III-V Photonic Crystal Lasers Heterogeneously Bonded to Silicon-On-Insulator Waveguides

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ABSTRACT
We report on the fabrication of InP-based 2D photonic crystal lasers operating around λ=1.55µm at room temperature, integrated with and evanescently coupled to Silicon-On-Insulator waveguides. Pulsed laser operation is obtained from a line defect photonic crystal waveguide accurately aligned (<30nm) on top the SOI circuitry. This active-passive integration is demonstrated using an adhesive bonding technique. Lasing action is demonstrated for several low group velocity modes of the photonic crystal defect waveguide.
Keywords: Photonic Crystals, lasers, active-passive integration, InP, SOI

1.INTRODUCTION

All-optical devices will play a crucial role in coming decades, in the domain of information and communication technology, due to their ability to bring efficient solutions to data transmission and processing. In this drive for efficiency, integrated optics has emerged as a major theme in both industrial and academic scientific communities. Integration aims to achieve, not only the routing of signals through passive waveguides, but also the processing of signals, on a single platform. Thus photonic circuits should constitute compact elements capable of realising passive functions such as guiding and filtering as well as elements dedicated to low-power-consuming active functions such as emission, switching and detection, thus capable of manipulating optical information. Two principal technologies are very much in evidence: Silicon Photonics and III-V semiconductor photonics.

Silicon is a well researched material, and is unsurpassed in terms of the quality of fabricated devices. Favourable electronic, optical, and physical properties and the mature CMOS processing technology make large-scale integration of passive optical devices possible. The natural oxide, so useful in electronics, is a highly effective waveguide cladding material, permitting fabrication of ultra-small waveguides with losses lower than 1dB/cm [1]. These photonic wires can be implemented with small radii of curvature, making it possible to build compact optical circuitry. Silicon, however, possesses an indirect electronic band gap and is therefore not the ideal material for light emission and light control. III-V based semiconductor alloys are far more suitable for this task; the direct band-gap of most III-V materials makes efficient stimulated emission possible, which enables the realization of lasers, amplifiers, detectors and modulators. Candidates for low refractive index cladding materials for the InP material system are eagerly sought. Fabrication processes are available which yield high quality wavelength scale structures, for example 2D photonic crystals (PhC). The high-contrast periodic nature of photonic crystals causes strong interference between forwards and backwards travelling waves and can be exploited to slow the group velocity of the signal. This allows for greater interaction between the signal and the material and thus can reduce the device size or the switching energy. The enhancement of silicon photonics by III-V based optical functions would make for a versatile integrated photonics platform [2,3].

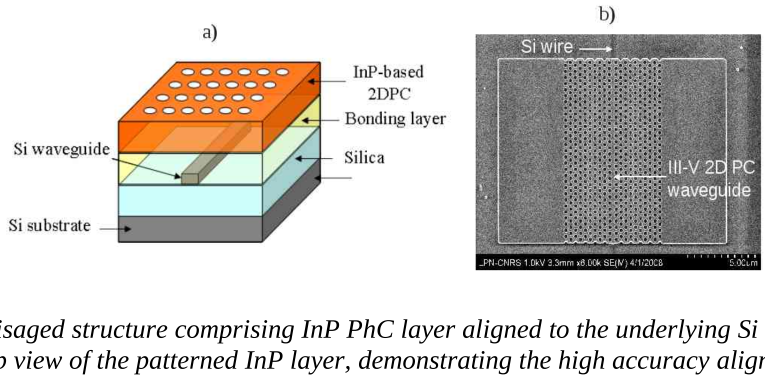

Figure 1. a) Envisaged structure comprising InP PhC layer aligned to the underlying Si waveguide layer . b) Top view of the patterned InP layer, demonstrating the high accuracy alignment.

2. FABRICATION OF THE HETEROGENEOUS STRUCTURES

The first challenge to tackle is the fabrication of this “heterogeneous” structure. The process begins with the adhesive bonding of the InP-based heterostructure onto the SOI wires, using the planarising polymer BCB [3]. The success of the bonding depends on the local structure [4] and cleanliness of the two component parts (SOI and InP). The coupling between the two levels depends on the vertical spacing, the accuracy and the repeatability of the alignment between the PhC structures and the subjacent silicon waveguide. 500nm×220nm Si wire waveguides are fabricated using the CMOS line at IMEC, Leuven (Belgium) using 193nm DUV lithography on 200mm SOI. InP Quantum Well material is grown at LPN. Alignment markers written on same mask level as the Si waveguides allow us to align the PhC level defined by electron beam lithography to the Si waveguides. The PhC is patterned in the III-V membrane using reactive ion etching and inductively coupled plasma etching. High resolution SEM measurements (see Fig.1.b)) taken of many different waveguide samples allow us to demonstrate that our 2D PhC structures are aligned on top of SOI wires with an accuracy better than 30nm.

3.LASER CHARACTERISATION

The device under test is a 2D PhC line-defect W1 waveguide made in a 250nm thick InP membrane containing 4 InGaAsP/InGaAs QWs whose luminescence peaks at 1530nm. The lattice constant (455nm) and the hole diameter (250nm) are chosen to place the slow modes of these PhC 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 6mm long SOI waveguides through grating couplers using a cleaved optical fibre. The laser emission power is plotted on Fig. 2 as a function of the pump pulse energy in a log-log scale. From the standard S-shaped curve, we can determine a threshold of about 5pJ. In this particular sample the laser emission occurs 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.

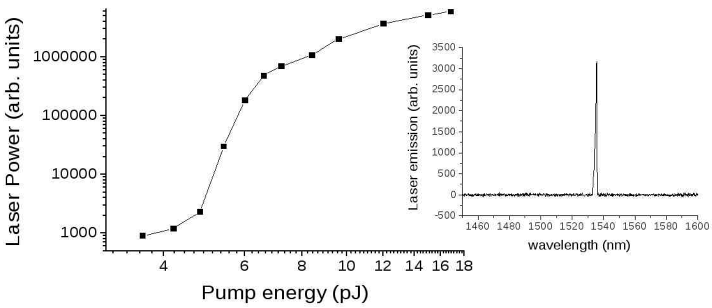

Figure 2. Laser power vs Pump energy log-log scale. Inset:Laser spectrum for pump energy 9.6pJ.

4.CONCLUSIONS

We have demonstrated the integration of III-V photonic crystal lasers with silicon wire waveguides. High accuracy alignment allows light emitted by the optically pumped PhC waveguides to be coupled into the wires.

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