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# Study of the variation of refractive index for different organic liquids of an optical channel drop filter on a 2D photonic crystal ring resonator

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***Abstract*— in this work, a study of the variation of refractive index for different organic liquids of an optical channel drop filter (CDFs) based on 2D photonic crystal ring resonators (PCRRs) is presented. The structure is composed of dielectric rods immersed in air. We set square-fold quasi crystal at the middle of 3X3 square cavity for creating a ring resonator structure and designed an optical channel drop filter by using a finite element method (FEM). At λ=1550nm, an important wave length for optical communication systems, the numerical results shows the propagation and transmission for different refractive index of water, silicone oil and carbon disulfide: 1.333, 1.52045 and 1.628 respectively. As follows, the dielectric rods ($\varepsilon_r$), the radius (r) of the rods and the lattice constant (a) are three important parameters. At this work we focus our study on the refractive index variation and we fix the radius 'r' of the rods at 118.37 nm and the lattice constant 'a' to 623 nm.***

***Keywords*—** Photonic crystals, Channel drop filter, ring resonators, FEM.

## I. INTRODUCTION

Photonic crystals (Phcs) are defined as periodicity structures having a refractive index that are modulated with a wavelength –scale periodicity in one to three dimensions [1]. Phcs have a special frequency (wavelength) range in which the propagation of optical waves inside these artificial structures is forbidden. This special range is called the photonic band gap [2].

The PBG effect has been adapted to develop many optical devices such as: power splitters [3], optical reflectors [4]. A lot of structures channel drop filters based on 2D Pcs have been designed like Pc ring resonators (PcRRs) [5]. We remove some rods or holes inside the Pc structure in order to have a ring shape.

Not long ago, several researches were based on CDF ring resonator of square and triangular lattices as: David and Abrishamian who work on a multichannel –drop filter with PhcRR by using two different refractive indexes in the 2D –PC with square lattice [6]. Other authors like Mehdizadeh et al studied the effect of several parameters such as refractive index of dielectric rods and so on…which are important parameters for tuning the filter [7].

This article will investigate a variation of refractive index for different organic liquids of an optical channel CDF based on new configuration of 2D photonic crystal ring resonator by using finite element method (FEM).

## II. DESIGN PROCEDURE

A lot of methods have been proposed for studying, analyzing, and extracting the proprieties of PC devices. We used COMSOL software that is based on finite element method to investigate the band gap characteristics of 2D crystal photonic composed of square lattice of rods embedded in air which is verified by plane wave expansion method (PWE). The results are very reliable, proving that COMSOL® can be used for the full characterization of the structures.

In this work, we took a two dimensional photonic crystal composed of square lattice of rods in an air background with lattice constant a=0.623μm. The effective refractive index of the rods is taken to be 2.838 and for the air background is1. The radius of rods of perfect PC (with no defects) is r=0.19a.

Firstly and before designing the filter, we should define the PBG region. By using Eigen-value, the band diagram of the PC is calculated and depicted in Fig 2.

In this paper, we investigated the photonic band structure, propagation and transmission calculations of 2D photonic by using finite element method (FEM). F.E.M method is a very reliable and effective numerical approach for modelling and simulating a large range of problems in physics, in particular for complex structures. Moreover, it is possible to resolve and express wave propagation in the same way of the dispersion diagram of photonic crystal structures [8-10]. We put into operation for our calculations commercial software COMSOL based on finite element method [11].

First, we considered photonic crystals composing of dielectric rods in air arranged by lattice arrays. By solving Maxwell's Equations, we studied electromagnetic wave propagation in a photonic crystal structure [12].


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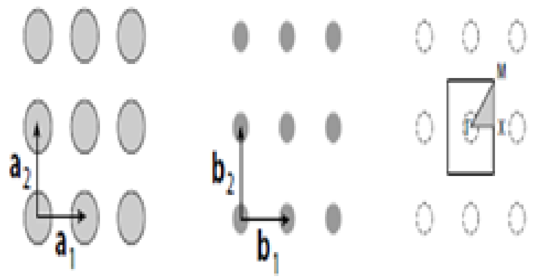
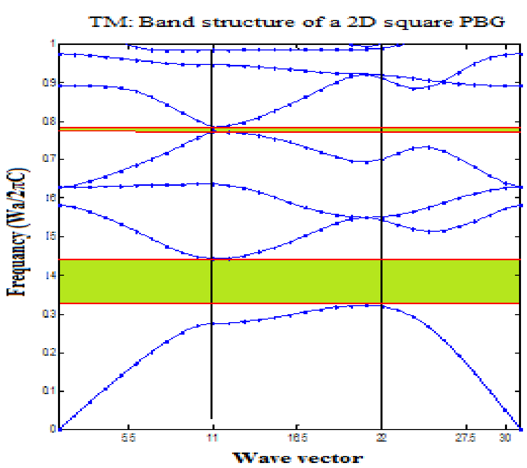



Fig. 1 Direct lattice, reciprocal lattice and Brillouin zone including symmetry points of the most common lattices in dimension: square lattice. The high symmetry points of the first Brillouin zone are shown ($\Gamma, X, M$).

Fig.1 show the direct lattice, reciprocal lattice and Brillouin zone of in gray areas, indicating the high symmetry points

*Filter design*

Firstly and before designing the filter, we should solve eigenvalue calculations for band structures of the 2D dielectric photonic crystals in order to design our proposed structure which is 33X20 square lattice of dielectric rods immersed in air. The FEM calculation is applied for the dispersion relation of square lattice pattern for TE and TM polarizations. The studied geometry is two- dimensional PC cylindrical dielectric (silicon) rods in square lattice in air background. The effective refractive index 2.838 and the radius of dielectric rods is r=0.19*a embedded in air (ε=1) as shown schematically in Fig.1, where "a" is the lattice constant of the Phc structure. The rods from a square lattice array with lattice spacing (a=623nm). Light propagation is considered in the xy plane of the square lattice structure. The band structure diagram of the Phc with aforementioned values is depicted in Fig.2. In the next section our simulations are adapted to the proposed structure of a channel drop filter based on 2D photonic crystal ring resonator.



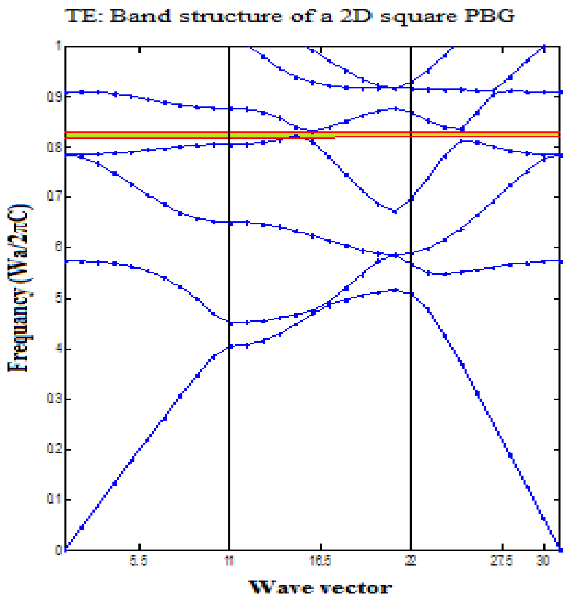




Fig. 2 The calculated diagram bands with FEM of TM and TE of the Photonic crystal in square lattice of Silicon rods in Air, radius=0.19a.

From the figure above, we notice that our structure displays three PBGs. The First two PBGs in TM mode and one PBG in TE mode. The TM PBGs are in 0.32 < a/λ< 0.44 and 0.77< a/λ< 0.78 range and the TE PBGs is in 0.85< a/λ< 0.86 range. Only the first PBG in TM mode is large enough for covering the sufficient wavelengths for optical communication applications. We choose the lattice constant a= 623nm in order to have maximum compatibility with optical communication ranges. Then, the suitable PBG of our initial PhC structure will be in 1415nm<λ<1946nm range in TM mode.

The next step consists in realizing the proposed filter in a fundamental platform, by removing a complete row of dielectric rods in the Γ-M direction to create the bus waveguide and then, by removing some rods in the M-X direction we created the output waveguide. After that is creating resonant ring between bus waveguide and the output waveguide, first we removed from a 7X7 array of dielectric rods at the appropriate place some rods for creating a square form. This square shape is created by 9-fold quasi crystal which is quasi-periodic structure and composed of one central air pore as core rod. The radius of the square form is the same as the radius of all other rods in the initial Pc structure. The final schematic diagram of the proposed filter is depicted in Fig.3.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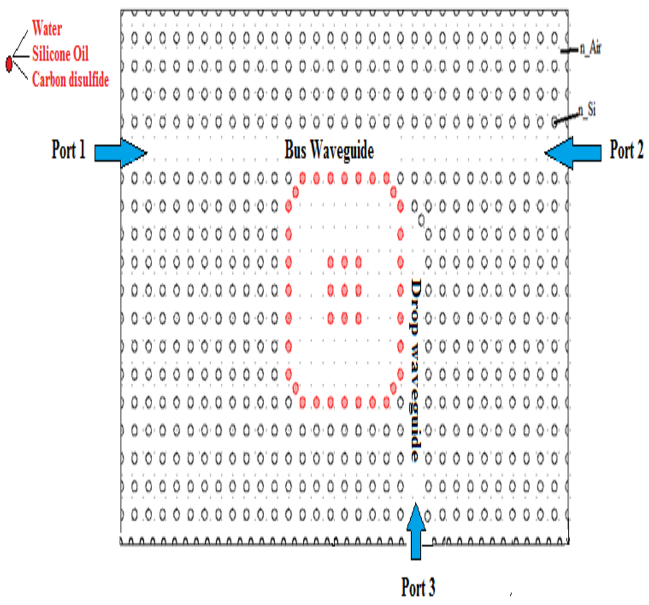


Fig. 3 The schematic diagram of the filter

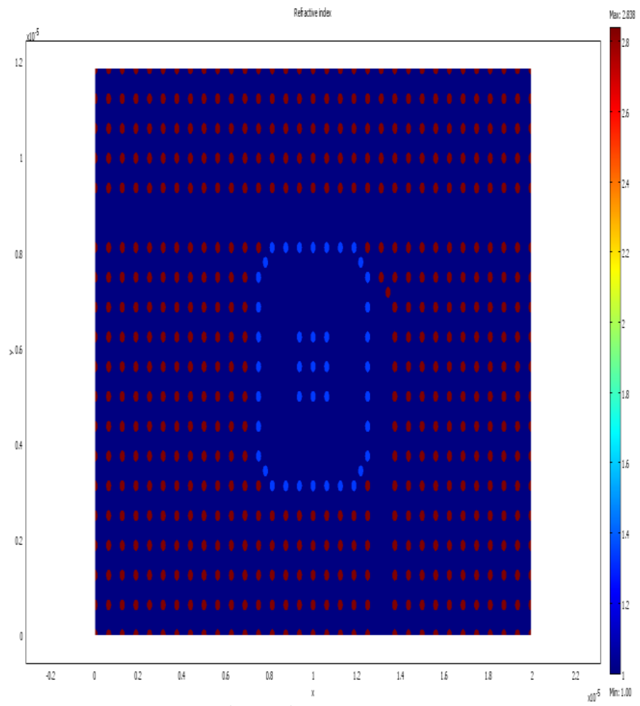

Fig. 4 The distribution of the refractive index in the proposed structure

Similar to any other PCRR-based CDF, our proposed filter has 3 ports: The input port in the left side of the top (bus) waveguide is marked as port (1) whereas the output waveguide is marked as port (2) and called as the forward transmission terminal. The port (3) of waveguide is denoted as forward dropping. Optical waves enter the structure through port (1) and exit it from port (2), however at the desired wavelength the optical wavelengths drop to drop waveguide through the resonant ring and travel toward port (3). Square shape have similar radius and effective refractive index ($n_d$=2.838) as the initial structure. Moreover, as depicted in Fig. 3. The refractive index of the frame surrounding the square resonator has been changed for different organic liquids such as water, silicone oil and carbon disulfide. The refractive index rods changed are labelled with blue circle as shown in fig4.

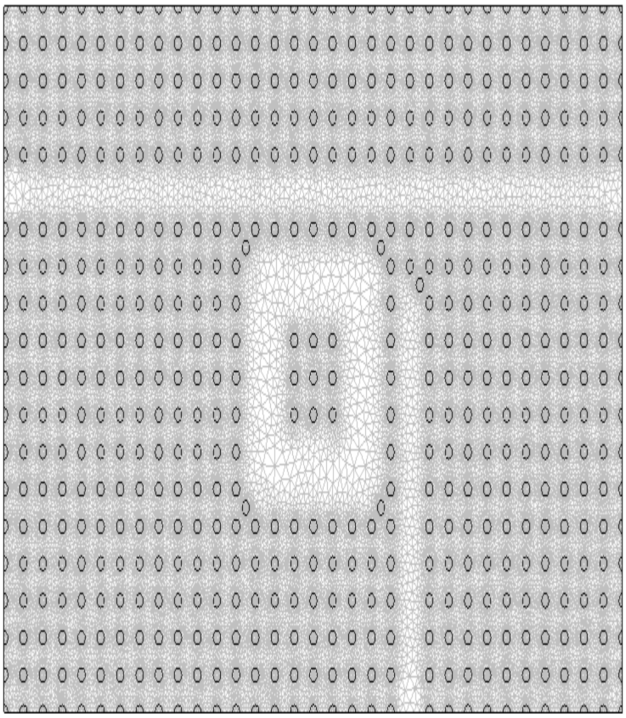

Fig. 5 The proposed structure with fine mesh


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(a)
(b)
(c)

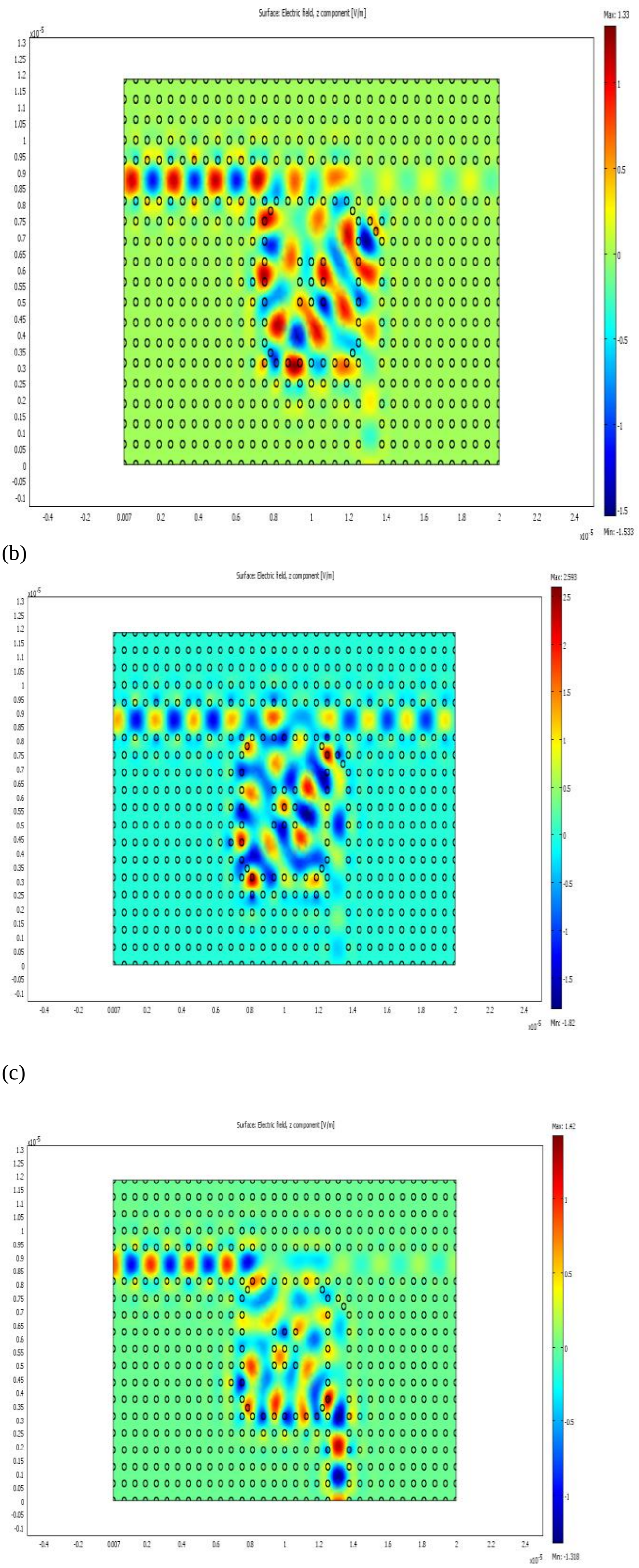

Fig.6. The propagation of the field distribution of the proposed CDF for different refractive index of (a) Water, Silicone oil (b) and Carbon disulfide (c) respectively at $\lambda = 1550$nm

(d)
(e)
(f)

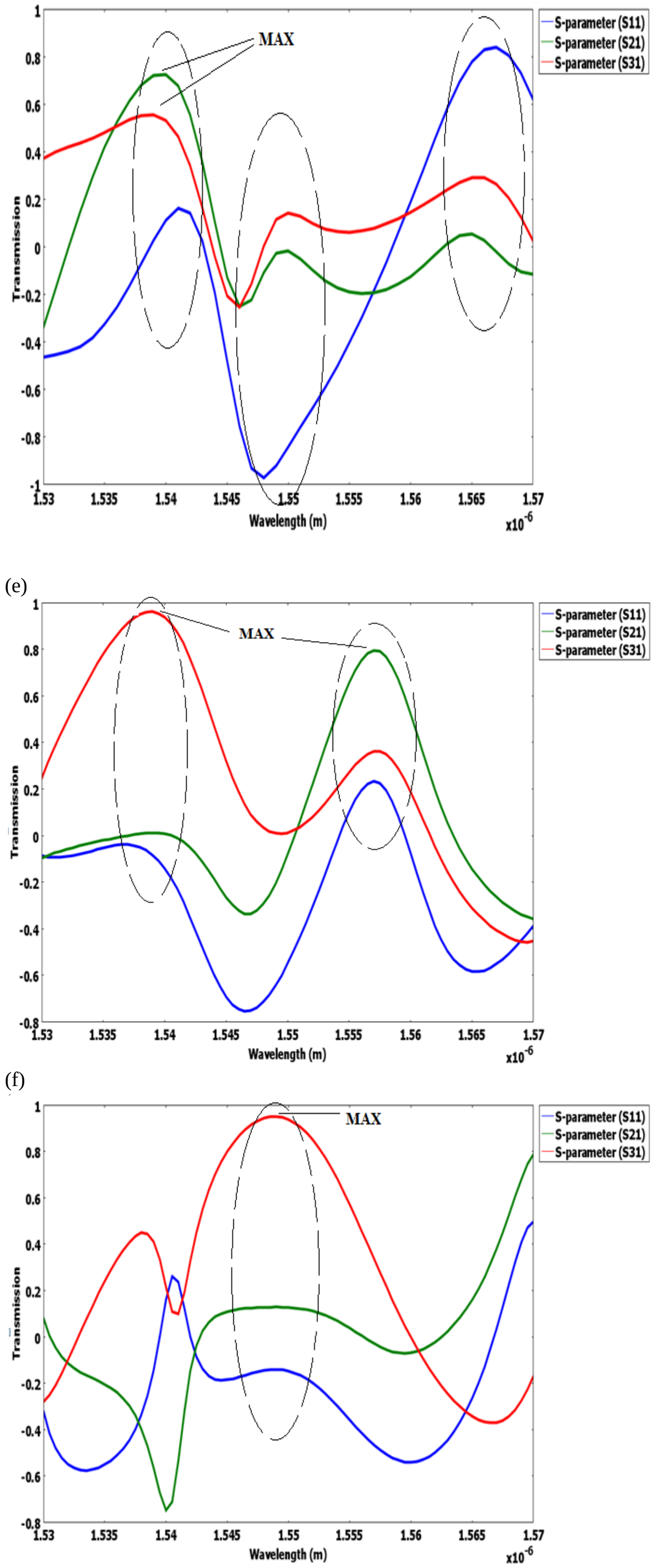


Fig7. The output spectrum of the proposed CDF for water (d), Silicone oil (e) and carbon disulfide (f).


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## III. Simulation and Results

Numerical simulations were performed using Finite Element Method (FEM) COMSOL Multiphysics software [13]. We use the RF module to solve 2D model Maxwell's equations for optical field distribution and other optical properties of PhCs. In this paper, the method is used to investigate the influence of refractive index of different organic liquids of water, silicone oil and carbon disulfide respectively. The Finite element method (FEM) by COMSOL Multiphysics [14] was employed to simulate the transmission and the propagation (distribution of electromagnetic field) in photonic crystals structures and versus wavelength.

*Finite Element Method (FEM) simulations:*

This section is devoted to calculate the transmission spectra and distribution of magnetic field of 2D-photonic crystals square lattice of dielectric rods of Si ($n_{Si}$= 2.838)/air. COMSOL Multiphysics considers the plane (xz) as the plane of propagation of the electromagnetic wave. The TE mode (where H located in the planes (xz)) or TM mode is in the plane (xy). The transmission spectrum of magnetic field is shown in Fig.7 for wavelength range from 1.53µm to 1.57µm. This frequency range is associated with the PBGs (calculated by the PWE method in the first section). The transmission spectrum of the filter is shown in Fig.7. In this figure the normalized transmission of the structure at port (2) and (3) are depicted with green and red curves.

from Figure 7, the transmission efficiency for the three indices of refraction, water, silicone oil and carbon disulfide will pass through maximums, for the case of water we see that the transfer of energy from port 1 to port 3 reaches a transmission efficiency maximum of 0.5552 for a wavelength at 1.539 µm, as well as for the case of silicone oil which reaches a transmission efficiency maximum of 0.9613 for a wavelength of 1.539 µm and for the disulfide of carbon which completes a transmission efficiency maximum of 0.951 for the telecommunication wavelength $\lambda$ = 1.55 µm.

Therefore, carbon disulphide is the best refractive index for the transfer of the signal from port 1 to port 3 (see fig.7 (d)) where the resonance is maximum for the telecommunication wavelength $\lambda$ = 1.55 µm. ratio to the water whose maximum signal will be transferred to the port 2 (fig.7 (e)) for a wavelength $\lambda$ = 1.539 µm and for the silicone oil the maximum of the signal towards the port 3 but a length of wave $\lambda$ = 1.539 µm (fig7 (f)) which suffers losses for a max of 88 as well as for silicone oil which reaches a max for a wavelength of 1.54 µm.

## IV. Conclusion

In summary, a new structure for designing CDF based on PhCRR. 2D-FEM (Finite element method) was used to analyze the proposed structure. The results of our simulations by using COMSOL Multiphysics provide the different behavior of the signal compared to the organic liquids used. The results obtained from simulation show that the resonant wavelength of filter depends on refractive index. Such structures have the abilities to be used as nano-materials for bio-sensing.

## Acknowledgment

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