Optimization of two dimensional chiral photonic crystal nanostructures

Mezache Zinelabiddine [1,*], Seghaouil Samir[2], Chaibi Walid[2] and Benabdelaziz Fatiha[2]

[1]Institue of Optics and fine mechanics,
University of Ferhat Abbas Setif 1, Setif, Algeria
[2]Department of Electronic,
University of Brothers Mentouri Constantine 1, Constantine, Algeria

**Corresponding author E-mail*: zinemezaache@yahoo.fr

(Received 10 November 2017, Accepted 24 January 2018, Published 29 January 2018)

Abstract

A chiral photonic crystal (CPC) in 2D is a structure that presents the variation of the dielectric permittivity and the chirality parameter along two directions of space. The objective of this paper is to simulate and study geometric effects on the characteristics of 2D chiral photonic crystal based on dielectric material using Comsol Multiphysics 5.0 environment. The properties of Chiral Photonic Crystal are discussed based on transmission coefficient (S_{21}) and reflection coefficient (S_{11}).

***Keywords*:** Chiral Photonic Crystals, Optical Nanostructure, COMSOL Multiphysics

1. Introduction

The rapid evolution of computer resources and scientific computing software, numerical methods have taken a predominant part in solving problems in several scientific fields such as medicine, biology, and telecommunications. COMSOL Multiphysics is part of this modeling and calculation software. It's based on the finite element method, which makes it possible to explore physical phenomena on a computer, in order to optimize the design of the prototypes in the laboratories, and to reduce, consequently, the cost and the effort. A notable advantage of this software lies in the fact that it takes into account highly heterogeneous structures, through the use of space mesh and a 3D visualization of the phenomenon can be studied.

In this paper we will simulate Chiral Photonic Crystal (CPC) structures by COMSOL Multiphysics. Then, we will study the state of polarization of the incident electromagnetic wave, which propagates in its environment, by studying the physical and geometric effects on the characteristics of 2D chiral photonic crystal structures based on dielectric material. At first, we studied a CPC structure similar to that of the literature [1-8] by simulating it by COMSOL Multiphysics. We also put the previous CPC structure into arrays of four elements in order to study, characterize, and emphasize the array effect relative to the case of a single element. A 2D CPC crystal is a structure that presents along two directions of space the variation of the dielectric permittivity and the chirality parameter, relative to the third direction which remains invariable. There are two types of dielectric periodic structures:

- The "connected" structures: the elementary patterns are of index n_1, and the dielectric matrix is of index n_2 (Fig.1).

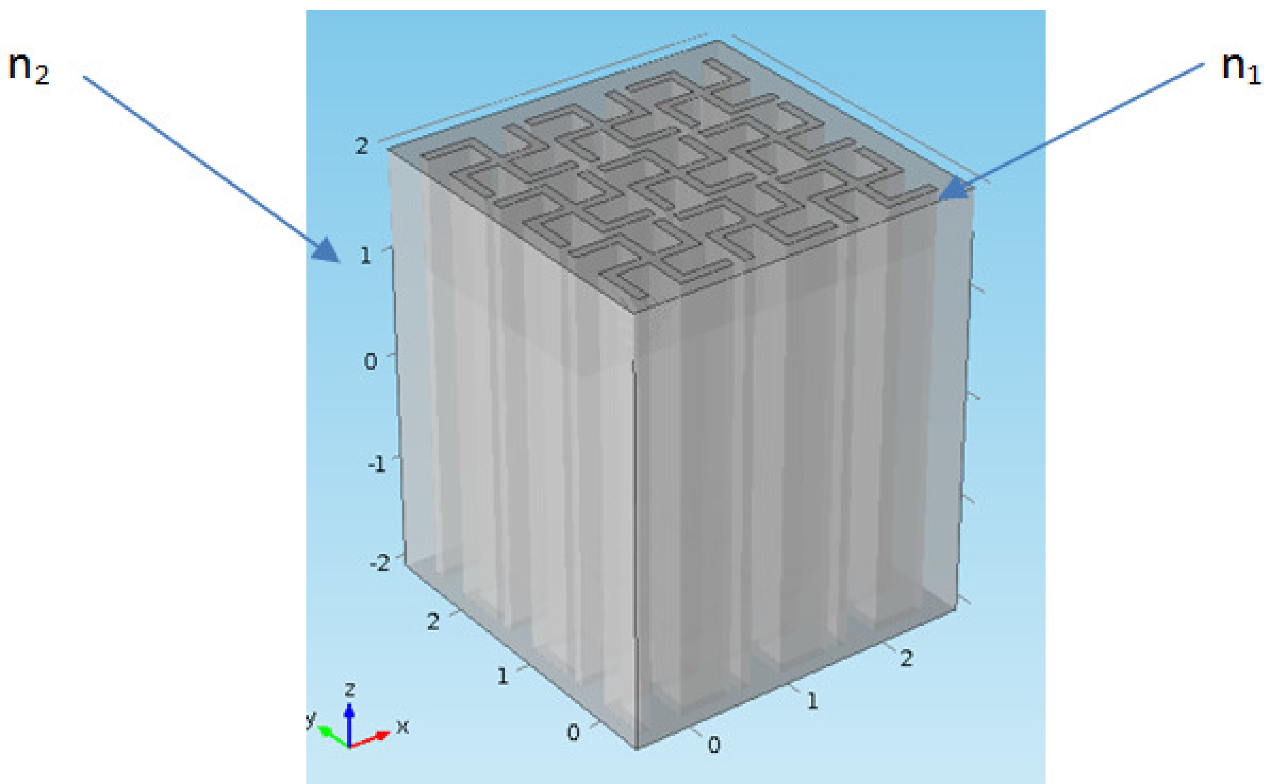


Figure 1 Connected periodic structures 2D.

• The "disconnected" structures: the elementary patterns are of index n_1, greater than the index n_2 of the inter-pattern space. They consist of dielectric or metal structures periodically aligned (Fig.2).

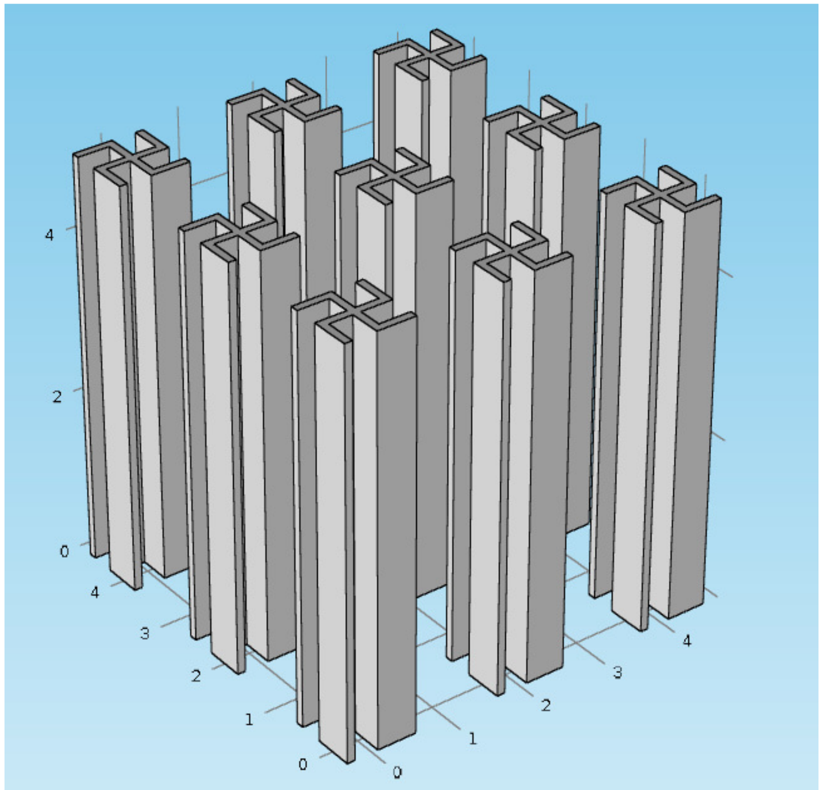
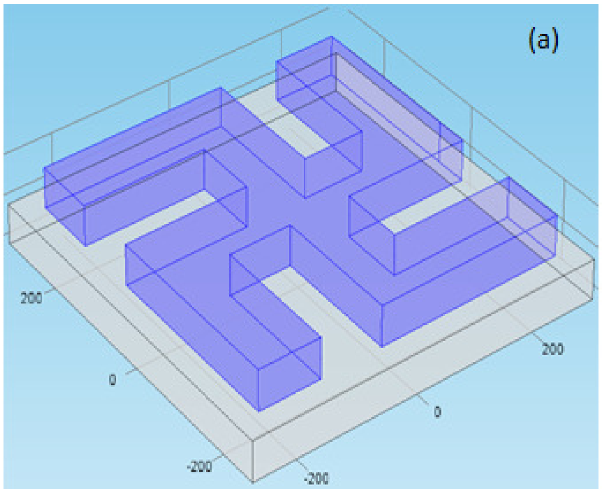


Figure 2 Disconnected periodic structures 2D.

2. Modeling of the CPC nanostructure

To study the CPC nanostructures by COMSOL Multiphysics, we chose the domain of electromagnetic waves as frequency domain in which we develop our structures implanted on a substrate in a waveguide with two ports (Fig.3). Port 1 represents the excited side by the right circularly polarized (RCP) wave, then by the left circularly polarized (LCP) wave both polarized in TE mode. The second port 2 is kept inactive to prevent reflection of the wave. As for the other faces of the waveguide, they are considered as perfect electrical conductors. The interior of this guide is filled with air (Fig.4). The chiral structure is titanium dioxide of refractive index n_g = 2.909 and the substrate is silicon oxide SiO_2 of refractive index n_h = 1.7 which are dielectrics.



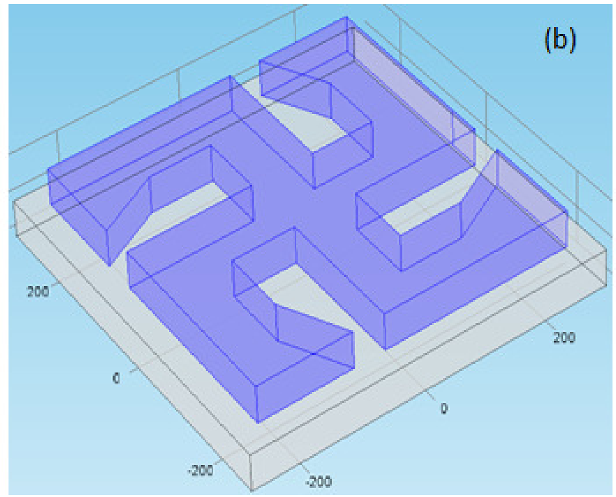


Figure 3 Square chiral structure 500nm side, 100 nm high, on a square substrate 600nm side 100nm high (a) a single symmetrical element (b) a single modified element

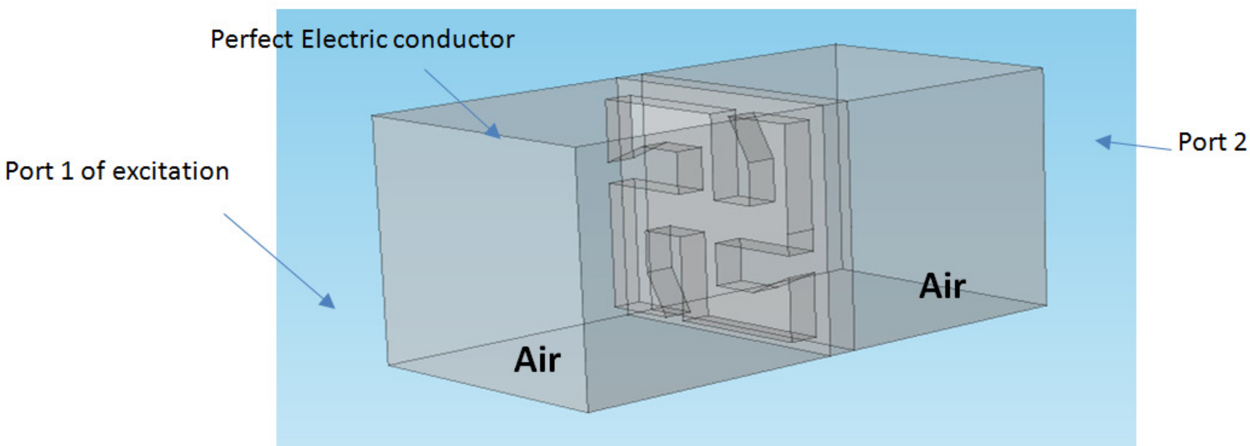


Figure 4 The model of the structure placed in a waveguide

3. Results in the case of the nanostructure with single element

According to Fig. 5 of the simulated structure, the curves of the parameters S_{11} (reflection coefficient) and S_{21} (transmission coefficient) of the RCP wave are shown at frequencies F_1, F_2 and F_3 with the presence of certain harmful disturbances. On the other hand, the curves (Fig. 6) of the geometrically modified structure are distinctly improved and have windows on the transmission of the structure, clearly separated and in well-defined frequency range domains for applications.

According to Fig. 7 of the simulated structure, the curves of the parameters S_{11} (reflection coefficient) and S_{21} (transmission coefficient) of the LCP wave are shown at frequencies F_1, F_2 and

F_3 with the presence of certain adverse perturbations. On the other hand, the curves of Fig. 8 of the geometrically modified structure are significantly improved. In particular, the appearance of the peak at the frequency F_3 = 467THz which is clearly separated is useful for applications that needs precise frequency range.

It is found that the resonance frequencies for modified structures as given in Fig. 6 and Fig. 8 are the same for RCP polarization and LCP. This can be related to the geometric shape of the chosen structure leading to a stable response to different polarization states. We calculated the quality factor Q (Q = F/ΔF) at each peak, in order to compare the diversity of the results (F=resonance frequency of the peak. ΔF=frequency width of the peak at half height). The largest quality factor was Q_1=170.29 in the case of the single element model of Fig 7 located at the frequency F_1 = 431THz. This allows us to accurately determine the operating bandwidth for proper application.

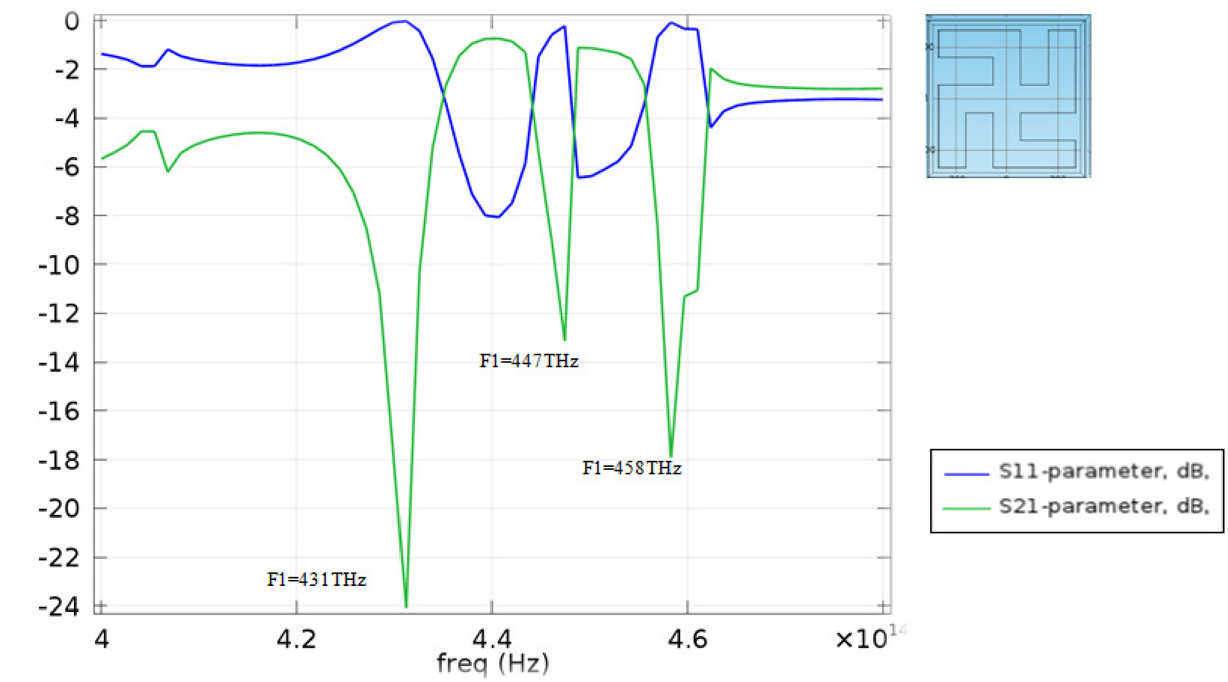


Figure 5 The curves of the parameters S_{11} in dB and S_{21} in dB of the symmetrical structure polarized by RCP wave

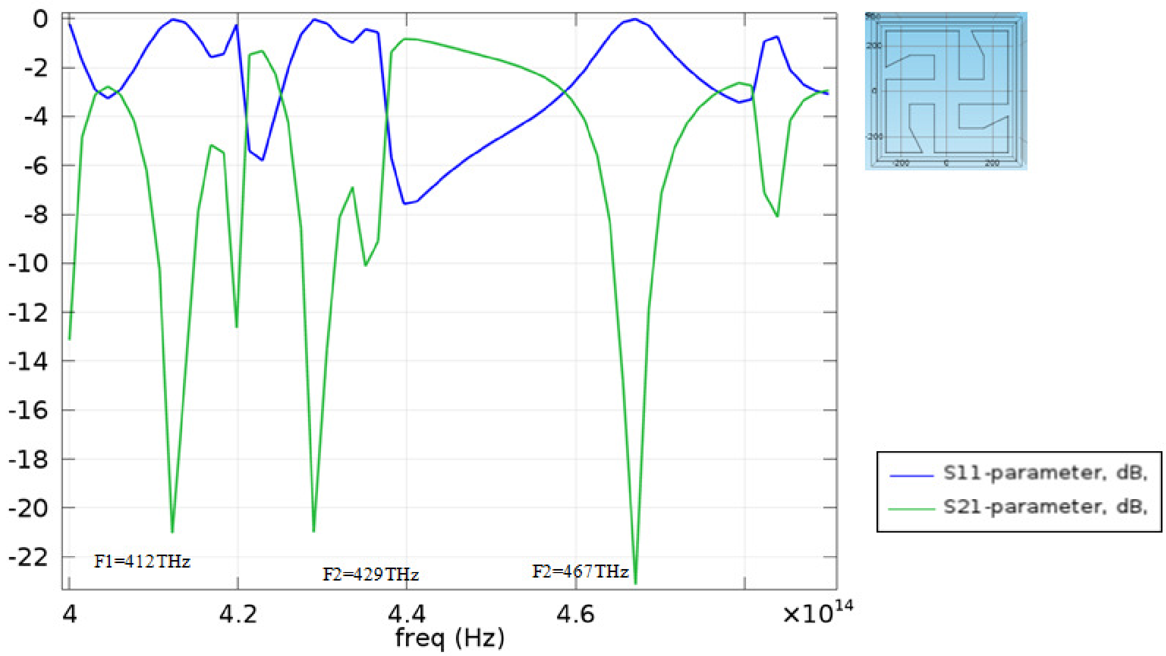


Figure 6 The curves of the parameters S_{11} in dB and S_{21} in dB of the structure with single modified element polarized by RCP wave

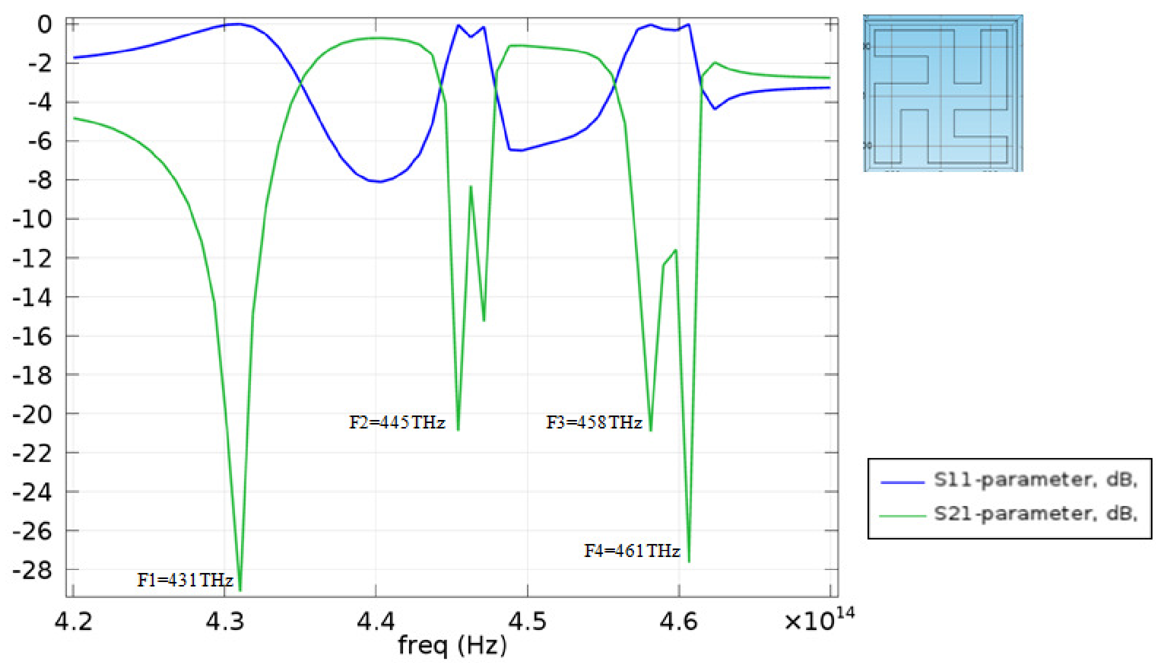


Figure 7 The curves of the parameters S_{11} in dB and S_{21} in dB of the symmetrical structure polarized by LCP wave

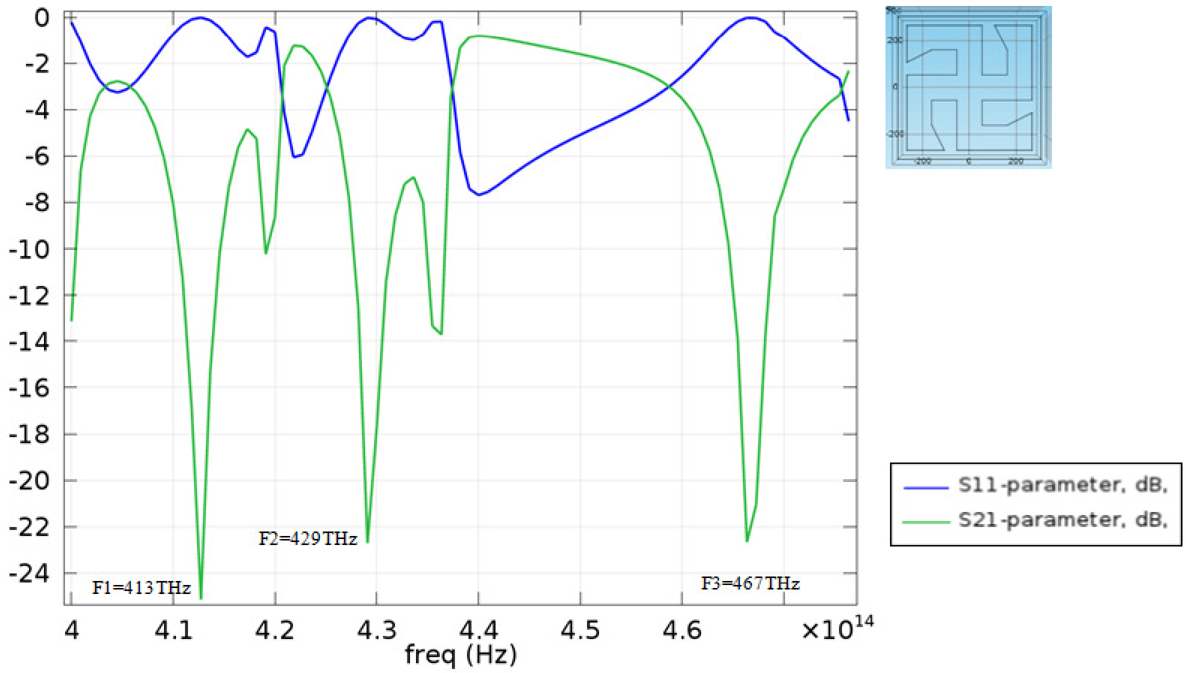


Figure 8 The curves of the parameters S_{11} in dB and S_{21} in dB of the structure with single modified element polarized by LCP wave

4. Conclusion

In this article, we have presented and compared the results of a COMSOL software modeling for a single 2D CPC structure and for a geometrically modified structure. The curves for the geometrically modified structure were found to be significantly improved.

References

[1] S. Noda, M. Fujita, and T. Asano, "Spontaneous-emission control by photonic crystals and nanocavities," *Nature Photonics,* **1**, 449–458 (2007)

[2] H. Altug, D. Englund, and J. Vučković, "Ultrafast photonic crystal nanocavity laser," *Nature Phyics,* **2**, 484-488 (2006)

[3] Benfeng Bai,Yuri Svirko, "Optical activity in planar chiral metamaterials: Theoretical study" *Physical Review A*, **76**, 023811 (2007)

[4] M. Thiel, G. von Freymann, and M. Wegener, "Layer-by-layer three-dimensional chiral photonic crystals," *Opt. Lett.*, **32**, 2547-2549 (2007)

[5] M. Thiel, M. Hermatschweiler, M. Wegener, and G. von Freymann, "Thin-film polarizer based on a onedimensional–three-dimensional–one-dimensional photonic crystal heterostructure," *Appl. Phys. Lett.,* **91**, 123515 (2007)

[6] Mezache Z, Seghaouil S, Chaibi W, Benabdelaziz F, "Optimization of Optical Nanoantenna Based on Structures Chiral Photonic Crystal", *American Journal of Nanosciences,* **3**(3), 47-52 (2017), doi: 10.11648/j.ajn.20170303.13

[7] Mezache Z, Zara Ch, Larioui F, Benabdelaziz F, "Detection and analysis of human hemoglobin HB and HBO2 with new Nano-sensor based on chiral metamaterials", *International Journal of Physical Research*, **5**(2), 36-38 (2017)

[8] Mezache Z, Zara Ch, Larioui F, Benabdelaziz F, "New study of geometry effect on chiral metamaterial nanostructures", *International Journal of Physical Research*, **5** (2), 101-103 (2017)