

LUMINESCENCE AND TRAPPING OF LIGHT IN POROUS InP NETWORKS

E. Monaico¹, V. V. Ursaki², A. Burlacu¹ and I. M. Tiginyanu^{1,2}

¹ *National Center for Materials Study and Testing, Technical University of Moldova, MD-2004 Chisinau, Moldova*

² *Laboratory of Low-Dimensional Semiconductor Structures, Institute of Applied Physics, Academy of Sciences of Moldova, MD-2028 Chisinau, Moldova*

The wide electronic band gap of III-V compounds and the possibility to produce different kinds of pores with sizes down to a few tens of nanometers depending on etching conditions designate porous III-Vs as promising materials for different photonic applications. Electrochemical etching was shown to represent a unique approach for tailoring linear and nonlinear optical properties of III-V compounds. Porosity-induced modifications of the phonon spectrum and new possibilities for optical phonon engineering in polar materials were explored [1-3]. The enhanced optical second harmonic generation (SHG) was found to be inherent to porous membranes of GaP [4,5] and InP [6]. A significant enhancement in both the radiated terahertz field and second-harmonic radiation from the porous InP(100) surface, relative to the bulk InP(100) surface, was recently observed [6,7]. Photon-assisted electrochemical etching of semiconductor materials provides a cheap nonlithographic method for preparation of random media with controlled morphology starting from discrete scatterers with strong short-range disorder, up to smooth long-range inhomogeneity in weakly disordered media. In case of a non-uniform distribution of pores the membranes become optically inhomogeneous which leads to pronounced light scattering and trapping of light inside the porous network. Different types of laser cavity can be engineered with special porosity design. Gain of luminescence was recently observed in specific porous CdSe nanostructures and attributed to the formation of ring microcavities for light in the porous network [8].

In this paper we investigate the effect of light trapping inside highly scattering InP porous layers on the luminescence properties of the material

Bulk n-type (100)-oriented InP wafers with the thickness of 0.5 mm and electron concentration $n = 10^{18} \text{ cm}^{-3}$ at 300 K were used in this work. The porosity was introduced by

etching in an HCl-based solution under anodic potential of 9 V and in-situ UV illumination for 10 min.

The photoluminescence (PL) was excited by the 514.5 nm line of an Ar⁺ SpectraPhysics laser and analyzed in a quasi-backscattering geometry through a double SDL-1 (LOMO) spectrometer. The signal from a FEU-62 photomultiplier amplified by a Unipan 232 lock-in nanovoltmeter was introduced in an IBM computer via the IEEE-488 interface. The resolution was better than 2 meV. The samples were mounted on the cold station of a LTS-22-C-330 optical cryogenic system. The excitation power density was decreased by using neutral filters when measuring the dependence of luminescence upon the excitation power density.

Fig. 1 presents the top view SEM image taken from a porous InP layer. One can estimate from Fig. 1 that the respective etching conditions result in an average pore density of $1 \times 10^9 \text{ cm}^{-2}$ with a random distribution of pores with average dimensions of 200 nm. Fig. 2 illustrates the evolution of the PL spectra of this sample with the temperature increase. At low temperature the luminescence spectrum is predominated by a near-bandgap PL band at 1.412 eV, and a PL band at 1.376 eV with a phonon replica at 1.333 eV. The energy separation between the PL bands at 1.376 and 1.333 eV (43 meV) corresponds to the LO phonon energy in InP [9]. The PL band at 1.376 eV in InP is commonly believed to come from donor-acceptor (DA) recombination [10,11]. With increasing temperature the PL intensity is redistributed in the favor of the near-bandgap luminescence. This behavior is explained by the quenching of the DA luminescence due to the ionization of the impurity with smaller binding energy involved in DA transitions.

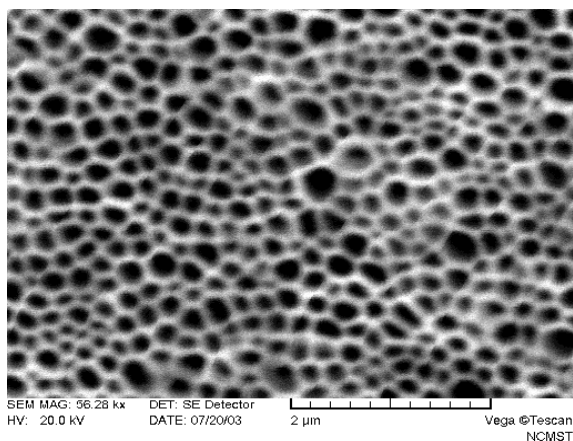


Fig. 1. SEM image taken from a porous InP network.

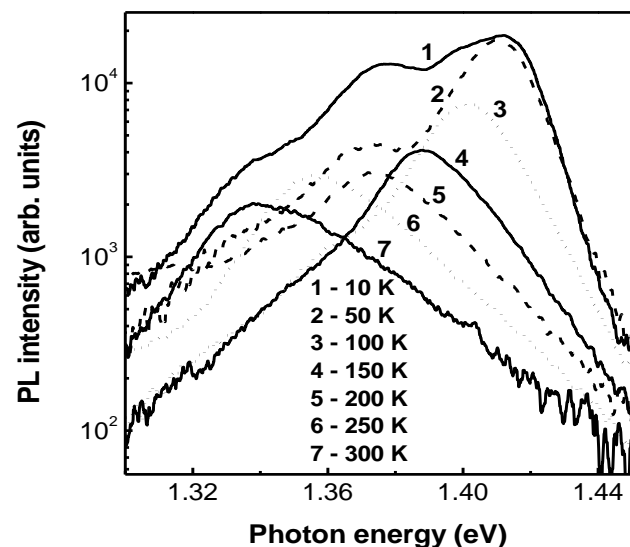


Fig. 2. PL spectra of a porous InP sample measured at different temperatures with the excitation power density of 50 W/cm^2 .

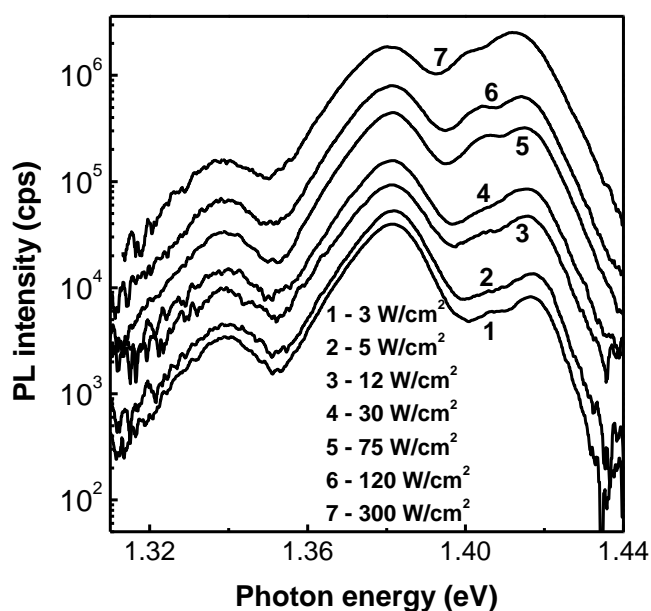


Fig. 3. PL spectra of a bulk InP sample measured with different excitation power density.

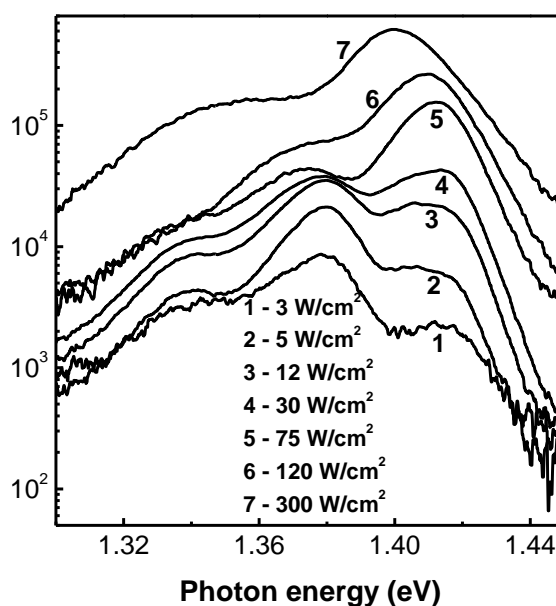


Fig. 4. PL spectra of a porous InP sample measured with different excitation power density.

Figs 3 and 4 compare the evolution of the PL spectra with the increase of excitation power density in bulk and porous samples, respectively.

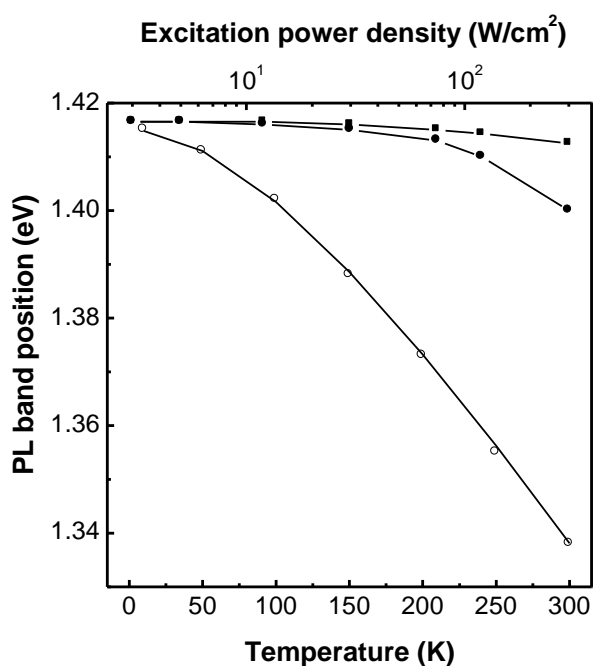


Fig. 5. Temperature (open symbols) and excitation power density (closed symbols) dependence of the near band-edge luminescence in a bulk (squares) and porous (circles) sample.

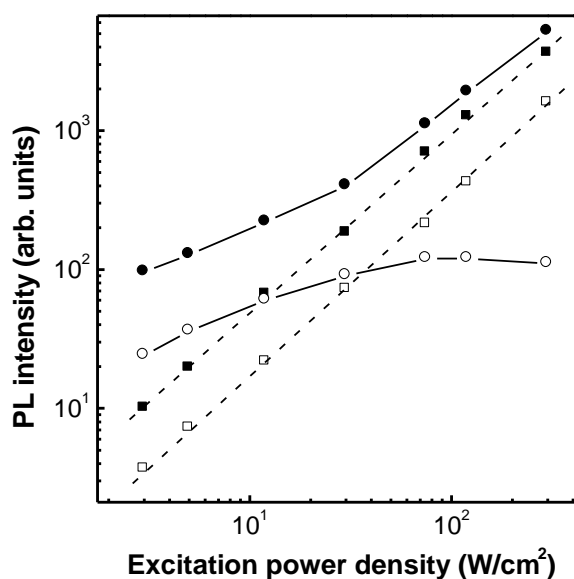


Fig. 6. Excitation power density dependence of the near band-edge (squares) and DAP (circles) luminescence in a bulk (closed symbols) and porous (open symbols) sample.

The PL bands shift to lower energies with the increase of excitation power density. We attribute this shift to the local heating of the sample under the action of excitation laser radiation. A weak

dependence of PL spectra upon the excitation power density is observed in the bulk material, while in porous layers this dependence is much stronger at excitation power density higher than 30 W/cm². Fig. 5 presents the temperature and excitation power density dependence of the near band-edge luminescence in the bulk and porous samples. The temperature dependence is well fitted with the phenomenological Varshni formula [12]

$$E(T) = E_0 - \alpha T^2 / (T + \beta), \text{ with } E_0 = 1.415 \text{ eV}, \alpha = 4.7 \times 10^{-4} \text{ eV K}^{-1}, \text{ and } \beta = 250 \text{ K parameters.}$$

From the dependence of the energy position of the near band-edge PL band upon the excitation power density one can estimate that the bulk sample is heated up to 40 K under the laser radiation of 300 W/cm² power density, while the porous sample is heated up to 100 K. We attribute this difference to the trapping of the laser light inside the porous network which results in a more effective heating of the sample. The effect of the light trapping is also reflected in the dependence of the DAP PL band intensity upon the excitation power density as illustrated in Fig. 6. As one can see from Fig. 6, the intensity of the DAP PL band decreases much faster in the porous sample as compared to the bulk one.

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