Highly Sensitive Hexagonal Dual Core Photonic Crystal Fiber as Refractive Index Sensor

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Abstract- A refractive index sensor photonic crystal fiber based on dual core with hexagonal lattic is proposed in this paper. The two fiber core is separated by one elliptical air hole is filled with analyte whose refractive indices range from 1.33 to 1.41.Finite Element Method is used to analyze the guiding properties of proposed structure by considering perfectly matched layer (PML) .The sensitivity that have achieved is 7,500 nm/RIU when refractive index of analyte varies from 1.33 to 1.41. Application for this type of sensor can be found in field of chemical sensing and bio- sensing as it provide a high sensitivity

Keywords- Photonic crystal fiber, Refractive index , Sensitivity.

I. INTRODUCTION

Photonic Crystal Fiber (PCF) is a new class of fiber gaining much attention to the researchers due to its design flexibility and wide application areas. Photonic crystal fiber is an holey fiber also called as microstructured fiber, which consist of number of air holes arranged in periodic manner [1]. PCF has number of advantage such as high nonlinearity, ultra low loss, high birefringence and endless single mode fiber compared with conversional fiber [2].Light in PCF is confined in the defect mode in regular periodic structure. PCF in divided into two parts, i.e index guided mode PCF which guide light using total internal reflection with high refractive index core and photonic bandgap PCF which guide light using photonic bandgap with low refractive index core[3]. Compared with convensional optical fiber, PCF with different properties can be used in optical fiber such as fiber sensor, optical communication and optical lasers[5]. PCF sensor are also based on surface plasmon resonance technology, resonant coupling and different photonic bandgap properties [6].Basically surface plasmon resonance method are also used in measuring the refractive index which has application in, remote real time detection chemical and biosensing[7]. Most of this sensors are filled with metal wire such as Au, Ag ,copper ,etc. or coated with thin layer with metal wire. But all these type of sensors are not easy to fabricate for industrial application. Therefore we proposed such type of sensor based on PCF which gives larger sensitivity which is not to be filled with any metal. The typical sensing for refractive index sensor depend upon the interaction of evanescent field of guiding mode with analyte (liquid)for detection.[8].

Futhermore refractive index sensors given a lot of attention in area of chemical sensing and biological sensing which gives a large range for detection for high sensitivity. The sensitivity of refractive index sensor can be better by filling the centre hole with analyte.

In proposed work, we designed hexagonal lattic dual core PCF sensor which gives high sensitivity of sensor which is based on analyte filled photonic crystal fiber .The dual core PCF sensor which is proposed in this paper has elliptical shape in between two core. The ellipse is filled with analyte. The sensitivity of dual core sensor is calculated according to coupling energy between the two core. A finite element method (FEM) is used to analyze and simulating the sensing of this designed dual core photonic crystal fiber(DC-PCF). The complete coupling of DC-PCF sensor is analyzed by couple mode theory.

II. DC- PCF STRUCTURE AND RESULT ANALYSIS

Schematics the designed structure of DC-PCF sensor shown in fig(1).The cross section of these DC-PCF sensor with hexagonal lattic is shown.The guiding properties of given structure have been analyzed with the Finite Element Method by taking perfectly matched layer (PML) and by considering scattering boundary condition to lower the energy given by using COMSOL Multiphysics software.

In proposed DC-PCF structure one elliptical air hole is shown in centre which separate the two core. The elliptical air hole in the DC-PCF structure is designed vertically. The analyte is flush with elliptical air hole present in between two core.Diameter of air hole is $d=2\mu m$ and pitch of adjacent air hole is $\Lambda=3\mu m$.The background material is taken as silica glass whose material dispersion can be obtained by using sellmeier equation [9]

$$n^2(\lambda) = 1 + \frac{0.696166300\,\lambda^2}{\lambda^2 - 0.068404\,3^2} + \frac{0.407942600\,\lambda^2}{\lambda^2 - 0.116241\,4^2} + \frac{0.897479400\,\lambda^2}{\lambda^2 - 9.89616\,1^2} \quad (1)$$

where , λ is the operation wavelength in free space

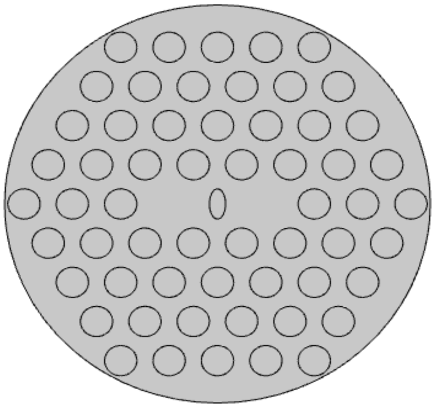


Fig 1.cross section of the designed DC-PCF sensor

Regarding the fabrication process, the refractive index of DC-PCF that we considered is more simpler and easier compared to the other complex structure [11,12]. As shown in fig.1.two core are divided by one elliptical air hole filled with analyte.By coupling mode theory, the DC-PCF has four mode as super-mode as x-mode and y-mode (x-even, y-even, x- odd, y- odd). Fig2.show the field distribution for proposed DC-PCF structure. In x-even mode and y-even field distribution is in same direction and the direction of field in x-odd mode and y-odd mode in opposite way.

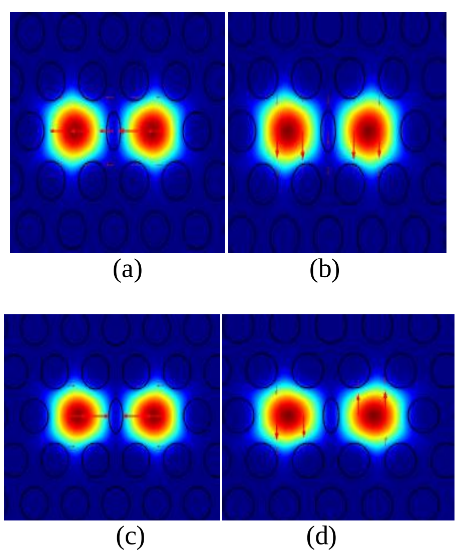


Fig.2.Field distribution of four supermodes for proposed DC-PCF sensor (a).even mode for x-polarized,(b)even mode for y-polarized,(c) odd mode for x-polarized,(d) odd mode for y-polarized

The coupling length of DC-PCF shoes the variation in power transfer between the two cores. Coupling length formula can be given by equation [10]

$$L_i = \frac{\pi}{\beta_e^i - \beta_o^i}\; L_i = \frac{\pi}{\beta_e^i - \beta_o^i} = \frac{\lambda}{2(n_e^i - n_o^i)} \quad (2)$$

Where β_1^i and β_2^i shows propagation constant of i-polarized even mode and odd mode respectively,n_e and n_o are the effective refractive index of i-polarized even and odd super modes respectively.

Fig.3 shows change in coupling length for wavelength in x-polarization and y-polarization when refractive index of analyte n_a =1.41. Decrease in coupling length with the wavelength in x-polarization and y-polarization. Coupling length in y-polarization is higher than in x-polarization.
According to conventional coupled mode theory. The power coupled in two core is given by equation

$$P_B(z) = sin^2(|n_e - n_o|\frac{\pi}{\lambda}z) \quad (3)$$

Coupling length varies according to wavelength in x-polarization and y-polarization mode shown in fig 3. So it is obvious that increasing the wavelength in x-polarization mode and y-polarization mode, the coupling length become smaller. So the coupling length for y-polarization is higher than that for x-polarization

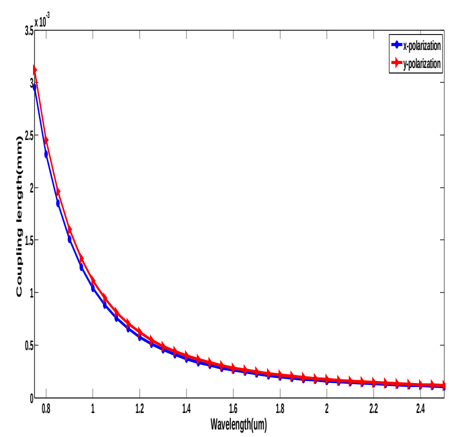
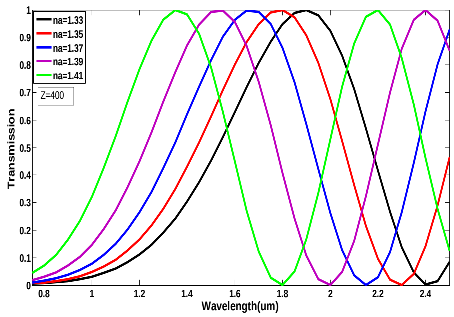


Fig.3.Stimulated coupling length of DC-PCF in x-pol mode and y-pol mode

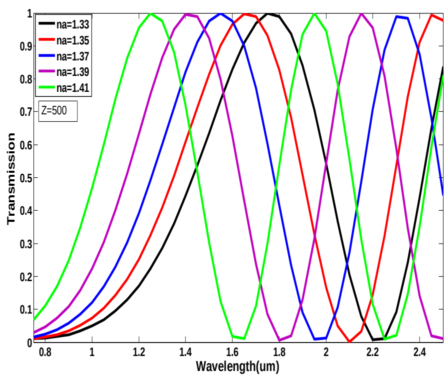
III. RESULT AND DISCUSSION

Figure 4.shows the transmission curve for x-polarized light for various transmission length were stimulated. All wavelength peak experience a black move when refractive

index changes from 1.33 to 1.41. Also every peak of transmission curve is separated from each other with the increasing of fiber length from 400 μm to 600 μm, the distance between the peak slight decreases .Increasing the fiber length from 400 μm to 600 μm sensitivity decreases. There is possibility that some peak intersect with other peak when fiber length increases. So it is difficult to detect refractive index when two peak intersect in different indices. In order to eliminate the influence and to separate the two peak,we choose the fiber length 400 μm which can avoid intersection.

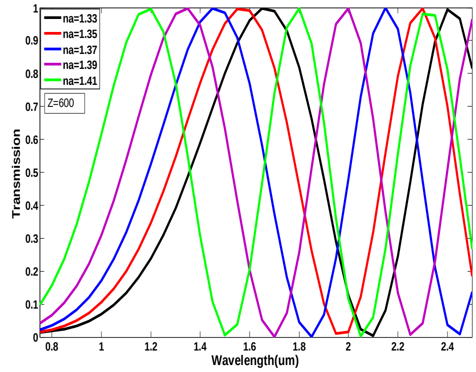


(a)



(b)

We have taken the fiber length as 400 μm because only at this fiber length we get best first peak as the signal detection and high sensitivity. As we can see that increasing the wavelength the period of sine wave become smaller as shown in fig.4.



(c)

Fig.4.Transmission curve for x-polarized light with varying refractive index of analyte from n_a =1.33 to n_a= 1.41 for various fiber length

Using peak shift with the variation of analyte refractive index we calculated the refractive index sensitivity. The refractive index sensitivity S can be given as:

$$S_\lambda(nmRIU^{-1}) = \Delta\lambda_{peak} / \Delta n_a \quad (4)$$

where λ_{peak} is the peak shift of transmission curve and Δn_a is the change in analyte refractive index. Numerical fitting result is shown in figure 5 where slope of curve gives the sensitivity of proposed sensor.

From the calculated result,sensitivity is 7,500 nm/RIU when their is increase the refractive index of analyte. This sensitivity calculated when refractive index of analyte was n_a=1.41.The calculated sensitivity for proposed DC-PCF structure is much greater than other sensor proposed in previous literature. Tab.1.show the different sensitivity comparions for previous literature

Tab.1.Comparison table for proposed work with different reported previous work

References	Detection RI Range	Maximum Sensitivity nm/RIU
[13]	1.35-1.36	2200
[14]	1.345-1.350	3400
[16]	1.33-1.34	4000
[15]	1.36-1.37	4200
Proposed DC-PCF	1.33-1.41	7500

By changing the refractive index of analyte from n_a =1.33 to n_a =1.41 we get maximum peak point which varies from other peak point .All peak points are different at different analyte refractive index.Fig.5.shows the numerical linear fitting peak wavelength with change in refractive index of analyte.

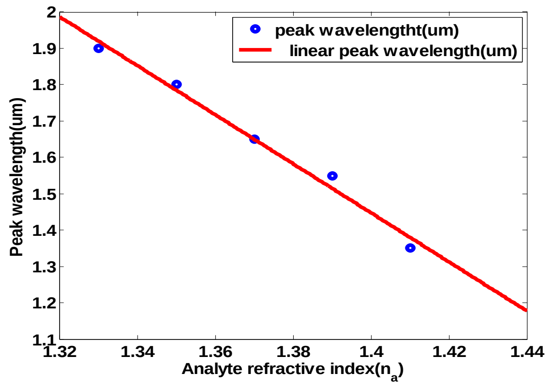


Fig.5 Numerical fitting between refractive index of analyte and wavelength peak

Numerical fitting line is calculated for wavelength shift which gives maximum energy by changing shift with other peak point shift shown in fig 6.

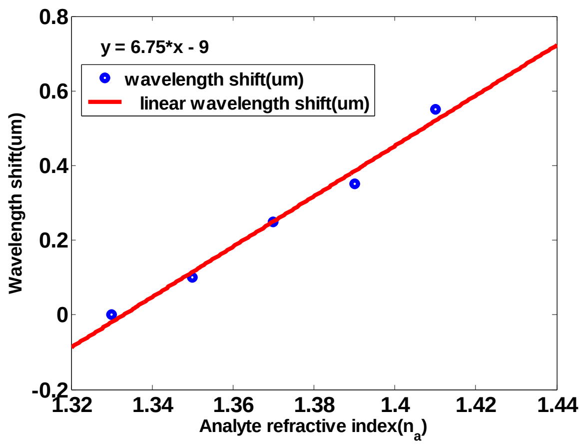


Fig.6.Calculated numerical fitting result for analyte refractive index and wavelength shift

IV. CONCLUSION

In conclusion we proposed highly sensitive hexagonal dual core lattic structure.Numerical investigation were performed by using FEM with scattering boundary condition by filling the core with analyte. Numerical result shows that the highest sensitivity for this structure is 7,500 nm/RIU when their is change in refractive index for analyte which changes from n_a =1.41 to 1.33.High sensitivity sensor can be used in the application of chemical sensing and bio-sensing

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