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Simulation of metamaterials negative refractive index

Tahar Ghadbane and Hocine Guessas

Laboratory of Photonic systems and nonlinear optics, Institute of Optics and Precision Mechanics(IOMP)
University Ferhat Abbas – Setif UFAS (Algeria)

E-mail : egfpfp@yahoo.fr

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Abstract

Research on artificial structures have practically achieve what Victor Veselago predicted in the 70s, namely engineering permeability and permittivity, which made both simultaneously negative, make possible the existence of effects negative refractive. John Pendry mentioned the possibility of making perfect lens using a flat layer of material left-hand whose relative permittivity and permeability equal to -1 must be able to focus a point source with perfect resolution. In his demonstration, Pendry capital shows the importance of the evanescent waves in this property, these waves undergoing amplification in the left hand material, breaking the Rayleigh limit $\lambda/2$ *. Here we are in the field of metamaterials characterized by a structure largely under-wavelength. we present the results obtained for the determination of all possible operating points, seeking the band gaps can TE and TM and the band gaps in a common two-dimensional periodic structure of triangular air holes in a dielectric with a refractive index n = 3.26.*

Keywords: Simulation, nanophotonics, metamaterials, photonic crystals, electromagnetism

1. Introduction

The ability of photonic crystals to manipulate, control and confine light in three directions of space raises many applications. They are mainly in the areas of computing and communication, with the manufacture of reproducing the operating principles of the various components of an integrated circuit, using photons as information carrier instead of the electron system. Light has several advantages compared to electrons. It can travel through a dielectric material faster than an electron in a metal wire, it can carry a large amount of information per second, and the interactions between photons and dielectric material are smaller than those between electrons and metal material, which reduces energy losses.

Photonic crystals have been proposed to control the spontaneous emission of light. Consider a photosensitive body, buried in a photonic crystal is excited. The electronic transition to a lower level of energy cannot be done easily, if the frequency of the emitted photon is contained in the complete photonic Band prohibited. The lifetime of the excited state can then be increased and the rate of spontaneous emission changed.

In the present paper, our job is to see where the highest allowed by varying the filling factor band is, and see the influence of the geometry of the system of obtaining negative index of refraction.

2. Simulation method

Using the method of plane waves which is a digital tool to calculate the frequency bands authorized or prohibited electromagnetic waves may propagate in the material considered propagating environment and this for any direction; this method allows us to obtain scatter plots.

Wave vector for each of the contour formed by the high symmetry points Γ, X, M of the first Brillouin zone (Fig.2), there are several frequencies corresponding to the different propagation modes capable of propagating in the photonic crystal.

To calculate the band diagram consists of all curves $\omega(k)$ of the photonic crystal, it is possible to consider the set of vectors constituting the first Brillouin zone reduced. The Brillouin [10] zone is a subspace of the space defined by the mutual primitive cell, said Wigner-Seitz [11], in the space of the wave vectors k.

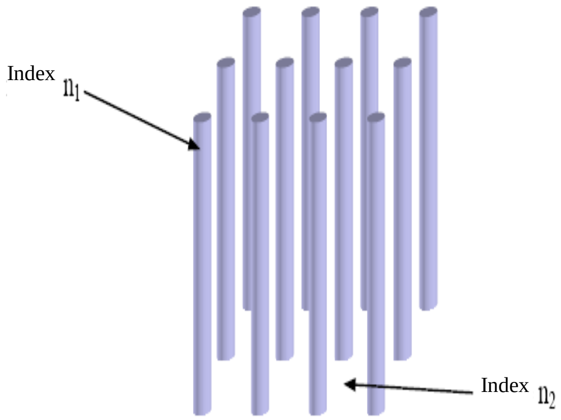

Figure 1. 2D periodic structure

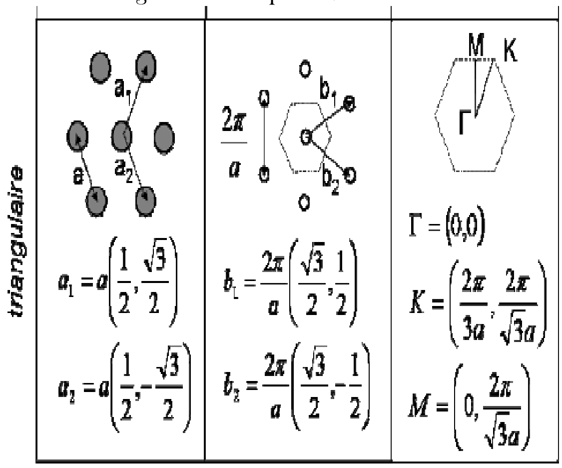

Figure 2. Representation of the triangular lattice of period in the direct space and corresponding reciprocal, the reduced Brillouin zone is described by the high symmetry points [5].

3. Results and discussion

3.1. Choosing the optimal filling factor

From the results we can see that the best fill factor and one which has a width of common high band gap corresponding to f = 50% (Tab.1).

Table 1 : Variation of the width band gap as a function of filling factor.

Filling factor	Width of the band gap TM	Width of the band gap TE	Width of the common band gap
0.2	0,04000166	0,04000166	0,00649317
0.3	0,06793692	0,02084131	0,00992539
0.4	0,10013801	0,02549701	0,01214728
0.5	0,13525624	0,029136	0,01284678
0.6	0,16845625	0,03231061	0,01163537
0.7	0,18845923	0,03546292	0,00746605
0.8	0,17387638	0,03886554	0
0.9	0,07746318	0,04161296	0

Thus the band structure of the TM polarization (Fig.3) presents a wide frequency range that extends from 0 .22 to 0.36 for which we can define negative refractive indices.

TE polarization (Fig.4) Presents a forbidden frequency band extending from 0.21 to 0.24.

Finally, (Fig.5) presents the common band gap that extends from 0.22 to 0.24 is a width of 0.0128.

We can evaluate the results from the influence of the filling factor on the dispersion properties namely the opening of band gaps and the frequency range of the second allowed band of interest for the applications of negative refraction.

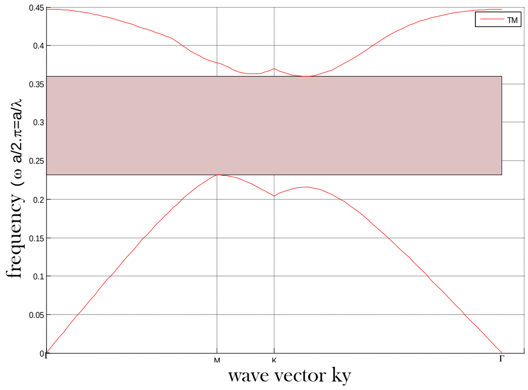

Figure 3. TM band gap, for a filling factor of 50%

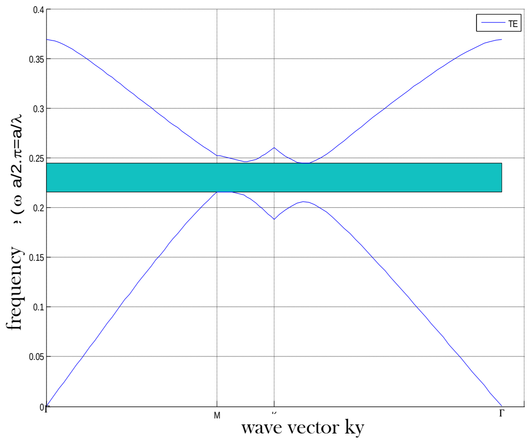

Fig.4 TE band gap, for a filling factor of 50%

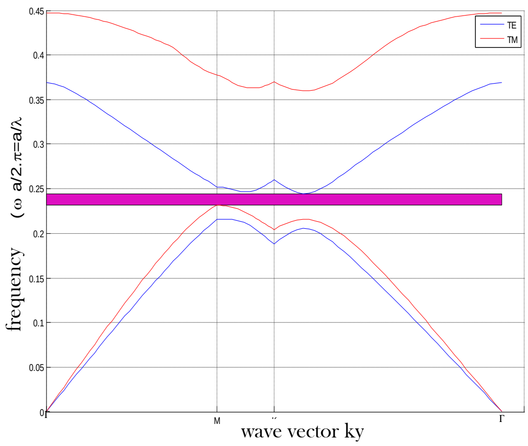

Figure 5. Band gap common, for a filling factor of 50%

3.2. Calculating the index of refraction

Table 2 : variation of the refractive index as a function of the frequency

n	dw/dk	w
-0.01	-0.003609281	0.44736412
-0.14	-0.04554845	0.44606604
-0.16	-0.052330226	0.44560136
-0.18	-0.05901523	0.44506748
-0.20	-0.065588147	0.4444654
-0.22	-0.07203329	0.44379627
-0.24	-0.078334792	0.44306138
-0.25	-0.084476838	0.44226221
-0.27	-0.090443909	0.44140037
-0.29	-0.096221032	0.44047766
-0.31	-0.101794021	0.43949601
-0.32	-0.1071497	0.4384575
-0.34	-0.112276089	0.43736436
-0.41	-0.137729443	0.4297958
-0.42	-0.141038047	0.42839068
-0.43	-0.144074886	0.42695181
-0.44	-0.146841365	0.42548195
-0.45	-0.149340381	0.42398387
-0.45	-0.151576537	0.42246029
-0.46	-0.153556738	0.4209139
-0.47	-0.155291696	0.41934731
-0.47	-0.156799944	0.41776301
-0.47	-0.158120041	0.41616334
-0.48	-0.159356401	0.41455019
-0.48	-0.160928835	0.41292443
-0.50	-0.166570151	0.41128263
-0.75	-0.250233396	0.40958327
-0.98	-0.327699012	0.40703038
-0.96	-0.320743276	0.40368718
-0.92	-0.308023398	0.40041494
-0.88	-0.293358152	0.39727248
-0.83	-0.277079154	0.39427962
-0.78	-0.259198407	0.39145285
-0.72	-0.239672551	0.3888085
-0.66	-0.218458177	0.38636335
-0.59	-0.195534336	0.38413463
-0.51	-0.170917983	0.38213978
-0.43	-0.144677233	0.38039607
-0.35	-0.116942641	0.37892007

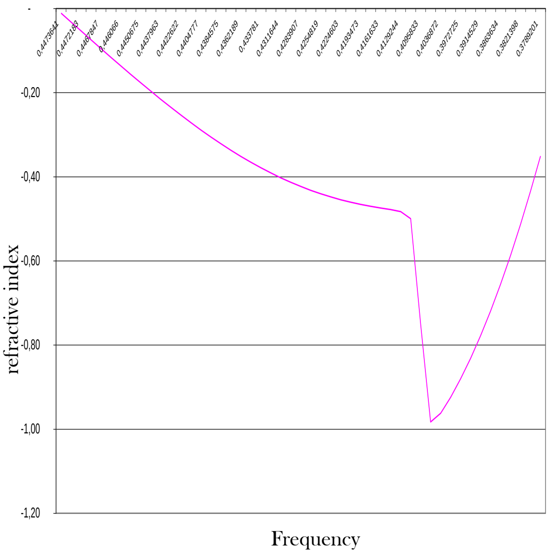

Figure 6. Evolution in the refractive index as a function of the frequency

Figure.6 shows the evolution of the refractive index that can be extracted from the second band. It varied between -0.98 and -0.01 (Tab.2), the values of negative evidence that allows us to consider the application of flat type lens.

4. Conclusion

The calculation made by simulations based on the method of plane waves applied in our calculations for a photonic crystal consisting of air holes drilled in a dielectric matrix for a triangular lattice, shows that the group velocity is negative for frequencies in the direction Γ, M of the area brouilouin.

The diagram shows that the photonic band gap for a fill factor of 50%, to a TM polarization wide band extending from 0.23 to 0.36 and has a width of 0.128 shown in the simulations test, which led to this choice.

which is the same for many published research in this area based on the plane wave method for photonic crystals.

Thus, the velocity of the group corresponds to the slope of the dispersion curve, By analyzing the different band diagrams, and calculating the slope of the second allowed band in the direction Γ, M , in a frequency range where the velocity is negative.

For this frequency range, we can define negative refractions indices, we also note that in this region there is a TE band gap that extends from 0.216 and 0.244 and has a width of 0028.

As also noted that there is a band gap that is common (between band gap TM and TE band gap) which lies between 0.231 and 0.244, and has a width of 0.013.

In this work a dielectric approach to negative refraction in photonic crystals is studied by simulation using the method of plane waves, as well as on various simulations has led to results that allow us an opening to other applications empoilant the properties of negative refraction associated with bandwidths or prohibited by these photonic crystals.

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