InP 2D Photonic Crystal Lasers integrated onto SOI waveguides

Y. Halioua[1,2], T. Karle[1], I. Sagnes[1], G. Roelkens[2], D. Van Thourhout[2], R. Raj[1] and F. Raineri[1,3]

[1]Laboratoire de Photonique et de Nanostructures (CNRS UPR20), Route de Nozay, 91460 Marcoussis, France
[2]Ghent University – IMEC, Photonics Research Group (INTEC), Sint-Pietersnieuwstraat 41, B-9000 Ghent Belgium
[3]Université Paris-Diderot, 75205 Paris Cedex 13, France
E-mail: fabrice.raineri@lpn.cnrs.fr

Abstract: We report on the fabrication of InP-based 2D photonic crystal lasers operating around 1.5µm at room temperature integrated and evanescently coupled to SOI waveguides. Laser operation is obtained from a line defect structure accurately aligned on top the SOI circuitry.

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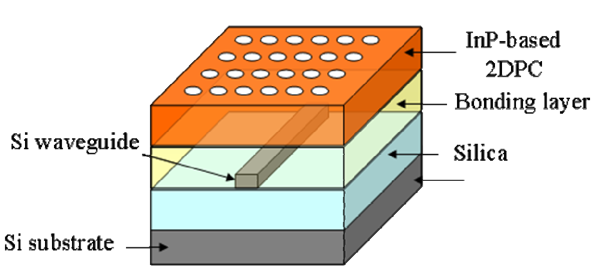
All-optical devices will play a crucial role in the next decades, in the domain of information and communication technology due to their ability to bring efficient solutions to data transmission and processing. In this context, the domain of integrated optics has emerged as a major actor both in the industrial and academic scientific communities. "Integrated" takes on a particular meaning in that the propagation as well as the processing of signals takes place on a single platform. Thus the photonic circuits should be constituted of elements able to control perfectly the propagation of light with a view to realising "passive" functions such as guiding and filtering as well as elements dedicated to active functions such as emission, switching and a multitude of others, capable of manipulating optical information at will. In this context, two principal technological choices have emerged: Silicon Photonics and III-V semiconductors photonics.

Silicon is a thoroughly studied material, and unsurpassed in quality of fabrication with very high yield due to decades of investment from the microelectronics industry. Because of the favourable electronic, optical, and physical properties of silicon and the mature complementary metal-oxide semi-conductor (CMOS) fabrication & processing technology, large-scale integration of functional optical devices becomes possible, including integration with relatively complex electronic components. However, Silicon, due to its indirect electronic band gap is not the ideal material for light emission and light control; III-V-based semiconductors alloys are far more suitable but not so well suited for guiding the light in ultra small waveguides because of the absence of a natural oxide and because of a less mature processing technology. But the direct band-gap of most III-V materials makes efficient stimulated emission possible, which enables the realization of lasers, amplifiers, detectors and modulators. The combination of silicon photonics, enhanced by III-V based optical functions could combine the best of both worlds leading to highly versatile silicon/III-V photonics platform and leading the way to large scale photonic integration [1,2].



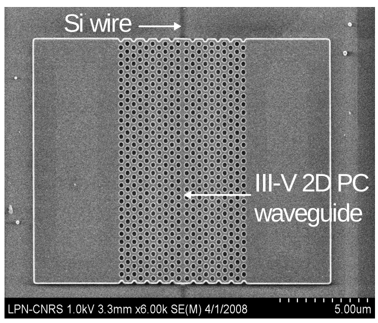


Fig.1. a) Schematics of the hybrid structure. b) SEM image of the 2D PC waveguide aligned to the Si Wire

We investigate a new optical platform based on the heterogeneous integration of InP-based active 2D Photonic crystals (PCs) on top of silicon on insulator (SOI) waveguides. The platform consists in a two level structure (see Fig. 1.a)). The bottom level is composed of SOI narrow waveguides (width ~500nm and ~220nm height) where the light propagates in a passive way, i.e. without nonlinear interaction with the matter. The upper layer is a thin membrane (~265nm) of InP which contains an active medium. Here, the light interacts strongly with the matter to achieve laser emission. The 2 levels are separated by a thin transparent layer of low refractive index (n=1.54 for BCB) allowing evanescent coupling.

The first challenge to tackle is the fabrication of this "hybrid" structure. The fabrication relies on the adhesive bonding of the InP-based heterostructure on the SOI wires through the use of the planarising polymer BCB. The success of the fabrication also depends obviously on the quality of the two parts (SOI and InP structures) and to a very large extent on the accuracy and the repeatability of the alignment of the PC structures with subjacent waveguide. 500nm wide Silicon waveguides are fabricated at in the CMOS fab of IMEC, Leuven (Belgium) using 193nm DUV lithography on SOI, InP wafers being grown at LPN. Alignment markers written on same mask level as the waveguides allow us to align the PC level defined by electron beam lithography to the Si waveguides. The PC is patterned in the III-V membrane using reactive ion etching and inductively coupled plasma etching. SEM measurements (see Fig.1.b)) allow us to demonstrate that our 2DPC structures are aligned on top of SOI wires with accuracies better than 30nm.

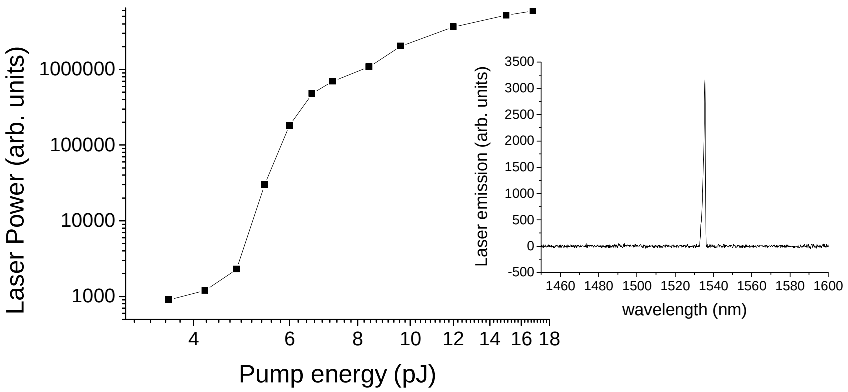


Fig.2. Laser power vs Pump energy in log-log scale. Inset: Laser spectrum for Pump energy = 9.6pJ.

The sample under study is a 2DPC line-defect W1 waveguide made in a 265nm thick InP membrane embedding 4 InGaAsP/InGaAs quantum wells whose luminescence peaks at 1530nm. The lattice constant (455nm) and the hole diameter (250nm) are chosen to place the slow mode of these waveguides in the gain region of the QWs. Here, the BCB layer separating the membrane from the SOI level is 400nm thick. The samples are optically pumped by the surface using a Ti:Sa laser delivering 100fs pulses at 800nm at a repetition rate of 80MHz. The emission is collected at the end of 12mm long SOI waveguides through grating couplers using an optical fibre. The laser emission power is plotted on Fig. 2 as a function of the pump pulses energy in a log-log scale. From the standard S-shaped curve, can be determined a threshold of about only 5pJ. In this sample the laser emission peaked at 1535nm as can be seen in the inset of Fig.2. Observation of laser emission at different wavelengths from lithographically tuned PCs will also be presented and discussed.

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