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Invited Paper

Laser nanosources based on planar photonic crystals as new platforms for nanophotonic devices

P.A. Postigo [a,*], A.R. Alija [a], L.J. Martínez [a], M.L. Dotor [a], D. Golmayo [a], J. Sánchez-Dehesa [b], C. Seassal [c], P. Viktorovitch [c], M. Galli [d], A. Politi [d], M. Patrini [d], L.C. Andreani [d]

[a] *Departamento de Dispositivos, Sensores y Biosensores, Instituto de Microelectrónica de Madrid (IMM-CNM-CSIC), Isaac Newton 8-PTM, Tres Cantos, 28760 Madrid, Spain*

[b] *Laboratoire d'Electronique, Optoélectronique et Microsystèmes, Ecole Centrale de Lyon, 36 avenue Guy de Collongue, BP 163, 69131 Ecully Cedex, France*

[c] *Wave-Phenomena Group, Nanophotonics Technology Center and Department of Electronic Engineering, Polytechnic University of Valencia, Valencia E-46022, Spain*

[d] *Dipartimento di Fisica "A. Volta", Universitá di Pavia, via Bassi 6, I-27100 Pavia, Italy*

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Abstract

Two-dimensional photonic crystal lasers have been fabricated on III–V semiconductor slabs. Tuning of the spontaneous emission in micro and nanocavities has been achieved by accurate control of the slab thickness. Different structures, some of them of new application to photonic crystal lasers, have been fabricated like the Suzuki-phase or the coupled-cavity ring-like resonators. Laser emission has been obtained by pulsed optical pumping. Optical characterization of the lasing modes have been performed showing one or more laser peaks centred around 1.55 μm. Far field characterization of the emission pattern has been realized showing different patterns depending on the geometrical shape of the structures. These kinds of devices may be used as efficient nanolaser sources for optical communications or optical sensors.

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1. Introduction

The quest for compact laser sources has been a central part of research in the field of integrated optics. Photonic crystals [1] and planar photonic crystals (PPC) in particular [2] are promising candidates for the realization of compact optical nanocavities and their integration with waveguides, modulators, and detectors. So far, there have been several reports on room temperature lasing in two-dimensional PPC nanocavities [3,4] and more recently, new designs based on modification of two-dimensional (2D) photonic crystals have been proposed [5]. In this work, we show the design, fabrication and characterization of new types of two-dimensional (planar) photonic crystal structures. Some of them exhibit lasing features (like the single defect or the ring-like structures), whereas others are good candidates for laser emission, with very low group velocities for specific regions of the reciprocal lattice.

* Corresponding author.
E-mail address: aitor@imm.cnm.csic.es (P.A. Postigo).

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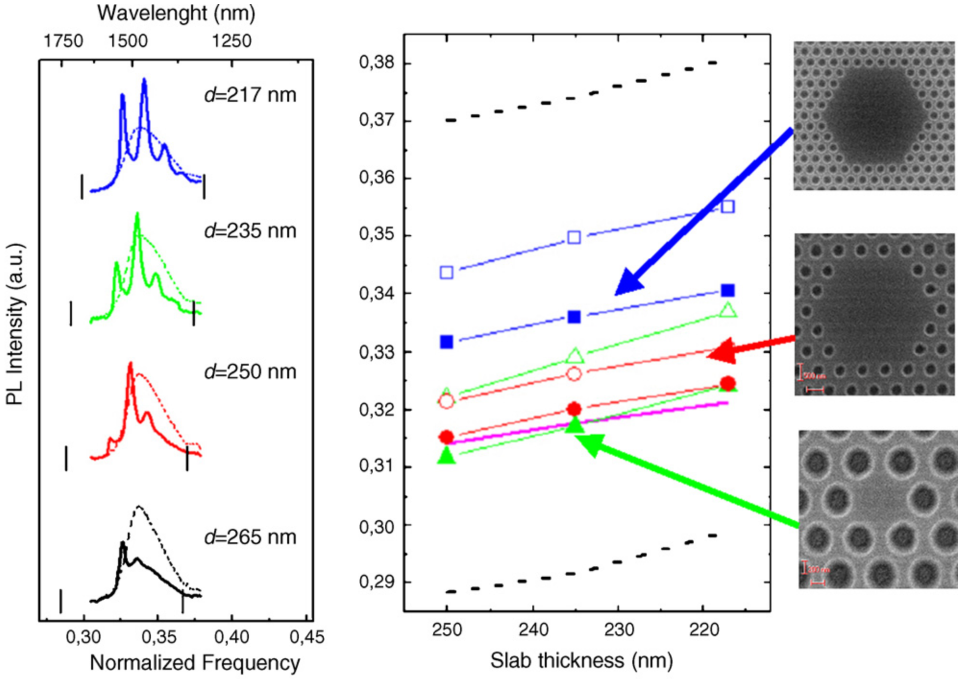

Fig. 1. Left panel: Spontaneous emission spectra of a H5 cavity as the thickness are decreased. Right panel: Shift in energy of the cavity modes as the thickness is decreased for different cavities H5, H3 and H1 (see Ref. [7]).

We have measured the spectral position of the laser emission and under pulsed optical excitation. Finally, we have obtained far field images of the emission patterns that change depending on the geometrical shape of the structure used. Laser emission either in whispering gallery modes extended along whole rings or located in nanocavities placed in the corners of the ring have been observed.

2. Experimental

We have used typically InP-based epitaxial semiconductor as the active material. Molecular beam epitaxy has been used to grow heterostructures typically comprising four InAsP quantum wells (5 nm thick) that emit in ~1.5 μm, separated by 20 nm thick barriers. The total structure is ~237 nm thick. The epitaxial material is wafer-bonded to a Si substrate by a SiO_2 layer. To process the samples we have used electron-beam lithography and reactive ion beam etching (RIBE) [7] or CH_4/H_2 reactive ion etching (RIE) [6]. Different patterns consisting of arrays of circles with triangular symmetry can be exposed. Lattice parameters a ranging between 400 and 500 nm and radius r of the holes from 120 to 150 nm were used to obtain filling factors ~40% and $r/a \sim 0.3$ [7]. Optical characterization has been performed by optical micro-photoluminescence spectroscopy. Optical excitation is performed using a 780 nm pulsed laser diode focused by a high NA microscope objective to form a spot of ~2.5 μm of diameter. Using this setup we have studied the effect of the third dimension (the thickness) in the spontaneous emission of planar photonic crystal microcavities, formed by the removal of one or more holes in a triangular lattice of holes. Fig. 1 shows the blue-shift in the cavity modes confined in the photonic crystal microcavities when the thickness of the slab is varied uniformly by accurately controlled RIBE etching. The shifts in the wavelength of the cavity modes are around 2 nm towards shorter wavelengths per nanometer reduced in the thickness of the slab [7]. This tuning effect after fabrication is important for the case of structures with quantum dots (QD) inside photonic crystal cavities, where a post-fabrication tuning is very useful in order to achieve good coupling between several or single QD emission and the cavity mode [8]. All of these cavities are good candidates for laser emission since the light is strongly confined. The light inside the H1-type cavity spreads in a size of around one half of the lattice parameter (225 nm) and has a well-defined energy. This localisation of light in space and energy can be used for the fabrication of submicronic, laser nanosources able to be integrated in multi-wavelength laser devices. Fig. 2 shows the laser