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Effect of Wafer Dimension on the Mode Profile in Photonic Crystal Fiber

Ritu Sharma, Vijay Janyani, Rahul Gupta
Department of Electronics and Communication Engineering,
Malaviya National Institute of Technology, Jaipur (Rajasthan), India
ritusharma.mnit@gmail.com

***Abstract*—The mode profile of a holey index guided 2-Dimensional Photonic Crystal Fiber (PCF) is investigated using the effective index model of PCF . The effect of variation in wafer dimension (simulating region in OptiFDTD), of a constant lattice size, on the mode profile is analyzed for getting the Fundamental Space- Filling Mode (FSM).**

***Keywords*— Photonic Crystal Fiber (PCF), Total Internal Reflection (TIR), Effective Refractive Index (n_{eff}), Fundamental Space-Filling Mode (FSM), Normalized Frequency (V), Finite Difference Time Domain (FDTD)**

I. INTRODUCTION

The PCF are new class of fibres which offer a great deal of freedom in their design to achieve lot of peculiar properties.

A PCF (also called holey fibre, hole assisted fibre, or microstructure fibre) is an optical fibre which obtains its waveguide properties not from a spatially varying glass composition but an arrangement of very tiny and closely spaced air holes which can be obtained by using a perform with larger holes made by stacking capillary tubes (stacked tube technique). The simplest (and most often used) type of PCF has a triangular lattice of air holes, with one hole missing at centre acts as core, shown in Fig. 1. The light guides through these fibres by principal of Total Internal Reflection (TIR) between the core and cladding region. Single mode property of a PCF is very useful for communication system application .

In this paper the PCF is analysed using effective index method[2].Here by changing the wafer dimension the effective refractive index of cladding region is calculated and the mode profiles are obtained, which could be a great help in the fabrication of PCF.

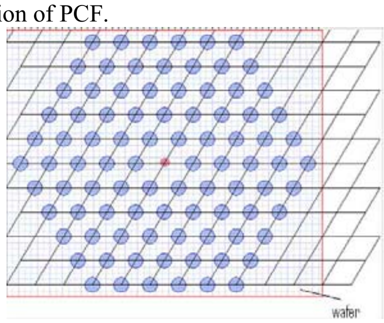


Fig. 1 Layout of a hexagonal PCF with triangular lattice of air holes using OptiFDTD simulator

II. LAYOUT DESIGNING OF THE PCF

The PCF is formed by a 5 rings triangular pattern of air holes in hexagonal layout. The wafer choosen is of pure silica with refractive index 1.492. The air holes, with refractive index 1, are of radius a=0.58 μm and the centre to centre spacing between two nearest air holes is referred as the pitch Λ of 2.3 μm. The core of pure silica with refractive index n_{core} is surrounded by the cladding of effective refractive index $n_{eff.}$ The n_{eff} is defined by the propagation constant of the lowest order mode that could propagate in the infinite cladding material β_{FSM} . This mode is called the Fundamental Space-Filling Mode (FSM).

$$n_{eff} = \beta_{FSM} / k \qquad \text{------------------(1)}$$

where k=2π/λ = Free space propagation constant of light with wavelength λ

The light should concentrate within the core region and the light intensity distribution should decrease towards the cladding. The n_{eff} is smaller than the n_{core} , therefore the TIR results that is, the propagation constant β to guide the light in the core should be in range of

$$k^* n_{core} > \beta > \beta_{FSM} \qquad \text{-------------------(2)}$$

The number of guided modes is obtained by the V-number (or normalized frequency) defined as

$$V = \frac{2\pi\Lambda}{\lambda}(n_{core}^2 - n_{eff}^2)^{½} \qquad \text{----------------- (3)}$$

The V-number should be less than 2.405 for a PCF to be single moded.

As the wafer size outside the PCF lattice is varied, the n_{eff} value and the β_{FSM} changes which changes the single mode property of the PCF.

III. VARIATION IN WAFER DIMENSIONS

The variation in wafer dimension which is the simulating region (including length and breadth in terms of pitch Λ) results the change in the number of points in the mesh for analysis as shown in table I.

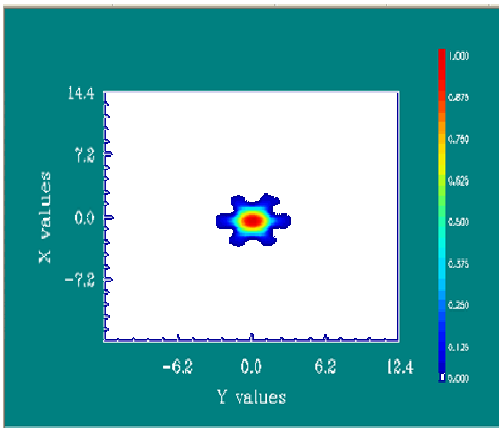
The mode field pattern should be a flower like arrangement with the entire field being concentrated in the core and not leaking in the cladding. The wafer breadth is increased as 11xΛ, 12xΛ, 12.5xΛ, 13xΛ and 13.5xΛ and corresponding length is sin (60^0) times of the breadth.

TABLE I

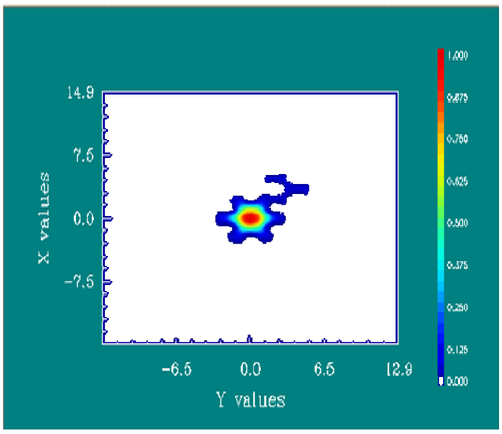
Configuration	Breadth of wafer(x) (length) (in µm)	Length of wafer(y) (breadth) (in µm)	No. of points in mesh	
			Along Y- axis	Along X- axis
First (I)	21.9104	25.3	304	264
Second (II)	23.9024	27.6	316	274
Third (III)	24.8982	28.75	329	285
Forth (IV)	25.8942	29.9	343	297
Fifth (V)	26.89	31.05	358	310

IV.RESULTS

The mode field patterns corresponding to these PCF layouts are shown in Fig. 2 and the field intensity plots of the propagated light in PCF is also shown in Fig. 3. The figures. (2) and (3) clearly specify that the as the wafer size is increased, the number of points in the mesh increases and n_{eff} decreases, hence the lowest order mode may leak in cladding region. The n_{eff} variation for above wafer sizes with respect to wavelength λ is shown in Fig. 4. Using these values and equation (3), the normalized frequency V is plotted in Fig. 5.



(a)



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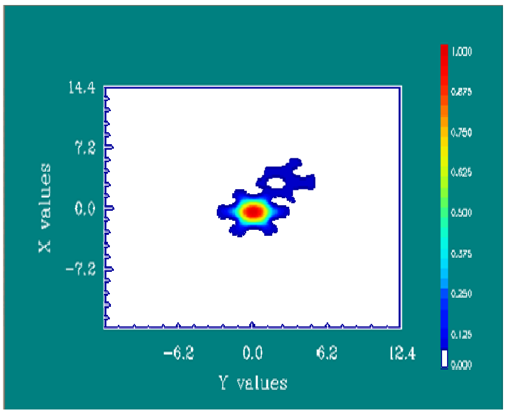
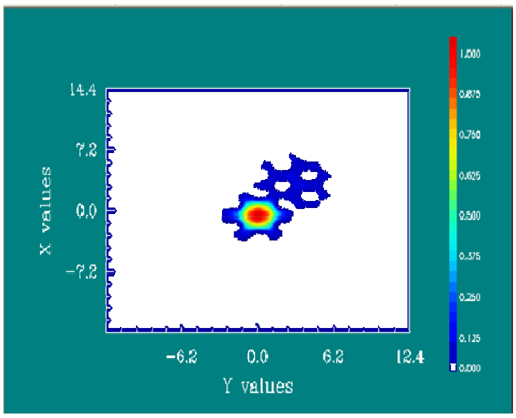


(c)



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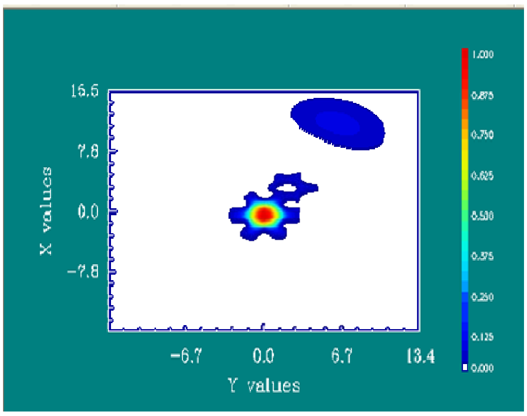
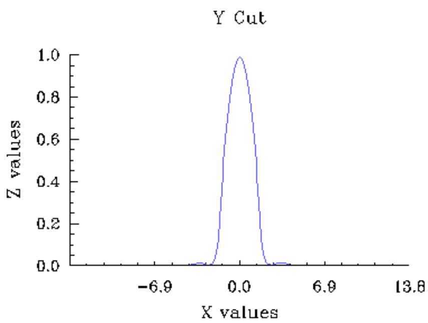
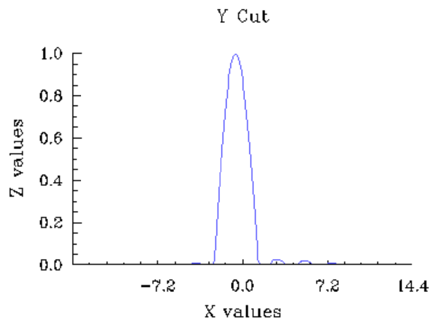


(e)

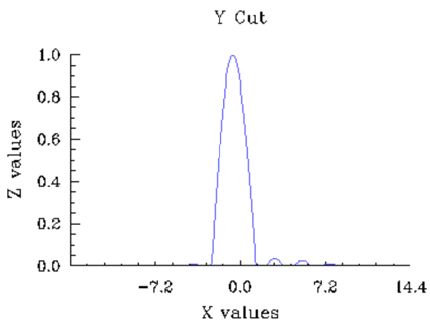
Fig. 2 Mode profiles(TM modes) of PCF with wafer dimensions (length*breadth) at wavelength 0.69 um (a) I configuration (b) II configuration (c) III configuration (d) IV configuration (e) V configuration as per table I



(a)



(b)



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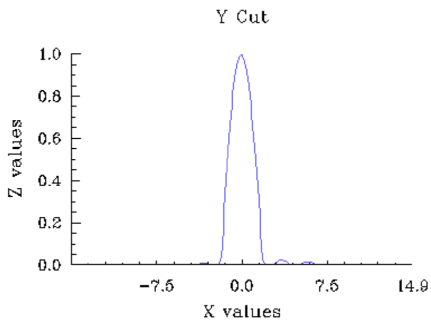
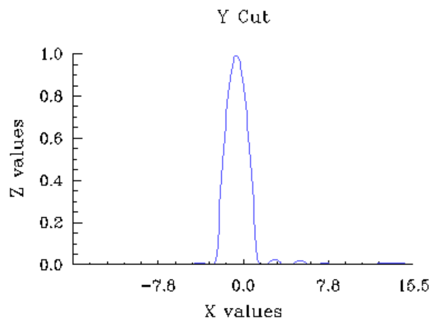


(d)



(e)

Fig. 3 Field Intensity (TM modes) of PCF with wafer dimensions (length*breadth) at wavelength 0.69 um (a) I configuration (b) II configuration (c) III configuration (d) IV configuration (e) V configuration as per table I

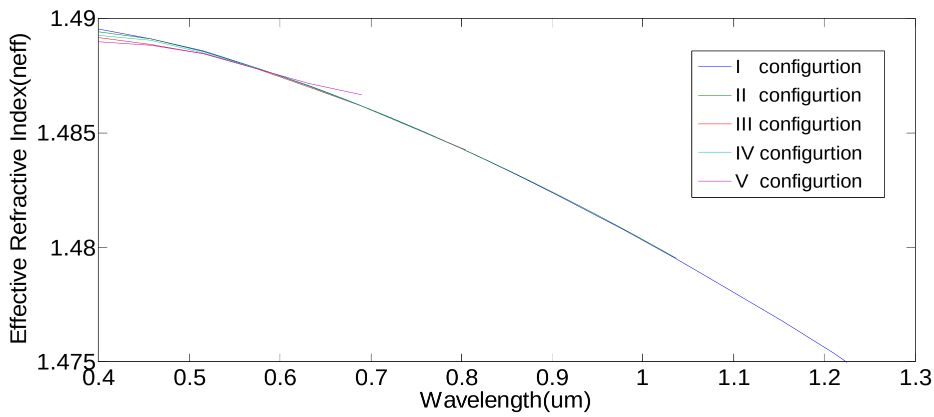


Fig. 4 Plot between n_{eff} and wavelength (in µm)

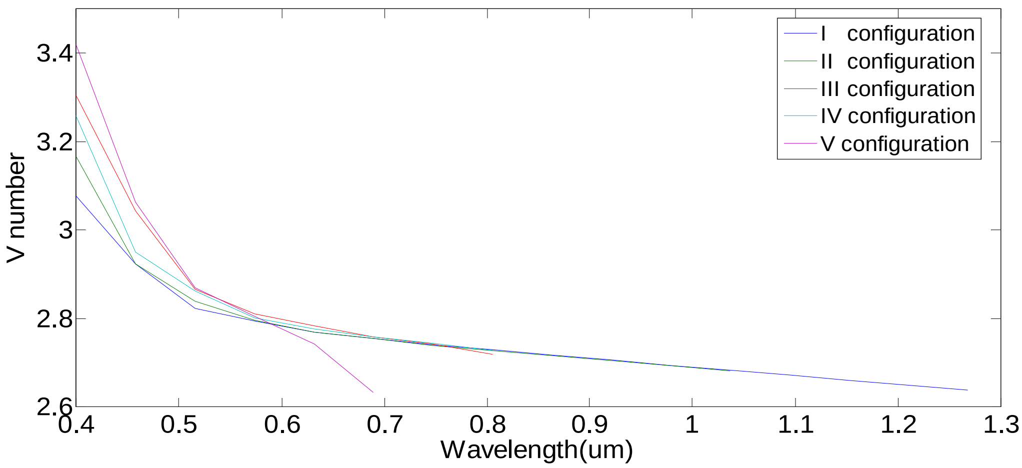


Fig. 5 Plot between V number and wavelength (in µm)

V DISCUSSION

As shown in above results, as the wafer dimension is increased, the n_{eff} decreases which violates the equation (2) and light starts to leak in the cladding region as cladding has finite number of holes. Similarly with increase in the wafer dimension, the cut off wavelength starts to decrease. As the operating wavelength is nearer to cut off wavelength, the mode field pattern becomes asymmetric. Hence dimensions of I configuration is most appropriate for manufacturing purpose.

VI CONCLUSION

The minimum simulating region of wafer (which is of pure silica) should be designed such that the propagating field shouldn't leak into the cladding region. This would guide the manufacturer, as what should be the minimum size of wafer so that the light can be guided without leaking into the cladding. More or less a +5% extra wafer is also included for cleaving purpose so that the required circular shape may be given to the layout without effecting the mode profile.

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