IJCSI International Journal of Computer Science Issues, Vol. 9, Issue 3, No 1, May 2012
ISSN (Online): 1694-0814
www.IJCSI.org

Superlens Biosensor with Photonic Crystals in Negative Refraction

Zohreh Dorrani[1], Mohammad Ali Mansouri-Birjandi[2]

[1, 2] Faculty of Electrical and Computer Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

Abstract— We have presented the study on one structure fabricated with photonic crystals for use as biosensors with superlensing property in dimensions of nano and micro with negative refractive index. In a special frequency, this type of photonic crystal acts as Left-Handed Metamaterial (LHM). It is shown that by a suitable choice of design parameters, such as, dimensions of bars, it is possible to reach sensing property by this structure in two-dimensional triangular photonic crystals. The structure investigated in three size and results shows the slab of photonic crystals prosperous process that, with sensing applications can has imaging applications.

Keywords- **Biosensor, Imaging, Left-handed materials, Negative refraction, Photonic crystals**.

I. Introduction

Sometimes in science, there are the assumptions that we fancy impossible in the real world. These hypotheses existed in the past and now that science and technology have progressed, it still exists. One type of hypothesis is the Veselago hypothesis about negative refractive index concept and materials with this property, which was introduced in 1967 [1]. He called this substance, Negative Index Materials (NIMs).Thereafter, this property has been seeing in the material that called Metamatrial (MTM). Also, this material is called a left-handed metamaterial [1]. Metamaterials have property which cannot be found in the nature and show qualitatively new electromagnetic response functions.

The prefix Meta is interpreted as "outside of" that has the Greek origin and translate the term "meta-substances" as constructions whose effective electromagnetic manners falls outside of the property limits its forming components. Therefore, metamaterials refers to substances that value of permittivity and magnetic permeability are both simultaneously negative. In conventional materials, electric field, magnetic field and the wave vector conform the right-hand law. Thus, Poynting vector of a wave and the energy velocity have the same direction as their phase velocities. In metamaterial, these three vectors constitute a left-handed set of vectors. Therefore in metamaterials, the Poynting vector is anti-parallel to the wave vector [1, 2].

Metamaterials are artificially arrangements that have attractive applications. One type of metamaterials created in [3], in this paper have investigated a new design and systematic studied of transmission properties of conjugate omega shaped MTM. Low-index and zero-index metamaterials have been manufactured using frequency choosy ranges [4], which can be used for electromagnetic cloaking [5] or to focus the energy radiated with a source entrenched in a slab of zero-index metamaterial and improve the directivity of dual polarization and dual band patch antennas [6]. Under certain conditions, two-dimensional Photonic Crystals (PhCs) structures can operate as a medium with negative refractive index [7-8], that can be considered as one of the most attractive of the light properties.

Photonic Crystals, are dielectric structures with the optical refractive index where can be arranged periodically in one, two or three dimensions arrangements with a lattice constant. Such periodicity configurations can prohibit propagation of the electromagnetic waves in certain frequency ranges. There is a band gap where caused by electromagnetic waves didn't published at certain frequencies [9-10].

Photonic crystals in a certain frequency can act as a material with negative refractive index and illustrate metamatrial behavior. In this paper, we proposed PhC sensor based on negative refraction that has several applications. This structure is a sensor that has biomedical application. Using the 2D photonic crystals, in [9] be studied a biosensor based on collimation effects in nano dimensional. But different structure used in this paper. There with, this arrangement theoretically demonstrates optical imaging by a negative refraction PhC that proposed in [11] only in a dimensional. We demonstrate imaging in three dimensional. Details of the calculations and discussion of the results will be proposed in follow.

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.

II. THEORY OF NEGATIVE REFRACTION

In 2000, a combined material with simultaneously permittivity and permeability negative values was made up in the optical frequency range [7].
Permittivity and permeability type wasn't Contradiction with the metamaterial type and for this material have:

$$n = \sqrt{\mu\varepsilon} \quad (1)$$

But what are different metamatrial with natural materials and how could there be these materials? To answer this question, first we studied the rules of the Maxwell.

$$)\nabla \times E = -j\omega B \qquad (Faraday's \;\; Low) \quad (2)$$
$$\nabla \times H = j\omega D \qquad (Generalized \; Amper \; Low) \quad (3)$$

Where E and H are electric field intensity and magnetic intensity, respectively, B and D is magnetic flux intensity and electric flux intensity, respectively. Equation 4 represents Poynting vector:

$$S=E\times H \quad (4)$$

These equations show right-hand rule in conventional materials and this law is for positive μ and ε values. Now phase velocity direction (v_{ph}) matched with the group velocity direction (v_g).
What happen if suppose the phase and the group velocities vector of aren't parallel? Now E, H and V should conform a left-hand set and this property happen only with the medium is characterized by negative values of μ and ε. Therefore, if μ and ε are negative, then the phase velocity direction and the group velocity directions are anti parallel, so, E, H and V conform a left-hand set. This property there is in metamatrials.

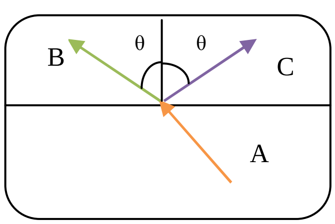


Fig. 1. The light propagation in positive refractive index perimeter (B) and negative refractive index perimeter (C).

Now, we can change equation (1), for left-handed material added negative sign.

$$n = \pm\sqrt{\mu\varepsilon} \quad (5)$$

III. DESIGN AND ANALYZE

A. Sensor

The PhC structures investigated consist of a periodic hexagonal lattice of dielectric bars. Now we choose parameters used in Ref. [9], the bar dimensions is $r_x=0.40a$ and $r_y=0.80a$, that a is the center to center partition between bars called lattice constant and constant dielectric (ε) of bars is 12.96. Value of lattice constant is variable, because sensor should apply in several sizes.
We have developed and employed well known two-dimensional finite-difference time-domain (FDTD) with perfectly matched layer (PML) boundary condition based on the Yee's algorithm and in order to investigate the proposed sensor behavior, switch on a point source, outside and left of the slab.
This structure in $f=0.192$ act such as metamatirial and have negative refraction index.
In this frequency, bars refractive index be fixed, but background dielectric constant (N) is variant. We choose four materials for background contain of air, dry air, gas and water. Values of lattice constant and refractive index of above materials for background give in Table 1.

Table 1. Values of background refractive index and lattice constant

Refractive index for background		Lattice constant	
Material	Refractive index(n)	Microsensor	1.5875
Air	1	Nanosensor	0.15875
Dry Air	1.243	Nanosensor	0.015875
Water	1.33	-	-
Butane Gas	1.3803	-	-

Range of background refractive index is chosen between 1-1.5.
In order to study effects of these variables in detail and investigate this structure for sensing applications, we turn-on a Gaussian source of waves outside and to the left of the slab of the PhC and the amplitude of H_y is measured at outside and to the right of the slab.
In first section, we analyze the wave propagation maps for microsensor and calculate the field amplitude with N variation. Figure 2 shows the calculated field pattern. Our simulations show that field amplitude is drastically sensitive to refractive index.
Next, we investigate to changed size of PhC slab which formed by new value of lattice constant ($a=0.15875$). Figure 3 shows simulation results.

IJCSI
www.IJCSI.org

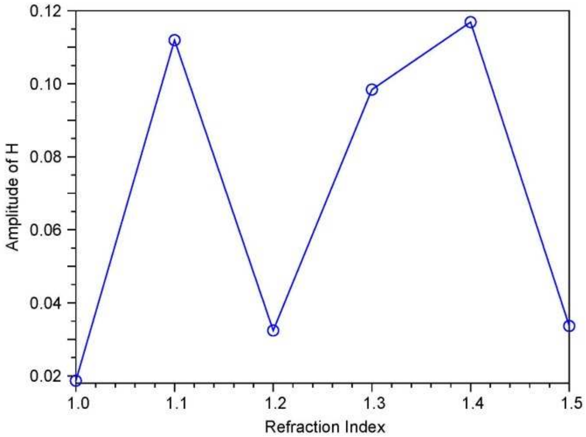


Fig.2. Amplitude of magnetic field across background refractive index changes when background is filled with air, dry air, water, butane gas for lattice constant 1.5875.

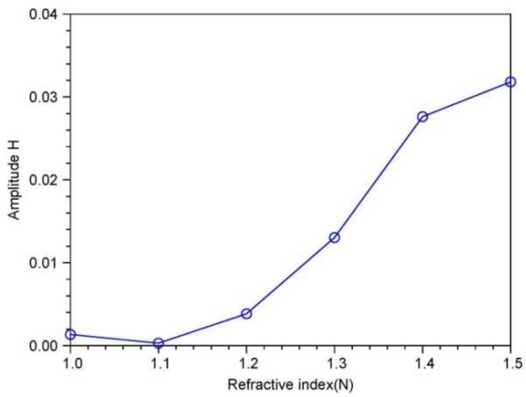


Fig.3. Amplitude of magnetic field across background refractive index changes when background is filled with air, dry air, water, butane gas for lattice constant 0.15875.

In this condition, field amplitude is sensitive with refractive index.

If be reduced size of PhC, like previous results repeat and Our FDTD simulations in Figure 4 indicate that there is a strong sensitive.

Results show that our structure is very sensitive to small refractive index difference. In sensor have medicine application and very useful on recognizing different polluted liquids and gases passing through the sensing area and this structure can be called nano and micro photonic biosensor.

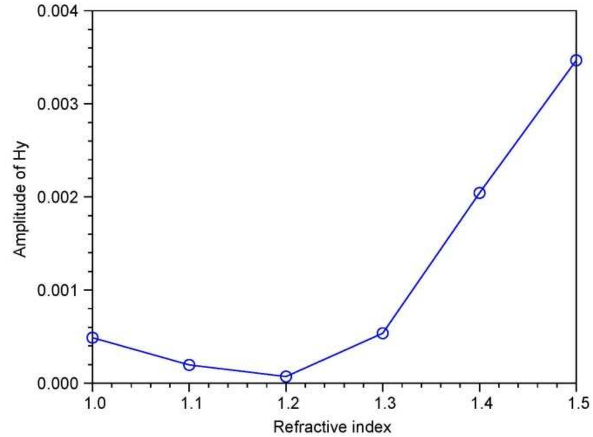


Fig.4. Amplitude of magnetic field across background refractive index changes when background is filled with air, dry air, Water, Butane gas for lattice constant 0.015875.

B. Superlensing

Theoretically, we study the superlensing behavior within same above slab of PhC that acts as a medium whit n=-1. Superlensing describes to the unusual imaging effects due to the existence of the extra near-field light. Figures 5 show the snapshots of the H_z field. The slab focuses the image and therefore the superlensing is happened. Again, for imaging changed size of slab and for three sizes repeat simulation. Comparing to results, can see imaging in all sizes.

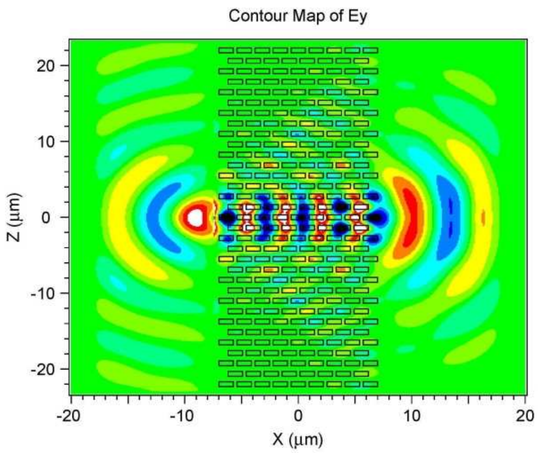
Results of simulation show the negative refraction as well as the superlensing phenomenon and demonstrate the perfect image reproduced by this structure in nano and micro dimensions.

IV. CONCLUSIONS

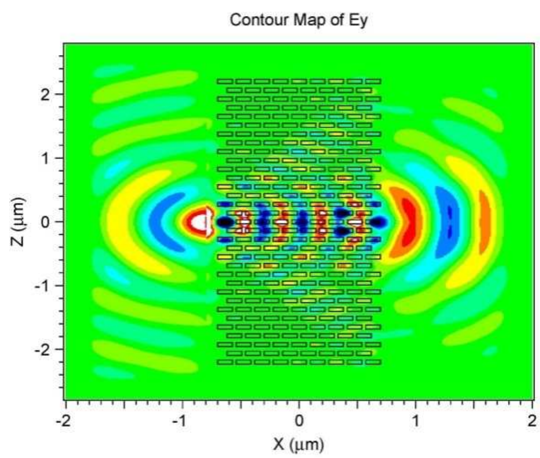
In this paper we proposed a biosensor of PC with negative refraction that has imaging ability.

Sensor investigated in three sizes both of sensing applications and imaging applications. The proportion maps of biosensor that can be employed in various biomedical applications is demonstrated that background is filled with liquids and gases and in this conditions is very sensitive to small refractive index changes. Simulation results establish that superlensing is possible with premeditated photonic crystals. Therefore, we make an imaging biosensor in three sizes.

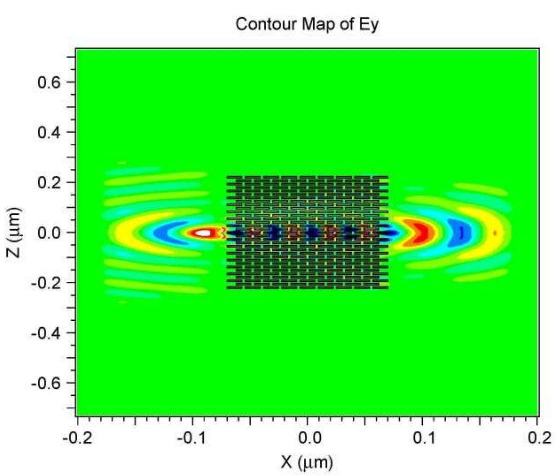
Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.



(a)



(b)



(c)

Fig. 5. The propagation map (magnetic field distribution across space) for slab of the hexagonal 2D-PhC of structure. (a) Imaging in lattice constant 1.5875, (b) imaging in lattice constant 0.15875, (C) imaging in lattice constant 0.015875.

REFERENCES

[1] V. G. Veselago, "The electrodynamics of substances with simultaneously negative values of ε and μ", Soviet Physics Uspekhi, 1968, 10 (4), 509-514.

[2] S. T. Chui, Z. F. Lin, L. B. Hu, "Left – handed materials in metallic magnetic granular composites", Physics Letters A 31985-88, Vol. 319, I. 1-2, 2003, pp. 85-88.

[3] A. K. Panda, A. Mohanty, "Realization of a Dual Transmission Band Conjugate Omega Shaped Metamaterial", International Journal of Computer Science Issues (IJCSI), Vol. 8, I. 6, No. 2, 2011, pp.175-179.

[4] A. Sharkawy, S. Shi and D. W. Prather, "Multichannel Wavelength Division Multiplexing Using Photonic Crystals", Applied Optics, Vol. 40, I. 14, 2001, pp. 2247-2252.

[5] G. Ma, J. Shen, Z.Zhang, Z. Hua, and S. H. Tang, "Ultrafast all-optical switching in one-dimensional photonic crystal with two defects", Optics Express 14, 2006, pp. 858-865.

[6] Z. H. Zhu, W. M. Ye, J. R. Ji, X. D. Yuan, and C. Zen, "High-contrast light-by-light switching and and gate based on nonlinear photonic crystals", Optics Express 14, 2006, pp. 1783-1788.

[7] V. Veselago, L. Braginsky, V. Shklover, and C. Hafner, "Negative Refractive Index Materials", Journal of Computational and Theoretical Nanoscience, Vol. 3, 2006, pp.1- 30.

[8] F. Ouerghi, F. Abdel Malek, S. Haxha, R. Abid, H. Mejatty, I. Dayoub, "Nanophotonic Sensor Based on Photonic Crystal Structure Using Negative Refraction for Effective Light Coupling", Journal of light wave technology, Vol. 27, I. 15, 2009, pp. 3269-3274.

[9] K. Inoue, and K. Ohtaka, "Photonic crystals: Physics, Fabrication and Applications", Springer-Verlog, 2004.

[10] J. D. Joannopoulos, S. G. Johnson, J. N. Winn, and R. D. Meade, "Photonic crystals: Molding the flow of light", Princeton University Press, 2008.

[11] R. Moussa, S. Foteinopoulou, Lei Zhang, G. Tuttle, K. Guven, E. Ozbay, and C. M. Soukoulis1, "Negative refraction and superlens behavior in a two-dimensional photonic crystal", physical review, B 71, 2005, pp. 085106-1, 085106-3.

Zohreh Dorani obtained her BSc and MSc degrees in electrical engineering from the University of Khayyam, Mashhad, Iran, and the University of Sistan and Baluchestan, Iran in 2009 and 2011, respectively. Her areas of research include metamaterial and photonic crystal, and refractive indexes.

Mohammad Ali Mansouri-Birjandi received his BSc and MSc degrees in electrical engineering from the University of Sistan and Baluchestan, Iran and the University of Tehran, Iran in 1986 and 1991, respectively. He then joined the University of Sistan and Baluchestan, Iran. In 2008, he obtained his PhD degree in electrical engineering from Trabiat Modares University, Iran.

As an assistant professor at the University of Sistan and Baluchestan, his research areas are photonics, optoelectronics, analog integrated circuits, and metamaterial. Dr. Mansouri has served as a reviewer for a number of journals and conferences.

Copyright (c) 2012 International Journal of Computer Science Issues. All Rights Reserved.