGaAs/InP with a different mismatches $f$ InGaAs/InP: 1.0, 1.3 and 1.6 % by molecular-beam epitaxy. X-ray diffraction analysis of the samples demonstrated a good agreement between measured and predetermenid values of elemental composition and layer thicknesses of the heterostructures. Study of the optical properties of the samples confirmed the possibility to use developed SSH InGaAlAs/InGaAs/InP with a mismatch $f$ InGaAs/InP 1.6 % for active regions of the laser diode with emission wavelength 1520-1580 nm.

Investigated heterostructures were grown by MBE technique with Riber MBE49 system at the company "Connector Optics".
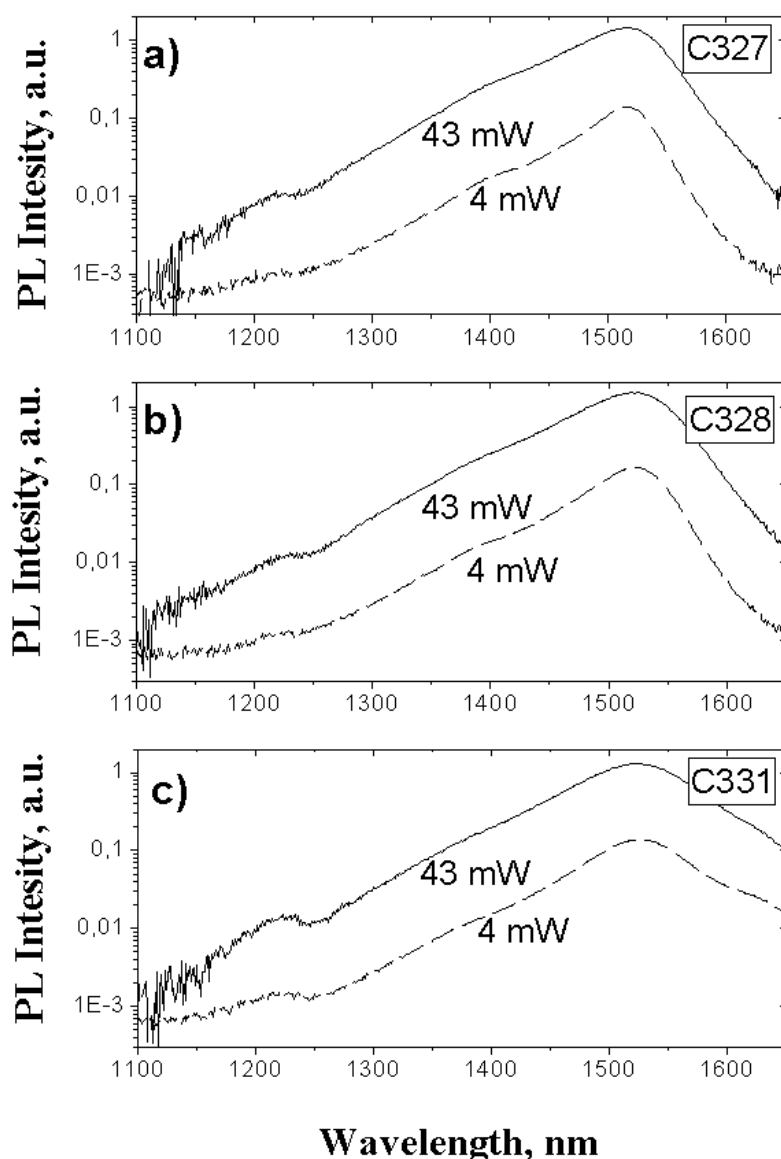
**Fig. 2.** PL spectra measured at the room temperature and with pump power of 4 and 43 mW, for SSH InGaAlAs/InGaAs/InP with mismatch $f$: a) 1 %; b) 1.3 %; c) 1.6%.

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