High amplitude sensitivity gold-coated trichannel photonic crystal fibre for refractive index sensor

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Abstract

We propose highly sensitive trichannel photonic crystal fibre (TCPCF) refractive index (RI) sensor based surface plasmon resonance (SPR). In this design, we have integrated the sensing layer with thin gold metal deposited over the surface of the TCPCF for fabrication feasible and easy liquid infiltration. Then, Y-shaped channel is formed through reducing the diametre of air holes for controlling the direction of light through photonic crystal fibre to attain high sensitivity. Also, effective coupling between surface plasmon polariton mode at the metal layer and the core-guided mode is obtained by numerical simulation of finite element method. The optimized TCPCF sensor exhibits maximum amplitude sensitivity of 1938.5 RIU\textsuperscript{−1} and wavelength sensitivity of 11,000 nm. RIU\textsuperscript{−1} within the analyte range from 1.34 to 1.39. Further, we have achieved amplitude resolution of \(5.2 \times 10^{-6}\) RIU and wavelength resolution of 9.1 \(\times 10^{-6}\) RIU. It is confirmed high detection accuracy for small changes in RI analyte. Moreover, high figure of merit of 623.9 RIU\textsuperscript{−1} is obtained for the proposed sensor. Therefore, the proposed TCPCF RI sensor can be utilized in the chemical, bio and gas sensing applications.

1 | INTRODUCTION

In the recent years, surface plasmon resonance (SPR) has been added up in the field of refractive index (RI) sensor and it is reaching one of the trending topics around the researchers [1, 2]. Because, it has a high sensitivity and offers numerous applications such as security, biomolecular analyte detection [3], bioimaging, chemical detection, environmental monitoring [4], food safety [5], disease diagnostics [6, 7], street light systems [8] and absorber [9]. The fundamental theoretical concept of SPR was first introduced by Ritchie et al. [10]. In 1983, Liedberg was the first scientist who introduced the SPR on the ethic of prism coupling where the prism was used to trigger the surface plasmon’s [11]. Unfortunately, they faced few limitations such as bulky size, moving mechanical components with the prism and also not suitable in remote sensing applications due to problem faced in fabrication on a huge scale for real-time application. Optical fibres were substituted instead of prism to overcome the drawbacks of prism-coupled sensors [2]. R.C. Jorgenson in 1993 was the first scientist who approached the optical fibre with gold film coated to attain the plasmon response on the fibre core surface [12]. When the optical fibre was combined along with SPR sensing they exposed the high-resolution results and large scale operating domain, but their usage was scarce because of narrow acceptance angles [4].

Recently, the photonic crystal fibre (PCF) based SPR RI sensor has considerable attention due to high design flexibility, high sensitivity, tunability, wide bandwidth, small size and portability. In contrast to conventional optical fibre, PCF has large effective index difference between the core and cladding, which could enhance the sensing performance [1, 13].

There are few recently reported PCF based sensors along with SPR phenomenon using the plasmonic materials such as gold, silver, aluminium and copper which expose different results. These approaches reveal that, the SPR phenomenon mainly depends on the plasmonic material. Gold nanoparticles expose better chemical alert and do not oxidize easily. They are biocompatible and offers long resonance wavelength shift which leads the gold nanoparticles to be a better choice for the active plasmonic layer [4, 14]. The PCF based SPR techniques are operated by two different sensing methods such as internal and external sensing. In internal sensing, the selected air hole is filled...
with liquid sample which is coated with the plasmonic material [15]. But, it consumes more time for emptying and refilling of the target air hole which makes them not practicable for real-time sensors [3]. Whereas, in the case of external sensing approaches, the deposition of plasmonic layer was in the outer surface of PCF [15]. In this method, the cleaning and reuse of the fibre sensor are done with upcoming dielectrics where the dielectric fluid and outer metallic layer of PCF are placed in contact with [3].

So far, there are number of research works has been reported with the gold nanoparticles as plasmonic materials along with external sensing technique. Chakma et al. have proposed gold-coated PCF for RI sensing and achieved maximum amplitude sensitivity (AS) of 318 RIU⁻¹ and wavelength sensitivity (WS) of 9000 nm.RIU⁻¹ at RI range from 1.34 to 1.37 [2]. D-shaped PCF sensor with the air holes arranged in a rectangular lattice was proposed with gold deposited in its flat surface. The sensor offers high birefringence and also gains high spectral sensitivity of 7481 nm.RIU⁻¹ [16]. Recently, dual core D-shape PCF-SPR sensor was proposed that had approached external sensing using gold as the active plasmonic layer. The sensor operates for analyte range from 1.45 to 1.48 that gains 8000 nm/RIU as maximum WS and 700 RIU⁻¹ as the maximum AS [17]. A novel PCF RI sensor was proposed for biosensing applications with RI range from 1.33 to 1.37, and obtained the AS and WS values of 478 RIU⁻¹ and 4000 nm.RIU⁻¹, respectively [18]. A simple plasmonic sensor designed with four large air holes forming a square lattice with gold coated externally was proposed. The sensor operates for RI range of 1.38 to 1.42 and obtained high spectral sensitivity of 7250 nm.RIU⁻¹ [19]. A D-shape designed PCF was coated with gold that was based on the SPR effect. The maximum WS reached was 9000 nm/RIU which has the sensing range from 1.43 to 1.46 [20]. Later, a circular lattice PCF based SPR was investigated for an analyte RI range of 1.34 to 1.37. The sensor approaches external sensing which reveals high WS and AS of 9000 nm.RIU⁻¹ and 318 RIU⁻¹ [21]. Moreover, the recent updates on the open channel at two sides based RI sensor were described and reported the maximum AS of 396 RIU⁻¹ and maximum WS of 5000 nm.RIU⁻¹ [22]. Besides, gold coated outside the PCF along with the analyte was discussed with square lattice for the range 1.36 to 1.39. It attained maximum WS of 6000 nm.RIU⁻¹ and maximum AS of 442.11 RIU⁻¹ [23].

In our article, we have proposed an SPR based simple tri-channel PCF structural design that achieves high WS, AS and figure of merit (FOM). The numerical investigation in our analysis is performed with RI ranges from 1.34 to 1.39. For improving the sensitivity, several parameters of the prepared sensor structure are being optimized such as thickness of gold layer and air holes diametre. The approached plasmonic material is chosen as gold and analyte layer is placed in the external layer of fibre in which major fabrication challenges are limited.

2 | STRUCTURAL DESIGN ANALYSIS

The proposed cross-sectional view of the gold-coated SPR based TCPCF RI sensor has been illustrated in Figure 1. The proposed TCPCF design exposes the air holes in two rings along with a central small air hole. The formation of trichannel at the centre of the SiO₂ by the use of scaled down air holes of diameters \( d_c = 0.2 \mu \text{m} \) and \( d_s = 0.2 \mu \text{m} \), which control the direction of electromagnetic wave from centre core region to metal region. It also helps to strong coupling between surface Plasmon polariton (SPP) mode and core mode. The arrangement of remaining air holes diametre of \( d = 1.6 \mu \text{m} \) in the cladding region for electromagnetic field strong interaction to the metal. Further, it has also generated strong plasmonic effect in the created channels. The distance between two air holes is called pitch \( \Lambda = 1.8 \mu \text{m} \). In this designed structure, fused silica is used as the background material. The Sellmeier equation for the fused silica is realized by [24],

\[
n^2(\lambda) = 1 + \frac{P_1 \lambda^2}{\lambda^2 - Q_1} + \frac{P_2 \lambda^2}{\lambda^2 - Q_2} + \frac{P_3 \lambda^2}{\lambda^2 - Q_3}
\]

where \( \lambda \) is the input wavelength in micron and \( n \) is the RI of fused silica. Here, the Sellmeier constants are \( P_1 = 0.6961663, P_2 = 0.4079426, P_3 = 0.8974794, Q_1 = 0.00467914826, Q_2 = 0.0135120631 \) and \( Q_3 = 97.9340025 \).

In the outer circular layer of designed TCPCF with gold thickness of \( t_g = 30 \text{ nm} \) is coated, which is acting as the preferred plasmonic material for generating SPP mode in the designed sensor. This thin layer of gold can be applied by the assist of radio sputtering technique [25], thermal evaporation [26] and wet chemistry deposition [27]. But the formation of extreme surface roughness issue during coatings, limits these coating methods. To overcome the rough surface accumulation during coating process, the potential coating method named as chemical vapour deposition [28] is approached, which allows uniform layer coating on the surface along with minimum surface roughness. The Drude–Lorentz model for gold dielectric constant mathematical expression written as [29],

\[
\varepsilon_{\text{gold}}(\omega) = \varepsilon_{\infty} - \frac{\omega_{p}^2}{\omega(\omega + i\gamma_{D})} - \frac{\Delta\varepsilon \Omega_{p}^2}{(\omega)^2 - \Omega_{p}^2 + i\gamma_{L}\omega}
\]

where the gold permittivity is \( \varepsilon_{\text{gold}} \), the high-frequency permittivity is \( \varepsilon_{\infty} = 5.9673, \omega = 6.283 \text{ c/\lambda} \) is angular frequency and the weighting factor \( \Delta\varepsilon = 1.09 \). The plasma and damping
frequency is denoted as \( \omega_D = 2\pi \times 2113.6 \text{ THz} \) and \( \gamma_D = 2\pi \times 15.92 \text{ THz} \), respectively. Moreover, the spectral width is \( \Gamma_L = 2\pi \times 104.86 \text{ THz} \) and the oscillator strength is \( \Omega_L = 2\pi \times 650.07 \text{ THz} \) of the Lorentz oscillators. The analyte layer performs as the sensing medium, which is coated on the gold layer. The proposed fibre can be fabricated by stack and draw method [30].

A perfectly matching layer (PML) is imposed at the outer most layer of the computing domain. For the reflected energy to be reduced, the scattering boundary conditions are applied at the outer circle. The FEM based commercially available software COMSOL multiphysics 5.4 is utilized to study the numerical analysis of proposed TCPCF RI sensing performances. The electric field distribution of the proposed TCPCF RI sensors is displayed in Figure 2(a) and 2(b), where the light confinement of the core-guided mode and SPP mode is revealed. Further, Figure 2(c) reveals the coupling between core-guided mode and SPP mode.

3 | RESULTS ANALYSIS

The sensing mechanism is based on the coupling condition between the decaying evanescent fields (SPP) at the gold layer and the core mode of the fibre. The coupling condition can be altered when the RI of sensing medium above the gold changes, which can be recorded as a spectral wavelength shift as well as peak intensity change in the transmission loss spectra. Strong coupling between silica core mode and SPP mode is possible through scale down air holes in the channel. Figure 3 describes the dispersion relation (real part of effective index) of fundamental silica core mode and SPP mode of gold layer, and loss spectrum of fundamental silica core mode when RI analyte is 1.39.

\[ \alpha_L \left( \frac{dB}{cm} \right) = 8.686 \times k_0 \text{Im}(n_{eff}) \times 10^4 \]  

(3)

where \( k_0 = 2\pi/\lambda \) denotes number of free space, \( \lambda \) indicates the input wavelength in microns and \( \text{Im}(n_{eff}) \) signifies the effective RI of the imaginary part. The intersection between core mode and SPP mode at a wavelength of about 0.86 \( \mu \)m with peak loss of 336.3 dB/cm. In particular, the effective index of both modes is equal (incomplete coupling) and silica core mode obtained maximum loss value at the coupling wavelength.

The SPR principle has high capability to identify slight changes in the RI around their surrounding medium, which can be recorded as a spectral wavelength shift as well as peak intensity change in the transmission loss spectra. Due to this, the effective RI of SPP will change significantly which results in a resonance wavelength shift towards a longer (red shift) or shorter wavelength (blue shift), from which anonymous samples can be identified [3, 15]. The loss spectrum acquired for the proposed TCPCF RI sensor is displayed for the range of analyte RI from 1.34 to 1.39 in Figure 4(a). It is observed that when the analyte RI is incremented, the result is observed as red shift. When the index contrast between the core and SPP mode to be low, which results in dramatic increment of peak loss. The highest peak loss of 336.3 dB/cm at 0.86 \( \mu \)m is observed for the analyte 1.39.

In wavelength interrogation process, the sensitivity is dependent on the maximum resonance wavelength shift. It is calculated as [32]:

\[ S_L \left( \frac{nm}{RIU} \right) = \frac{\Delta \lambda_{peak}}{\Delta n_a} \]  

(4)

\( \Delta \lambda_{peak} \) is the wavelength shift of resonance and \( \Delta n_a \) is the difference in RI of analyte.
where $\Delta \lambda_{peak}$ symbolizes the wavelength difference between the peak wavelength shift and $\Delta n_a$ was the difference in RI analyte. In addition, another method of amplitude interrogation technique is utilized, which is defined as the ratio of confinement loss peak changes to the changes in RI. The mathematical expression can be realized as [33]:

$$S_{Amp}(RIU^{-1}) = \frac{-1}{\alpha(\lambda, n_a)} \frac{\delta \alpha(\lambda, n_a)}{\delta n_a}$$

(5)

where $\alpha(\lambda, n_a)$ is the overall confinement loss, $\delta n_a$ is the change in RI and $\delta \alpha(\lambda, n_a)$ is discrepancy between two adjacent confinement losses with respect to varying analyte RI.

Another important parameter for sensing, which is known as resolution, describes how the sensor allows sensing a minimum deviation in the RI of sample. The sensor resolution is dependent on both wavelength and AS. The resolution can be characterized as [3]:

$$R(\text{RIU}) = \frac{\Delta n_a \Delta \lambda_{min}}{\Delta \lambda_{peak}}$$

(6)

where $\Delta n_a$ is the analyte RI variation, $\Delta \lambda_{min}$ gives the minimum spectral resolution and $\Delta \lambda_{peak}$ symbolizes the wavelength difference between the loss peak shift. FOM is a noteworthy parameter that indicates the quality and overall sensing performance of the sensor. FOM is defined as the ratio of sensitivity to full width at half maximum (FWHM) [34].

$$\text{FOM}(\text{RIU}^{-1}) = \frac{\text{Sensitivity}}{\text{FWHM}}$$

(7)

where FWHM denotes full width at half maximum. To produce a high-performance sensor, the FOM should be very high. It is evident from Equation (7) that, high FOM can be achieved when the sensitivity rises high and FWHM falls low.

According to the Equation (4), using $\Delta n_a$ of 0.01 and acquired wavelength sensitivities are 2000 nm.RIU$^{-1}$, 3000 nm. RIU$^{-1}$, 4000 nm.RIU$^{-1}$, 6000 nm.RIU$^{-1}$ and 11,000 nm. RIU$^{-1}$ for the RI range of 1.34, 1.35, 1.36, 1.37 and 1.38, respectively. With aid of this technique, the maximum wavelength sensing resolution is obtained as $9.1 \times 10^{-6}$ RIU by minimum spectral resolution ($\Delta \lambda_{min}$) assumed as 0.1 nm for

![Figure 4](image-url) The sensitivity analysis of proposed TCPCF RI sensor: (a) loss spectrum for analyte ranging from 1.34 to 1.39 and (b) amplitude sensitivity.

**Table 1** The sensing performance analysis for analyte RI ranging from 1.34 to 1.39

| Analyte RI (RI) | Resonance peak wavelength (µm) | Peak loss (dB/cm) | Peak wavelength shift (nm) | WS (nm. RIU$^{-1}$) | AS (RIU$^{-1}$) | Wavelength resolution (RIU) | Amp. resolution (RIU) | FOM (RIU$^{-1}$) |
|-----------------|-------------------------------|------------------|-----------------------------|---------------------|---------------|-----------------------------|----------------------|---------------|
| 1.34            | 0.6                           | 43.7             | 20                          | 2000                | 216.7         | 5.0 x 10$^{-5}$             | 4.6 x 10$^{-5}$      | 63.7          |
| 1.35            | 0.62                          | 59.0             | 30                          | 3000                | 412.5         | 3.3 x 10$^{-5}$             | 2.4 x 10$^{-5}$      | 96.6          |
| 1.36            | 0.65                          | 88.2             | 40                          | 4000                | 694.4         | 2.5 x 10$^{-5}$             | 1.4 x 10$^{-5}$      | 122.8         |
| 1.37            | 0.69                          | 134.5            | 60                          | 6000                | 1447.6        | 1.7 x 10$^{-5}$             | 6.9 x 10$^{-6}$      | 204.8         |
| 1.38            | 0.75                          | 236.5            | 110                         | 11,000              | 1938.5        | 9.1 x 10$^{-6}$             | 5.2 x 10$^{-6}$      | 623.9         |
| 1.39            | 0.86                          | 336.3            | N/A                         | N/A                 | N/A           | N/A                         | N/A                  | N/A           |
best-case estimation. This indicates the sensor can be able to detection of slight variations in RI of the order $10^{-6}$. Figure 4(b) represents the AS is varied with analyte RI range from 1.34 to 1.39. The obtained AS are 216.7 RIU^{-1}, 412.5 RIU^{-1}, 694.4 RIU^{-1}, 1447.6 RIU^{-1} and 1938.5 RIU^{-1} for analyte 1.34, 1.35, 1.36, 1.37, and 1.38 respectively. Our proposed TCPCF RI sensor exposes a maximum amplitude sensor resolution of about $5.2 \times 10^{-6}$ RIU. To be detected accurately by the sensor, the resolution value is obtained by considering a minimum transmitted intensity of 1%. Therefore, the proposed TCPCF RI sensor can be able to perform better in detection of slight variations in RI of the order $10^{-6}$. The FOM acquired for the different analyte from 1.34 to 1.38 is presented in Table 1. Since FOM is a wavelength-dependent parameter, we reported the maximum FOM of the sensor, which is 623.9 RIU^{-1} for the analyte 1.38.

A good sensor can be attested by its high linearity characteristic. Figure 5 exhibits linear fitting characteristic of the proposed sensor. In a fitted regression line, between analyte RI and resonance wavelength the degree of linear relationship is represented by using $R^2$. The near-ideal linearity is hit, when $R^2$ value is close to unity [4]. Linear fitting regression equation acquired for the proposed sensor can be written as $Y = -6.052 + 4.94X$, where $X$ indicates the analyte RI and $Y$ indicates the resonance wavelength. $R^2$ value attained for the linear fitting curve is about 0.910665, which provides a good linearity with iteration of 0.01. For such high $R^2$ value establishing high linear characteristics, which show that, the proposed TCPCF RI sensor can be used for accurate analyte detection.

The WS calculated from Equation (4) for its corresponding wavelength shift is plotted in Figure 6. It is observed from Figure 6 that, the maximum wavelength shift reached to 260 nm (with respect to minimum RI of 1.34). Table 1 shows an overview
of the sensing performance of the proposed TCPCF RI sensor, with the range varied from 1.34 to 1.38 for analyte RI.

4 | STRUCTURAL OPTIMIZATION OF TCPCF RI SENSOR PERFORMANCE

The optimum analysis of the proposed TCPCF RI sensor was accomplished by optimizing the geometrical parameters which included air holes diameter \(d\), \(d_a\), and \(d_e\) and thickness of gold layer \(t_g\). Both wavelength shift and peak loss intensity change can be considered as a sensing parameter for the proposed PCF sensor. However, peak loss intensity variation is more linear compared to wavelength shift with variation in RI of analyte. So, we have preferred peak loss intensity (AS) as the sensing parameter for all the optimizing geometrical parameters. The sensitivity can be detected by utilizing a specific wavelength which makes the detection process simpler. Further, the AS is also cost-effective owing to its simple detection method. On the other hand, full spectrum of the signal is essential for the WS to be detected which makes the

\[ \text{FIGURE 8} \quad (a) \text{ Loss spectrum and (b) amplitude sensitivity with big air hole diameter of } d_i \text{ altered from } 1.4 \text{ to } 1.6 \mu m \]

detection process complicated and highly expensive. Moreover, the designed sensor also exposes high peak intensity variation when compared to wavelength shift with variation in RI of analyte, hence we consider peak intensity (AS) in our further analysis.

A prevailing effect is observed in the loss depth and the AS, with the varied \(t_g\). The deposited \(t_g\) is increased from 20 to 50 nm for the analyte RI of 1.38 and 1.39. When \(t_g\) is 30 nm, the maximum loss depth of 310.5 dB/cm and 381.2 dB/cm is observed for the analyte RI 1.38 and 1.39 at the resonance wavelength 0.77 \(\mu m\) and 0.91 \(\mu m\), respectively as illustrated in Figure 7(a). The performed results outcome reveals that, the elevation of gold layer thickness, leads to decrease in interaction between the analyte and the evanescent field, which is due to high damping loss of gold [18]. The same synopsis is observed in the case of AS analysis as well. As the thickness is increased as 20 nm, 30 nm, 40 nm and 50 nm the corresponding amplitude sensitivities are achieved as 452.6 RIU\(^{-1}\), 1197.1 RIU\(^{-1}\), 479.8 RIU\(^{-1}\) and 286 RIU\(^{-1}\) as shown in Figure 7(b). Hence, the highest AS value of 1197.1 RIU\(^{-1}\) is

\[ \text{FIGURE 9} \quad (a) \text{ Loss spectrum and (b) amplitude sensitivity with variation of } d_i \text{ from } 0.15 \text{ to } 0.2 \mu m \]
represented as the red shift. So that, we opted the gold coating layer thickness as 30 nm for further optimization.

The impact of fluctuation of the diameter \( d \) in cladding is shown in Figure 8(a) and 8(b). When the \( d \) is increased from 1.4 to 1.7 \( \mu m \), there is a corresponding increment in the loss peak from 281.8 to 321.9 dB/cm for the analyte 1.38 is observed as shown in Figure 8(a). The increase in the loss depth occurs, when the big air holes diameter increases, inducing the gap to be reduced between the air holes which decrease the core effective index, thus the key reason for the enrichment in the propagation loss [14]. Followed by the increase in the confinement loss, there is a notable increment in the resonant wavelength shifts from lower to higher wavelength which is denoted as a red shift. For diameter 1.4 \( \mu m \), 1.5 \( \mu m \), 1.6 \( \mu m \) and 1.7 \( \mu m \), the corresponding AS reached is 1164.1 RIU\(^{-1}\), 1153.3 RIU\(^{-1}\), 1197.1 RIU\(^{-1}\) and 565.9 RIU\(^{-1}\), respectively as shown in Figure 8(b). Thus, for diameter 1.6 \( \mu m \), the highest AS of 1197.1 RIU\(^{-1}\) is achieved which has been chosen as the optimized value of diameter of big air hole.

Further, a remarkable impact is noted in the sensing performance, with the varied diameter scaled down air holes as displayed in Figure 9(a) and (b). As the \( d \) is raised from 0.15, 0.175, 0.2 to 0.225, the loss depth observed is 262.2, 297.7, 310.5 and 283.5 dB/cm at the same wavelength 0.77 \( \mu m \) for the analyte 1.38 as shown in Figure 9(a). Similarly, for the analyte 1.39 the loss depth observed is 347.8, 365.8, 381.2 and 263.9 dB/cm at the same wavelength 0.91 \( \mu m \). The increase of \( d \) leads to the decrease in the light confinement in the core, permitting the light to penetrate across the cladding, resulting in increased confinement loss [14]. The corresponding obtained AS is 673.3 RIU\(^{-1}\), 889.7 RIU\(^{-1}\), 1197.1 RIU\(^{-1}\) and 700 RIU\(^{-1}\). The highest AS of 1197.1 RIU\(^{-1}\) is observed, for the diameter 0.2 \( \mu m \) as shown in Figure 9(b). So, the optimized value of the \( d \) is considered as 0.2 \( \mu m \) for the entire analysis.

Moreover, the examination of changing the \( d \) is epitomized in Figure 10(a) and (b). It is clearly viewed from Figure 10(a) that the highest loss peak can be acquired by optimizing the value of \( d \). When \( d \) is gradually raised from 0.1 \( \mu m \), 0.15 \( \mu m \), 0.2 \( \mu m \) to 0.25 \( \mu m \), they attained loss as peak 162.3 dB/cm, 236.5 dB/cm, 310.5 dB/cm and 312.9 dB/cm

![Figure 10](image)

**Figure 10** (a) Loss spectrum and (b) amplitude sensitivity with variation of \( d \), from 0.15 to 0.25 \( \mu m \)

| Structure types | Range of RI (nm.RIU\(^{-1}\)) | WS (RIU\(^{-1}\)) | AS (RIU\(^{-1}\)) | Wavelength resolution (RIU) | Amp. resolution (RIU) |
|----------------|-----------------------------|-----------------|-------------------|-----------------------------|----------------------|
| Gold-coated circular lattice PCF [2] | 1.34–1.37 | 9000 | 318 | 1.11 \( \times 10^{-5} \) | N/A |
| Dual polarized spiral PCF [4] | 1.33–1.38 | 4600 | 420.4 | 2.17 \( \times 10^{-5} \) | 2.69 \( \times 10^{-5} \) |
| Two open channel PCF [22] | 1.33–1.38 | 5000 | 396 | 2 \( \times 10^{-5} \) | 2.53 \( \times 10^{-5} \) |
| TiN-coated PCF-SPR [33] | 1.385–1.4 | 10,000 | 70 | 2 \( \times 10^{-5} \) | N/A |
| Dual core with hybrid cladding PCF [35] | 1.33–1.4 | 9000 | 1085 | 1.11 \( \times 10^{-5} \) | N/A |
| AZO-coated PCF [36] | 1.32–1.34 | 5000 | 167 | 2 \( \times 10^{-5} \) | N/A |
| Al\(_2\)O\(_3\) coated over niobium nanofilm on PCF [37] | 1.36–1.4 | 8000 | 1560 | 1.25 \( \times 10^{-5} \) | 6.4 \( \times 10^{-6} \) |
| Hexagonal PCF with dual optofluid channel [38] | 1.32–1.38 | 5500 | 150 | 1.82 \( \times 10^{-5} \) | N/A |
| TCPF(C) proposed work | 1.34–1.39 | 11,000 | 1938.5 | 9.1 \( \times 10^{-6} \) | 5.16 \( \times 10^{-6} \) |
for analyte 1.38 and 212.9 dB/cm, 336.3 dB/cm, 381.2 dB/cm and 466.9 dB/cm for the analyte 1.39. With the increase of $d_s$, the red shift obtained is displayed in Figure 10(a). The corresponding AS acquired is $1291.3\, \text{RIU}^{-1}$, $1938.5\, \text{RIU}^{-1}$, $1197.1\, \text{RIU}^{-1}$ and $854\, \text{RIU}^{-1}$ as shown in Figure 10(b). The maximum AS of $1938.5\, \text{RIU}^{-1}$ is attained with the $d_s$ value of about 0.15 µm, which is considered to be the optimized diameter.

Finally, based on the design with AS as priority, maximum AS of $1938.5\, \text{RIU}^{-1}$ is obtained for which the optimized parameters are $t_g = 30$ nm, $d = 1.6$ µm, pitch $\langle \lambda \rangle = 1.8$ µm, $d_1 = 0.2$ µm and $d_c = 0.15$ µm. A detail comparative study of the proposed sensor with existing PCF sensor is shown in Table 2. The comparative analysis is carried out with several features such as structure of sensor, RI range of analyte, WS, AS, wavelength and amplitude resolution. It gives a clear-cut conclusion from Table 2, that enhanced performance is achieved by the proposed TCPCF RI sensor as compared with the previously proposed sensor.

5 | CONCLUSION

To achieve high sensitivity, the SPR based TCPCF RI sensor has been designed with the assist of scaled down approach and the analysis is performed successfully with the RI ranging from 1.34 to 1.39. The external sensing method is approached for ease of fabrication, where the sensing layer is integrated with the thin gold film-coated surface. The numerical investigations and sensing mechanism for the proposed TCPCF RI sensor are carried out with the assist of FEM method. The structural parameters have been tuned to obtain high amplitude characteristics. As a result, maximum AS is achieved for the proposed TCPCF RI sensor as $1938.5\, \text{RIU}^{-1}$ along with maximum amplitude resolution of $5.2 \times 10^{-6}$ RIU. Further, maximum WS of 11,000 nm RIU$^{-1}$, yields a maximum wavelength resolution of $9.1 \times 10^{-6}$ RIU. Moreover, high FOM of 623.9 RIU$^{-1}$ is acquired for analyte 1.38. The excellent sensitivity is achieved owing to PML coatings and scattering bound conditions at the outer surface of TCPCF RI sensor. Moreover, the promising sensing results and having simple compact fibre design of the proposed TCPCF RI sensor can be expected to have high future scope in various sensing applications.

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