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PROMIS

PROMIS – Postgraduate Research on Dilute Metamorphic Nanostructures and Metamaterials in Semiconductor Photonics

Marie Sklodowska-Curie Initial Training network (ITN)

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Report on Deliverable D 1.1: (InGa)(AsN)/GaAs quantum wells emitting at 1.31 and 1.55 µm

Introduction

Silica optical fibres are nowadays the backbone of photon-based telecommunications. Optimal performance (*e.g.*, high bit rate and low signal regeneration frequency) of optical fibres relies on the capability to transmit optical signals with minimum attenuation and dispersion. In silica, these effects are sizably reduced for signal wavelengths equal to 1.31 and 1.55 µm. Therefore, detectors and light sources operating at those wavelengths are of pivotal importance. This requires semiconductor materials with band gaps between 0.95 and 0.78 eV. To date, the materials combination allowing operation in that band gap interval is InGaAsP grown on InP substrates. However, InP-based systems suffer from the absence of a good combination of alloys to produce Bragg reflectors with adequate thermal conductivity. Bragg reflectors are indeed indispensable for the fabrication of vertical-cavity lasers. In this respect, InGaAsN grown on GaAs features several advantages comprising easy monolithic integration with GaAs high-speed electronics.

Research objectives and background

Efficient light sources can be obtained by confining electrons and holes into nanometre-sized regions, where strong quantum confinement effects take place. Semiconductor quantum dots (QDs) are the most widely investigated nanostructures for the attainment of such strong confinement conditions. Researchers have developed over the past decades many methods to fabricate QDs aiming at the realization of threshold-less lasers and efficient single-photon sources for quantum information applications. However, QDs emitting in wavelength regions of interest for telecommunications are realizable only by few nanostructured materials. Among these, self-assembled InAs/GaAs QDs are those showing the best characteristics to date. However, the growth of self-assembled QDs is based on a spontaneous bottom-up formation process whereby precise control over the QD size and position can be hardly obtained. Recently, we developed an alternative route toward the patterning of III-V semiconductor heterostructures based on the hydrogen-induced passivation of N atoms in GaAsN crystals [1]. Indeed, H atoms form stable N-2H-H complexes that wipe out the N effects in the lattice thus modifying in a controllable manner the electronic properties, most notably the band gap energy, of these materials [2]. In particular, H binding to N atoms in GaAsN leads to an increase in the band gap energy of the N-containing material. Therefore, by allowing H incorporation in selected regions of the sample, it is possible to attain a spatially controlled modulation of the band gap energy [3].

A first objective of our WP is to extend this approach to InGaAsN material, whose band gap energy falls in the desired wavelength range.

Description of Work

Testing of hydrogen effects on the electronic properties of InGaAsN quantum wells (QWs) has been performed on samples previously acquired from the University of Wuerzburg (UW) and from the École Polytechnique Fédérale de Lausanne (EPFL). Photoluminescence (PL) measurements have been employed to address the band gap energy of the InGaAsN QWs before and after H irradiation. Growth of InGaAsN QWs at UMR is currently under development and, as soon as samples from UMR will be available, similar tests will be performed. Two couples of InGaAsN/GaAs single QWs were grown by solid source molecular beam epitaxy (MBE) at UW. One couple consists of an N-free InGaAs QW with In concentration equal to 0.32 and an N-containing QW with the same nominal In content and N concentration equal to 0.015. Another QW couple consists of an N-free InGaAs QW with In concentration equal to 0.38 and an N-containing QW with the same nominal In content and N concentration equal to 0.022. All QWs are 6.5 nm thick. The sample from EPFL was grown by metal organic vapor phase epitaxy (MOVPE) and is a double QW structure containing 8 nm thick QWs. The nominal In concentration is nominally equal to 0.27 for both QWs, of which one QW is N-free and the other contains N atoms with concentration equal to 0.017.

Results

Figure 1 shows the PL spectra at room temperature of the two couples of QWs grown at UW. The spectra demonstrate the possibility to achieve light emission at 1.3 and 1.55 µm upon N incorporation.

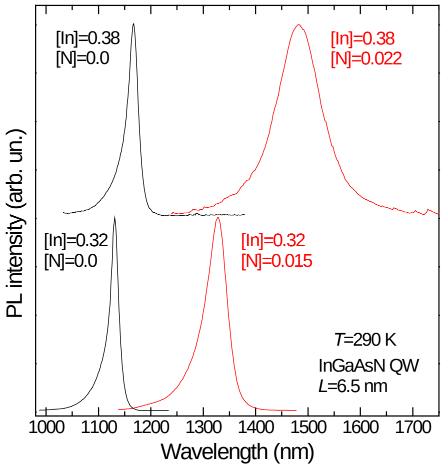

Figure 1. Photoluminescence (PL) spectra recorded at room temperature on two couples of InGaAsN quantum wells and on their N-free reference. Notice the large red-shift of the PL emission peak.

The consequences of H irradiation on the N-containing samples are displayed in Figure 2. The PL spectra were recorded at *T*=150 K because H causes a decrease in the PL signal. The origin of this large decrease in the emission efficiency was not found in GaAsN samples. The presence of In leads likely to an augmented "fragility" of the crystal with respect to defects induced by the hydrogenation process. This effect needs further investigation and it will studied in the samples that are being grown at UMR. Most importantly, it is worth noticing the sizable blue-shift of the PL peak following hydrogenation. In particular, the band gap energy of the N-passivated QWs approaches that of the N-free reference samples.

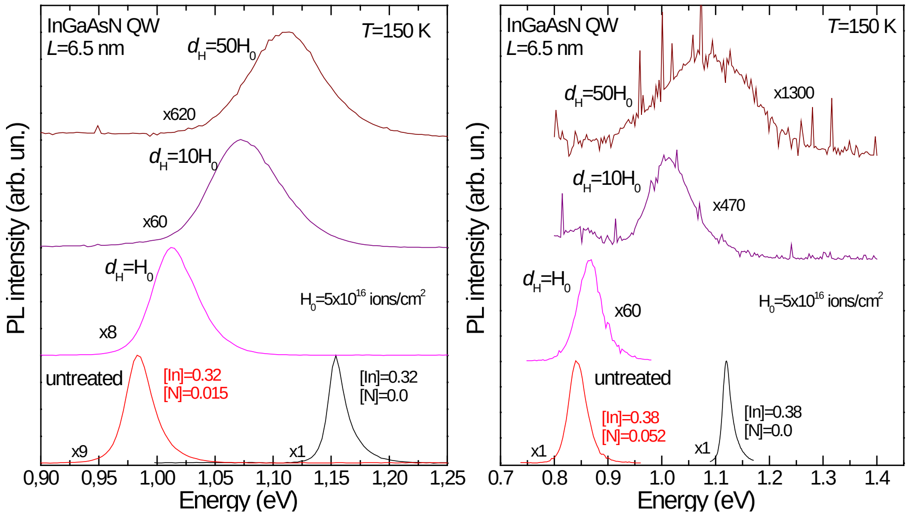

Figure 2. Photoluminescence (PL) spectra recorded at 150 K on InGaAsN quantum wells irradiated with different hydrogen dose d_H. The N-free reference QW is also shown. Notice the large blue-shift of the PL peak energy with increasing d_H caused by the passivation of the N electronic activity in the crystal. The PL intensity multiplication factors are shown.

Very similar effects were observed in the EPFL samples, whose PL spectra for different H doses are shown in Figure 3. Also in this case, a large increase in the band gap energy is found in the N-containing QW.

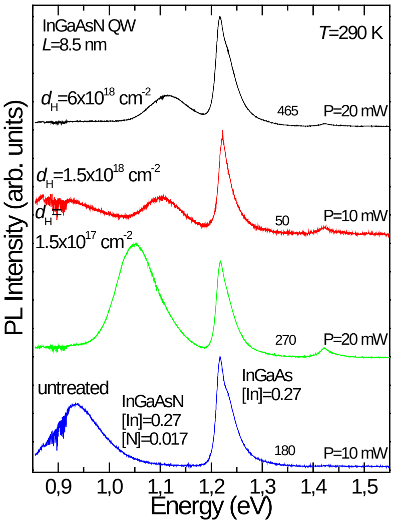

Figure 3. Photoluminescence (PL) spectra recorded at room temperature on a double QW structure with an InGaAs and an InGaAsN QW. The sample was irradiated with different H dose d_H.. Notice the large N-induced blue-shift of the PL peak energy of the N-containing QW, while no effect is observed on the InGaAs reference QW. The signal intensity is displayed for each spectrum along with the laser power employed. In this case, large PL signal decrease is observed with H incorporation, but at the largest dose employed.

Conclusion

We have shown the possibility to extend to InGaAsN the effects of hydrogen irradiation already observed in GaAsN. Sample damage following H incorporation has been observed in MBE-grown QWs, while this detrimental effect has been shown to be smaller in MOVPE samples. Work is in progress to grow high-quality InGaAsN samples at UMR by MOVPE.

References

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[2] R. Trotta et al., Adv. Funct. Mater. **22**, 1782 (2012).
[3] S. Birindelli et al., Nano Lett. **14**, 1275 (2014).

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