On chip light handling with single and twinned nanobeam cavities

B. Cluzel[1], K. Foubert[1,2], L. Lalouat[1], E. Picard[2], D. Peyrade[3], F. de Fornel[1] and E. Hadji[2]

Optical information processing at the chip level has been a long standing dream. However it requires both on chip light generation and manipulation at sub-wavelength scale which remains challenging. In this context, nanobeam cavities appeared as one of the key players thanks to their field confinement capability and their ridge waveguide integrated geometry. In this context, we showed that strong light localization within nanobeam cavities was possible and was moreover tuneable by near-filed interaction with an external nanometric tip. We showed as well that twinned high Q nanobeam cavities placed in the near-field of each other can optically couple to form a new optical system with discrete field maps addressable by wavelength selection.

The nanobeam cavities presented here integrate tapered mirrors [2]. Thanks to the mirror Bloch mode - cavity wave guided mode mismatch decrease; they allowed achieving record high Q/V ratios [1]. For those nanobeam cavities, near-field scanning optical microscopy (NSOM) is an effective tool to evidence sub-wavelength sized features in the light localization [3]. But it appeared also as a mean to achieve lossless cavity tuning [4]. The evanescent part of the strongly localized optical field can indeed interact with the NSOM nanometric tip [5]. As a result wavelength shifts larger than the cavity line width were observed under the presence of the NSOM tip leading to drastic change of the cavity transmission at the resonant wavelength. On/off ratios (with and without the tip above the nanobeam cavity) larger than 30 db were observed with Q = 50.000 nanobeam cavities.

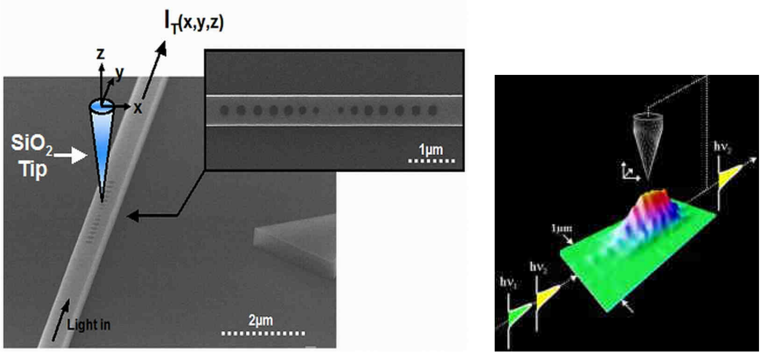

Figure 1: (left) schematic of tip-nanobeam cavity interaction, (inset) details of the nanobeam cavity; (right) resonant optical field as recorded by NSOM.

Then, if two of these cavities are moved within the near-field of each other, the optical fields can evanescently couple to each other. The easiest way to observe this near-field coupling effect is to fabricate two parallel ridge wave-guides separated by a thin air-slot spacer. A careful recording of optical fields above the structure by NSOM clearly demonstrate the field enhancement in the air slot [6] that result from the coupling effects. Now, if nanobeam cavities, instead of simple optical waveguides, are evanescently coupled, an entirely new optical system can be achieved.

In order to understand the coupling mechanism, we first set two cavities, called twinned cavities since they are strictly identical to each other, at lateral coupling distances ranging from 50 to 500 nm. We observed that the original optical field distribution of one single cavity is now reconfigured over the system made by the twinned cavities. The fundamental mode appears to be splitted into two new modes of different parities [7]. This property means that the light localization within the system of twinned cavities is now wavelength dependent, and thus wavelength addressable.

---

[1] LICB/OCP, Unité mixte de recherche n°5209 CNRS - Université de Bourgogne, France

[2] INAC /SP2M - Laboratoire SiNaPS, UMR-E 9002, CEA-Grenoble, France

[3] Laboratoire des Technologies de la Microélectronique, CNRS, Grenoble, France

In order to further exploit this effect, we fabricated structures for which the spacing between nanobeam cavities is maintained constant at 100 nm but the number of coupled cavities is varied from 2 to 4 and 8 cavities.

We then recorded the optical field evolution as a function of the number of coupled cavities and observed that the more we increase the number of cavities the more we generate splitted optical modes [8].As a result, since each mode carries its own wavelength, we create for n coupled cavities a set of n different field localizations or field maps over the sample, each of them being addressable by a specific wavelength.

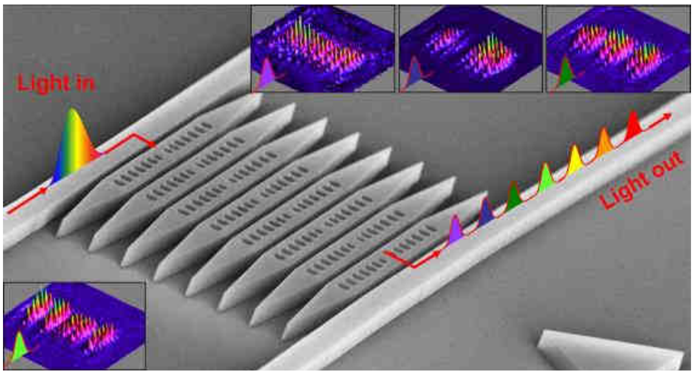

Figure 2: An array of nanobeam cavities generates sub-wavelength grids of confined light. The spatial distribution of the grids can be modified on demand by changing the wavelength in the nanosystem.

So we evidence here that the electromagnetic field distribution within the reported nanosystems can be engineered on demand at the sub-wavelength scale giving access to a whole range of fields map distribution as a function of the input wavelength.

This new architecture offers an unprecedented opportunity to mold on a chip the morphology of the optical field and opens therefore exciting new perspectives for the future development of configurable optical traps, sensors or opto-mechanical oscillators at the nanoscale.

The authors gratefully acknowledge their fruitful discussions with Dr. Philippe Lalanne from Laboratoire Charles Fabry - Institut d'Optique Graduate School, who pioneered the development of the nanobeam cavities.

References

[1] P. Velha, J. C. Rodier, P. Lalanne, J.P. Hugonin, D. Peyrade, E. Picard, T. Charvolin, E. Hadji, " Ultracompact silicon-on-insulator ridge-waveguide mirrors with high reflectance", **Appl. Phys. Lett.** 89, 171121 (2006).

[2] P.Velha, E.Picard, T.Charvolin, E.Hadji, J.C.Rodier, P.Lalanne, D.Peyrade, "Ultra-High Q/V Fabry-Perot microcavity on SOI substrate", **Optics Express** 15 (24), 16090 (2007).

[3] L. Lalouat, B. Cluzel, P. Velha, E. Picard, D. Peyrade, J.C Rodier, T. Charvolin, P. Lalanne, F. de Fornel, E. Hadji, "Sub wavelength imaging of light confinement in high Q small V photonic crystal nanocavity", **Appl. Phys. Lett.** 92, 111111 (2008).

[4] B.Cluzel, L.Lalouat, P.Velha, E.Picard, D.Peyrade, J.C Rodier, T.Charvolin, P.Lalanne, F. de Fornel, E. Hadji, "A near-field actuated optical nanocavity", **Optics Express**, 16 (1), 279 (2008).

[5] L.Lalouat, B.Cluzel, P.Velha, E.Picard, D.Peyrade, J.P Hugonin, P.Lalanne, E.Hadji, F. de Fornel, "Near-field interactions between a subwavelength tip and a small-volume photonic-crystal nanocavity", **Phys. Rev. B 76**, 041102 (2007).

[6] K. Foubert, L. Lalouat, B. Cluzel, E. Picard, D. Peyrade, E. Delamadeleine, F. de Fornel et E. Hadji, "Near-field modal microscopy of the subwavelength confinement in multi-mode silicon slot waveguides", **Appl. Phys. Lett.** 93, 251103 (2008).

[7] K. Foubert, L. Lalouat, B. Cluzel, E. Picard, D. Peyrade, F. de Fornel et E. Hadji, "An air-slotted nanoresonator relying on coupled high-Q small-V Fabry Perot nanocavities", **Appl. Phys. Lett.** 94, 251111 (2009).

[8] B. Cluzel, K. Foubert, L. Lalouat, J. Dellinger, D. Peyrade, E. Picard, E. Hadji e t F. de Fornel, "Addressable sub-wavelength grids of confined light in a multi-slotted nanoresonator", **Appl. Phys. Lett.** 98, 081101 (2011).