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InP-based 2D photonic crystal lasers heterogeneously integrated and coupled to SOI wires

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Abstract : **The fabrication of 2D InP-based photonic crystal lasers accurately aligned with SOI wire waveguides will be presented. Low threshold pulsed lasing operation is achieved by pumping via the SOI waveguide.**

I. Introduction

Silicon photonics is presently a major subject of research opening the road to low cost ultra-compact optical integrated circuits. Many years of research in microelectronics and intense investment in technological processing has benefitted the development of a prototype integrated optical technology. For example, low loss Silicon-On-Insulator (SOI) wire waveguides have been demonstrated [1]. Unfortunately, because of its indirect electronic band gap, silicon is not the first choice for the realisation of high performance active devices, in spite of promising demonstrations such as Raman lasing [2] and optical gain using silicon [3], the performance is far inferior to that of III-V semiconductors. Indeed, III-V materials exhibit strong non-linearities and benefit from a direct electronic band gap. III-V semiconductors are an ideal choice in order to achieve active functionality, using gain, for amplification or laser operation, and index changing for bistability and optical switching. These observations naturally lead to the idea of combining the best of both worlds in a single heterogeneously integrated structure.
The structure under study is shown in Figure. 1. The passive part of the system is an SOI wire and the active part is a 2D InP photonic crystal which is bonded above the SOI waveguide. These two guides are evanescently coupled together.

Using a 2D Photonic Crystal (PhC) allows us to benefit from both the tight confinement offered by the photonic band gap and the strong dispersive properties evident at the band edge of these structures. In this work in particular we benefit from the low group velocity found at the mode edge of a photonic crystal line defect waveguide [4]. This leads to a strong enhancement of the light-matter interaction.

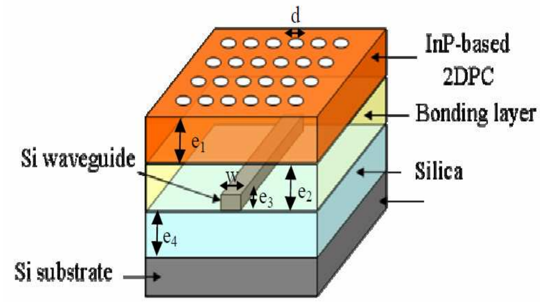

Fig 1. Schematic view of the structure

II. Design and fabrication of the heterogeneous structure

We report here the fabrication of an heterogeneous system composed of a SOI waveguide coupled to a 2D photonic crystal. The waveguides are coupled evanescently. Particular attention has been given to the design of both waveguides in order to access a region where the system is single moded and is coupled strongly. The SOI waveguides are defined at IMEC using deep UV lithography and processed on the CMOS line. They have cross-sectional dimensions of 220nm by 300nm. The PhCs have a lattice constant of 455nm with a hole diameter of 250nm, chosen to place the slow modes of these PhC waveguides in the gain region of the QWs. The InGaAsP/InGaAs QWs emit at 1530nm. The BCB polymer layer separating the membrane from the SOI level is 400nm thick. Considering the size and tight optical confinement of the different elements, one can understand that alignment is critical for the control of the coupling.

The key points in the fabrication are the BCB bonding and accurate alignment between the two levels of lithography. Adhesive bonding of the InP and SOI dies is achieved using Benzo-Cyclo-

Butene (BCB) [5]. This technique offers a simple and reproducible way to perform the bonding because of its superior planarising properties and tolerance of materials with differing surface qualities and chemistries.
Accurate control of the thickness of the BCB is achieved by dilution in mesitylene. The final critical step concerns the alignment, and uses marks defined on the Si layer which are then detected using our Leica 5000+ e-beam Lithography System. An alignment tolerance of 30 nm between the ~100µm long InP PhC defect waveguide pattern and the SOI wire waveguide is demonstrated (see fig. 2) with a very high reproducibility. Etching of the III-V PhC is performed in a quite standard process in LPN.

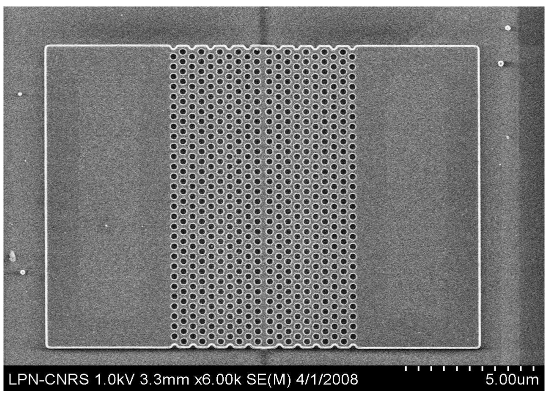

Fig 2. Top view of the patterned InP layer, demonstrating the high accuracy alignment.

III . 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 samples are optically pumped through the silicon wire using an OPO to deliver 100fs pulses at 1.18 µm at a repetition rate of 80MHz. This wavelength is beneath the silicon absorption edge, but is absorbed in the barriers of our quantum wells. The strong evanescent field of the pump laser in the waveguide is enough to pump the III-V layer. The emission is collected at the end of 3mm long SOI waveguides through grating couplers using a cleaved optical fibre.

The laser emission power is plotted on Fig. 3 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 1pJ. In this particular sample the laser emission occurs at, this wavelength correspond to the PhC waveguide slow mode. Observation of laser emission at different wavelengths from lithographically tuned PCs will also be presented and discussed.

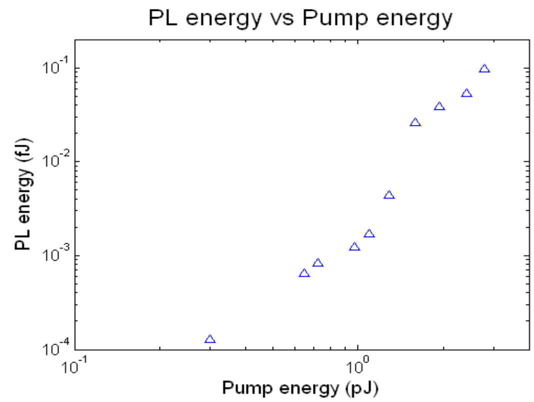

Fig. 3 Laser power vs Pump energy log-log scale

IV. 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 to be captured efficiently by the SOI wires.

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