MIRAMAN

***LCFIO**, CNRS, ORSAY, France.*
*S. Mazoyer, J.P. Hugonin, J.C.. Rodier, C. Sauvan, N. Dubreuil and **P. Lalanne** (Coordinator)*
***LTM**, CNRS,GRENOBLE, France.*
P.Velha, C. Jocteur, K. Berton and D. Peyrade
***DRFMC/SiNaPS**, Minatec, CEA-GRENOBLE, France.*
E. Picard,T. Charvolin, V. Calvo and E. Hadji

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 achievment 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

*P.Velha et al, **Appl. Phys. Lett.**, 89 (2006)*
*P.Velha et al, **New Journ. Phys.**, 8 (2006)*
*P. Velha et al. **Optics Express,** 15-24 (2007)*
*P. Velha et al. Proceedings of SPIE **6989** (2008)*

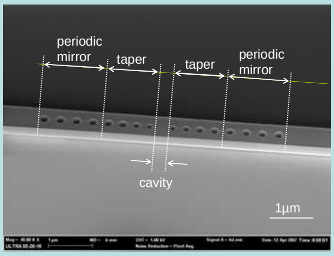

Fig.1. **SEM picture of the lineic Fabry-Perot cavity inserted in the silicon waveguide**.
On both sides of the cavity, each mirror is composed of a taper and of a periodic section. The taper is located on the cavity side of the mirror and is made of four holes with increasing diameter (130, 170, 200, 200 nm) and separated by increasing distances (300, 320, 350 nm respectively). 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.

P. Velha et al., Opt. Express Opt Express **15**, 16090-96 (2007)

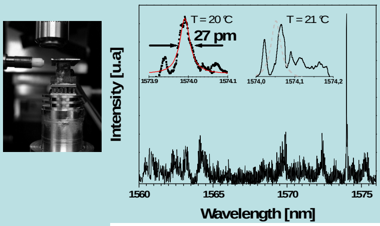

Fig. 2 : **Resonant cavity peak collected on the top of cavity**. The insert details the resonant peak for two regulated temperature of the sample. Left-inset is fitted with a lorenzian curve replicate in dashed line in the right-inset.

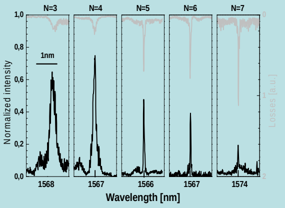

Fig. 3 : **Evolution of the resonant peak with increasing the number of holes in the periodic mirror (N).** The black curve presents the normalized transmission across the cavities, the grey one shows the vertical losses collected by the top of the sample in arbitrary units with inverted axis.

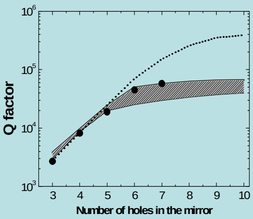

Fig. 4 : **Experimental (dot) evolution of the Q factor for the lineic Fabry-Perot cavity with increasing N**. The shaded region represents the theoretical values for an increasing number of holes in the periodic mirror of the cavity and for a tolerance of +/- 10 nm on the nominal value of the hole diameters.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

3- Propagation of slow waves in PERTURBED photonic crystal waveguides

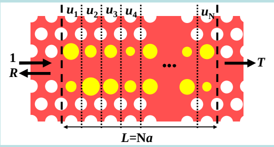

Fig. 5. **Instance of a disorder realization for a PhCW with a finite length *L=Na*.** It is defined by a random sequence $U=[u_1, u_2 \ldots u_N]$ of N independent elementary single-cell disorder realizations u, in which the hole radii of the two inner rows are randomly and independently varied. R and T are the back-reflection and transmission of the fundamental Bloch-mode.

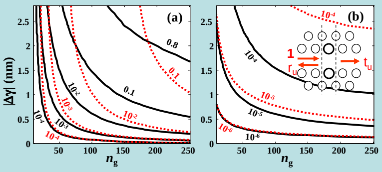

Fig. 6. **Elementary single-cell scattering events for single cell transports**. The results are obtained for $5<n_g<250$, for -3 nm<Dg<3 nm and for symmetrical hole perturbations, $g_1=g_2=g+Dg$. (a) Back–reflection $R_u=|r_u|^2$. (b) Out-of-plane loss $L_u=1-|r_u|^2-|t_u|^2$. The solid red (resp. dotted black) curves correspond to positive (resp. negative) hole size perturbations. They should be superimposed within the framework of first-order perturbation theory. r_u and t_u are defined in the inset.

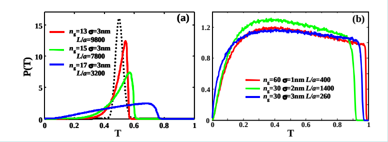

Fig. 7. B**Probability density functions P(T) for the transmission T.** The results for various values of s, n_g and L are all gathered at $<T>\approx 0.5$, i.e. for PhCW lengths nearly equal to the effective mean free paths. (a) Gaussian-like distributions are obtained in the presence of a substantial out-of-plane leakage for small n_g's. The dashed curve is a log-normal distribution with <ln(T)>=ln(0.5) and with the same standard deviation as the red curve. (b) For large n_g's, backscattering largely prevails and uniform laws (showing almost equally likely outcomes over the interval [0 1]) are obtained. The histograms are calculated for 5.10^6 independent disorder realizations.

S. Mazoyer et al. Phys. Rev. Lett. 103, 063903 (2009)

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 leads Q/V ratios close to 10^6.

An other 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 theoritically this injection. We have shown that very short couplers whose length are scaling as log(c/vg), 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 vg<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.