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Photonics and Nanostructures – Fundamentals and Applications 9 (2011) 269–275
PHOTONICS AND NANOSTRUCTURES
Fundamentals and Applications
www.elsevier.com/locate/photonics

Extraordinary tuning of a nanocavity by a near-field probe

Benoit Cluzel [a], Loïc Lalouat [a], Philippe Velha [b,c,d,*], Emmanuel Picard [b], Emmanuel Hadji [b], David Peyrade [d], Frédérique de Fornel [a]

[a] *Groupe d'Optique de Champ Proche, Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR CNRS 5209, LRC SiNOPTIC CEA n°DSM-08-36, Université de Bourgogne, 9, Avenue A. Savary, BP 47870, F-21078 Dijon, France*
[b] *SiNaPS-MINATEC, CEA Grenoble, 17 rue des Martyrs, F-38054 Grenoble, France*
[c] *Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Université de Paris-Sud, Campus Polytechnique, RD 128, F-91127 Palaiseau, France*
[d] *Laboratoire des Technologies de la Microélectronique, CNRS, 17 rue des Martyrs, F-38054 Grenoble, France*

Received 15 November 2010; received in revised form 28 April 2011; accepted 2 May 2011
Available online 13 May 2011

Abstract

We report here an experimental observation of an extraordinary near-field interaction between a local probe and a small-volume solid-state nanocavity. We directly compare the normally observed near-field interaction regime driven by the perturbation theory and then report the extraordinary interaction regime. Subsequently, we show that the cavity can take up to 2 min to recover from this interaction after removing the probe and that leads to an extraordinary blue-shift of the cavity resonance wavelength (∼15 nm) which depends on the probe motion above the cavity and not the position. The reasons for this effect are not fully understood yet but we try to give some explanations.

Keywords: Photonic crystals; Near-field optics; Optomechanics; Silicon photonics; Microcavity; Anomalous regime; Nanotechnology; Tuning; Extraordinary regime

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1. Introduction

1.1. General introduction

Near-field microscopy techniques are devoted to visualize and analyse matter properties at the nanoscale. Among the near-field techniques that have been studied since the early 1980s, the optical near-field techniques which allow probing the light at a sub-wavelength scale, have been intensively investigated with the emerging field of nanophotonics [1,2]. In this context, scanning near-field optical microscopy (SNOM) techniques have proven their ability to analyse and visualize the spatial [3], spectral [4] and temporal [5] light behaviour in integrated optics components such as photonic crystals or plasmonic devices. However, in the same way that the scanning tunnelling microscopy (STM) and atomic force microscopy (AFM) probes permit the manipulation of individual atoms [6,7], molecules [8] or particles [9], the SNOM probes can also be used to manipulate the properties of confined electromagnetic fields [10–12]. The near-field interaction involved in these recent experiments relies on a local perturbation of the electromagnetic field induced by the probe.

In this letter, we report an experimental observation of an extraordinary near-field interaction that occurs between a local probe and a small-volume solid-state

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* Corresponding author at: SiNaPS-MINATEC, CEA Grenoble, 17 rue des Martyrs, F-38054 Grenoble, France. Tel.: +44 0141 330 6022; fax: +44 0141 330 4907.
E-mail address: philippe.gmail@gmail.com (P. Velha).

doi:10.1016/j.photonics.2011.05.002

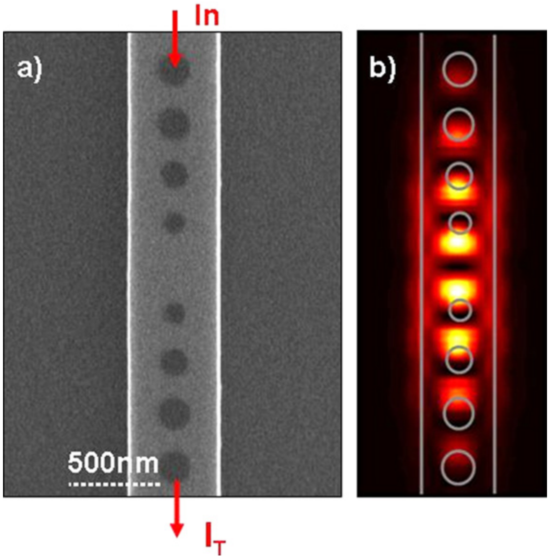

Fig. 1. (a) Scanning electron microscope view of the studied nanocavity. Air holes are nano-patterned inside a silicon ridge waveguide. (b) Three-dimensional calculation of the electric field distribution of the nanocavity at resonance. We define the axis as *X* being perpendicular to waveguide direction and as *Y* the axis along the waveguide.

nanocavity that cannot be explained by the standard perturbation theory. In the first part of this letter, we directly compare the well-known near-field interaction regime driven by the perturbation theory and the reported extraordinary interaction regime. Secondly, we show that the interaction leads to a modification of the intrinsic properties of the cavity, which can persist up to 2 min after removing the probe from the cavity optical near-field. Finally, we show that the modification of the cavity properties leads to an extraordinary blue-shift of the cavity resonance wavelength (∼15 nm) and depends on the probe motion inside the cavity optical near-field.

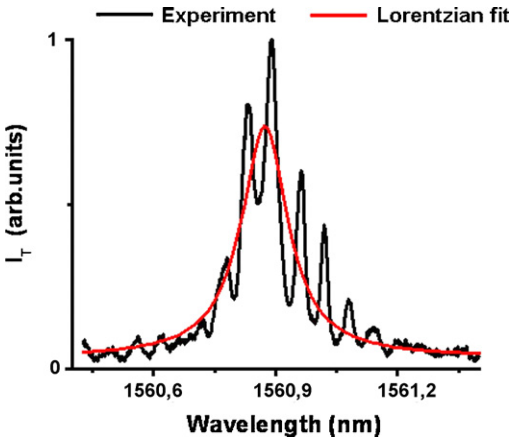

Fig. 2. High resolution transmittance spectrum of the nanocavity at resonance. The Lorentzian-shaped cavity resonance is modulated by high frequency oscillations corresponding to the interferences of the light bouncing between the two cleaved facets of the sample.

The nano-cavities studied in this work are similar to that one reported in our previous [13,14] work. As shown in the SEM view of Fig. 1a, they consists in a Fabry Perot-like resonator composed of two mirrors etched in a silicon ridge waveguide and designed to suppress the radiation losses at the mirror termination [15]. For a Transverse Electrical polarization (TE with the H-field taken as normal to the substrate plane) the nanocavity exhibits a single resonance at telecommunication wavelength [16]. A typical high resolution transmittance spectrum of a nanocavity is given in Fig. 2.

2. Experimental

As reported in our previous works [13,14] and confirmed by other groups [11,12] introducing a near-field probe (dielectric: SiO_2, Silicon and other related materials or non-magnetic metals: Au, Al) inside the electromagnetic field induces a local adiabatic perturbation of the effective index. This perturbation strength is proportional to electrical field distribution within the resonator. Consequently, scanning the near-field probes inside the resonator optical near-field while recording the far-field resonator transmittance as a function of the probe position, gives a map of the electrical field distribution of the resonator eigenmode. A typical near-field image recorded above the nanocavity in such an interaction scanning mode is plotted in Fig. 3a. As a comparison, we also show in Fig. 1b the electric field distribution above the cavity at resonance calculated by using a 3D modal method [17]).

3. Results

3.1. Experimental anomaly

However, in several cases we measured cavities which do not follow the perturbation theory and instead exhibit an extraordinary regime of perturbation. At first, this regime seems to occur for random structures. No micro-structural modification between devices was found under SEM observation. At last, we found that the phenomenon reported hereafter seems to be correlated with the presence of surface bonds. It was systematically observed that soaking the structures in a 1% diluted hydrofluorhydric acid solution suppress the reported "extraordinary" interaction regime.