Detection of Immunoglobulin G (IgG) and Immunoglobulin M (IgM) Antibodies Using Circular Photonic Crystal Fiber Sensor

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Abstract. In this paper, a circular Photonic Crystal fiber (C-PCF) is designed to detect two types of antibodies such as Immunoglobulin G (IgG) and Immunoglobulin M (IgM). Light guiding property of different refractive index (RI) of IgG and IgM are analyzed. For various RI value confinement losses, relative sensitivity and effective mode area are analyzed. The projected C-PCF sensor produces low confinement loss and high sensitivity for the detection of IgM and IgG. Realistic execution of the proposed PCF sensor is viable by accessible technology and it is applicable to sense corona virus disease.

Keywords - Circular Photonic Crystal fiber (C-PCF), Refractive Index (RI), Immunoglobulin G (IgG), Immunoglobulin M (IgM), Relative sensitivity.

1. Introduction

PCF offers great design liveness; the design structure parameters take part in a foremost part in regulating the luminosity in the core region. PCF based sensing devices are used because of optimal cost, light-weight and the insensitivity in the hazardous environments. It emphasizes the optical communication with the low confinement loss with large effective area and supports all the homogeneous characters [1–4].

Coronavirus (Covid-19) is an infected disease that spreads in the majority part of the world. Day by day large numbers of people are getting infected with this disease in some cases it may lead to even death. This virus will spread when a person touches the infected area it will start to spread to others. This virus will be alive for 14 days, if the person washes his hands regularly without touching his/her eyes, nose and mouth he/she can get rid of this coronavirus.

Since the count of the infected person was rising regularly. To analyze the virus presence by numerous methods such as LiangLiang Liu et.al [5] projected a technique to find out IgM by optical method which was coated by tri layers of silica core, poly (allylamine hydrochloride) and gold shell nano particles was used. The different mode of concentrations is used for IgM detections. The three diverse concentrations of IgM deferral are 19nM, 83nM and 0.3μM. The sensor response time was good. By detecting the boundary of detection of 0.0218 ng/mm². Eva Melnik et.al [6] anticipated to detect IgG in serum of the human being using a Mach Zender interferometer for the excellent recovery of the signal in the range of 5-200nM. The IgG was sensed for the concentration of 100pM. Bo-TaoWang et al [7] It was analysed by single mode fiber immunosensor type sensing device with huge core offset area. The RI term was in the range of 1.3328-1.3398 and the resolution in the order of 1.44×10−6 and the low down detection limit of 47 ng/ml was observed. Hu X, et.al [8] a easy approach was projected for sensitivity finding of antibodies of Covid-19, rapidly the antibodies are IgM/IgG, it is sensed by immuno chromatographic strip test it is of gold colloidal substance. The final results are then compared with the strip and the RT-PCR to find out the proper terms.
Kelvin Kai-Wang [9] in this work, the saliva samples are collected for the testing purpose and it was carried out by Public Health Laboratory Services in Hong Kong. This was done by the patient to cough out the saliva from the throat into a sterilized bottle, and 2mL of viral carry standard was added and the virus was checked out. Rishikesh Magar, et.al [10] the rapid way of testing can save the many people live from the COVID-19. Here the work was carried out with the help of Machine Learning (ML) model. To detect corona virus by ML the several samples from the patients are to be trained for the proper analysis it was carried out around 1933. With the help of diagram features with diversity of ML methods, thousands of theoretical antibodies were analyzed. Bing Sun et.al [11] in this process the conventional form of testing were used but it was a time consuming process this method is called a Dispersion Turning Point (DTP) method by using various levels of concentrations of 10 fg/mL of IgG was detected. These are the various forms of testing process carried out in various works. Some are time lasting testing and other are needed several models are to be trained. Not only ML other testing platforms are also there. In which the samples are taken from enormous individual for the testing process. So the use of the optical fiber method is ease of designing and the outcomes are analyzed by the graphical mode of comparison.

Mucahid Barstugan et.al [12] the detection process was carried out in the abdominal images. The viral shows the different mode of phenomena from the CT images since the COVID-19 shows the changing behavioral pattern. The characters are get analyzed from the tomography images from the screen. The radiologists’ experts detect the disease from these images shows the effect. COVID-19 shows different behaviors from other viral pneumonia. The virus to be analyzed in an early stage. So four datasets were taken from the patches sized as 16x16, 32x32, 48x48, 64x64 from 150 CT images. To increase the classification performance the feature extraction process was applied to patches. The various feature extraction methods are Local Directional Pattern (LDP), Grey Level Co-occurrence Matrix (GLCM), Grey-Level Size Zone Matrix (GLSZM), Grey Level Run Length Matrix (GLRLM) and Discrete Wavelet Transform (DWT) algorithms were used. The extracted feature such as Support Vector Machines (SVM) is used. In the classification process 2-fold, 5-fold and 10-fold cross-validations were implemented. For the best result 10 fold is used and GLSZM also added in it. Lin Jia, Kewen [13] In this paper tri form of mathematical model is i.e., Bertalanffy model, Logistic model and Gompertz model. To prove the validity of the current models the outbreak trends of SARS are used in order to be fitted. For different parameters and for diverse regions the 3 mathematical models to be used. Out of these three fitting models the logistic model will be the better one while the correct effect of Gompertz model may be superior than Bertalanffy model.

In this document, a C-PCF is designed it consisting of circular structure. The core and cladding are in elliptical shape. The proposed structure is used to detect antibodies such as IgG and IgM. These antibodies have different RI, for IgG the three different RI such as maximum, minimum and an average RI are 1.34930, 1.34300 and 1.34566 respectively and for IgG different RI are 1.34414, 1.34448 and 1.34480 are measured. These diverse RI values are sensed by the designed C-PCF sensor in a well-organized manner.
2. Measures of the proposed PCF

The projected C-PCF is made up of cladding and core. The inner part is of an elliptical shape. The structure of the proposed C-PCF is shown in figure 1. The structure shown in the fig. is the proposed design for the chemical sensor. The outer cladding is designed with diameter of a-semiaxis = [0.8μm] and b-semiaxis = [1.2μm]. Since the proposed design is based on the Photonic band gap (PBG) method the air holes in the cladding region is drilled in the form of ellipse shape. Where the ellipse bent air holes are set in the form of round pattern inside the cladding region. There were 3 layers of air holes designed in the sensor with the pitch $^\wedge = [3.2\mu m]$. Since the air holes are elliptical shape get drilled by various process drilling [23], stack-and-draw [24], extrusion [25] and sol-gel casting [26] etc. The sample solution to be detect is placed in the core region to calculate the chemical properties of model to be placed and the diameter of total core region $d = [2\mu m]$. A small air hole is drilled in the center of the core around which the vertical ellipse air holes are placed. The 2 vertical ellipse shaped holes is provided at both top and bottom of the center air hole, 1 vertical ellipse shaped hole is placed in left and another one in right. Totally 6 vertical ellipse shaped air holes is placed around the center air holes. The diameter of the core is of a-semiaxis = [1μm] and b-semiaxis = [1.5μm]. The taster elucidation is located in 6 upright ellipse fashioned air holes provided at inner region. The cladding region is fitted with silicon material. The refractive index of air and silicon are 1, 1.45 respectively. The characteristics that can be determined are Relative sensitivity, Confinement loss and $n_{eff}$ respectively. The air hole is packed with analytes, while filling the analytes in the center the difficulty of the core will amplify. In order to defeat this issue an efficient method is used [31], where the substantial process involves UV-curable polymer pressurized method.

3. Numerical Analysis

The C-PCF sensor explains the relative sensing capacity. Relative sensitivity is known by $r$, and it can be intended by using the subsequent equation

$$r = \frac{n_s}{Re[n_{eff}]} \times f$$  

Where $n_s$ is called as RI of the target species, normally considered as one. $Re[n_{eff}]$ is the real part of $n_{eff}$ mode index. Here, $f$ is the part of the hole power divided by the total power.
Where, $H_y$, $H_x$ are transverse magnetic field in y and x axis and $E_y$, $E_x$ are electric field in y and x axis respectively. The confinement loss or leaky loss occurs due to the irregular nature of air holes. These air holes act as dielectric medium. To avoid reflection perfectly matched layer (PML) surrounds the structure. The confinement loss is calculated by the imaginary part of the $n_{eff}$ index. The confinement loss can be calculated by the following equation

$$L_c (\text{dB/m}) = 8.686k_0x l_m \left(n_{eff}\right) x 10^6$$

$$k_0 = \frac{2\pi}{\lambda}$$, is the wave number.

The $n_{eff}$ area generally considers the light carrying region. The effective mode area is determined by

$$n_{eff} = \frac{\iint |\mathbf{E}|^2 \, dx \, dy}{\iint |\mathbf{E}|^2 \, dx \, dy}$$

4. Results and Discussions

Figure 2 shows the light confinement in the core area.

![Light controlling diagram of PCF sensor](image)

Fig.2 Light controlling diagram of PCF sensor

The various factors like sensitivity, confinement loss and $n_{eff}$ are calculated for various concentration factors here three values are taken. The core part get consists of the unique concentrations with the various RI. The silica is used as the background material. Initially the concentrations are placed in the inner part from low medium to the high rate. Initially the sensitivity for the lower RI of IgG is analyzed. The lower RI of the IgG is 1.3430, which is placed at the core area, this IgG is analyzed for the wavelength range of 1μm to 2.4μm. Likewise, the average and elevated RI of IgG is placed in the core of the C-PCF sensor and the sensitivity graph is drawn. Figure 3 shows the sensitivity graph of IgG. It is inferred that from the graph of sensitivity it is established that an utmost RI of 1.3493 produce a relative sensitivity of 47.47% for the wavelength of 2.4μm, the average RI of 1.34566 produces a sensitivity of 39.87% and the minimum RI of 1.34300 gives 40.22%. The RI of 1.3493 is better compare to other RI.

The attenuation graph for the IgG is shown in figure 4, from the graph it is analyzed that the attenuation for different RI is decreases as the wavelength increases. For the wavelength of 2.4μm the attenuation is very much reduced, this is achieved because the light is very much confined in the core area and produce high sensitivity. The loss in the confinement gets depends on the wavelength used for transmitted, hole figure and number of rings. The confinement loss of IgG is less, as the wavelength
amplify it reaches to its minimum values.

Now, the three different RI of IgM is analyzed, the three different RI starting from smallest amount to greatest values are 1.34414, 1.34448 and 1.34480 respectively. The sensitivity, effective area and confinement graph for this IgM is shown in figure 6, 7 and 8. The sensitivity graph for IgM is increasing for the wavelength of 1 μm to 2.4μm. The maximum sensitivity of 40.96% is achieved for the 1.34480 RI. In this IgM all the three sensitivity terms are very close to each other. The attenuation for this IgM is also less as the wavelength increases; similarly, the confinement loss for this IgM will reach its minimum value for the maximum wavelength.
5. Conclusion

A circular shaped elliptical core and cladding PCF base sensor that utilizes silica as background material and operates in 1 to 2.4 μm is developed. Simulation results reveals that the developed fiber is suitable for detecting IgG and IgM antibodies. High sensitivity of 47.47% and 40.96% for the RI of 1.34930 and 1.34480 respectively. For the range of frequency, the attenuation and confinement loss are thoroughly investigated. As this sensor sense the IgG and IgM antibodies, this C-PCF sensor is appropriate for detecting corona virus.
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