

Photonic Crystal Based Gas-Sensor On Inp Substrate

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ABSTRACT

We propose the simulation of photonic crystal (Phc) gas-sensor structure with multi-hole defect. The Phc is consisted of holes on dielectric slab waveguide of InP/InGaAsP/InP layers in hexagonal lattice. The radius and the lattice constant of holes are equal to 270 nm and 635 nm, respectively, by optimizing the bandgap and output optical power. The calculation results show that a change in hole refractive index of about 0.0003, by using CO gas instead of air, the center wavelength of microcavity will shift about 1.3 nm. And then compare it that change in hole refractive index of about 0.0017, by using benzene gas instead of air, the center wavelength of microcavity will shift about 2.9 nm.

Key words: Gas-sensor; Photonic crystal; InP material; index refractive

INTRODUCTION

The use of gas sensors for industrial and indoor applications is continuously increased on past decades. The interest for nanosensors is under attention of researchers due to their small cost, small dimensions and easy monolithic integration with light sources (Lasers and LEDs) and photodetectors. Meanwhile, the photonic crystals (PhCs) nanotechnology has allowed the possibility of manipulating photons in the periodic structures by the transmission and reflection properties of light in a specific directions and frequency ranges [1].

Several types of sensors based on PhC technology are designed or realized at photonic research centres. Wang [2-8] designed an ultra-compact gas sensor based on the two-dimensional PhC microcavity by using a point-defect resonant cavity at 1.55 μm wavelength. The resonance wavelength shift is about 0.04 nm for a refractive index (RI) change of about 0.0001. A multi-hole defect in a PhC structure instead of single hole with holes smaller than the PhC lattice creates more cavity quality factor and higher resonance frequency shift [5]. In [6] a biosensor based on PhC nano-ring resonator is suggested which showing a shift at resonant wavelength from 0 nm to 0.7 nm and Q-factor of more than 2000 for different materials. Benz [3] described a gas-sensor based on PhC pillars on air background. These pillars are formed of an active

THz quantum-cascade laser medium. These pillars can be pumped electrically to lase. So, there is no need an external Laser source. An experimental frequency shift of 10^{-3} times the centre lasing frequency is achieved.

In this article, we present a PhC gas-sensor based on hole defect microcavity resonator which can operate at 1.55 μm wavelength on InP substrate which can monolithically integrated with an active laser and photodetector.

The structure of the phc sensor The Structure of the PhC Sensor:

The layer stack of sensor includes three layers of a 500 nm InGaAsP ($\lambda_g = 1.25 \mu\text{m}$) guiding layer and cladding layers of InP material with a thickness of more than 1000 nm. The refractive indices of materials are 3.3640 and 3.1693 respectively by using COMSOL software [7]. Due to memory limitations, the simulations are determined with the geometry of two-dimensional holes in the dielectric three layers slab. The lattice constant of the hexagonal structure is equal to a shown in figure 1 with holes radius of r . A plane-wave expansion (PWE) calculation is performed to determine the bandgaps for TE and TM modes. To evaluate the optimized radius of holes at 1.55 μm wavelength for a wide frequency range, the radius is scanned from 50 to 300 nm for a lattice constant of 635 nm shown in

figure 2. The maximum bandgap can be obtained in a radius of 270nm at a normalized wavelength range of 280nm to 450nm corresponding to the wavelength of 1370-2240nm. The band structure is determined for the radius of 260nm for both TE and TM mode

which showing a joint TE/TM regions at the wavelength window of 1550nm (figure 3). So, this structure behaves as a polarization independent device.

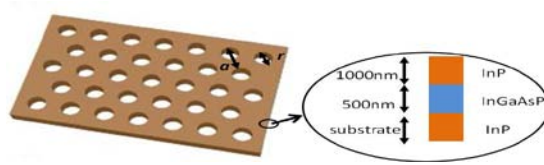


Fig. 1: PhC structure with layer specifications.

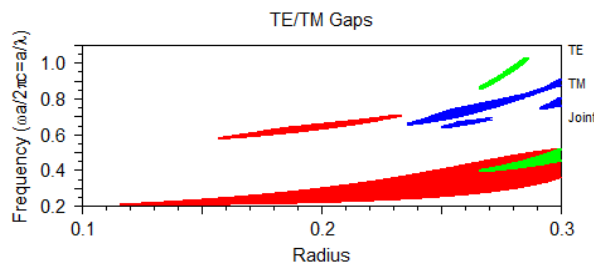


Fig. 2: Photonic bandgap as a function of radius for TE, TM and joint polarizations.

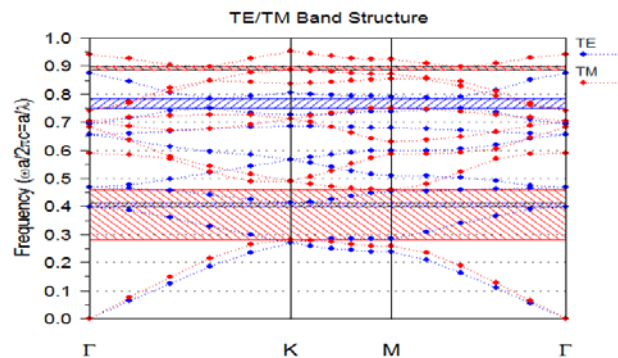


Fig. 3: Band diagram of TE and TM and joint polarization modes for the photonic crystal with hole radii of $r=0.426a$.

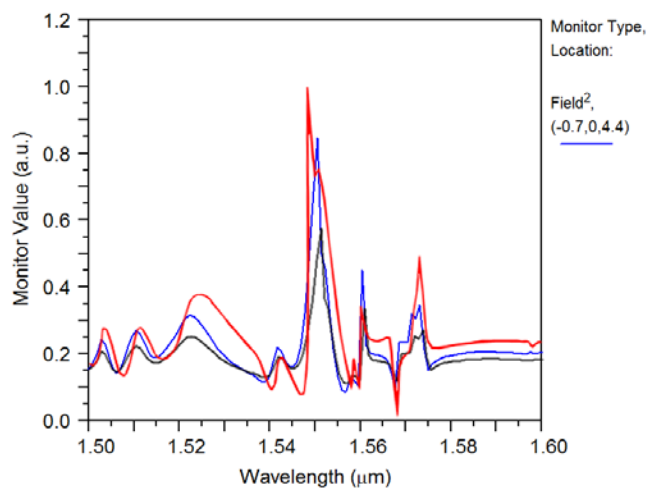


Fig. 6: Normalized transmission spectra of the gas-sensor (red line) the holes are filled with air ($n=1$) and (blue line) the holes are filled with CO ($n=1.0003$) and (black line) the holes are filled with benzene gas.

PhC-Based Gas Sensor:

The PhC sketch of gas-sensor is depicted in figure 4 which is based on the cavity-resonator scheme. The cavity is designed by changing the radius of a hole and by modifying the radii of the surrounding six holes with radius of $R_{C2-7}=0.254$ nm $R_{C1}=0.285$ nm and remove 12 hole around the center. The input and output waveguides is formed as a line defect.

A Gaussian continuous light with a beam width of a lattice constant at 1550nm wavelength is coupled into input waveguide. The light signal propagates and then coupled to the microcavity. The field distribution is shown in figure 5.

To evaluate the resonance wavelength of the cavity, a temporal light pulse is launched into the cavity resonator and monitored in the output port. The spectral transmission is obtained by performing the Fast Fourier Transform (FFT) on the time signal. Figure 6 shows the spectral transmission of gas-sensor when holes are filled with air. It demonstrates that the cavity resonance wavelength occurs at 1550.4 wavelength.

When the PhC cavity air holes are filled by sample gas of benzene resonance wavelength of gas-sensor will shift about 2.9 nm accordingly due to the variation of refractive index of the cavity holes.

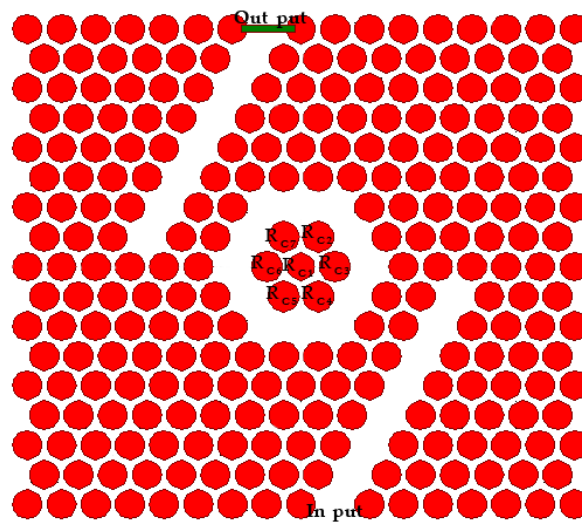


Fig. 4: 2D-structure of gas-sensor. White regions indicate slab waveguide with the effective refractive index of 3.2634. The defect holes radius is $R_{C1}=0.19$ nm, $R_{C2}=22$ nm

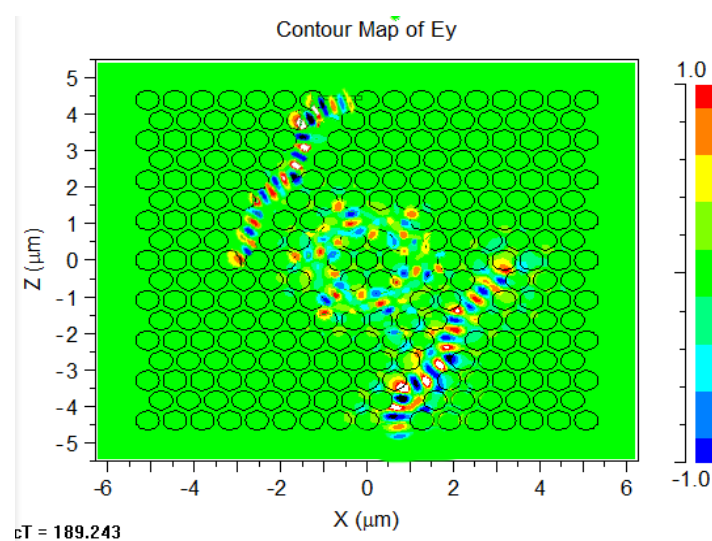


Fig. 5: Field distribution for an input Gaussian beam at wavelength 1550nm.

Conclusion:

In this study, we designed a PhC-based gas sensor by using a hexagonal lattice of air holes. The gas sensor is consisted of a microcavity and two input and output waveguides. By changing the refractive index of air holes to benzene and CO, the resonance wavelength of cavity will shifted about 2.9 and 1.3 nm.

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