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1-Introduction

This project aims at *developing theoretical and technological tools for the management of slow waves in silicon-on-insulator technology for light matter interaction in linear and nonlinear optics*. The objectives are : (1) the implementation of slow modes in ridge waveguides periodically corrugated (2) the engineering of these mode with respect to their propagation losses due to fabrication defects (roughness and geometry inhomogeneities) and with respect to their coupling to conventional z-invariant waveguides (3) the study of nonlinear effects in these types of modes and in particular the generation of light by Raman silicon lasers.

The success of this project would result in an important step towards the integration of all-optical silicon photonic circuits.

In order to break through the scientific and technological challenges, the project gathers several teams belonging to three French laboratories which are leaders in the fields of silicon nano-fabrication, nonlinear optics in photonic crystals and modeling of optical nanostructures.

We will present our recent achievement in the development of Ultra-High Q/V Fabry-Perot microcavity on SOI substrate and our first results in the optical non-linearity study of nanocavities.

Keywords: Fabry-Perot resonator, slow mode, Raman laser.

2- Ultra-High Q/V Fabry-Perot microcavity on SOI substrate

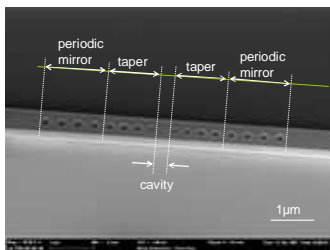


Fig.1. SEM picture of the lineic Fabry-Perot cavity inserted in the silicon waveguide.

On both sides of the cavity, each mirror is composed of a taper and of a periodic section. The taper is located on the cavity side of the mirror and is made of four holes with increasing diameter and separated by increasing distances. The periodic mirror is made of N holes (N=4 on the picture) with a diameter of 200 nm and a period of 370 nm.

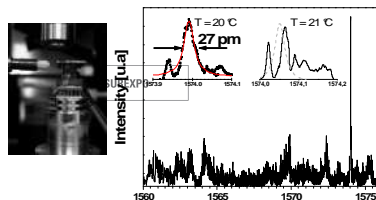


Fig. 2 : Resonant cavity peak collected on the top of cavity. The insert details the resonant peak for two regulated temperature of the sample. Left-inset is fitted with a Lorentzian curve replicate in dashed line in the right-inset.

P. Velha et al, *Appl. Phys. Lett.*, **89** (2006)
P. Velha et al, *New Journ. Phys.*, **8** (2006)
P. Velha et al. *Submitted to Optics Express*

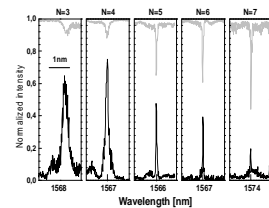


Fig. 3 : Evolution of the resonant peak with increasing the number of holes in the periodic mirror (N). The black curve presents the normalized transmission across the cavities, the grey one shows the vertical losses collected by the top of the sample in arbitrary units with inverted axis.

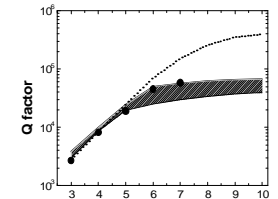


Fig. 4 : Experimental evolution of the Q factor for the lineic Fabry-Perot cavity with increasing N. The shaded region represents the theoretical values for an increasing number of holes in the periodic mirror of the cavity and for a tolerance of +/- 10 nm on the nominal value of the hole diameters. The dot curve shows the optimum Q factor value calculated for an optimal cavity length for each N.

3- Optical non-linearities in SOI microcavities (Efficient injection in slow modes)

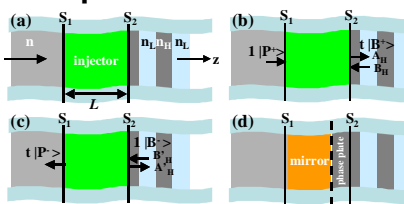


Fig. 5. A slow-mode injector at a single frequency is basically a mirror. (a) Definition of the injector parameters (b) Perfect injector at a single frequency. (c) Reciprocal problem. The incident illumination is the reciprocal Bloch mode propagating towards the negative z-direction. (d) General solution of the synthesis problem : the injector is composed of a mirror and of a phase plate.

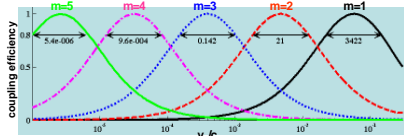


Fig. 6. Coupling efficiency into the slow-mode as a function of its group velocity. Different injectors are considered, composed of Bragg mirrors with an increasing number of repeated pairs, m=1, ...5. The results are obtained in the vicinity of the valence band edge of the periodic stack. The horizontal arrows indicate the bandwidths in GHz of the different injectors for T=0.8 (-1dB).

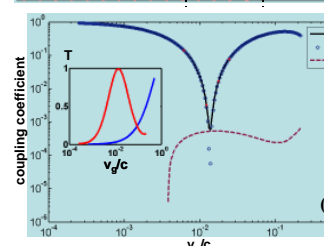
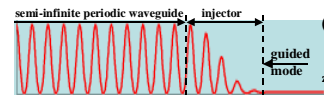


Fig. 7. Broadband injection from a planar waveguide to a periodic waveguide near the valence-band edge ($\lambda=1.65 \mu\text{m}$). (a) Injector geometry optimized for coupling at $v_g/c=0.01$. Red curve: $|E|^2$ at optimal coupling. (b) Performance of the injector predicted by fully vectorial computational results for the radiation loss L (dashed curve), the modal reflection R (blue circles) and the transmission T (actually 1-T is shown with a solid black curve). Inset: Injection efficiency T as a function of v_g with (red) and without (blue) injector. The maximum injection efficiency is as large as 0.999. In the absence of injector, this efficiency is only 0.25%.

4-Conclusion

Concerning FP microcavity, we experimentally demonstrate an ultra high Q/V nanocavity on SOI substrate. The design is based on modal adaptation within the cavity and allows us to measure a quality factor of 58.000 for a modal volume of $0.6(\lambda/n)^3$. This record Q/V value of 10^5 achieved for a structure standing on a physical substrate, rather than on membrane, is in very good agreement with theoretical predictions also shown. Based on these experimental results, we show that further refinements in the cavity design could lead Q/V ratios close to 10^6 .

Another strategy to enhance the light-matter interaction is to slow down the light. Despite intensive research, the injection in such slow modes is still a serious problem. We study theoretically this injection. We have shown that very short couplers whose length are scaling as $\log(c/v_g)$, may provide perfect injection (100% coupling efficiency) for arbitrary-small group velocities. For 2D geometries we have shown that radiation losses are not a critical issue. We rather found that high injection efficiency together with a broadband injection is indeed difficult to manage both together, especially for $v_g < c/100$. There is a compromise. These conclusions have been reached in 1D and 2D structures, but are expected to remain valid for other kinds of periodic ridge waveguides. We are now working on the next step to design, fabricate and study optically a Raman laser based on slow group velocity designs.