Measurement of Fluidic Sensitivity of Fluidic Sensor

Bilkish Mondal

Dept. of ECE. VTU, Ghousia College of Engineering,
Ramanagaram,Bangalore, Karnataka, INDIA

Abstract - The optical sensors developed so far are based on different mechanisms like measurement of change in refractive index at the surface of the sensor. Photonic Crystal offers many new or improved features which reduce sizes and costs. Here we propose a novel photonic crystal with a point defect design and analyzed using the capability of refractive index change at the holes of the photonic crystal. The propagation solutions of electro magnetic waves in photonic crystals is analyzed using FDTD method. The frequency and wave length spectrums for the case samples are been simulated, the results indicate photonic crystal to be a fluidic sensor.

Keywords - **Photonic Crystal Fibre, Finite difference time domain(FDTD), Fluidic Sensor, Maxwell's Curl equations**.

1. Introduction

As telecommunication traffic increases due to the rapid growth in the use of telephone, television, data transmission, and the Internet, the need for communication systems that can handle more and more information increases rapidly all over the world. Accordingly, more channels over wider bandwidths are required to fulfill the increased demand. Wavelength- division multiplexing (WDM) [1] to process multiple communication channels together in an optical link has been established as a promising solution for the increased capacity. The WDM technique allows long-haul point-to-point light wave transmission systems to provide multiple channels simultaneously in the 1.55m wavelength regime. Fiber Bragg gratings (FBG) have been applied in sensors for many years. As a type of sensor, FBGs have advantages over conventional sensors such as immunity to electromagnetic interference, remote sensing, easy handling, low cost and small size.

In recent years, photonic crystal fibers (PCFs) have attracted great research interest due to its unique optical properties, such as endless single-mode guiding, nonlinearity, tailorable chromatic dispersion and high birefringence[2-6].It has been conjectured that photonic crystal fibers (PCFs), also known as holey fibers (HFs) or microstructure optical fibers, are promising platforms for many novel applications in the telecommunication industry, as well as in the traditional sensor industry, because they can enable light to be controlled in the fiber in ways not previously possible or even imaginable. They have attracted considerable attention in recent years [7] due to the unlimited possibilities in engineering their modal properties.

Unlike conventional fibers—which contain at least two different glasses, each with a different thermal expansion coefficient, thereby giving rise to a relatively high thermal expansion coefficient—PCFs are virtually insensitive to temperature because it is made of only one material (and air holes) This property can be utilized to obtain temperature-insensitive PCF-based devices, as demonstrated in [8]. However, the single material property of PCFs leads to non photosensitivity to ultraviolet (UV) light; therefore FBGs and Long period gratings cannot normally be formed in PCFs by use of the conventional UV-written technique, unless a PCF with a Ge-doped photosensitive core is used [9]. Photonic crystal fiber geometry is characterized by a periodic arrangement of air holes running along the entire length of the fiber, centered on a solid or hollow core.

The Finite Difference Time Domain(FDTD) method is used to model gratings in photonic crystal fiber. In contrast with standard optical fibers, photonic crystal fibers can be made of a single material and have several geometric parameters which can be manipulated offering large flexibility of design. In this paper, the comparative analysis of temperature sensitivity in conventional optical fiber and photonic crystal gratings are done.

The Finite Difference Time Domain Method (FDTD) is a powerful space grid time domain technique which gives direct numerical solution of Maxwell's curl equations for EM field. In this method the computational domain is discretised into fine grids and Maxwell's curl equations are discretised by approximating the time and space derivatives by first order finite differences as follows.

$$\frac{\partial f}{\partial x}(i\Delta x, j\Delta y, k\Delta z)=\frac{f^{n}(i+1/2,j,k)-f^{n}(i-1/2,j,k)}{\Delta x}+o[(\Delta t)^2] \quad (1)$$

$$\frac{\partial f}{\partial t}(i\Delta x, j\Delta y, k\Delta z)=\frac{f^{n+1/2}(i,j,k)-f^{n-1/2}(i,j,k)}{\Delta t}+o[(\Delta t)^2] \quad (2)$$

The structure is excited by a sinusoidally modulated Gaussian pulse and the fields at every point in the grid are updated in accordance with finite differences form of Maxwell's curl equations until the steady state condition is reached. The output time domain samples are Fourier Transformed and normalised with respect to input signal. This gives spectral characteristics of the structure.

FDTD Equations on Rectangular Yee Lattice

3D Yee lattice is shown in Figure 1. Maxwell's Curl equations are expanded in rectangular Coordinate system which results in six coupled Partial Differential Equations [10].

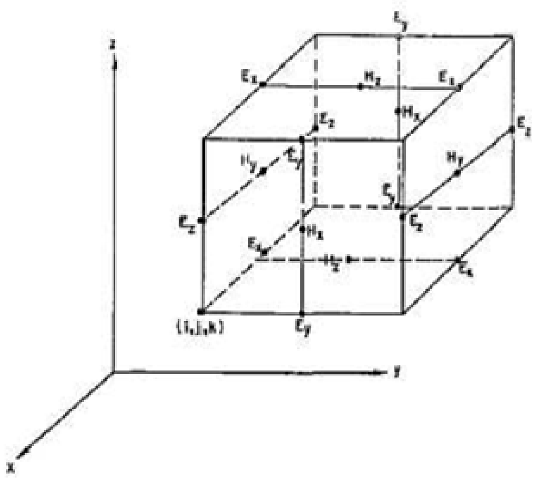

Fig. 1: 3D Yee lattice

When these Partial Differential equations- are approximated by Centered Finite Differences the following Difference equations are obtained.

$$E_x^{n+1/2}(i,j+1/2,k+1/2) = E_x^{n-1/2}(i,j+1/2,k+1/2)+\frac{\Delta t}{\varepsilon(i,j+1/2,k+1/2)}\times\left[\frac{H_z^{n}(i,j+1,k+1/2)-H_z^{n}(i,j,k+1/2)}{\Delta y}-\frac{H_y^{n}(i,j+1/2,k+1)-H_y^{n}(i,j+1/2,k)}{\Delta z}\right]H_x^{n+1} \quad (3)$$

$$H_x^{n+1}(i-1/2,j+1,k+1)=H_x^{n}(i1/2,j+1,k+1)-\frac{\Delta t}{\mu(i-1/2,j+1,k+1)}\times\left[\frac{E_y^{n+1/2}(i-1/2,j+1,k+3/2)-E_y^{n+1/2}(i-1/2,j+1,k+1/2)}{\Delta z}-\frac{E_z^{n+1/2}(i-1/2,j+3/2,k+1)-E_z^{n+1/2}(i-1/2,j+1/2,k+1)}{\Delta y}\right] \quad (4)$$

The other four equations for Ey, Ez, Hy, Hz are considered as similar as above.

The FDTD method is a rigorous solution to Maxwell's equations and does not have any approximations or theoretical restrictions. This method is widely used as a propagation solution technique in integrated optics, especially in situations where solutions obtained via other methods cannot cope with the structure geometry or are not adequate solutions. Since FDTD is a direct solution of Maxwell's curl equations, it therefore includes many more effects than other approximate methods.

2. Simulation Results

The given amount of sample is taken and our 2-d structure with point defect is dipped in the solution which results in change in background material. When there is a change in that our waveguide mode also changes. Then change in shift is compared with standard structure. Since different fluid has different density we can easily relate our change in wavelength or frequency to the given fluid sample. It is used to sense the different types of fluid based on their density value. The photonic crystal can be used as the fluid sensor by creating a point defect in a photonic crystal.

By using the 2 dimensional photonic crystals we have designed a fluid sensor. A fluid sensor is one which takes the given input samples for the user and determines what fluid sample was given. Here 2-D photonics crystal is used because it is more sensitive than the 1-D crystal and easy to analyze when compared to 3-D crystals.

This acts as a reference model. As a case study we have taken 6 fluids with different refractive index. The fluids are as follows.

Table 1: Fluids with refractive index and density

Fluid Name	Refractive Index	Density in kg/m3
Kerosene	1.44	820.1
Heptane	1.387	679.5
Cotton seed oil	1.4580	96
Methanol	1.3284	786.5
Cresol	1.5398	1024
Acetic acid	1.3716	1049

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In proposed sensor a hexagonal lattice with point defect is used.

The design parameters used are as follows:

- Radius of rods 0.19um
- Hole material is varied with respect to fluid taken
- Lattice constant 1um

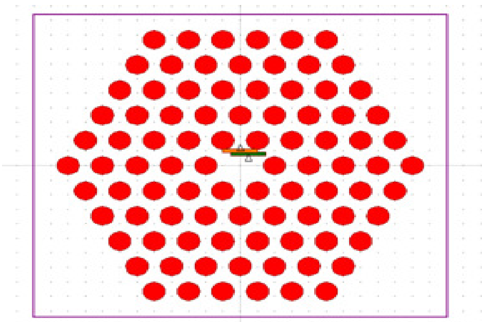


Fig.2 The design structure of phonic crystal in RSoft CAD layout

The effective index obtained after simulation is 3.454502 and remains constant for all the fluids. The designed structure of photonic crystal in RSoft CAD layout is shown in the Fig.2 and the contour map of the corresponding design is shown in the Fig.3.

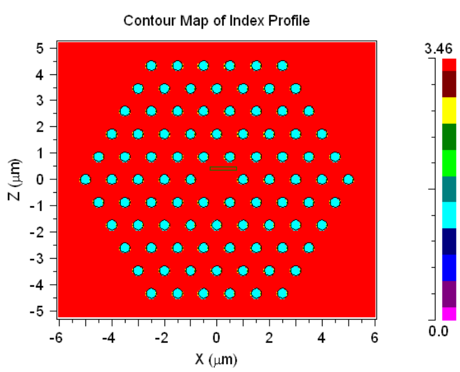


Fig.3Contour Map of Index profile

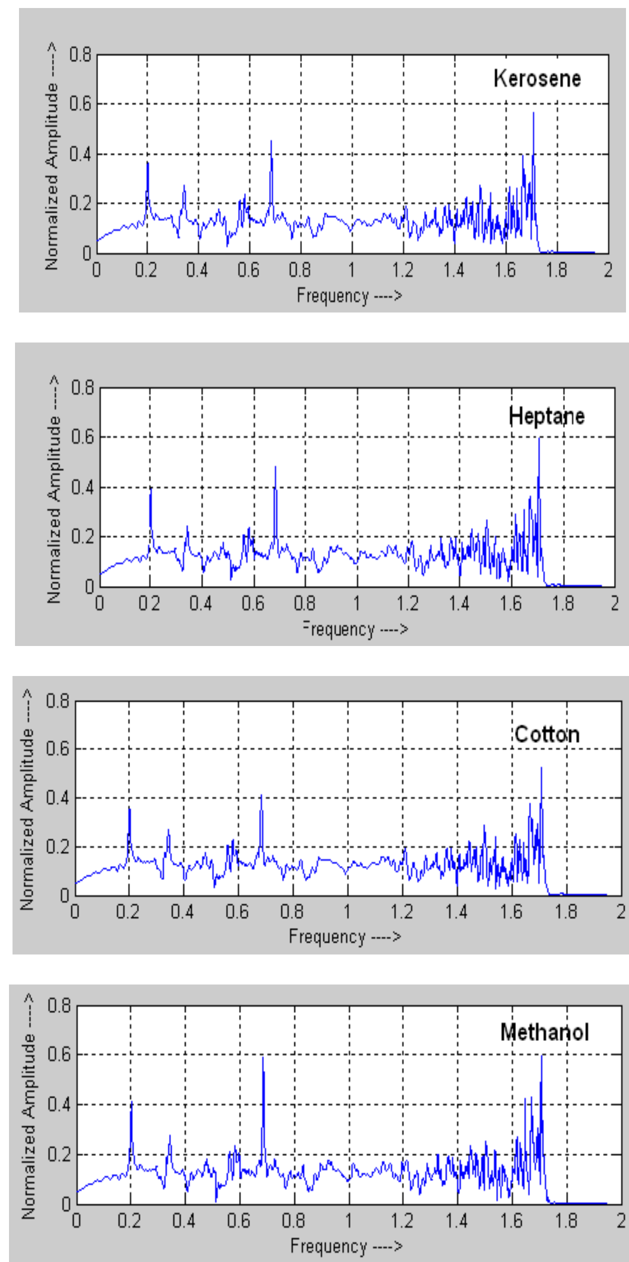
Table 2: Frequency and wavelength shift obtained at different fluids

Fluid Name	Refractive Index	Frequency shift	Wavelength shift
KEROSENE	1.44	0.66617	1.501
HEPTANE	1.387	0.68376	1.4625
COTTON SEED OIL	1.4580	0.6603	1.514
METHANOL	1.3284	0.7072	1.414
CRESOL	1.5398	0.6310	0.30288
ACETIC ACID	1.3716	0.6896	1.45

The designed structure of photonic crystal in RSoft CAD layout is shown in the Fig.2 and the contour map of the corresponding design is shown in the Fig.3.

From table 2, we observed that there is shift in frequency and wavelength corresponding to the different fluids. Thus it shows that the designed model acting as fluid sensor.

The frequency spectrum obtained by varying refractive index corresponding to different fluids is depicted in Fig 4.We observe that there is shift in frequency at different fluids.



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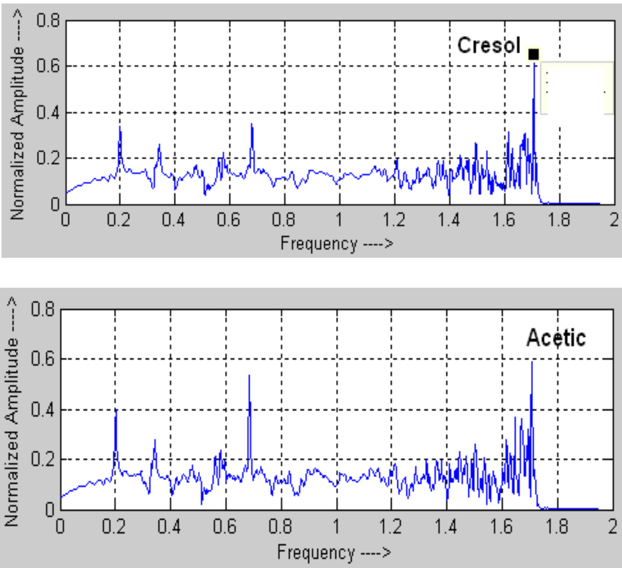
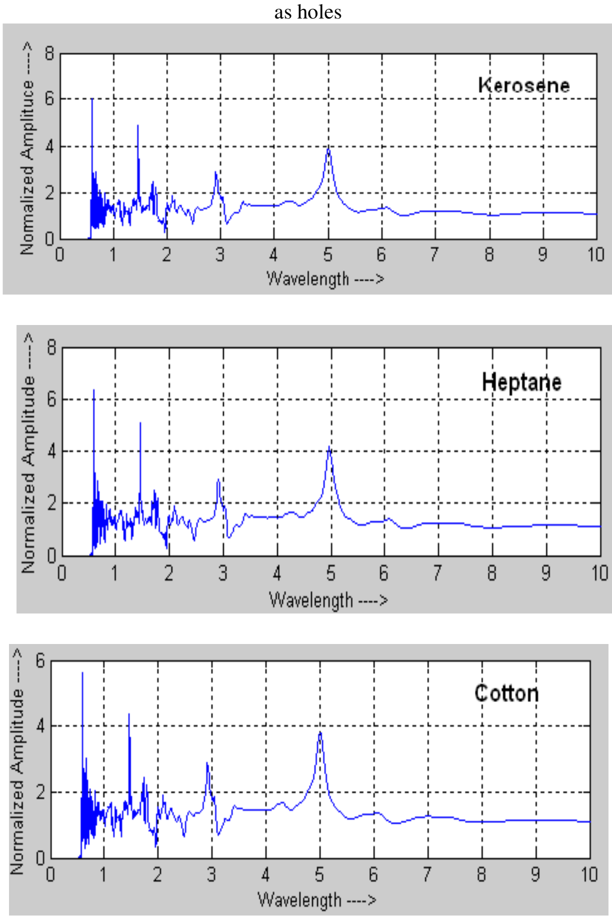


Fig.4 Frequency spectrum obtained by varying refractive index of fluids as holes



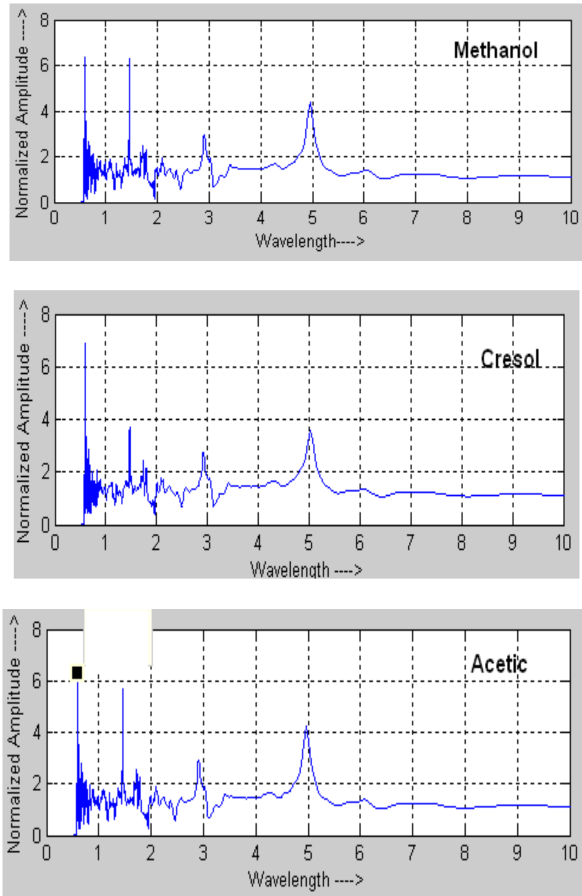


Fig.5 Wavelength spectrum obtained by varying refractive index of fluids as holes

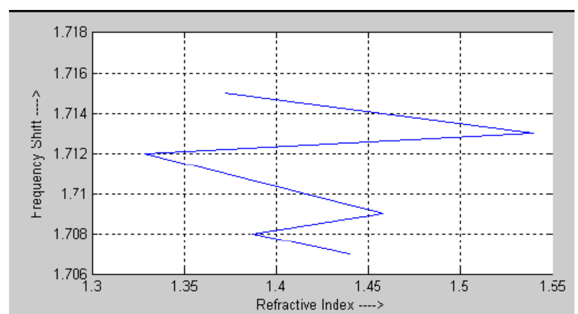


Fig.6 Plot of refractive index vs frequency shift

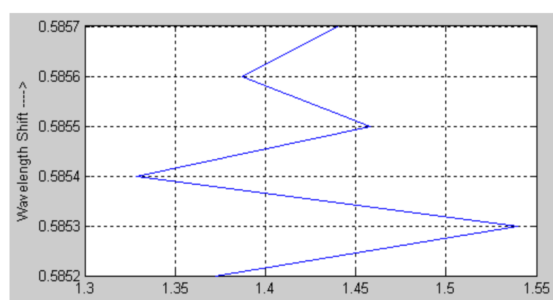


Fig.7 Plot of effective index vs wavelength shift

As the refractive index of fluids increases, the corresponding frequency shift decreases is shown in Fig 6.Linear change in refractive index shows linear shift in frequency due to fluids.

As the refractive index of water increases, the corresponding wavelength shift decreases is shown in Fig. 7.

The final calibration graph that we have obtained is for the fluid detection. The graph is obtained by plotting density to liquids at x-axis and the shift in frequency with reference to air at y-axis. The resulting graph is shown in Fig.8. Similarly the graph of density vs wavelength shift is shown in Fig.9.

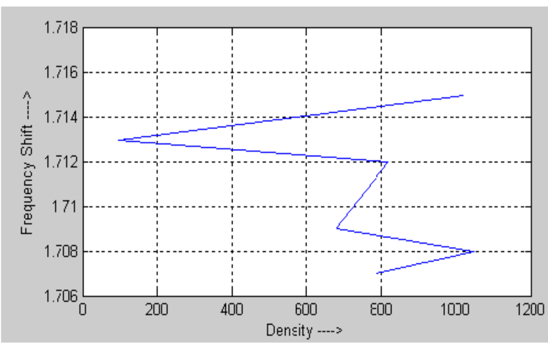


Fig.8 Plot of density vs frequency shift

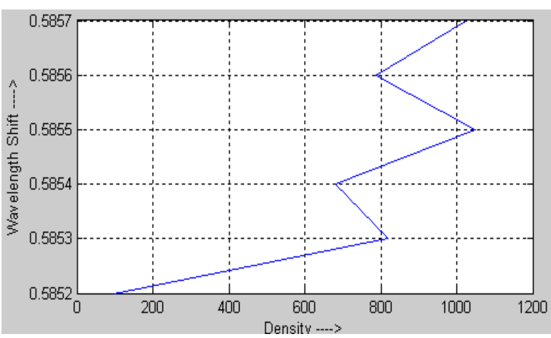


Fig. 9 Plot of density vs wavelength shift

As the Density of fluids increases, the corresponding wavelength shift decreases as shown in Fig 9. Change in refractive index shows linear shift in density due to fluids. Thus, by changing the configuration of fluid sensor, we observe here that the effective index remains constant, but there is shift in frequency and wavelength for different fluids. Thus the designed sensor acts as fluid sensor.

3. Conclusion

The design described can be broadly applicable to a wide range of fluids . We have designed the Photonic crystal based fluid sensor using fluids in rods configuration. The wavelength in which the light wave propagates inside the defect depends upon the refractive index of the fluids in the photonic crystal. The frequency spectrum and wavelength spectrum for each test fluid is calculated and plotted. The analysis of the spectrum shows the shift in the patterns obtained which pronounces that proposed photonic crystal design is a fluid sensor.. The effective refractive indices remains constant since slab material is always rods here and the hole materials are changing with respect to fluids.

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Authors Details:

Bilkish Mondal was born in Phulbari, West Garo Hills, Meghalaya on 8th November, 1990. She received BE (Electronics & Communication) degree from Visvaswara Technological University in 2012 from Ghousia College Of Engineering, Ramanagaram, Bengaluru, Karnataka. Presently She is working with some projects related with sensor.