STUDY OF THE BAND GAP OF PHOTONIC CRYSTAL FIBER

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Abstract: -Photonic crystal fiber PCF with silica/air hexagonal holes arrays and filling the first rings by silicon and the tunable photonic band gap PBG effect of photonic crystal fiber is proposed. The silicone with higher refractive index (>1.45) is filled into the air-holes of photonic crystal fiber to cancel the index guiding fiber effect and maximize the photonic band gap fiber effect. The proposed fiber takes full advantage of the sensitivity characteristic by create of photonic band gap fiber in-plane (in-plane gaps) and achieves a high band gap by filling the second holes ring close to the guiding core fiber by silicon; resolution in the plane of the fiber and out of plane, respectively, which are better than other fiber with silica/air hexagonal holes arrays.

Key words: -Band gap, Fiber, Filling Factor, propagation Constant, Silica, Silicone, Holes Arrays.

1 Introduction

Photonic crystal fibers (PCFs), have attracted much research attention and has been appointed as one of the most intriguing structures for various optical applications [1-5]. These fibers can be divided by the guidance type into two categories: effective index guidance [6-8] and photonic-band-gap (PBG) guidance [9-12]. The first type of fiber the light is guiding in the central defect with high index region. This allows the light to be guided by total internal reflection (TIR). In this work we study the second type of PCFs which based on the PBG and have the capability to control the guidance of light within a certain frequency band, light is confined in a low-index core by reflection from a photonic crystal cladding.

The study of photonic crystals and their specific properties, naturally leads to the study of the behavior of light in photonic band gap materials [13-15]. The manufacturing technology of PCFs allows the tuning of the optical properties by changing the size, shape and position of the cladding holes.

So several studies have been reported to improve the band gap width of PBG guidance fibers to increase the band transmission frequency.

For that in this work we study the band gap as a function of the propagation constant of modes, the based material and the filling factor for a hexagonal and square lattice holes[16-18] finally the influence of the filling holes of rings [19,20] to the band gap width.

2 Fiber hexagonal structure

2.1. Study of the band gap as a function of the propagation constant

Fig.1 shows the index profile of a photonic band gap-guided fiber with hexagonal *air holes* arrays.

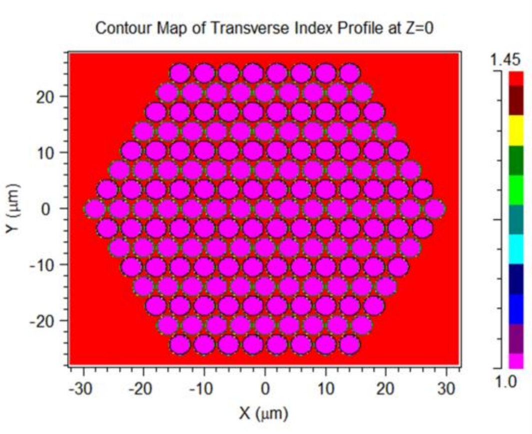


Fig.1. Photonic crystal fiber with hexagonal air holes arrays

The index profile shown in Fig.1 is calculated for the plane z = 0, it is a periodic air holes arrays (index n = 1) in a material based on Silicon (nSiO2 = 1.45). The light will be guided into the central air hole.

Fig.2 and Fig.3 represent the diagrams of the bands calculated for a hexagonal 2D lattice characterized by a filling factor 0.7, a propagation constant β and a period Λ. As a light source, we use a plane wave of the Gaussian type. One of the main results of these figures relates to the difference in behavior between the electric transverse TE, the magnetic transverse TM and the hybrid polarizations.

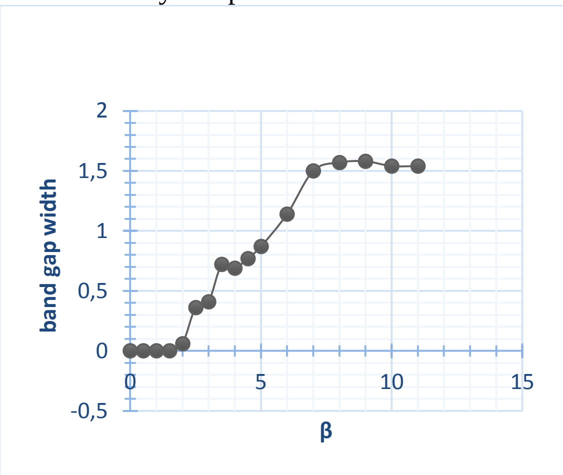
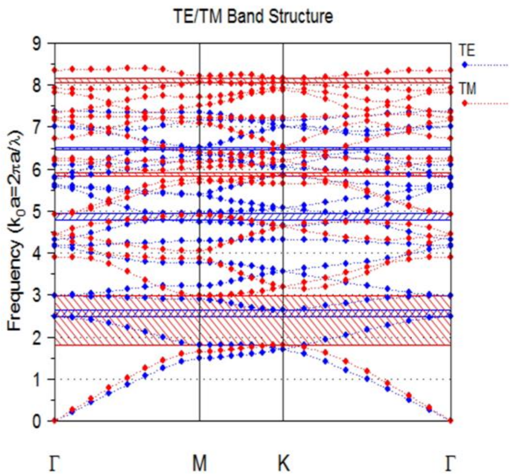


Fig.2. Variation of the band width for the silica/air hexagonal lattice versus the propagation constant $\beta(\mu m^{-1})$.

For the propagation constant null for silica-air lattices there is no gaps in either TE or TM polarization. But in fig.2, silica-air lattices can support bands gaps for propagation out of the plane in hybrid polarization.

(a)



(b)

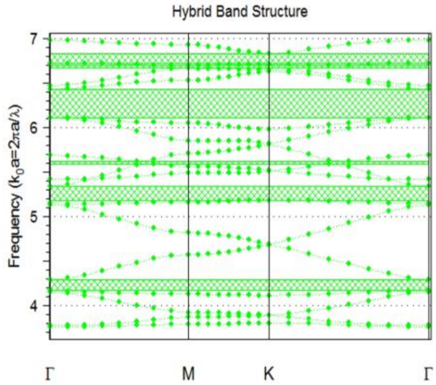


Fig.3. Band structures for the periodic air holes in silicon hexagonal lattice of fiber (a) for β=0 and (b) for $\beta = 2.25\ \mu m^{-1}$ with n=3.42

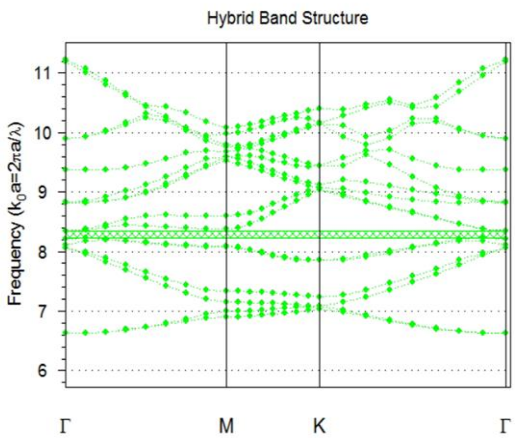
By comparison in Fig. III.2 and Fig. III.3, it is noted that if the index contrast between the matrix of the based material and the air holes is increased, the width of the spectral band increases in the plane of the fiber for β = 0 or out of plane when β is different from 0.

2.2 Study of the band gap width as a function of the based material and the filling factor of holes.

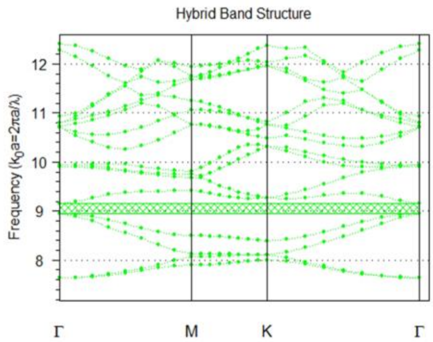
For the study of the band gap, simulations were made for different holes filling factors and for different materials.

1st case: for a silica based material and refraction index n=1.45.

(a)



(b)



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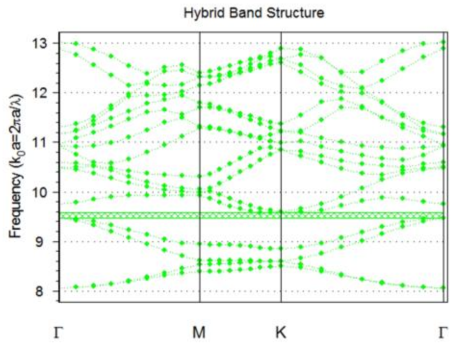

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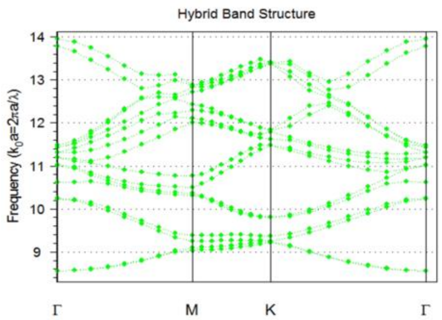


Fig.4. Band structures for the silica/air hexagonal lattice as a function of the filling factor of holes *f* (a) for *f*=0.3 (b) for *f*=0.7 (c) for *f*=0.8 (d) for *f* =0.9

Fig.4 shows the band diagrams versus the different filling factors (*f*) for a silica/air hexagonal lattice, based on these results, Fig.5 shows the filling factor variation curve as a function of the width of the spectral band.

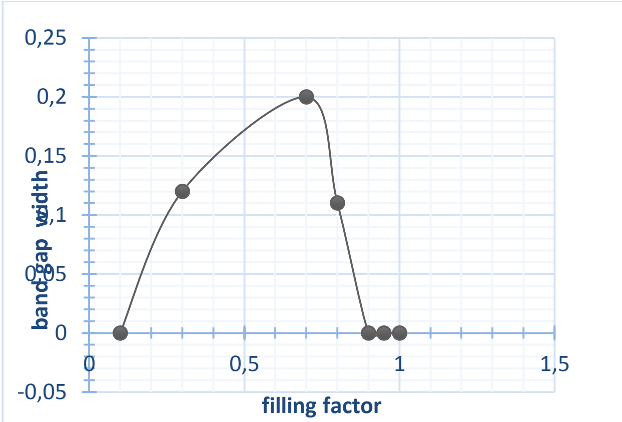
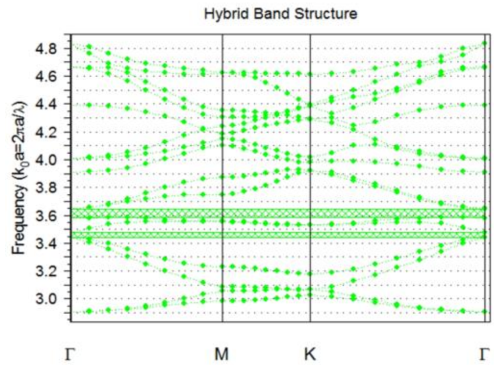


Fig.5. Spectral band width variation as a function of the filling factor for a silica/air hexagonal lattice.

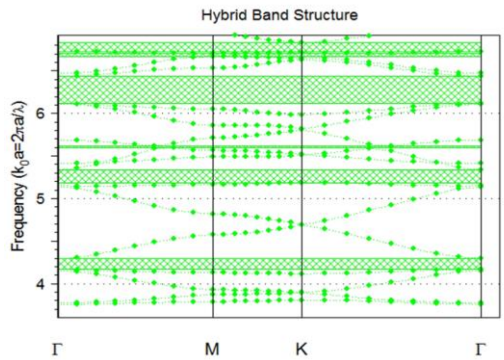
It can be seen from Fig.5, that the spectral band increases as a function of the filling factor increasing when $f \leq 0.7$, after this value, even if the filling factor value is increased, the spectral band decreases for $0.7 < f \leq 0.9$ and the band becomes null after that.

2nd case: for a silicon based material and refraction index n = 3.42

(a)



(b)



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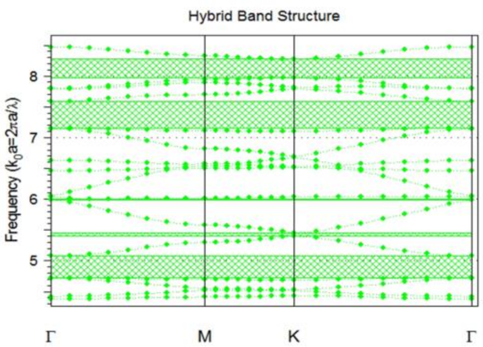

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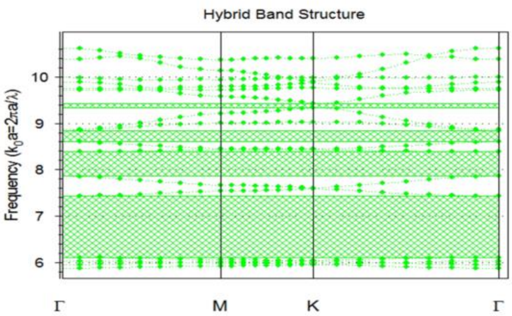


Fig.6. Band structures for the silicon/air hexagonal lattice as a function of the filling factor of holes *f* (a) for *f*=0.3 (b) for *f*=0.7 (c) for *f*=0.8 (d) for *f* =0.9

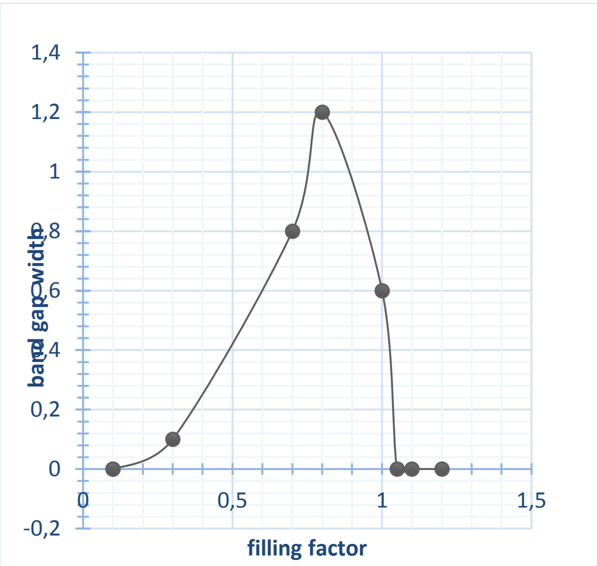


Fig.7. Spectral band width variation as a function of the filling factor for a silicon/air hexagonal lattice.

It can be seen from Fig.7 that in each case the value of the filling factor is increased, the spectral band increases to the maximum when $f \leq 0.9$, after this value the spectral band decreases for $0.9 < f \leq 1.04$ and the band becomes null after that.

It can also be seen from Fig.7 and Fig.5 that if the contrast of index is increased in a fiber the width of the band gap increases also. Thus, the contrast of index is proportional to the band gap width increasing.

3 Fiber square structure

3.1 Study of the band gap as a function of the propagation constant

The index profile of the photonic fiber based on silica/air square lattice is shown in Fig.8

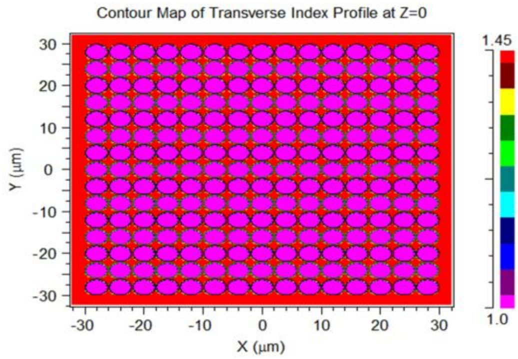
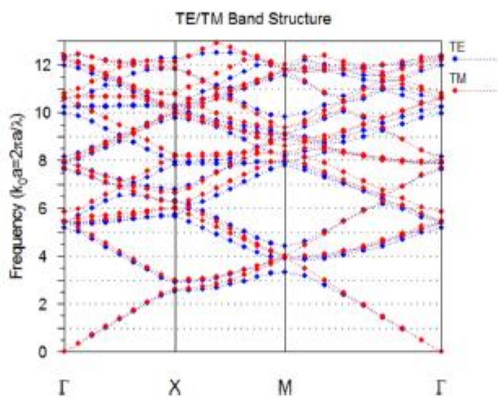


Fig.8. Photonic crystal fiber with square air holes arrays

The index profile shown in Fig.8 is calculated for the plane z = 0, it is a periodic square lattice of air holes (index n = 1) in silica ($n_{SiO2} = 1.45$). The light will be guided into the central air hole.
Figure III.15 and Figure III.16 represent the diagrams of the bands for the silica/air square lattice characterized by a fill factor, a propagation constant β and a period Λ.The results of these figures relates to the difference in behavior between the electric transverse TE, the magnetic transverse TM and the hybrid polarizations.

(a)



(b)

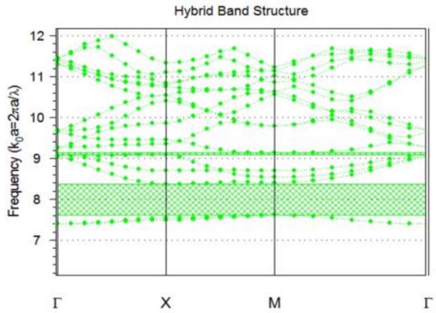


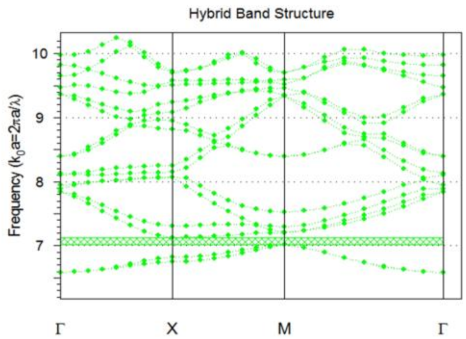
Fig.9. Band structures for the silica/air square lattice (a) for β=0 and (b) for $\beta = 2.25\ \mu m^{-1}$

By comparison between Fig.9 and Fig.2, if the lattice of holes is changed for the same characteristics of the fiber Fig.9 (a and b), the width of the spectral band increases out of plane (for β different from 0) but for β=0 in the plane of fiber always for low contrast (silica/air) and for both types of lattices it is found that there are no bands gaps.

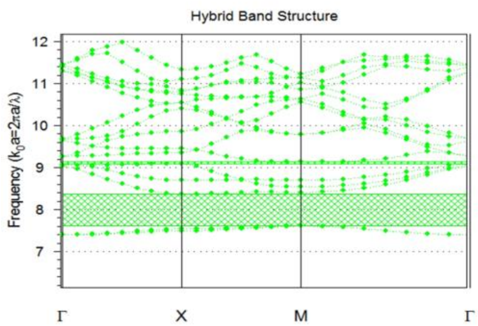
3.2 Study of the band gap width as a function of the based material and the filling factor of holes.

To study the band gap of fibers based on a square lattice as a function of the holes filling factors, simulations were performed for different filling factor values

(a)



(b)



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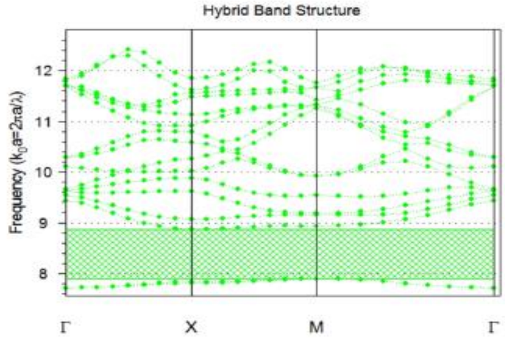

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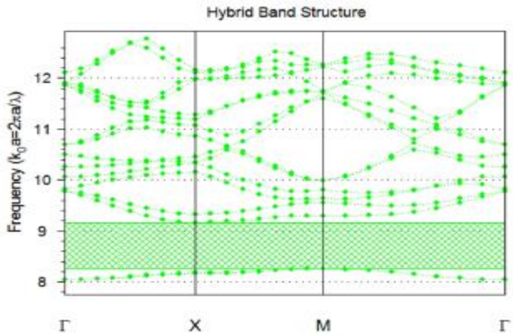


Fig.10. Band structures for the silica/air hexagonal lattice as a function of the filling factor of holes *f* (a) for *f*=0.3 (b) for *f*=0.7 (c) for *f*=0.8 (d) for *f* =0.9

Fig.10 shows the band diagrams for different filling factors (*f*) for a silica/air square lattice, based on these results, Fig.11 shows the filling factor variation curve as a function of the width of the spectral band.

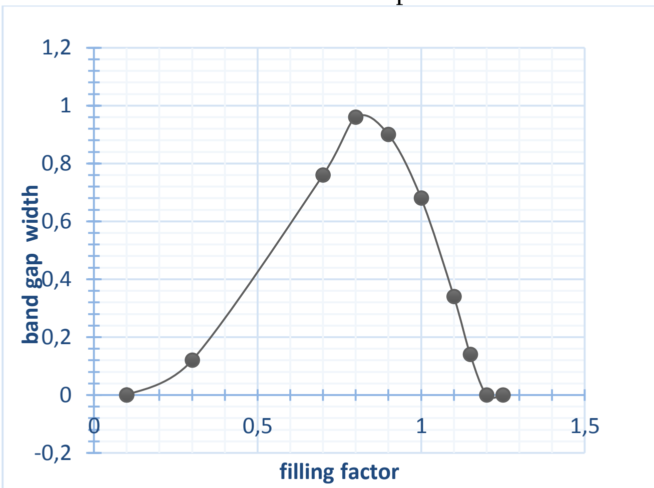


Fig.11. Spectral band width variation as a function of the filling factor for a silica/air square lattice.

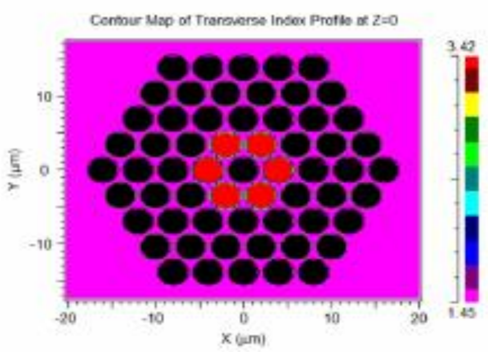
It can be seen from Fig.11 if the filling factor increases from 0 to 0.8, the spectral band increases proportional to the filling factor increasing, after that even if the filling factor value is increased the spectral band gap decreases and become null for *f=1.2*.

It can be concluded from this results that if the index contrast is increased in a fiber, the spectral band increases even in the plane of the fiber. This variation makes it possible to increase the number of guided waves in the fiber based on the photonic band gap guidance.
Also the variation of the spectral band for the square lattice structure is better than the hexagonal structure for the same filling factor value.
Thus, the ratio of the high and low index surfaces and the filling factor in a photonic crystal fiber are determining factors for the bands gaps width.

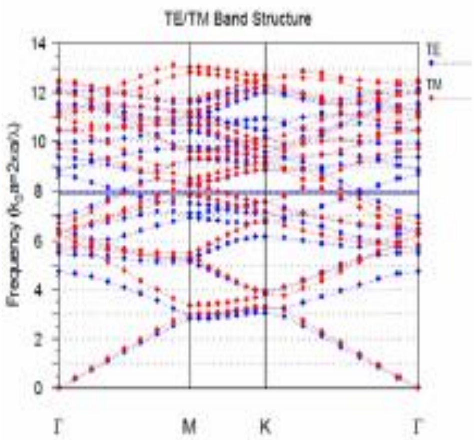
4. Study of the band gap width as a function of the rings filling

In this section, the band gap is studied as a function of the rings filling, for different steps the rings of different lines of fiber (ring 1, 2, 3 and 4) are filled with the silicon ($n_{Si} = 3.42$).

1st case: filling the first ring by silicon
(a)



(b)



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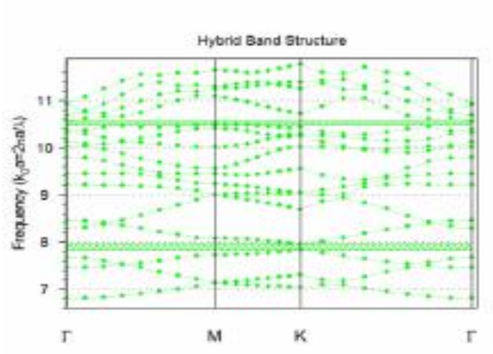
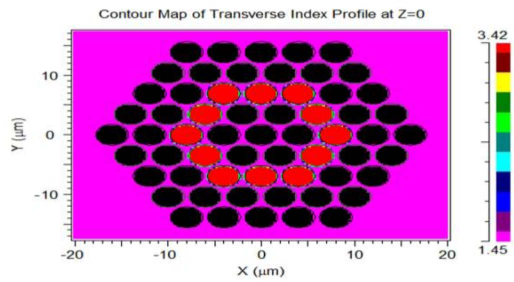


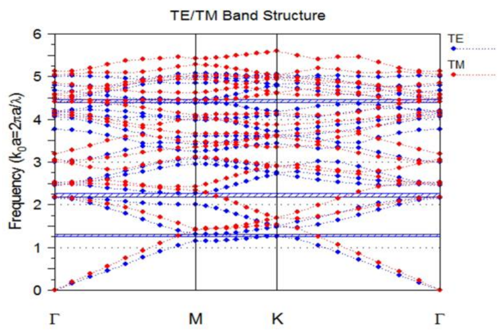
Fig.12. (a) Photonic crystal fiber with silica/air hexagonal air holes arrays and filling the first ring by silicon, (b) band diagram for β = 0, and (c) for β =9/*Λ*.

2nd case: filling the second ring by silicon

(a)



(b)



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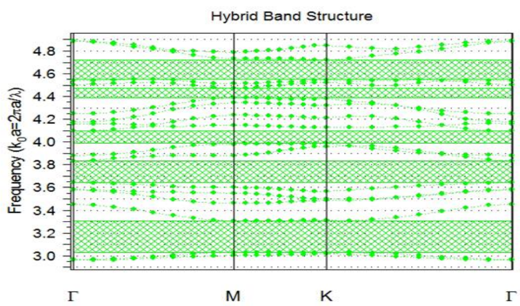
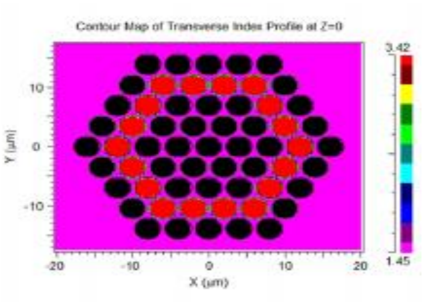


Fig.13. (a) Photonic crystal fiber with silica/air hexagonal air holes arrays and filling the second ring by silicon, (b) band diagram for β = 0, and (c) for β=9/*Λ*.

3rd case: filling the third ring by silicon

(a)



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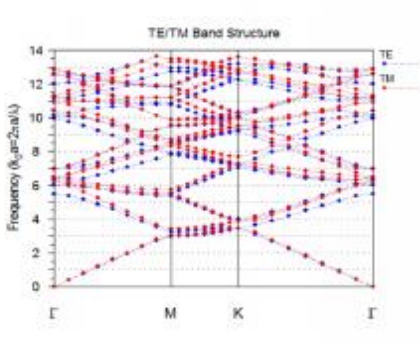

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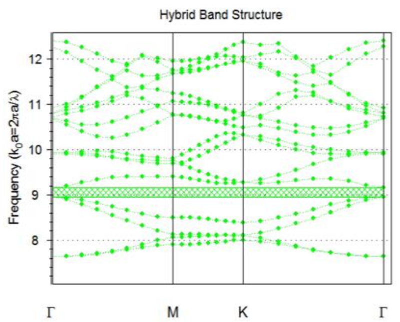
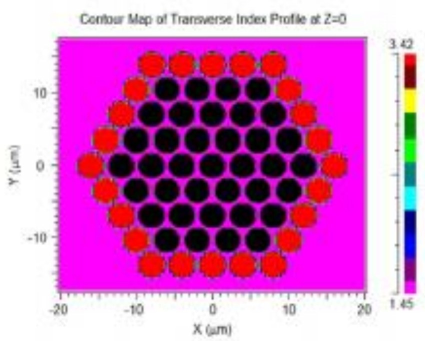


Fig.14. (a) Photonic crystal fiber with silica/air hexagonal air holes arrays and filling the third ring by silicon, (b) band diagram for β = 0, and (c) for β =9/*Λ*.

4th case: filling the fourth ring by silicon

(a)



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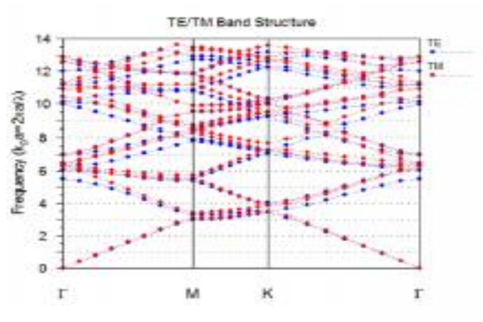

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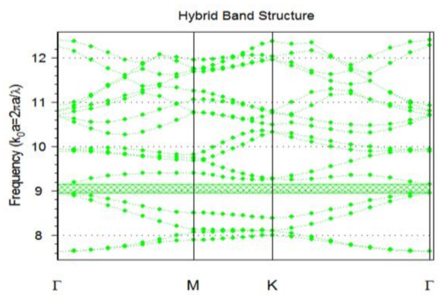

Fig.15. (a) Photonic crystal fiber with silica/air hexagonal air holes arrays and filling the fourth ring by silicon, (b) band diagram for β = 0, and (c) for β=9/*Λ*.

It is observed from this study, which represents the band gap width variation as a function of the rings filling in the plane of the fiber and out of plane, if the first or the second ring is filled with silicon the band gap width increases for in or out of plane as a function of the number of filled holes (first ring with 6 holes and 12 for the second ring) ; but if the filled holes distance is further from the core (the third and fourth ring), the behavior of the band gap diagram become as if the holes has not been filled with silicon.

5 Conclusion

The dependencies of photonic band gap PBG of photonic crystal fiber, the air holes lattice, the filling factor and the filled holes by silicone have been theoretically studied. The different PBG open for TE and TM and Hybrid modes is determined for various values of these three important parameters. Furthermore, we have optimized parameters of the fiber to achieve wider PBG which is useful for guiding light in very large spectral band and decreasing propagation losses.

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