Optimally coupled hybrid III-V Photonic Crystal Wire Cavity CW Lasers on passive SOI waveguides

Yacine Halioua[1,2], Alexandre Bazin[1], Timothy Karle[1], Paul Monnier[1], Isabelle Sagnes[1], Rama Raj[1] and Fabrice Raineri[1,3]

1-Laboratoire de Photonique et de Nanostructures, CNRS-UPR20, Route de Nozay, 91460 Marcoussis, France
2-Photonics Research Group, Department of Information Technology, Ghent University, B-9000 Ghent, Belgium
3-Université Paris Denis Diderot, 75205 Paris, France
*Corresponding author: yacine.halioua@lpn.cnrs.fr

Abstract: Preferential and efficient extraction and delivery of power of a compact low threshold hybrid III-V semiconductor photonic crystals lasers on SOI from/into a CMOS subjacent Silicon-On-Insulator waveguide is demonstrated. Probing the wire-cavity lasers through transmission, reveals a high (>80%) coupling efficiency.

Integrated optics community has recently turned its attention to the development of sub-wavelength, high-contrast photonic components in the quest for efficiency, compactness and low power operation. Preferably based upon a Silicon platform, these would allow one to envision high-speed, low-cost and high component density in photonic circuitry. In targeting these ambitious goals, Si technology takes advantage of processing know-how from the electronics industry. Mature CMOS processing technology renders Silicon unsurpassed in terms of fabricated device quality. Furthermore, the ability of low-loss Si wire waveguides to be bent with tight radii of curvature predisposes them to small device footprints and thus large scale integration.

In order to take it beyond purely passive features such as guiding and filtering it is important to include active components in the Si platform that would vastly enhance the portfolio of optical functions. For this we require devices capable of emitting, modulating and detecting light, ideally with low power expenditure. Just such a solution is provided by the heterogeneous integration of III-V materials onto Silicon which, indeed, provide tailor-made optoelectronic properties [1]. Patterning this active material on the wavelength scale gives it the an additional versatility: permits control of its photonic properties.

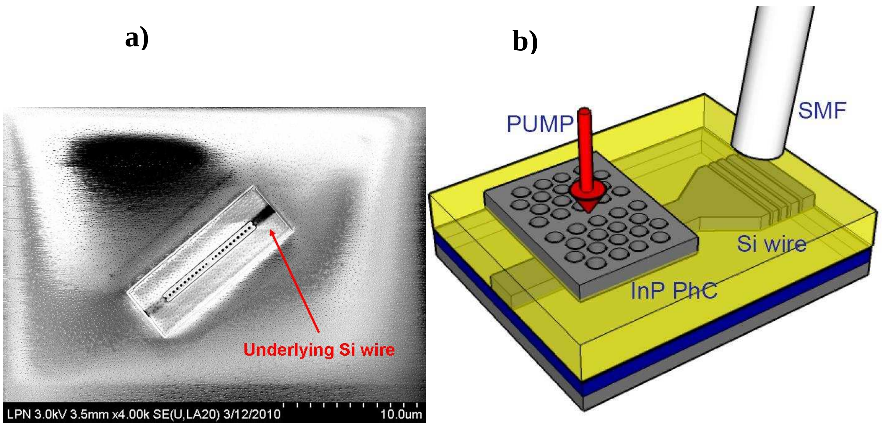

Figure 1. Saturated SEM image showing the Si wire beneath the III-V cavity and schematic of cavity aligned to wire.

In this context, the use of 2D Photonic Crystals (PhCs) allow us to achieve ultra-small components and can be configured to substantially augment the light-matter interaction, thus reducing laser thresholds and switching energies. The PhC lasers explored in this work are InP-based wire cavity lasers [2,3] which are bonded on top of SOI waveguides. The InP heterostructure membrane, containing 4 InGaAs/InGaAsP quantum wells with the peak emission at 1,55µm, is grown by MOCVD. The cavity is aligned to the SOI and patterned using electron beam lithography, fabrication details can be found in [4]. The SOI waveguides are fabricated in a CMOS fab using 193nm DUV lithograph. The heterogeneous bonding of the cavities to the SOI requires cavity designs which are robust against losses due to the reduced confinement due to relatively high index polymer bonding materials. The samples are depicted schematically in Figure 1.b, where the lower level comprises a 500nm wide by 220nm high Si wire where the light propagates without absorption and the top layer is the active InP-based wire cavity, consisting of wire cavity with 1D photonic crystal mirrors for longitudinal confinement. The transmission from one level to the other is thorough evanescent coupling.

First, laser emission, under 800nm optical pump pulse, from these high Q factor, III-V semiconductor wire cavity lasers is demonstrated (see fig. 2). Secondly, continuous laser emission is observed, the samples are explored at room temperature by optically pumping from the surface at lower energy ie. 1.2µm, the wavelength corresponding to where the barriers are absorptive in order to maximize the pumping efficiency of the quantum wells.

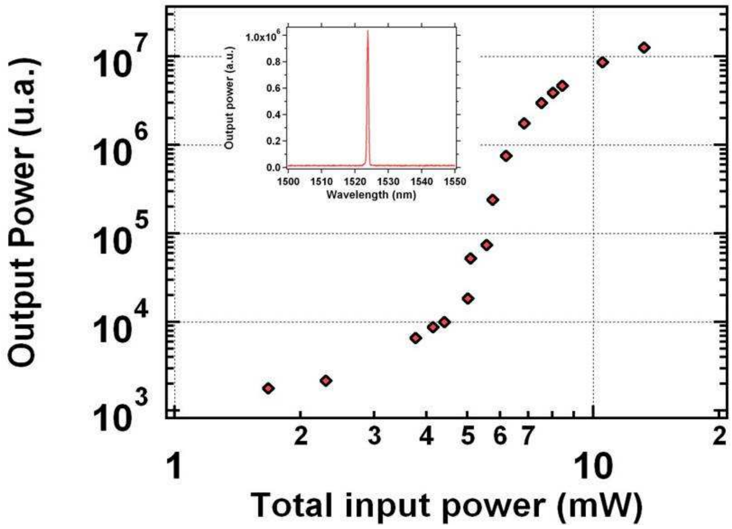

Figure 2. Light-Light curve of laser emission (log-log scale)

The laser emission from the 2DPhC is coupled to the TE mode of the 6mm long SOI waveguides and is extracted from the SOI thanks to gratings etched at their extremities. The light is then collected via a SMF-28 optical fiber positioned at 10° angle in order to maximize collection at 1.55µm (S polarization). The emission is analysed using a spectrometer equipped with a cooled InGaAs photodiode array. The nanolasers emit at 1.55µm with a threshold of 10mW, external power, with high output power. However, these structures are not ideally suited for pumping at this wavelength due to the presence of a thick InP layer which plays no role at all, future effort will be devoted to the lowering of the threshold by a custom designed structure. Continuous laser emission from these structures open the way to several functionalities.

One of the major concerns in nanophotonic circuitry, even more when dealing with photonic crystals where the strongest non-linear properties are located below the light line, is the ease of extraction from nanolasers and chanelling of light for use in subsequent stages of switch, flip-flop, detectors etc. With this in view, the coupling factor is experimentally studied to demonstrate optimal coupling and direct extraction by low loss SOI wire waveguides. Pump-probe experiments are performed on the samples, to explore the different processes which are in play, with a 800nm diode pump laser modulated at a repetition rate of 300kHz with a 2% duty cycle and a tunable probe launched via the silicon wire. A detailed analysis of the coupling factors, laser threshold and linewidth characteristics are carried out as a function of several critical parameters, as the phase matching condition or intermediate layer thickness, of the hybrid structure which permits us to not only estimate the coupling efficiency but also to define the criteria for the optimal use of these nanolasers. The resulting transmission characteristics [5, 6] (see fig. 3) allowed us to accurately estimate the coupling efficiency to be 80%.

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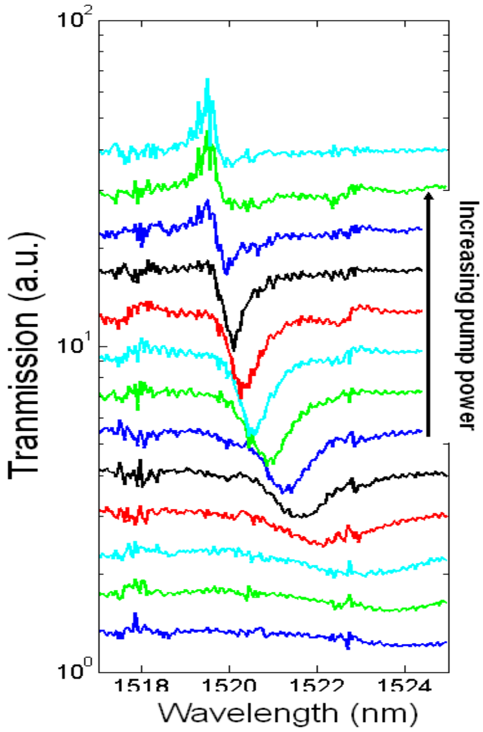

Figure 3. Typical transmission curves for different pump values

In conclusion, we believe avenues may open up in the domain of compact photonic circuits with these optimally coupled integrated 2DPhC on SOI wire nanolasers. Combining these two powerful elements permits us to derive the benefits of the world of Si and III-V compound semiconductor systems, allowing us envisage nanophotonic platforms which are both efficient and capable of evolving into versatile multifunctional CMOS compatible photonic circuits.

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