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| RESEARCH ARTICLE

Analysis of Dual Core Photonics Crystal Fiber with Circular Sensing Ring for Biochemical Detection from Blood Samples

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| ABSTRACT
This paper presents a proposed structure of Dual core photonic crystal fiber (DCPCF) along with a circular sensing ring for biochemical detection. Numerical analysis, Confinement loss and Relative sensitivity of PCF sensor have been observed for biochemical detection using Maxwell's equations with perfectly matched boundaries. The core region is filled with the patient's blood samples, and the light is confined through the core region. The circular sensing ring is utilized for trouble-free penetration to cope with biosensing applications. Since the occurrence of the blood samples is very in-differentiable in the human body, these sensors play a valuable role due to their trimness, small size, litheness, and isolated competence to identify diagonisive elements in human blood.

| KEYWORDS

Dual core PCF, Photonics Sensor, Confinement loss, Relative Sensitivity.

| ARTICLE INFORMATION

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1. Introduction

Photonic Crystal Fibers establishes effervescent relevance in all provinces consisting of Biomedicines, Industries, Detection and analysis of assorted ailments, and unadventurous communication exercise. The utilization of Photonic Crystal Fibers [Sunil, 2019] for sensing purposes is comprehensively explicated, and it envelops an intact state of function. The PCF sensors are alienated into two segments. The primary one is physical PCF sensors, and the secondary one is Bio chemical sensors. Mutually these types of sensors can be worn to execute the explicit procedure in definite functions.

A numerical way has to be used to achieve the time-domain [Ravindra, 2009] resolution of an inhomogeneous explanation. The finite-difference time domain (FDTD) method [Sunil, 2019], a numerical way, is predominantly appropriate for model discovery problems. Additionally, it is moderately adaptable and given it has been used with great achievement in solving such practical problems. In the finite difference technique, continuous space-time is substituted by means of a discrete space-time. Subsequently, in discrete space-time, fractional differential equations are substituted with difference equations. These difference equations are willingly executed on a digital computer [Kaur et al. 2019].

Let us consider first a scalar wave equation

Consider first a scalar wave equation of the form

$$\frac{1}{c^2}\frac{\partial^2 y}{(r)\partial t^2}\Phi(r,t) = \mu(r)\nabla.\mu^{-1}(r)\Phi(r,t) \qquad (1)$$

Several features are available related to PCF infiltration for sensing liquid in the air holes [Ravindra, 2018]. Blood is the most vital fluid in the human body, which performs all important functions in our body; when someone gets ill due to any insignificant disease or virus, doctors prescribe blood tests depending upon the symptoms of the patient [Xu, 2018]. A photonic biosensor is an ultimate device for the detection of these abnormalities, and these devices are more reliable, accurate, cost-effective small in size, and more compatible with the human body [Arif, 2016]. Solid-core photonic crystal fiber (SC-PCF) can also be utilized for this application, but there is a limitation of lower relative sensitivity, so to overcome this limitation, Dual core PCF is proposed. Park et al. [2015] have observed highly indexed GeO_2 doped silica rings surrounded by a hollow core to increase relative sensitivity to lower the confinement loss. Similarly, Morshed et al. [2015] have also observed the P_2O_5 PCF sensor for the identification of Methane and various toxic gases which are present in the environment and obtained a relative sensitivity greater than 42% and confinement loss equivalent to 4.73×10^{-6} dB⁄m. Kawsar et al. [2014] have designed a fused PCF sensor for C_6H_6, CH_3OH and H_2O detection and obtained maximum relative sensitivity of 49.30% and confinement loss equal to 3.31×10^{-10} dB⁄m for C_6H_6. Consequently, enhanced sensitivity of dual core PCF has been observed in terms of smart biochemical sensors. Some common blood disorder related diseases [Park, 2011] are malaria, anemia, leukemia, lymphoma, hemophilia, hepatitis B and C, etc. There is a need to develop a PCF sensor that can detect human abnormalities such as cancer tissue, diabetes tissue, and blood components. Since these waveguides are electrically inactive, not indicating a risk to patients, and there are no electrical connections to their bodies, most importantly, the ability for real-time measurement and the possibility to simultaneously measure several parameters will enhance the utility of these sensors.

FDTD method is a direct solution from Maxwell's time dependent curl equations.

$$\frac{\partial H_x}{\partial t} = -(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z})\frac{1}{\mu} \quad (2)$$

$$\frac{\partial H_y}{\partial t} = -(\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x})\frac{1}{\mu} \quad (3)$$

$$\frac{\partial H_z}{\partial t} = -(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x})\frac{1}{\mu} \quad (4)$$

$$\frac{\partial E_x}{\partial t} = -(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z})\frac{1}{\varepsilon} \quad (5)$$

$$\frac{\partial E_y}{\partial t} = -(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x})\frac{1}{\varepsilon} \quad (6)$$

$$\frac{\partial E_z}{\partial t} = -(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y})\frac{1}{\varepsilon} \quad (7)$$

Then the finite differential equations are constructed according to these equations.

$$\frac{{H_x}^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)-{H_x}^{n-\frac{1}{2}}(i,j+\frac{1}{2},k+\frac{1}{2})}{\nabla t} = \frac{{E_y}^{n}\left(i,j+\frac{1}{2},k+1\right)-{E_y}^{n}\left(i,j+\frac{1}{2},k\right)}{\mu\Delta z} - \frac{{E_z}^{n}\left(i,j+1,k+\frac{1}{2}\right)-{E_z}^{n}\left(i,j,k+\frac{1}{2}\right)}{\mu\Delta y}$$
(8)

$$\frac{{E_x}^{n}\left(i+\frac{1}{2},j,k\right)-{E_x}^{n-1}(i+\frac{1}{2},j,k)}{\nabla t} = \frac{{H_z}^{n-\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right)-{H_y}^{n}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)}{\varepsilon\Delta y} - \frac{{H_y}^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)-{H_y}^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k-\frac{1}{2}\right)}{\varepsilon\Delta z} \quad (9)$$

(8) and (9) are differential equations of H_x and E_x.

This paper proposes a dual core PCF sensor with a circular sensing ring for blood component detection. The result reveals high relative sensitivity and low-confinement loss for different refractive indices of blood samples [Sardar, 1998]. With this proposed design, the evanescent light interacts with sensing liquid in a uniform manner and offers high relative sensitivity.

Arrangement to simulate the work:

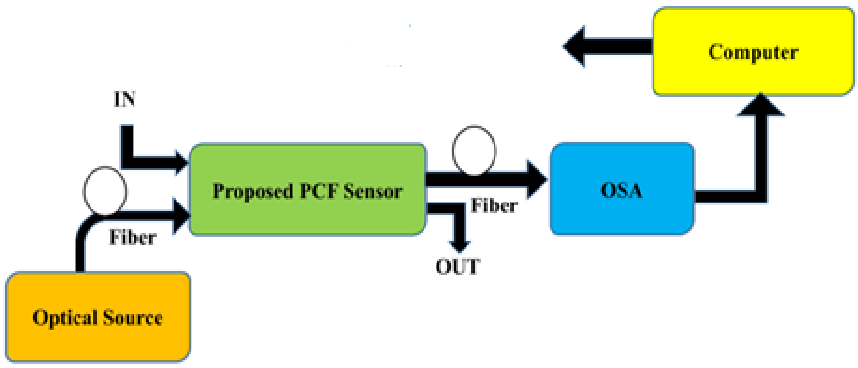

Figure: 1 Utilization of PCF sensors with Proposed Dual core PCF

The optical source is used to supply power in the single mode fiber (SMF) [Asaduzzaman, 2016]. Using the splicing technique, SMF can be connected with the PCF sensor. Here, IN and OUT ports are used to control the reserve of an unknown analyte whose RI [Ademgil, 2016] needs to be detected. When the analyte interacts with the legend, then the blue or red shift of the loss peaks occurs, which can be observed by an optical spectrum analyzer (OSA) [Asaduzzaman, 2016]. Therefore, unknown analytes can be detected adequately after analyzing the loss peak shift in the computer.

2. Proposed Design Analysis

Figure 1 depicts the cross-sectional view of the proposed dual core Silica PCF with a circular sensing ring for biochemical detection of the human blood of a patient. The diameter of the air hole is 1.2 µm. Here elliptical air hole is also used in the first layer, and the semi major and semi minor axis for that ellipse is 1.2 and 0.8 µm, respectively. The pitch value for the proposed structure is 2 µm. The Sellimier equation [Ademgil, 2015] is utilized to describe the refractive indices of the material used for this structure. For this case, Silica is preferred for this structure due to its below-mentioned characteristics.

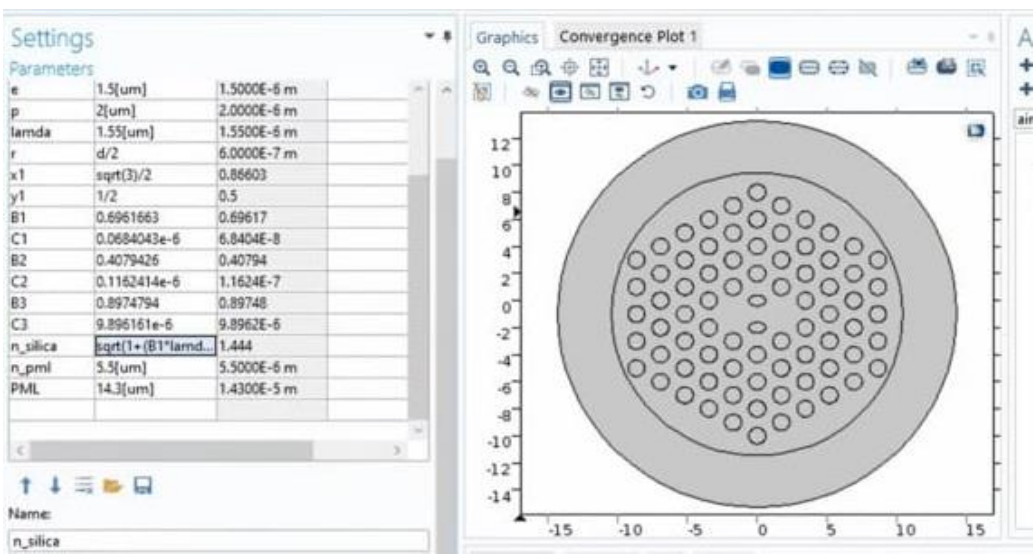

Figure: 2 Proposed Dual Core PCF with different parameters

Table: 1 Properties of Silica Glass Material

Properties	Silica Glass
Density (g/cm^3)	2.2
Refractive Index (micrometer)	1.458
Light Transmission wavelength (micrometer)	0.18 - 2.5
Max Temperature (Degree Centigrade)	1120
Poission's Ratio	0.17
Specific heat capacity (J/Kg-K)	720
Speed of sound (m/s)	180x10^3

The finite-difference method is the most accurate and numerically efficient method to solve Maxwell's equation and needs less computational time. Commercial available COMSOL Multi physics software [Lee, 2008] is used to compute the optimized results for the proposed structure.

Depending upon the refractive index of blood samples, the intensity of light is modulated and detected at the other end of PCF [Fini, 2004]. The relation between the evanescent field absorbed by sensing species and intensity modulation at the output end is shown in the above figures.

Sensitivity is obtained by using

$$r_f = f\left(\frac{n_r}{n_c}\right) \quad (10)$$

Where n_r is the refractive index of the fluid, n_c is the core refractive index, r_f is the relative sensitivity coefficient, and 'f' is the ratio of optical power within large holes to the total power, which is given as

$$f = \int[(E_x H_y - H_x E_y)_{samples} \;/\; \int[(E_x H_y - H_x E_y)]_{total} \quad (11)$$

Confinement loss of fundamental mode is calculated by

$$L_C = (40\pi/\ln(10)\,\lambda)\,\mathrm{Im}(neff)\;\;[\mathrm{dB/km}] \quad (12)$$

or it can be written as

$$L_C\,(\mathrm{dB/m}) = 8.686 k_0\, I_m\,(n_{eff}) \times 10^6 \quad (13)$$

Here n_{eff} signifies the imaginary part of the effective refractive index, and k_0 is the free-space number.

The extinction coefficient or Attenuation *coefficient [*Ma, 2012*]* refers to several different measures of the absorption of light in a medium. It is defined as the ratio of maximum to minimum transmission [Nagasaki, 2011] of a beam of light.

After designing above mentioned Dual Core PCF using COMSOL multi-physics, when there is a variation of index mode, then due to different mode index values, there is a variation measured in confining light through the designed PCF. This variation is shown in figure 2.

It indicates that as index mode value varies like 1.4053, 1.4055, 1.4088, 1.41..... The variation is observed in confining the light through the core of the proposed fiber.

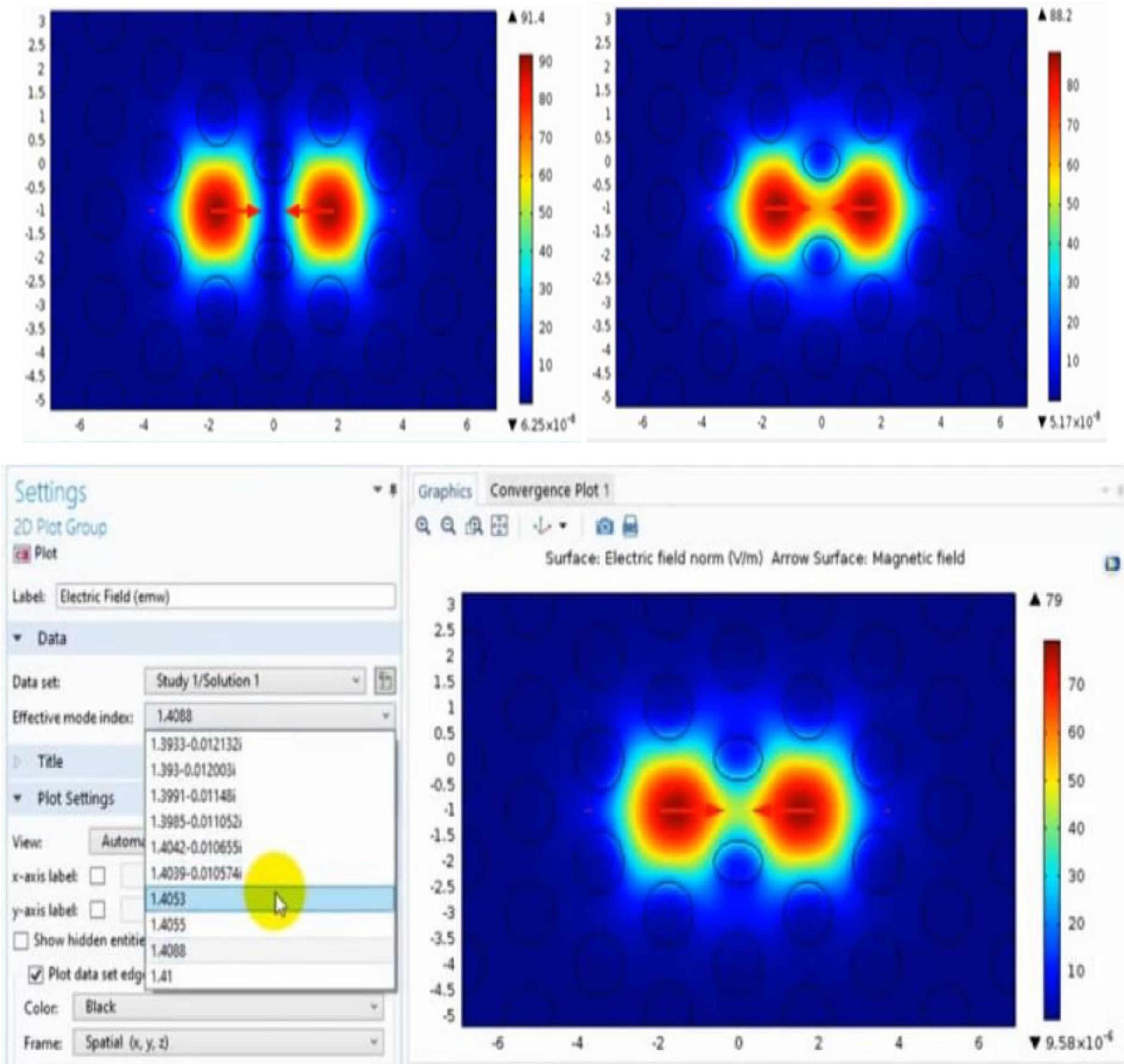

Figure: 3 Light Confinement through proposed design for different Index Modes

Parameter Tested	**Refractive Index**	**Relative Sensitivity (%)**	**Extinction coefficient (cm^{-1})**	**Confinement Loss (dB/km)**
Ethanol	1.33	56.90	0.7318	2.37×10^{-6}
Blood Serum	1.39	46.51	0.00106	3.814×10^{-10}
Water	1.32	53.57	0.6713	8.063×10^{-11}

Table: 2 Test Performed for various parameters

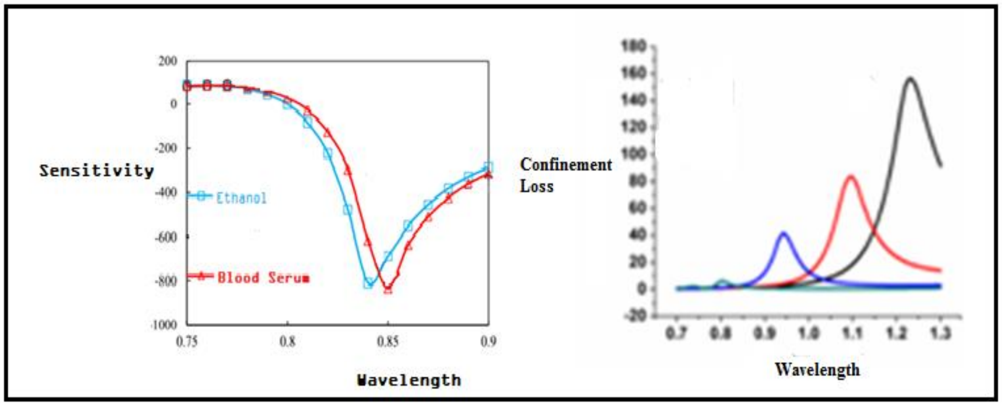

Figure: 4 Variation of Relative Sensitivity and Confinement Loss with reference to ellipticity constant

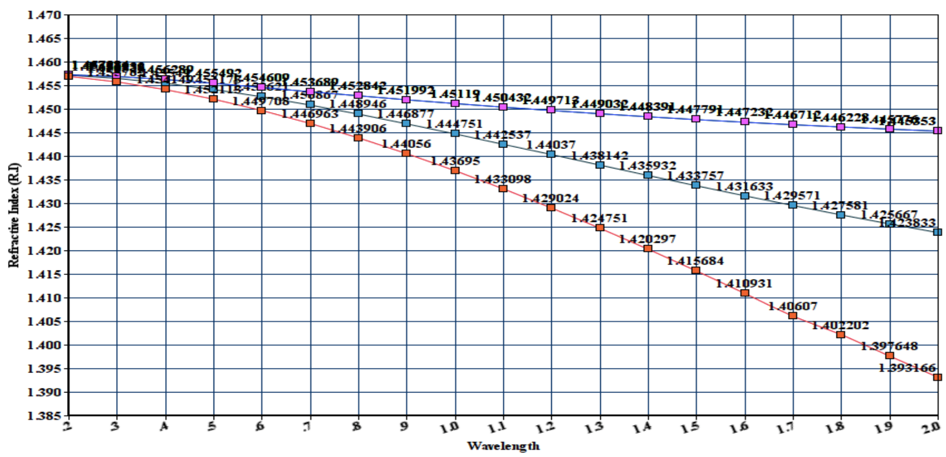

Figure: 5 Refractive Index of proposed Dual Core PCF

3. Conclusion

Analysis of biochemical detection of blood samples of a patient is obtained by means of a Dual core PCF sensor with a circular sensing ring. A constant wavelength of 1.3 micrometres is taken for the proposed design. The Confinement loss and relative sensitivity of blood serum and ethanol, shown in figure 4 above, indicate that confinement loss for Ethanol is 2.37×10^{-6} dB/km and for blood serum, it is 3.814×10^{-10} dB/km, while the relative sensitivity exhibited for Ethanol is 56.90% and for blood serum, it is 46.51%. Light confined through air holes of the proposed dial core PCF is shown above in figure 3. In future, the work can be extended with the incorporation of Artificial Intelligence (AI) to obtain optimized results and further sever virus detection can also be helpful by these tools and techniques**.**

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