Dual scaled approach SPR-based PCF RI sensor with ultra-low loss

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Abstract. We demonstrate an ultra-low loss photonic crystal fiber (PCF) sensor based on surface plasmon resonance (SPR) in this paper. In this refractive index (RI) sensor, we explored hexagonal-arrangement of airholes and employed only two different sizes of it. The formation of airholes makes the confinement loss (CL) surprisingly low. The maximum CL is as low as 10.71 and 28.58 dB/cm for x and y-pol modes, respectively within a range of refractive indices 1.33-1.40. The maximum gained amplitude sensitivity is -1212 RIU⁻¹ and -2430 RIU⁻¹, and the maximum figure of merit is as high as 583 and 467 respectively for x and y-polarization (pol) modes respectively. In addition to that, we got a maximum wavelength sensitivity, S_W of 14,000nm/RIU for both x and y-pol modes with a minimum sensor resolution of 7.143x10⁻⁶. Gold is preferred over other materials as the plasmonic material for its inert behaviour and higher chemical stability. The analysis was carried out using the finite element method (FEM). This sensor, with its elegant configuration, fabrication feasibility, ultra-low loss, stands out to be an effective and eminent prospect in the current burgeoning SPR sensor realm and also prompts further creative exploration in its hexagonal lattice arrangements.

1. Introduction
Surface plasmon resonance is an optical phenomenon pertaining to coherent localized electronic oscillations. This phenomenon is manipulated in eclectic fields covering nano-optics, photonics, photovoltaics [1]. It received much accolades in the vast-expanding field of chemical and biochemical analysis owing to it scrupulous and thorough real-time recognition and label-free sensing accuracy [2]. The technology subsequently accelerated the study of behaviour of light in manometer scale. Various configurations like micro-fluidic slot-based structures, long-period fiber Bragg grating, D-shaped structure, external and internal metal coated fibers have been extensively studied for SPR-sensing applications [3]. However, mass production of the SPR sensors wasn’t possible with their bulky configuration, thus, photonic crystal fiber (PCF) became a pertinent alternative to these methods as it scaled down the size even further while simultaneously elevating the overall sensitivity and sensor resolution. PCF is a category of optical fibers employing periodic bandgaps to trap light in a more efficacious manner than the optical fiber, providing not only better confinement but also lower loss [3]. Photonic crystal fibers through their high birefringence, non-linearity and regulatory chromatic dispersion has gradually gained repute and is employed in multifarious applications like polarization filters, rotators, splitters, and optical sensors [4]. Airholes in PCFs have been configured variously for the enhancement of light-confinement, incorporating diverse formations such as hexagonal, circular, squared, cylindrical, and above all, hybrid. There has been many configurations exhibiting remarkable
values of sensitivities, however, very few configurations have focused any attention towards low CL. Although high CL is an endearing attribute when fabricating a sensor as it has a substantial contribution in increasing the sensitivity, but it abruptly limits the sensor length. Thus, to gain higher sensitivity many configurations have to compromise on the prospect of having a lower loss and most of the designs, to the best of our knowledge have an average maximum CL greater than 150 dB/cm. However, with lower loss and reasonable sensitivity values, many designs with versatile sensing applications can come into fruition and lessen the complexity imposed when splicing these structures. Sakib et al. proposed a circularly slotted plasmonic biosensor which has 8 U-shaped slots with gold layer deposited on them [5]. The structure shows a maximum $S_W$ of 16000nm/RIU. However, the circular slots of the structure need polishing of the gold nanolayers individually. This kind of structure increases complexity of fabrication as mentioned. Haider et al. proposed a similar propagation-controlled PCF approach as our structure that shows high wavelength sensitivities of 30,000 and 22,000nm/RIU for x and y-pol respectively [6]. However, this structure displays a high propagation loss of 291 dB/cm and low $S_A$. Moutusi et al. proposed a solid-core flat fiber RI sensor which detects analyte RI within 1.49 to 1.54 and shows a maximum $S_W$ of 4782nm/RIU [7]. Biplob et al. proposed a D-shaped SPR-PCF that shows a high sensor resolution of $6.67 \times 10^{-6}$ [8]. It detects RI shifting from 1.42 to 1.46. A concave-shaped multi-fluidic channel (CSMFC)-based optical fiber RI sensor is proposed by Akhilesh et al. which exhibits a maximum $S_W$ of 9314.28 nm/RIU [9]. Li et al. proposed a Refractive Index sensor based on H-shaped PCF which displays a maximum $S_W$ of 12,600nm/RIU [10]. This structure comprises two U-shaped grooves comprising of gold layer and the analyte layer. Airholes of three different sizes constitute the propagation path. These features make the fabrication process arduous and complicated as said previously it includes further polishing schemes for making the D-shape or U-shape and pulsed lasers are used to implement the microchannel, if there is any, whereas the circular gold layer enables only the traditional stack and draw method [11 Sayed et al. proposed a similar circular structure and demonstrated maximum loss of 21 dB/cm with wavelength sensitivity of 8500 nm/RIU, however it had a low amplitude sensitivity of 335 RIU$^{-1}$ [12]. Mohammad et al. is another laudable mention as he proposed a sensor with a wavelength sensitivity as high as 23,000nm/RIU along with a low propagation loss of 2.87 dB/cm but then again there was no mention of amplitude sensitivity [13].

In this paper, we propose a simple SPR-based PCF sensor with only two sizes of airholes for fabrication feasibility for manipulating the effective RI. The airhole formation enables the asymmetric core configuration of the structure, which prompts two orthogonal x and y-pol modes. The analyte is inserted externally. For the plasmonic material, we used gold. This simplistic approach for the ease of fabrication has yielded unexpected yet ecclesiastical sensing properties. This device detects a long range of refractive indices with minimum loss as low as 0.112 dB/cm. We used FEM method to carry out the simulation and numerical analysis. The sensor performance was ascertained considering the confinement loss, wavelength and amplitude sensitivity, sensor resolution, FOM, and linearity. We have done an extensive research varying the parameters of the structure to get the optimized sensor. Taking the CL scheme and the wavelength interrogation method into consideration, both the x and y-pol modes render a maximum $S_W$ of 14,000nm/RIU, a maximum $S_A$ of -1212 RIU$^{-1}$ and -2430 RIU$^{-1}$, an FOM of 580 and 473 RIU$^{-1}$, respectively along with a Resolution=7.143×10$^{-6}$. All of these make it out to be a prominent and sterling candidate for biochemical detection. In addition to that, the proposed sensor crafts its way in cost-effectiveness as it provides ease and flexibility in the fabrication process and additionally removes the notion of compromising lower loss for higher sensitivity, also introducing a holistic approach in determining its efficiency as it succeeded in giving reasonable values in all measuring domains.

2. Modeling and Numerical Analysis

Fig-1 depicts the cross-sectional view of the proposed sensor. The following sensor comprises of a hexagonal lattice structure with two circular airhole diameters. The 1st and the 2nd ring of the structure possess scaled-down air holes to manipulate the dissemination of light throughout the fiber. Reduced air holes facilitate the excitation of the dielectric-metal interface electrons by inducing evanescent electromagnetic field. Owing to convenience of adequate space in the spatial arrangement
created by scaled-down air holes, phase-matching condition is obtained between the core and spp modes. Sustainability of dual-polarized modes is contingent on birefringence, obtained in the structure due to its asymmetric configuration. The center-to-center distance defined as pitch (Λ) is 1.8 μm, whereas the regular airhole diameter is 1.44 μm, and the scaled-down airhole diameter is 0.36μm. The gold layer thickness is 40 nm. Fig-2 illuminates the context of ease of fabrication. Thin-walled capillary represents regular-sized airholes, and thick-walled capillary represents small-scaled airholes.

A light absorbing virtual entity known as the PML encircles the structure to take in reflected light [14]. The thickness of the perfectly matched layer is kept at 1.2 um for optimized condition. Gold is selected as plasmonic material owing to its chemical inertness and stability [5]. It is evenly deposited throughout the fiber with the aid of chemical vapor deposition technique, a viable candidate for gold layer deposition [5].

PCF can be manufactured by the flexible and prominent stack-and-draw technique that has undergone numerous advancements over the past semi-centennial [14]. Silica is considered an apt background material. The RI of silica is evaluated by using the Sellmeier’s equation [11]-

\[ \eta^2 = 1 + \frac{B_1 \lambda^2}{\lambda^2 - C_1} + \frac{B_2 \lambda^2}{\lambda^2 - C_2} + \frac{B_3 \lambda^2}{\lambda^2 - C_3} \]  (1)

Where \( \eta \) represents the refractive index of silica, and \( B_1, B_2, B_3, C_1, C_2, \) and \( C_3 \) are the Sellmeier coefficients [11]. In accordance with the Drude Lorentz model, the dielectric constant is articulated as follows [5]-

\[ \eta_{Au}(\lambda) = \epsilon_{Au} - \frac{\omega_D^2}{\omega(\omega + j\gamma_D)} - \frac{\Delta \epsilon \Omega_L^2}{(\omega^2 - \Omega_L^2) + j\Gamma_L \omega} \]  (2)

Where \( \epsilon_{Au} \) specifies the permittivity of gold- the plasmonic medium, \( \epsilon_{\infty} \) is the permittivity at high frequency, and its value is 5.9673. Additionally, \( \omega_D \) and \( \gamma_D \) signify plasma frequency and damping frequency and all of them are derived from [5].
An optical source can be utilized as the light-launching source getting linear polarization through a polarizer controller. Splicing enables the coupling of fiber to the sensor. An analyte is made to flow over the surface of the sensor. To vary the analyte on the surface, inlet and outlet pumps can be augmented. The photodetector assesses the output intensity while the optical spectrum analyzer with the help of the computer measures the red or blue shift of the resonant wavelength.

3. Numerical Results of the Proposed Design

The numerical method assigned in conducting the analysis is Finite Element Method under Comsol Multiphysics environment. The PML layer has been generated virtually to capture the reflected light through the scattering boundary condition. Free electron oscillations occurring at the metal-dielectric interface are known as surface plasmon. On the other hand, light propagating along the fiber core emanate an evanescent field at the cladding. When frequency and real part refractive index of the core mode and Surface Plasmon Polariton (SPP) mode become identical to one another, a resonance condition occurs, and thus, enables phase-matching condition. This will commensurate with maximum power conveyance from core-guided mode to SPP mode aiding the CL to take the Gaussian form at a particular resonant wavelength, $R_\lambda$. Maximum $R_\lambda$ for this structure is 0.94 μm at the index 1.4. Numerical analysis is carried out by taking the CL into consideration as it varies with the shifting of RI of the analyte and is also a numerical factor dependent on the imaginary part of the refractive index. The formula used in calculating the CL is as follows [8]:

$$CL \, (\text{dB/cm}) = 8.686 \times \kappa_0 \times \text{Im}(n_{\text{eff}}) \times 10^4$$  \hspace{1cm} (3)

Where $\kappa_0 = \frac{2\pi}{\lambda}$ which denotes the wave propagation number in free space, $\lambda$ is the operating wavelength, and $\text{Im}(n_{\text{eff}})$ is the imaginary part of the effective mode index.

By applying wavelength interrogation method, $S_W$ has been selected as a parameter in determining the efficacy and superiority of the sensor’s performance [14].

$$S_W \, (\text{nm/RIU}) = \frac{\Delta \lambda}{\Delta n_a}$$  \hspace{1cm} (4)

Where $\Delta \lambda$ and $\Delta n_a$ signify the wavelength difference of the resonance peak and the RI difference of two successive analytes respectively.

The $S_A$ can be attained by utilizing amplitude interrogation method in the form of the following equation [10]:

$$S_A \, (\text{RIU}^{-1}) = -\frac{1}{\alpha(\lambda, n_a)} \frac{\delta \alpha(\lambda, n_a)}{\delta n_a}$$  \hspace{1cm} (5)

Where $\delta \alpha(\lambda, n_a)$ denotes the change in CL and $\alpha(\lambda, n_a)$ signifies confinement loss. The highest SA of the proposed sensor is -2430 RIU\(^{-1}\) and -1212 RIU\(^{-1}\) for y and x-pol respectively.

Sensor resolution is another critically acclaimed parameter in deducing the performance of the sensor [8].

$$R \, (\text{RIU}) = \Delta n_a \times \frac{\Delta \lambda_{\text{min}}}{\Delta \lambda_{\text{peak}}}$$  \hspace{1cm} (6)

Where $\Delta n_a = .01 \, \text{RIU}$, and $\Delta \lambda_{\text{min}} = 0.1 \, \text{nm}$. Taking $\Delta \lambda_{\text{peak}} = 140 \, \text{nm}$, the highest resolution of the proposed sensor is gained as $7.143 \times 10^{-6} \, \text{RIU}$. So, the offered sensor can successfully detect within $10^{-6}$ scale of analyte variation.

FOM is a parameter engaged in extrapolating the detection limit of the sensor, described by the following equation [8]:

$$\text{FOM} = \frac{S_W(\text{nm/RIU})}{\text{FWHM}}$$  \hspace{1cm} (7)
Through meticulous deliberation, the optimized performance of the sensor was obtained keeping \( \Lambda = 2 \mu m \), \( d_2 = 1.44 \mu m \), and \( d_1 = 0.36 \mu m \). The proposed sensor was able to detect indices within the range 1.33 - 1.40. The sensor was able to obtain a high \( S_W \) of 14,000 nm/RIU and AS of -1212 RIU\(^{-1}\) and -2430 RIU\(^{-1}\) at index 1.39 for the dual modes because of strong incomplete coupling of spp and core mode, plausible due to spatial arrangement of the structure. Fig-4(a), (b), (c) & (d) demonstrate the electric mode profiles of the core and spp modes at a particular index 1.37. For the case of core mode, with increment of RI there is a consequent infiltration of evanescent field into the metal dielectric surface. With further increase, it again pulls itself back towards the center. As for the spp mode, with the ascension of RI, the field appears to get more intensified along the metal-dielectric interface.

Figure 5. Loss curve for x and y-pol modes at RI 1.40
Fig-5 displays the dispersion relations of the core mode and spp mode at a particular index. The real part of the core mode and spp mode appear to be intersecting at a particular wavelength corresponding to a sharp peak in the CL spectra. The particular wavelength witnessing the sharp peak is defined as resonant wavelength.

![Figures](a) and (b) show the loss curve of x-pol modes for RI 1.33-1.38 (c) and (d) show the loss curve of y-pol modes for RI 1.33-1.38. 

Fig 6. (a) loss curve of x-pol modes for RI 1.33-1.38 (b) loss curves of RI 1.39-1.40 (x-pol) (c) loss curve of y-pol modes for RI 1.33-1.38 (d) loss curves of RI 1.39-1.40 (y-pol)

![Figures](c) and (d) show the S.A of x-pol and y-pol modes for RI 1.33-1.39.

![Figures](a) and (b) show the S.A of x-pol and y-pol modes for RI 1.33-1.39.

Based on the aforementioned parameters, the loss curves ranging from 1.33 to 1.4 have been portrayed for the proposed sensor. The resonant wavelengths are exhibiting a red shift with corresponding rise in RI. Furthermore, in Fig 6(a), (b), (c) and (d) a notable discrepancy is observed in the loss spectra in subsequent index variations, materializing as an increase, saturating itself at index 1.4 for both pols. The confinement losses for x-pol are observed to be 0.112, 0.134, 0.18, 0.284, 0.35, 0.656, 1.067, and 10.72 dB/cm whereas the CL for y-pol appear at 0.27, 0.331, 0.445, 0.706, 0.871, 1.648, 2.76, and 28.58 dB/cm respectively.
Table 1. Data Analysis of the Proposed Sensor for Analyte RI Variations

| RI   | Peak Wavelength (nm) | Maximum Loss (dB/cm) | Wavelength Sensitivity (nm/RIU) | Amplitude Sensitivity (RIU⁻¹) | Resolution | FOM  |
|------|----------------------|-----------------------|---------------------------------|-----------------------------|-------------|------|
|      |                      | x-pol                | y-pol                           | x-pol                       | y-pol       |      |
| 1.33 | 600                  | 0.112                | 0.27                            | 2000                        | 182.1       | 184.2 |
| 1.34 | 620                  | 0.134                | 0.331                           | 2000                        | 224.5       | 231.3 |
| 1.35 | 640                  | 0.180                | 0.445                           | 2000                        | 288.5       | 295.4 |
| 1.36 | 660                  | 0.284                | 0.706                           | 4000                        | 458.4       | 473.5 |
| 1.37 | 700                  | 0.350                | 0.871                           | 4000                        | 715.4       | 747.6 |
| 1.38 | 740                  | 0.656                | 1.648                           | 6000                        | 1025        | 1144  |
| 1.39 | 800                  | 1.067                | 2.76                            | 14000                       | 1212        | 2430  |
| 1.40 | 940                  | 10.72                | 28.58                           | --                          | 71.43×10⁵   | 286   |

A high CL is an impairment in sensor design as it entails the sensor to be limited in length [15]. The proposed sensor demonstrated considerable decline in CL to combat this impairment. Furthermore, incomplete coupling between core and spp mode get stronger with the accretion of refractive index. Along with it, the stark contrast between real part of effective indices of core and spp mode declines, ensuring the consequential increase of CL in Gaussian peak [16]. The maximum SW 14,000 nm/RIU was acquired at index 1.39 whilst other indices ranging from 1.33-1.38 exhibit SW of 2000, 2000, 4000, 4000, and 6000 nm/RIU for both x and y-pol modes respectively. Table 1 encapsulates the findings of the PCF sensor to illustrate its performance on the basis of the observations found from Fig-6.

4. Analysis of parameter varying

4.1. Effect of gold layer thickness on loss and sensitivity

Gold layer thickness heavily influences the coupling interaction between core mode and spp mode. Owing to the variation of gold layer thickness, there can be changes observed in CL along with a red shift in resonant wavelength. Keeping Λ=2μm, d2=1.44μm and d1=0.36μm at index 1.37, gold thickness was altered to observe its effect on the proposed sensor. A decrease in CL spectra with gold thickness variation can be demarcated from Fig-8 (a) and (b), and thus, ensuring a rise in AS. The maximum and minimum CL is found to be 0.54 dB/cm and 0.23 dB/cm for x-pol and similarly, for y-pol, CL is found at 1.38 and 0.56 dB/cm respectively for gold thickness 30 and 50 nm in fig-8(a) and (b). The maximum and minimum AS appear at -1617RIU⁻¹ and -459.4 RIU⁻¹ for x-pol modes, and for y-pol, the values range from -1719 to -476.9 as portrayed in Fig-9. So, a descent of value in CL and AS is articulated from the evaluation above. This occurs because a greater thickness of gold layer obstructs the infiltration of core mode into the metal-dielectric interface, causing a decrease in the corresponding CL and AS.
4.2. Effect of varying pitch size on loss and sensitivity

Pitch size was varied from 1.7 to 1.9μm keeping other parameters constant in order to articulate its effect on the loss spectra. Fig-10 delineates that on increasing pitch size from 1.7 to 1.9 μm, CL spectra peak, there is no apparent shifting of R and CL decreases from 0.67 to 0.19 dB/cm for x-pol. On the other hand, in Fig-11 (a) and (b), AS varies from -327.6 to -1339 RIU for x-pol and -276.5 to -1645 RIU for y-pol respectively.

Fig 8. Effect of varying Gold layer thickness on CL of (a)x-pol modes (b)y-pol modes

Fig 9. Effect of varying Gold layer thickness on S of (a)x-pol modes (b)y-pol modes

Fig 10. Effect of varying pitch on CL of (a)x-pol modes (b)y-pol modes
4.3. Effect of varying airhole diameter on sensitivity

Fig. 12(a), (b), and Fig. 13(a), (b) illustrates the effect of airhole $d_1$ diameter change in the proposed sensor. On altering $d_1$, from 0.1Λ to 0.3Λ, the CL values ranging from 0.93 to 0.17 dB/cm was obtained, along with AS whose values are -424.6, -714.5, and 420.6 RIU\(^1\) for x-pol. As for y-pol, the maximum and minimum CL peaks are found at 2.42 and 0.397 dB/cm, and the AS values were -434.2, -747.6, and -658 RIU\(^1\). The diameter $d_2$ was swept from 0.7 Λ to 0.9Λ in fig-14 and fig-15, which resulted in maximum and minimum values of CL for x-pol being 0.94 and 0.11 dB/cm respectively and the maximum and minimum value of AS are respectively -2328 and -215.8 RIU\(^1\). Likewise, for y-pol, CL ranges from 0.27 to 2.46 dB/cm, and AS ranges from -216.2 to -2565 RIU\(^1\). In the case of both airholes, shift in $R_j$ is not discernible.
Maximum resonant wavelength shifting for both polarizations is of 14000 nm which indicates a considerable wavelength sensitivity. The highest FOM of the proposed sensor was obtained at 583 and 467 RIU for x and y-pol. Additionally, the sensor taken into consideration has demonstrated FOMs of 368, 350, 250, 389, 292, 368, 286 and 583 for x-pol, and likewise, for y-pol it exhibits 359, 333, 326, 378, 298, 378, 275, and 467 for the complete RI range. The sensor resolution of the structure is $7.143 \times 10^{-6}$ RIU and thus it can detect analyte RI in the order of $10^{-6}$.

The characteristic of polynomial fitting is an incumbent factor to evaluate the operational performance of a sensor. With ascension of analyte RI, the resonant $\lambda$ shifts are outlined in Fig-16, which confirm a non-linear rise in $\lambda$. In order to investigate the characteristic equation of the sensor, a polynomial fit is applied. Our proposed sensor reveals a polynomial fitting of the 4th order. High linearity signifies superior sensing performance and reinforces its utility as an accurate sensing device [15]. A highly nonlinear response is regarded inept as it attenuates the average sensitivity and resolution of the sensor.

![Resonant wavelength vs refractive index](image16.png)

**Fig 16.** Resonant wavelength vs refractive index
In the proposed sensor, analysis and assessment were carried out on indices ranging from 1.33-1.4 possessing a wide array of applications in the field of biochemistry. Through this simplistic approach, the fabrication feasibility was prioritized rather than sensitivity. It has been observed that high values of wavelength sensitivity are normally obtained from d shaped structures rather than circular structures in most cases however there might be some exceptions. Increased area of the core mode ensues increased interaction with the metallic interface and that’s why greater pitches can result in high wavelength sensitivity and amplitude sensitivity [15-17]. But not all structure fall in this category and in the quest of increasing the wavelength sensitivity, sometimes the amplitude sensitivity can be compromised like in [18]. The structure displayed uniqueness in its confinement loss as it ranged from 0.112 dB/cm to 10.72 dB/cm for x polarized mode, a phenomenon seen quite rarely in SPR sensors to the best of our knowledge and in future, through further exploration in structures like these may contribute substantially in increasing the sensor’s length according to convenience. On top of that, aforementioned sensor also operates within a commendable IR range. The inundating applications of RI sensors can be intensely felt in considerable biochemical arenas. Table 2 crafts a synoptic argument comparing the results of the proposed sensor in terms of the wavelength interrogation method with recent published work.

Table 2. A Table of Comparison of The Proposed Design with Recent Published Works

| Structure Type                        | Refractive index | Polarization mode | Wavelength Sensitivity (nm/RIU) | Amplitude Sensitivity (RIU⁻¹) | Resolution |
|---------------------------------------|------------------|-------------------|---------------------------------|-------------------------------|------------|
| Single Solid Core Flat Fiber [7]      | 1.49-1.54 y-pol  | 4782              | --                              | 2.09x10⁻³                     |
| Quasi D-shaped SPR-PCF Biosensor [8]  | 1.42-1.46 N/A    | 15000             | 230                             | 6.67x10⁻⁶                     |
| Concave-shaped microfluidic channel RI sensor [9] | 1.33-1.38 N/A | 9314              | 1494                            | 1.073x10⁻⁵                     |
| H-shaped PCF with AG-Graphene layer [10] | 1.33-1.41 N/A | 12,600            | --                              | 7.94x10⁻⁶                     |
| D-shaped PCF [19]                     | 1.20-1.29 N/A    | 11055             | 1739                            | 9.05x10⁻⁶                     |
| Multicoating PCF-SPR RI sensor [20]   | 1.40-1.44 N/A    | 9600              | 1.04x10⁻³                       |
| Dual-Core PCF Biosensor [24]          | 1.34 x-pol y-pol | 10,000 5,000      | 334 395                         | 2x10⁻³                       |
| This work                            | 1.33-1.40 x-pol y-pol | 14,000 | 1212 2430                         | 7.143x10⁻⁶                     |

5. Conclusion
A dual-sized airhole approached external gold-coated PCF sensor has been demonstrated didactically and scrutinized in the given paper, which not only exuberates with high SA but also a discernible ultra-low loss. We opted for gold as the plasmonic material due to its fabrication feasibility and cost-effectiveness. The parameters which have been varied to extract its superior performance were gold thickness, pitch, and diameter of two present airholes. After exacting and meticulous deliberations, the sensor was perceived to be efficacious in its consistency within index range 1.33-1.4, which is a laudatory and an incumbent factor in biochemical and chemical detection schemes, along with a high SA of ~1212 RIU and -2430 RIU in x and y-pol, accompanied by an SW of 14,000 nm/RIU. The maximum loss is as low as 10.71 and 28.58 dB/cm for x and y-pol modes, a demanding aspect of the sensor as it removes hindrance concerning the sensor’s length. The minimum resolution of the proposed sensor is 7.143x10⁻⁶ RIU. In addition to that, the structure also proves to be economically...
viable due to its high amplitude sensitivity. All of these assorted and eclectic properties make it out to be a suitable and spectacular prospect for real time chemical and biochemical sensing application in the current millennia.

REFERENCES

[1] Leosson K 2012 Journal of Nanophotonics 6 061801
[2] Homola J 2003 Analytical and bioanalytical chemistry 377 528–539
[3] Rifat A A, Ahmed R, Mahdiraji G A and Adikan F M 2017 IEEE Sensors Journal 17 2776–2783
[4] Almewafy B H, Areed N F, Hameed M F O and Obayya S S 2019 Journal of Nanophotonics 13 016002
[5] Sakib M N, Islam S R, Mahendiran T, Abdulrazak L F, Islam M S, Mehedi I M, Kamrunnahar Q, Montaj M, Hassan M W, Amiri I et al. 2020 Results in Physics 17 103130.
[6] Haider F, Aoni R A, Ahmed R, Islam M S and Miroshnichenko A E 2018 IEEE Sensors Journal 19 962–969
[7] De M, Markides C, Singh V K, Themistos C and Rahman B 2020 Plasmonics 15 1429–1437
[8] Hossain M B, Hossain M S, Islam S R, Sakib M N, Islam K Z, Hossain M A, Hossain M S, Hosen A S and Cho G H 2020 Results in Physics 18 103281
[9] Pathak A K and Singh V K 2020 IEEE Photonics Technology Letters 32 465–468
[10] Li T, Zhu L, Yang X, Lou X and Yu L 2020 Sensors 20 741
[11] Haque E, Hossain M A, Namihira Y and Ahmed F 2019 Applied optics 58 1547–1554
[12] Asaduzzaman S and Ahmed K 2018 Results in Physics 11 358–361
[13] Mahfuz M A, Hossain M, Haque E, Hai N H, Namihira Y, Ahmed F et al. 2019 Sensors 19 3794
[14] Haque E, Hossain M A, Ahmed F and Namihira Y 2018 IEEE Sensors Journal 18 8287–8293
[15] Liang H Q, Liu B and Hu J F 2017 Optik 149 149–154
[16] Islam M R, Jamil M A, Zaman M S U, Ahsan S A H, Pulak M K, Mehjabin F, Khan M M I, Chowdhury J A and Islam M 2020 Optik 221 165311
[17] Al Mahfuz M, Hossain M A, Haque E, Hai N H, Namihira Y and Ahmed F 2020 IEEE Sensors Journal 20 7692–7700
[18] Gandhi M A, Senthilnathan K, Babu P R and Li Q 2019 Results in Physics 15 102590
[19] Chen X, Xia L and Li C 2018 IEEE Photonics Journal 10 1–9
[20] Li D, Zhang W, Liu H, Hu J and Zhou G 2017 IEEE Photonics Journal 9 1–8
[21] Revathi A A and Rajeswari D 2020 Journal of Optics 1–5