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Bonded photonic crystal components and circuits: Toward 2.5-D micro-nano-photonics

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Abstract: We will present various surface addressable active devices and surface emitting microlasers. These 2.5D structures combine planar photonic crystal resonators and vertical stacks. They can be fabricated using InP/Silicon wafer bonding, micro-nano-patterning and MOEMS technology.

Introduction:

Planar photonic crystal (PC) structures fabricated on semiconductor membranes are among the best candidates to build ultra-compact non linear optical devices including microlasers, modulators or swiches. Various designs including high quality factor PC microcavities were proposed and could be used as basic building blocks for highly integrated photonic integrated circuits. In order to exhibit a low operation threshold, PC cavities should be designed in such a way to minimize the vertical optical losses, while maintaining a limited modal volume.

A radically different approach consists of the exploitation of slow light optical modes that stand over the light line of PC structures. The goal is then not to inhibit, but to control and to use the interplay between “in-plane” resonances in PCs and free space modes and “vertical” resonances. Enabling manipulation of light in the three dimensions of space by using a combination of intrinsically planar 1D or 2D PC structures is referred to as a “2.5D micro-nanophotonics” approach.

In order to stack such membranes, we have developed two technological strategies. The first one is based on InP wafer bonding onto a silicon host wafer, that may include a Si/SiO_2 bragg reflector. The second one, that combines micro-nanopatterning of holes or slits and sacrificial layer etching, consists in the fabrication of a PC structure on one or more superimposed InP membranes.

Different examples of micro-nanostructures and devices based on this approach will be presented in this communication.

PC-based surface emitting microlasers:

A first activity concerns the control of high-Q slow light modes in PCs in order to achieve low threshold photonic crystal-based surface emitting lasers, surface addressable all-optical modulators and bistable devices. In particular, by using a resonant mode around the Γ-point (i.e., that may interact with free-space modes along the vertical direction), Q-factors and laser threshold can be controlled by combining such InP-based planar PC resonators and vertical Si/SiO_2 Bragg reflectors [1], see Fig. 1.

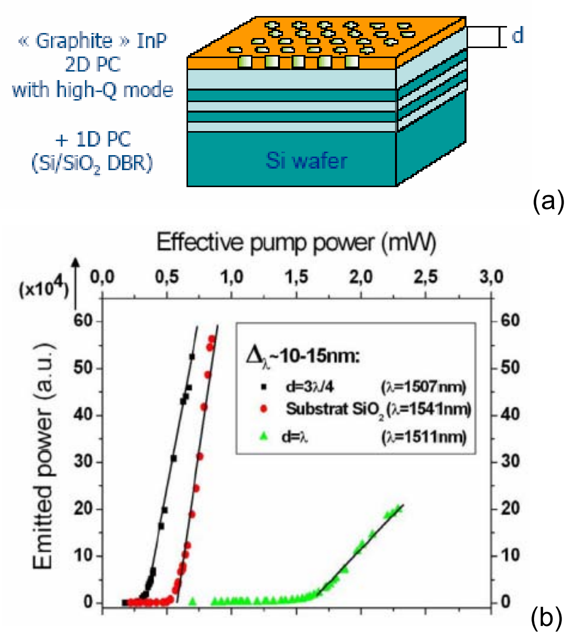

Fig. 1: Schematic view of a photonic crystal surface emitting laser assisted by a SiO_2/Si Bragg reflector (a), and L-L characteristics of such lasers with different values of d (distance between the PC and the reflector). These characteristics are compared to those of a reference photonic crystal laser, with no Bragg reflector.

Using this approach, the lasing threshold could be reduced down to ~200µW using an InAsP/InP multi-quantum well, and CW room temperature laser operation was achieved.
Moreover, on similar structures, laser emission could be achieved at room temperature using a single layer of InAs/InP quantum dots as the gain material [2].

PC-assisted VCSELs:
Another key feature of PC low group velocity modes is their ability to reflect light very efficiently. Indeed, by using and combining such resonances, and provided their Q-factor is limited, PC membrane may exhibit a very high reflectivity (possibly over 99.9%), on an extended wavelength range (typically some 100nm). We have proposed to combine such PC reflectors, processed using an SOI waveguide, together with an InP multi-quantum well heterostructure, and a standard top Bragg reflector (see Fig. 2). This constitutes an alternative to classical VCSELs where the PC membrane may control the lateral size of the resonant mode, and the polarization of the emitted light.

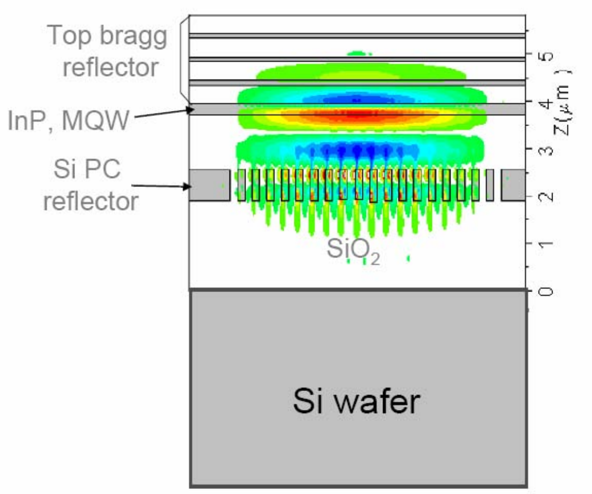

Fig. 2: Schematic cross-section view of the PC-VCSEL, and mapping of the electromagnetic field at resonance, as calculated by FDTD.

Another technological approach that may be used to reach the same goal is based on the combination of a PC membrane with a vertical Fabry-Perot-like cavity that both include the gain material and an air-gap. Corresponding devices were fabricated using a similar design as in the latter case, and vertical emission laser was achieved [3], see Fig. 3. These structures operate under optical pumping, exhibit a threshold of 15mW and a high directivity of the emission (+/- 4.5°).

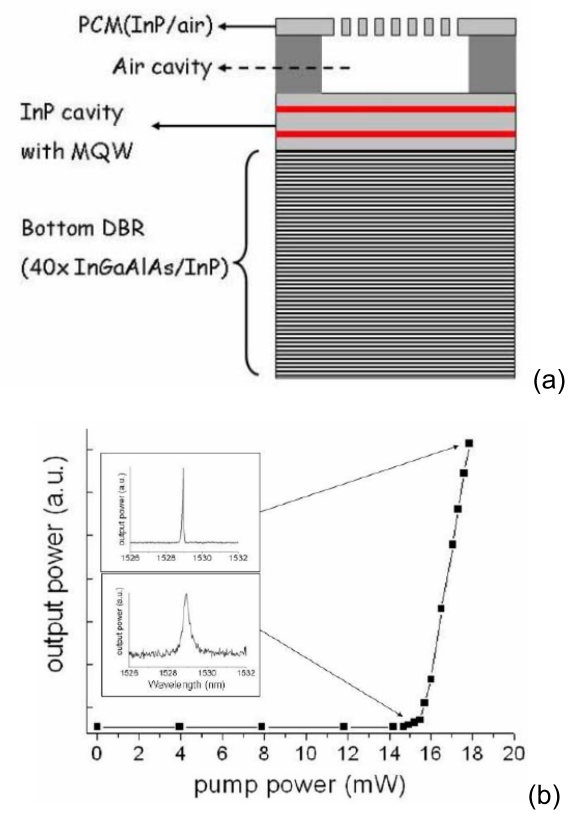

Fig. 3: Cross-section schematic view of a photonic-crystal assisted VCSEL (a), L-L characteristics, and spectra of the laser mode, over and under the laser threshold

The combination of slow light modes in PC membranes, vertical stacks and Fabry-Perot resonances could enable much more structure and devices development, including the integration of microlasers and passive integrated waveguides and circuits, 3D photonic intregrated circuits, as well as selective and tunable optical PC-MOEMS filters. Some of the perspectives will be discussed in the communication.

[1] B. Ben Bakir et al., Appl. Phys. Lett. (2006), **88** ,p.081113
[2] B. Ben Bakir et al., Opt. Express (2006), **14**, p.9269
[3] S. Boutami et al., to appear in Electron. Lett.