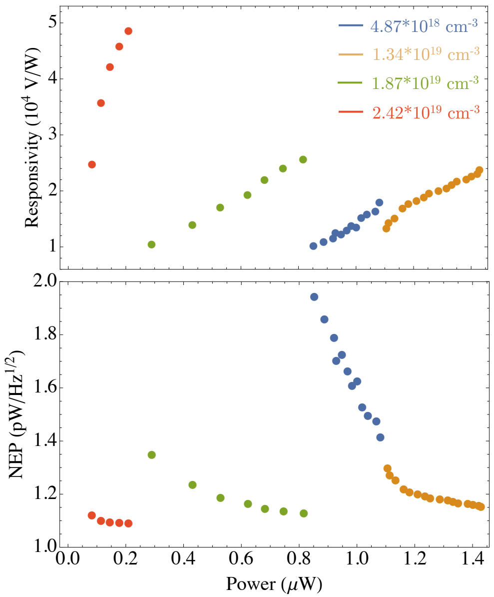
The sharp peaks are fingerprints of the trapped cavity mode, as the resonant radiation is evanescently coupled from the access waveguide to the very central region and part of it is transmitted and detected. The peak transmission value and the Q-factor drop as the doping concentration increases because the absorption is more efficient.

The same devices are then characterized electrically by measuring the resistance change upon light irradiation. Their performance are assessed by calculating the common figures of merit for a bolometer, namely the responsivity and the noise equivalent power (NEP). Experimental results are shown in the next two figures, where different colors refer to different doping concentrations.



The responsivity is the potential drop occurring across the device per unit input power. Clearly, the higher it is, the better the device. NEP is the input power causing a voltage drop equal to the noise level. The lower it is, the better is the device, as this means we could detect tiny power changes, which is essential if we want to detect small gas concentrations.

Conclusions and future work

The experimental values we obtained are extremely good and encouraging. To the best of our knowledge, no detectors (both commercially available or not) exhibit such high responsivity (tens of kV per W in input) and such low NEP (few pW per unit bandwidth). Their performances are at least one order of magnitude worse than our devices.

These brief considerations certainly pave the way for further studies and experimental tests on this cavity and in general on PhC cavity based detectors. The key point is the resonant trapping of radiation of interest, which allows for high-efficient absorption and conversion to an electrical signal. Hence, such a lab-on-chip scheme would definitely provide a really small, cost-effective and power-efficient device for gas detection.

In this context, Next immediate step would be to make the cavity working in the mid IR range (3-8 μm), where it could take advantage of gases' stronger absorption bands. This should not actually be difficult thanks to the scaling properties of Maxwell equations. All the geometrical parameters has to be increased according to wavelength scaling.

Acknowledgments

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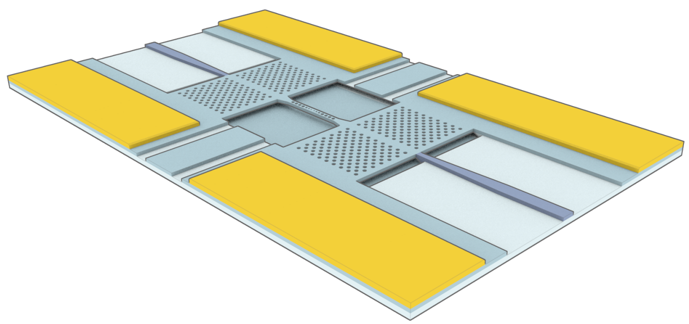
UNIVERSITÀ degli STUDI di CATANIA
DIPARTIMENTO di FISICA e ASTRONOMIA

CORSO DI LAUREA MAGISTRALE IN FISICA

GIAMPAOLO PITRUZZELLO

PHOTONIC CRYSTAL CAVITY BOLOMETER



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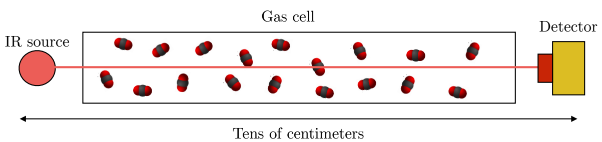
ACADEMIC YEAR 2014/2015

Introduction

In the last decades, a new technological frontier opened up with the possibility of controlling and engineering light-matter interaction at the nanoscale. In this context, a huge role is played by photonic crystals (PhCs) that are basically low-loss dielectric mediums exhibiting periodic modulation of the index of refraction. Indeed, it is actually possible to conceive and fabricate such structures to control the flow of light by guiding it, slowing it down and even trapping it in micron-sized volumes.

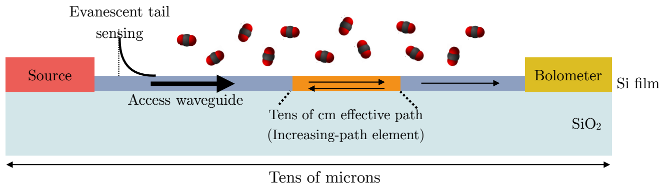
These properties would be really beneficial if applied in the field of photonic sensing, in particular in order to realize a novel design for IR gas detectors. Next figure shows a sketch of a usual Non Dispersive Infrared (NDIR) gas sensor.



An IR source generates light which travels inside a cell containing the gas to be sensed. Here, light is absorbed proportionally to the concentration of the gas of interest because of molecular vibrations. Transmitted radiation is then detected.

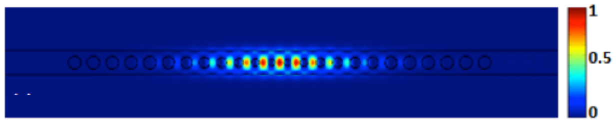
All the necessary components are centimeter-sized, making the device bulky and often expensive. Application of photonic crystal concepts to such devices, make it possible to realize them in a lab-on-chip configuration: each component is integrated on the same chip, allowing for the fabrication of thousands of them in a small area, resulting in a very compact, robust and cheap solution. Furthermore, for proper design, a PhC-based detector allows to selectively trap and resonantly absorb only the wavelength we are interested in.

Hence, the absorption is much more efficient, leading to much higher sensitivities. The goal of this work is precisely to design, fabricate and characterize a PhC cavity bolometer as a detector.



Design and fabrication

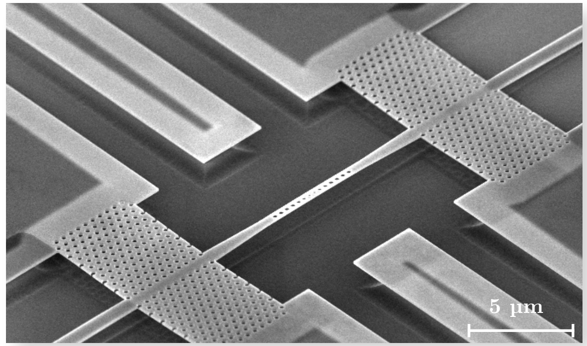
A sketch of the structure is shown in the frontispiece. It is realized on a Silicon On Insulator (SOI) platform consisting of a 220 nm-thick silicon film on a silicon dioxide (SiO_2) layer. Light is coupled through an access waveguide and guided to the very sensing element, that is the suspended nanowire in the central section. Some holes are etched through it, resulting in a one dimensional PhC cavity. For proper design, the nanowire shows a photonic band gap and a resonant mode within it, allowing only a specific wavelength to be coupled and thus trapped, as shown in the next figure, which displays the electric field within the wire.



The central section is highly n-doped in order to efficiently absorb the trapped radiation, thus heating the cavity and changing its electrical resistance. If the device is biased with a constant current, the potential drops across it changes as well.

Fabrication of the samples requires several steps, which are carried out by standard micro and nano fabrication techniques.

Patterns are defined by Electron Beam Lithography (EBL) and then etched through the silicon film by a Reactive Ion Etching (RIE) process. Doping is carried out in a horizontal furnace and the central section is undercut by hydrofluoric acid (HF) wet etching. The metal pads are realized with a thermal evaporator followed by a lift-off step. Next figure shows a SEM images of the complete structure.



Characterization and results

The samples have been optically characterized by the butt coupling technique. The chip is cleaved through the access waveguides, light from a laser source is focused on one of the facets and the transmitted radiation is collected from the other one. Thus, such a setup allows for measuring the device transmission spectra, as shown in the next figure.