

Ultra-broad mid-infrared plasmonic sensor based on soft-glass photonic crystal fiber for temperature detection

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A plasmonic sensor utilizing a soft-glass photonic crystal fiber (PCF) with two liquid cores is developed for temperature sensing over a -50–40 °C range. This sensor incorporates a central air hole coated with a thin gold film to achieve surface plasmon resonance (SPR) in the mid-infrared (MIR) spectral range. A comprehensive theoretical analysis of its detection properties indicates that the sensor can perform single-resonance sensing across the MIR range of 3.0–3.4 μm while accommodating temperature variations from -50 to 40 °C. It demonstrates a peak sensitivity of 6.30 nm/°C and a high temperature resolution of 0.0159 °C. Furthermore, within the range of -50–40 °C, it exhibits an average sensitivity of 3.6958 nm/°C and achieves a high linearity coefficient of 0.9963. As a result, this study opens new possibilities for applying PCF-based SPR technology to MIR temperature sensing.

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1. Introduction

The plasmonic sensor has garnered significant research interest due to its excellent capabilities. It allows for sampling without marking, offers good electromagnetic resistance, boasts high sensitivity, and enables online, label-free measurements [1–3]. As a result, it is widely utilized in various fields, including health monitoring, chemical analysis, water pollution monitoring, industrial safety control, and temperature sensing [4, 5]. To generate efficient surface plasmon resonance (SPR), traditional SPR sensors typically employ a coupling prism with a metal film deposited to achieve phase matching between plasmonic modes and guided modes [6, 7]. However, prism-based SPR sensors have several significant drawbacks, including angle-dependent sensitivity, a limited detection range, and a complicated setup [8]. To address these challenges, various SPR sensors utilizing optical fiber have been developed because of the benefits that optical fiber provides, including a high optical damage threshold, convenient integration, an extended detection range, and enhanced sensitivity [9, 10].

Temperature sensing via fiber-based SPR sensors is a prominent application that has garnered substantial attention in recent years. Numerous conventional fiber-based SPR temperature sensors have been reported to date. For instance, Zhao et al. fabricated an SPR temperature sensor based on multi-mode fiber (MMF). To achieve the SPR effect, they coated the unclad portion of the fiber with a layer of silver [11]. This design achieved a peak sensitivity of 1.5745 nm/°C and demonstrated a high linearity coefficient of 0.9994. In 2017, Zhu et al. developed an SPR temperature sensor using a single-mode

fiber (SMF) [12]. By depositing a thin gold film and a thin polydimethylsiloxane film on the fiber probe, this sensor achieved a maximum sensitivity of -4.13 nm/°C and a high figure of merit (FOM) of 0.034 /°C over the temperature range of 20–70 °C. In 2019, Lu et al. designed an SPR temperature sensor employing a side-polished MMF coated with a thin gold film [13]. Adopting a smartphone platform, a temperature resolution of 0.83 °C and a linearity coefficient of 0.9798 were obtained within the temperature range of 30–70 °C. In 2021, Wang et al. reported a highly sensitive tunable SPR temperature sensor utilizing a D-type helical-core fiber [14]. The peak sensitivity of the designed sensor was up to -19.56 nm/°C as the temperature varied from 20 to 70 °C. In 2022, Zhang et al. developed an SPR temperature sensor that utilizes a multi-hole structure in a silver-coated multimode fiber [15]. By filling two types of thermosensitive liquids into air holes, the designed sensor exhibited a high sensitivity of 7.72 nm/°C within 20–60 °C and -7.81 nm/°C within -20 - 20 °C. In 2023, Zhang et al. proposed a broadband SPR temperature sensor using a hollow fiber coated with GK570/Ag [16]. By optimizing the sensor structure, the sensitivity of this design reached a maximum of 20.5 nm/°C within the detection range of 20–170 °C. Recently, Nahid et al. developed a two-channel SPR temperature sensor employing a D-type fiber coated with gold [17]. Within the range of 10–70 °C, this design demonstrated a maximum sensitivity of 5 nm/°C. To further improve the detection performance of the fiber-SPR temperature sensor, various new materials and fiber structures have been investigated.

Photonic crystal fiber (PCF) features a highly flexible design that allows for improved control over light-guiding properties. This enhances its performance in plasmonic sensing and helps tackle issues related to phase matching

and sensor packing. As a result, various structures of SPR temperature sensors based on silica PCF have been developed and reported. For example, Liang et al. proposed an SPR temperature sensor using a silica birefringent PCF with two solid cores [18]. To fill toluene into the central sensing channel coated with a thin gold film, the temperature sensitivity of the sensor reached an average of $-19.695 \text{ nm}/^\circ\text{C}$ within the detection range of 0 to 80°C . A different type of two-solid-core PCF-based SPR temperature sensor was studied by Siddik et al. [19]. Applying a gold layer to the exterior of the PCF resulted in a flat sensitivity of $2.25 \text{ nm}/^\circ\text{C}$ over the temperature range of 0 to 60°C . Jabir proposed a plasmonic temperature sensor using a liquid core PCF filled with a gold nanowire [20]. By optimizing the sensor structure, a maximum sensitivity of $13 \text{ nm}/^\circ\text{C}$ was realized over the temperature range of 15 to 45°C . Mei et al. developed an SPR temperature sensor employing a silica dual-core PCF filled with toluene and ethanol [21]. To deposit a gold layer in the sensing channel, the designed sensor demonstrated a high sensitivity of $6.32 \text{ nm}/^\circ\text{C}$ within the temperature range of 10 to 70°C . Li et al. proposed a silica birefringent PCF-based SPR temperature sensor [22]. To adapt the sensing channel to the outer surface of the cladding, the peak sensitivity reached $15.4 \text{ nm}/^\circ\text{C}$ as the temperature varied from -10 to 60°C . An SPR temperature sensor utilizing a silica PCF with a metal-deposited trapezoidal surface was designed by Chao et al. [23]. The sensor exhibited a high sensitivity of $5.2 \text{ nm}/^\circ\text{C}$ from 10°C to 60°C by modifying the fiber parameters. Moreover, You et al. proposed an SPR temperature sensor using a PCF with a semicircular convex slot [24]. The sensitivity of the y-polarization mode was as high as $41.5 \text{ nm}/^\circ\text{C}$ from 16°C to 130°C , while the sensitivity of the x-polarization mode was $2.74 \text{ nm}/^\circ\text{C}$ from -25°C to 80°C . However, most reported silica PCF-based SPR temperature sensors are limited to operation in both the visible and near-infrared wavelength regions. To date, no non-silica PCF-based SPR temperature sensor capable of functioning in the mid-infrared (MIR) range has been reported.

To address the issues mentioned previously and to apply the PCF-based SPR temperature sensor in the field of MIR applications, including the detection of MIR radiation in the human body, fingerprint unlocking, environmental monitoring, medical diagnostics, and chemical analysis. A MIR SPR temperature sensor utilizing a PCF with two thermosensitive liquid cores is designed in this work. Soft-glass (SF57), which has been verified in practical mid-infrared supercontinuum generation (SCG) in the 2.5 – $5 \mu\text{m}$ band [25–28], is chosen as the background material for the PCF to minimize transmission loss, given its high optical transparency in the MIR. The sensing performance has been numerically studied in detail across a wide temperature range of -50 to 40°C . The simulation outputs demonstrate that the SPR effect can be induced by coating a thin gold film inside the fiber's central air hole, eliminating the need for a thermosensitive liquid. The sensor exhibits a maximum sensitivity of $6.30 \text{ nm}/^\circ\text{C}$ as the working wavelength falls within the range of 3.0 to $3.4 \mu\text{m}$. To our knowledge, this

non-silica PCF-based SPR sensor is the first example of ultra-broad and highly sensitive temperature sensing in the MIR region. Furthermore, adjusting the fiber parameters provides a high linearity coefficient of 0.9963 over an ultra-broadband range of -50 to 40°C .

2. Model and methods

Our proposed SF57 PCF-based SPR temperature sensor geometry is depicted in Fig. 1. To enhance the SPR effect, the holes located in the fiber cladding are ranked in a squeeze lattice. Two fiber cores filled with the thermosensitive liquid CS_2 are placed in the second layer of the cladding to facilitate temperature sensing. Unlike other SPR temperature sensors using PCF, this design uses only a thin gold film in the central sensing channel without any thermosensitive liquid. This design significantly enlarges the temperature detection range. The structure parameters include the central channel diameter d , the liquid core diameter d_c , the air hole diameter d_1 , the gold film thickness t , and the horizontal and vertical pitch Λ_1 , Λ_2 . Noting that $\Lambda_2 = \sqrt{3}\Lambda_1/2 - q$, where q is the squeezed factor. This temperature-sensing mechanism operates through thermal modulation of CS_2 's RI, which induces measurable shifts in the resonant wavelength. By monitoring these wavelength displacements, precise temperature determination becomes achievable.

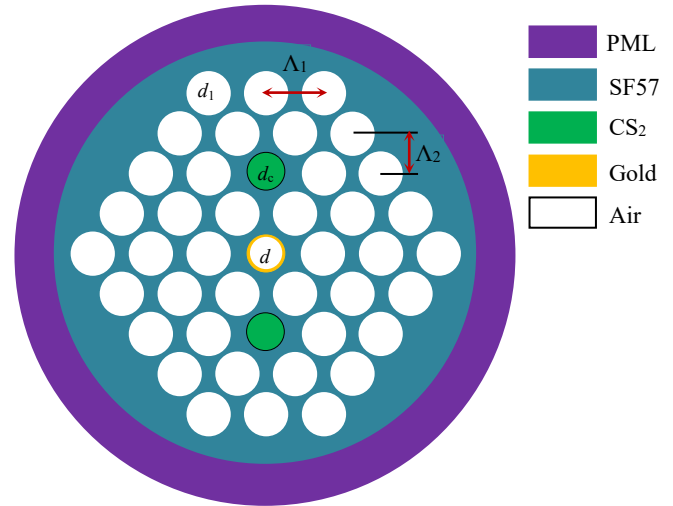


Fig. 1. Schematic diagram of the designed sensor (colour online)

The SF57's RI at 20°C is defined by the Sellmeier equation below [29].

$$n_{20}^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3} \quad (1)$$

where $B_1 = 1.87543831$, $B_2 = 0.37375749$, $B_3 = 2.30001797$, $C_1 = 0.0141749518$, $C_2 = 0.0640509927$, and $C_3 = 177.389795$. The thermo-optical coefficient of the

SF57 within the range of $-100 \sim 140$ °C is calculated by the following equation [30].

$$\frac{dn(\lambda, T)}{dT} = \frac{n^2(\lambda, T_0) - 1}{2n(\lambda, T_0)} \left(D_0 - 2D_1\Delta T + 3D_2\Delta T^2 + \frac{E_0 + 2E_1\Delta T}{\lambda^2 - \lambda_{fx}^2} \right) \quad (2)$$

where $D_0=7.26 \times 10^{-6}$, $D_1=1.88 \times 10^{-8}$, $D_2=-5.14 \times 10^{-11}$, $E_0=1.96 \times 10^{-6}$, $E_1=1.79 \times 10^{-9}$, and $\lambda_{TK}(\mu\text{m})=0.276$. Using equation (1), we find that $dn/dT=3.95 \times 10^{-6}$ /°C at 40 °C, with a resonance wavelength of 3.348 μm . Moreover, $dn/dT=5.62 \times 10^{-6}$ /°C at -50 °C, corresponding to a resonance wavelength of 3.000 μm .

We also calculate gold permittivity via the Drude model [31]

$$\varepsilon(\lambda) = 1 - \frac{\lambda^2 \lambda_c}{\lambda_p^2 (\lambda_c - i\lambda)} \quad (3)$$

where $\lambda_c = 8.934$, $\lambda_p = 0.16826$.

CS₂ serves as a temperature-sensitive fluid to obtain enhanced performance, its RI at 20 °C being determined by the equation below [32]

$$n_{20}(\lambda) = 1.580826 + 1.52389 \times 10^{-2} \lambda^{-2} + 4.8578 \times 10^{-4} \lambda^{-4} - 8.2863 \times 10^{-5} \lambda^{-6} + 1.4619 \times 10^{-5} \lambda^{-8} \quad (4)$$

where λ is the operation wavelength. The RI of CS₂ at other temperatures is determined using the equation provided below [32]

$$n(\lambda, T) = n_{20}(\lambda) + \frac{dn}{dT}(T - 20) \quad (5)$$

where $dn/dT = -7.91 \times 10^{-4}$ /°C. Compared with CS₂, the thermo-optical of SF57 is minor and can be neglected in the simulation.

The loss, wavelength sensitivity and temperature resolution are governed by [21]

$$\alpha(\text{dB/cm}) = 8.686 \times (2\pi/\lambda) \text{Im}(n_{\text{eff}}) \times 10^4 \quad (6)$$

$$S_\lambda(\text{nm}/^\circ\text{C}) = \Delta\lambda_{\text{peak}} / \Delta T \quad (7)$$

$$R(^\circ\text{C}) = \Delta T \times \Delta\lambda_{\text{min}} / \Delta\lambda_{\text{peak}} \quad (8)$$

3. Results and discussion

Initially, the coupling behavior between the fundamental fiber core mode and the plasmonic mode is examined in Fig. 2, using the following geometric parameters: $d=1.6$ μm , $d_c=2.2$ μm , $d_1=2.4$ μm , $A_1=3.0$ μm , $q=0.5$ μm , $t=25$ nm, and $T=20$ °C. One can observe that the y-polarized fundamental core mode shows stronger coupling with the SPP mode than the x-polarized mode,

primarily because the fiber cores are aligned along the y-axis. At 2.825 μm , the y-polarized core mode remains tightly confined within the core region as the plasmonic mode energy is concentrated at the gold film surface, signifying insufficient coupling resulting from phase mismatch. On the other hand, at the resonant wavelength of 3.253 μm , the closely matching field distributions of both modes confirm strong energy coupling, which means perfect phase matching. Moreover, weak coupling between the two modes at 3.675 μm occurs due to phase mismatch. Unlike the y-polarized fundamental core mode, the energy of the x-polarized fundamental mode in the 2.825 to 3.675 μm range is confined primarily to the core region, preventing the coupling of this mode to SPP modes. This improved interaction between the y-polarized mode and the plasmonic mode results in enhanced sensing performance, which is the focus of our simulation study.

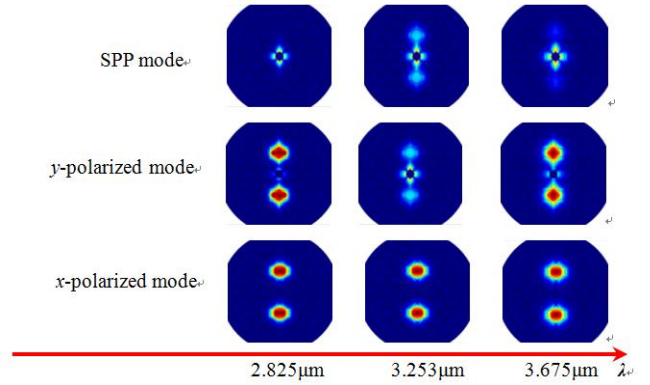


Fig. 2. E-field distributions of fundamental modes and plasmonic modes at different wavelengths (colour online)

To investigate the resonant properties of our sensor more effectively, we analyze the mode effective refractive index and its loss in relation to the operating wavelength. The simulation results are illustrated in Fig. 3 with the structural parameters unchanged. In Fig. 3(a), phase-matching occurs at 3.253 μm since the real part of the effective refractive indices for the fundamental y-polarization mode ($\text{Re}(n_y)$) and the plasmonic mode ($\text{Re}(n_{\text{spp}})$) are equal. As wavelengths below 3.253 μm , $\text{Re}(n_y) < \text{Re}(n_{\text{spp}})$ applies, whereas for wavelengths exceeding 3.253 μm , $\text{Re}(n_y) > \text{Re}(n_{\text{spp}})$ holds. Figure 3(b) shows the loss characteristics, indicating that the loss values for both the y-polarized mode and the plasmonic mode are nearly identical at 3.253 μm . This observation confirms that a significant transfer of energy occurs from the y-polarized mode to the plasmonic mode at this resonant point. Plasmonic mode losses are significantly greater than those of the y-polarization mode, except at the resonance point, as these two modes exist in a decoupled state. Moreover, the loss of the x-polarization mode remains small and nearly constant within the 2.8 to 3.7 μm range due to its inability to interact with the plasmonic mode.

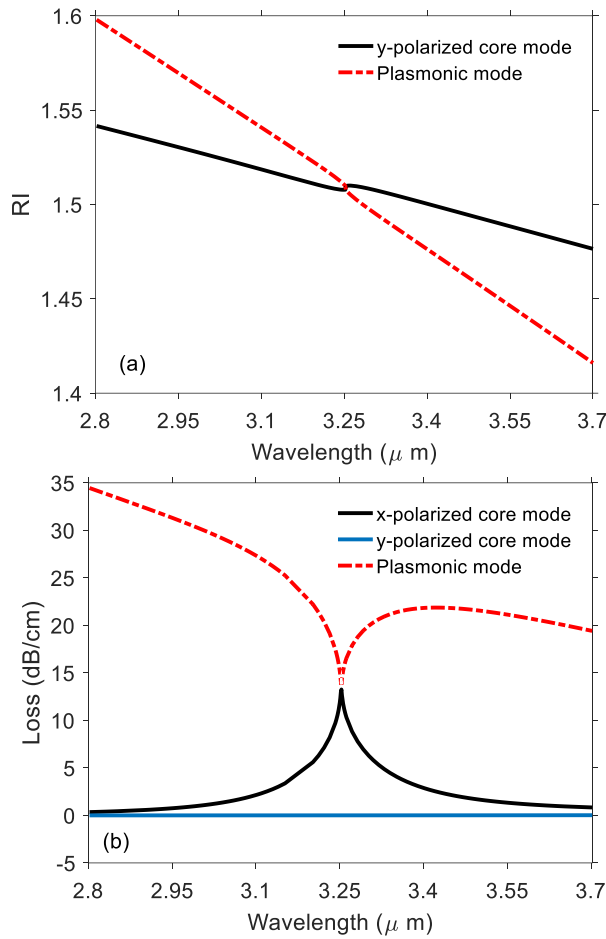


Fig. 3. (a) Dispersion characteristic at $T=20\text{ }^{\circ}\text{C}$ for the sensor; (b) Loss characteristic at $T=20\text{ }^{\circ}\text{C}$ for the sensor (colour online)

Fig. 4 systematically examines how temperature affects the resonant wavelength of the y-polarization fundamental mode while keeping the structural parameters unchanged. The spectral analysis shows a red shift of the resonance wavelength as T varies from -50 to $40\text{ }^{\circ}\text{C}$, indicating a positive sensitivity property. For example, the peak wavelength at $-50\text{ }^{\circ}\text{C}$ is only $3.000\text{ }\mu\text{m}$ while the peak wavelength at $40\text{ }^{\circ}\text{C}$ is as long as $3.348\text{ }\mu\text{m}$. This phenomenon arises from the decrease in $\text{Re}(n_{\text{eff}})$ induced by higher temperature. Consequently, $\text{Re}(n_{\text{eff}})$ at the resonance wavelength also decreases, causing the resonant wavelength to move to a longer wavelength range. Additionally, the peak loss at the resonant wavelength quickly increases from 313.03 dB/cm to 1325.1 dB/cm as the temperature rises from -50 to $20\text{ }^{\circ}\text{C}$. This effect arises from the intensified T -dependent coupling, enhancing energy transfer from the y-polarized mode to the plasmonic mode. As T increases from 20 to $40\text{ }^{\circ}\text{C}$, the peak loss remains almost unchanged. Note that the maximum sensitivity of $6.30\text{ nm}/^{\circ}\text{C}$ with a high temperature resolution of $0.0159\text{ }^{\circ}\text{C}$ is achieved when the temperature varies from 30 to $40\text{ }^{\circ}\text{C}$. Therefore, our proposed sensor has significant potential for detecting MIR radiation in the human body.

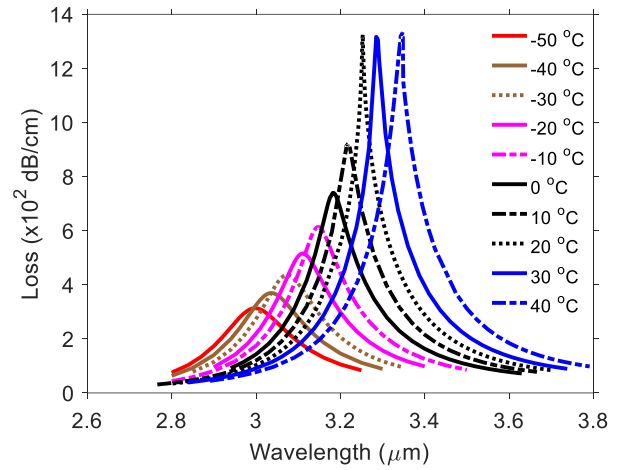


Fig. 4. Y-polarized mode loss versus wavelength as T varies from -50 to $40\text{ }^{\circ}\text{C}$ (colour online)

To accurately assess the temperature sensitivity of the designed sensor, we need to discuss the average sensitivity and linearity. Therefore, we performed a linear regression to correlate the resonance wavelength with temperature, as plotted in Fig. 5, while keeping other parameters constant. In Fig. 5, the formula for linear regression is expressed as $\lambda(\mu\text{m}) = 3.6958T + 3184.3$ ($-50\text{ }^{\circ}\text{C} \leq T \leq 40\text{ }^{\circ}\text{C}$). According to this formula, the average sensitivity in the temperature range of -50 to $40\text{ }^{\circ}\text{C}$ is $3.6958\text{ nm}/^{\circ}\text{C}$. Notably, an R^2 coefficient of 0.9963 indicates near-ideal linear behavior. Consequently, our designed sensor, which has excellent capabilities, possesses many applications in MIR temperature sensing.

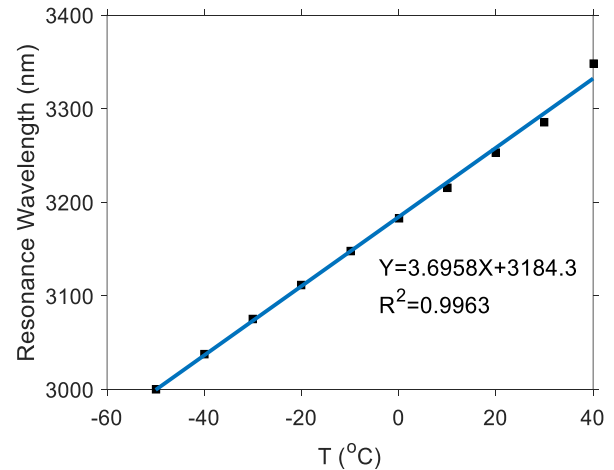


Fig. 5. The linear fit of the resonant wavelength as a function of T in the range of -50 to $40\text{ }^{\circ}\text{C}$ (colour online)

To further evaluate the sensing performance, we analyze how fiber parameters affect temperature sensitivity. Fig. 6 illustrates the impact of d_1 on the sensing property at $T=20, 30\text{ }^{\circ}\text{C}$ with all other parameters fixed. As shown in Fig. 6(a), there is a noticeable blue shift in the resonant wavelength as d_1 increases while maintaining T unchanged. For example, at $T=20\text{ }^{\circ}\text{C}$, the peak wavelength at $d_1=1.9\text{ }\mu\text{m}$ is as long as $3.345\text{ }\mu\text{m}$, while the

coupling wavelength at $d_1=2.5 \mu\text{m}$ is only $3.211 \mu\text{m}$. This happens because the duty ratio of cladding air holes enlargers as d_1 increases, leading to SPP coupling occurring only for the y-polarized mode at shorter wavelengths. Furthermore, the peak loss initially increases before decreasing as d_1 increases. For example, at $T=20^\circ\text{C}$, the peak loss rises significantly from 832.91 dB/cm to 1324.75 dB/cm when d_1 changes from $1.9 \mu\text{m}$ to $2.4 \mu\text{m}$. However, if d_1 is increased further from $2.4 \mu\text{m}$ to $2.5 \mu\text{m}$, the loss decreases by $1324.75 - 555.77 \text{ dB/cm}$. This behavior occurs because the coupling intensity increases as d_1 goes from $1.9 \mu\text{m}$ to $2.4 \mu\text{m}$, but it begins to decrease when d_1 varies from 2.4 to $2.5 \mu\text{m}$. Fig. 6(b) shows that the sensitivity changes nonlinearly as d_1 ranges from $1.9 \mu\text{m}$ to $2.5 \mu\text{m}$. A minimum sensitivity of $3.0 \text{ nm/}^\circ\text{C}$ is achieved at $d_1=2.1 \mu\text{m}$, while a maximum sensitivity of $3.6 \text{ nm/}^\circ\text{C}$ is obtained at $d_1=2.0, 2.2, 2.3, 2.4 \mu\text{m}$. Considering that the sensor has the strongest coupling strength and maximum sensitivity at $d_1=2.4 \mu\text{m}$, we set $d_1=2.4 \mu\text{m}$ as the optimal operating point.

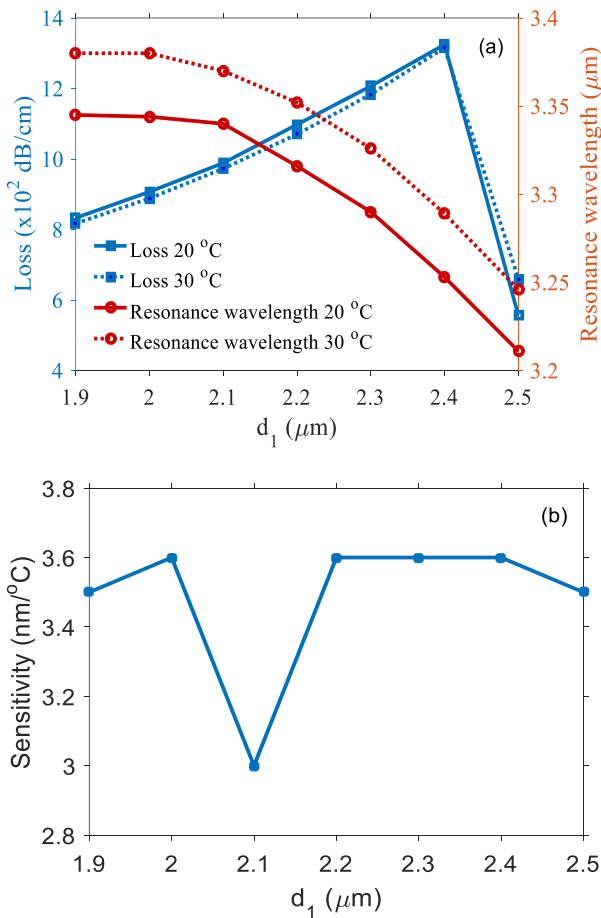


Fig. 6. (a) The effect of d_1 on the peak loss and peak wavelength for $T=20, 30^\circ\text{C}$; (b) The effect of d_1 on the sensitivity for $T=20, 30^\circ\text{C}$ (colour online)

Fig. 7 illustrates the effect of d on the measurement performance at $T=20, 30^\circ\text{C}$ with other parameters fixed. As shown in Fig. 7(a), increasing d from 1.3 to $1.8 \mu\text{m}$ results in a gradual shift of the peak wavelength at

$T=20^\circ\text{C}$ from $3.129 \mu\text{m}$ to $3.278 \mu\text{m}$, while the resonant wavelength at $T=30^\circ\text{C}$ increases from $3.165 \mu\text{m}$ to $3.314 \mu\text{m}$. Additionally, the peak loss curves indicate that for d values ranging from $1.3 \mu\text{m}$ to $1.9 \mu\text{m}$, the peak loss at $T=20^\circ\text{C}$ is almost equal to that at $T=30^\circ\text{C}$, which means the coupling efficiency of these two modes remains unchanged as T rises from 20 to 30°C . As illustrated in Fig. 7(b), the parameter d does not affect the wavelength sensitivity within the 1.3 - $1.8 \mu\text{m}$ range. This indicates that the sensitivity of our proposed sensor is insensitive to fluctuations in d , thereby enhancing tolerance for variations and defects in sensor fabrication.

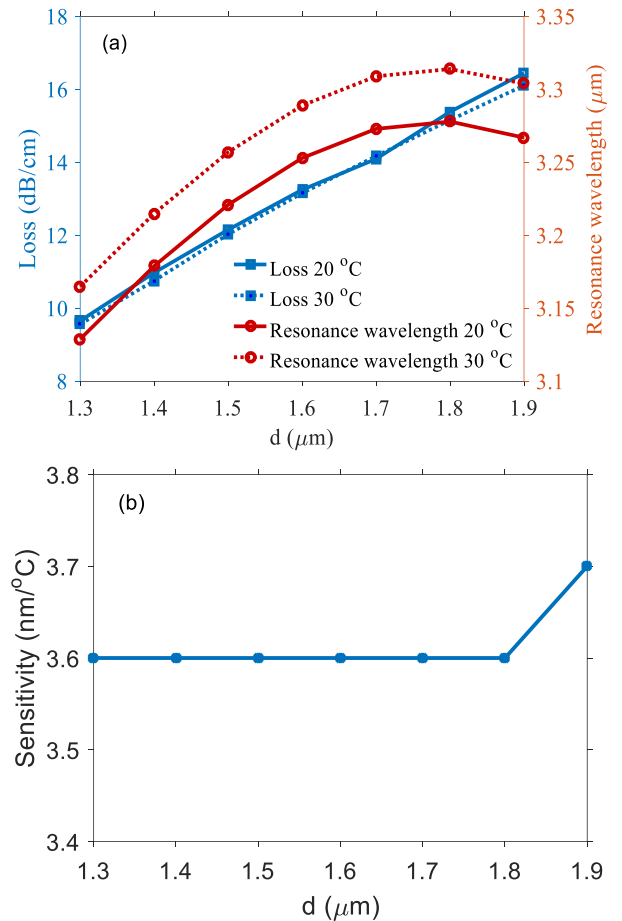


Fig. 7. (a) The effect of d on the peak loss and peak wavelength for $T=20, 30^\circ\text{C}$; (b) The effect of d on the sensitivity for $T=20, 30^\circ\text{C}$ (colour online)

Fig. 8 gives the influence of d_c on the sensing performance as T varies from 20 to 30°C with other parameters fixed. Fig. 8(a) shows that as d_c varies from $1.9 \mu\text{m}$ to $2.2 \mu\text{m}$, the peak loss at $T=20^\circ\text{C}$ rapidly increases from 465.55 dB/cm to 1325.0 dB/cm because a larger d_c leads to much more y-polarized mode energy leaking onto the central metal surface, which enhances the interaction strength of these two modes. However, as d_c changes by 2.2 - $2.5 \mu\text{m}$, the peak loss at $T=20^\circ\text{C}$ gradually decreases to 1245.5 dB/cm . Similarly, d_c has a comparable effect on the peak loss at $T=30^\circ\text{C}$. Moreover, as d_c varies of 1.9 - $2.5 \mu\text{m}$, the resonance wavelength at $T=20^\circ\text{C}$ varies by 3.52 -

3.789 μm , and the resonance wavelength at $T=30^\circ\text{C}$ increases by 3.336–3.714 μm . In Fig. 8(b), temperature sensitivity is directly proportional to d_c , increasing across 1.9–2.5 μm with maximum sensitivity 4.1 nm/ $^\circ\text{C}$ at $d_c=2.5$ μm .

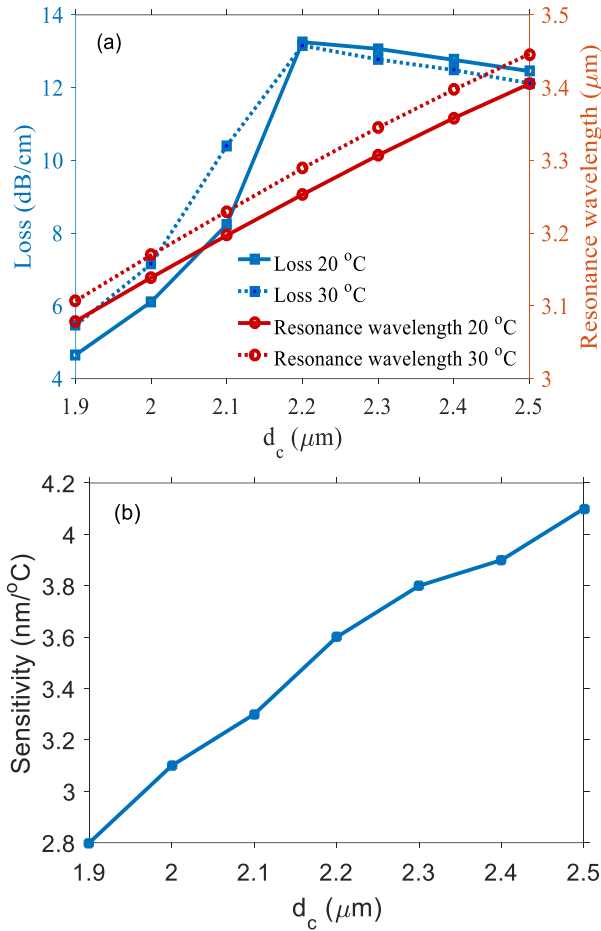


Fig. 8. (a) The effect of d_c on the peak loss and peak wavelength for $T=20, 30^\circ\text{C}$; (b) The effect of d_c on the sensitivity for $T=20, 30^\circ\text{C}$ (colour online)

The influence of t on the detection property at $T=20, 30^\circ\text{C}$ with other parameters fixed is presented in Fig. 9. As Fig. 9(a) indicates, as t increases by 19–31 nm, the resonant wavelength at $T=20^\circ\text{C}$ changes from 3.343 μm to 3.208 μm , as the resonant wavelength at $T=30^\circ\text{C}$ varies from 3.374 μm to 3.245 μm . This occurs because the mode index increases with t , resulting in a redshift of the resonant wavelength. Additionally, the peak loss at $T=20^\circ\text{C}$ increases with the increment t from 19 to 25 nm, while it decreases with the increment t from 25 to 31 nm. A similar phenomenon occurs at $T=30^\circ\text{C}$. In Fig. 9(b), the temperature sensitivity exhibits a nonlinear variation when t varies from 19 nm to 31 nm. A minimum sensitivity of 3.1 nm/ $^\circ\text{C}$ is obtained at $t=19$ nm, and a maximum sensitivity of 3.7 nm/ $^\circ\text{C}$ is realized at $t=29, 31$ nm. Based on these observations, we set $t=25$ nm as the optimal operating point to balance the sensing performance and structural cost.

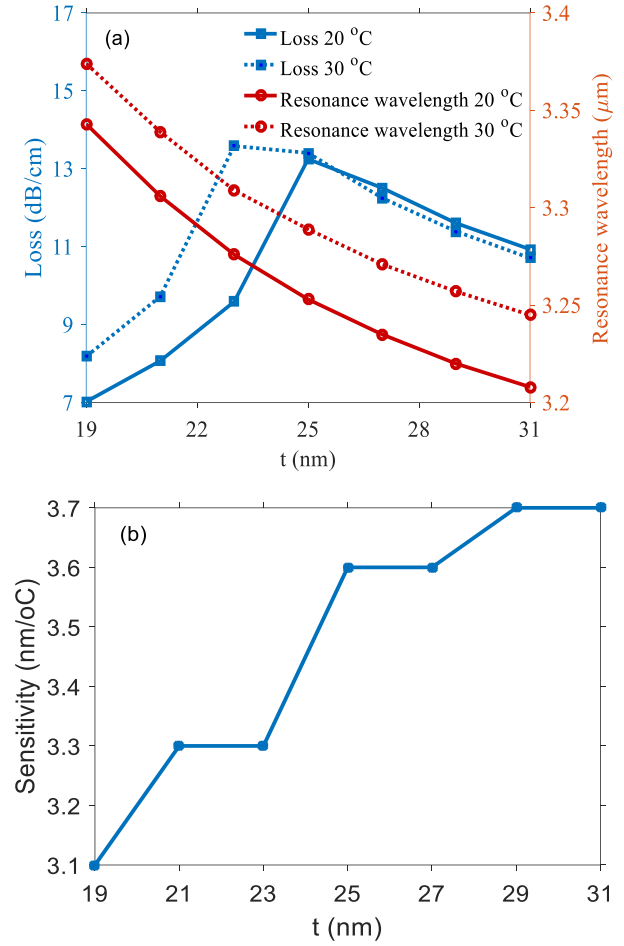


Fig. 9. (a) The effect of t on the peak loss and peak wavelength for $T=20, 30^\circ\text{C}$; (b) The effect of t on the sensitivity for $T=20, 30^\circ\text{C}$ (colour online)

We have examined the deformation of the central gold-coated circular hole caused by the change in temperature, and the numerical results are presented in Fig. 10 with other parameters remaining unchanged. As shown in Fig. 10(a), the non-circularity of the central gold-coated hole is defined as $\eta=a/b$, where a is the diameter of the hole in the x -axis direction and b is the diameter of the hole in the y -axis direction. As η varies from 0.85 to 1.15, the peak wavelength at 20°C gradually increases from 3.212 μm to 3.285 μm , while at 30°C it increases from 3.248 μm to 3.318 μm . On the other hand, the peak loss first increases and then decreases when η varies from 0.85 to 1.15. It is clear from Fig. 10(b) that the temperature sensitivity remains unchanged when η varies from 0.85 to 1.1, which means the sensitivity of our proposed sensor is insensitive to the deformation caused by the thermal expansion difference between gold and SF57.

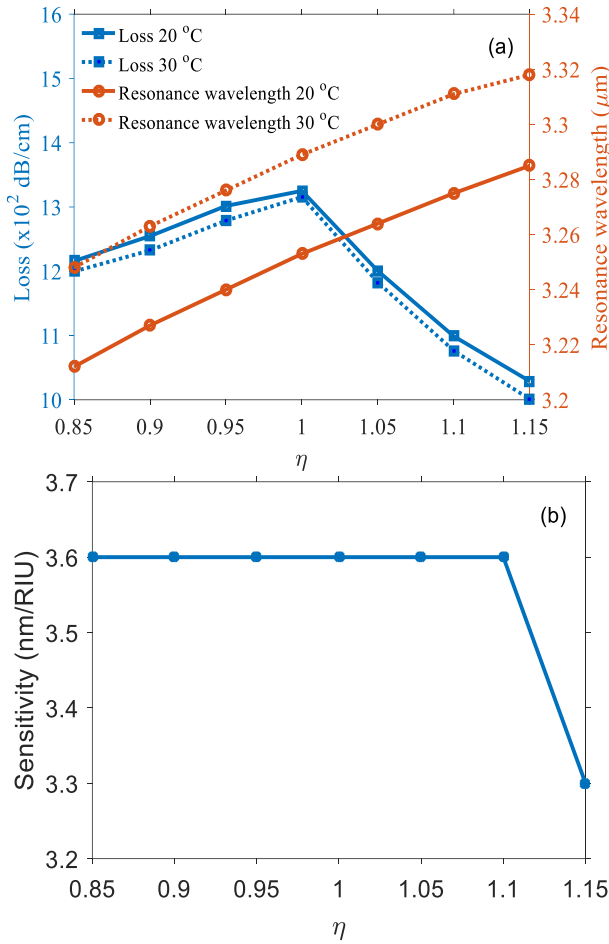


Fig. 10. (a) The effect of η on the peak loss and peak wavelength for $T=20, 30^\circ\text{C}$; (b) The effect of η on the sensitivity for $T=20, 30^\circ\text{C}$ (colour online)

The peak wavelength and sensitivity with a variation of $\pm 5\%$ for all structure parameters at $T=20, 30^\circ\text{C}$ are given in Fig. 11. Here, the optimum structure parameters identified are $d=1.6\ \mu\text{m}$, $d_c=2.2\ \mu\text{m}$, $d_1=2.4\ \mu\text{m}$, $A_1=3.0\ \mu\text{m}$, $q=0.5\ \mu\text{m}$, and $t=25\ \text{nm}$. Comparative analysis in Fig. 4 confirms peak wavelength reduction at 20°C relative to 30°C , as all fiber parameters vary from -5% to $+5\%$. Since CS_2 RI exhibits negative temperature dependence, a corresponding decrease occurs in $\text{Re}(n_{\text{eff}})$. Ultimately, reduced $\text{Re}(n_{\text{eff}})$ triggers resonant wavelength red-shift. Moreover, the wavelength sensitivity gradually increases as the values of all structural parameters range from -5% to $+5\%$. The wavelength sensitivity values of the sensor with a variation of -5% , an optimum structure, and a variation of $+5\%$ are $3.4, 3.6$, and $3.7\ \text{nm}/^\circ\text{C}$, respectively. This is because d_c has the most significant effect on the sensor's sensitivity, and the enlargement of d_c directly enhances system sensitivity. To sum up, a change of $\pm 5\%$ in all optimized parameters has a minor effect on sensitivity, indicating that our designed sensor is resilient to fabrication imperfections. Note that the proposed sensor can be fabricated through the following steps: Firstly, the soft-glass PCF should be manufactured using the stack-and-draw method. Secondly, the gold film can be deposited within the sensing channel using the high-

pressure chemical vapor deposition method. Finally, the sensing liquid can be infiltrated in the sensing channel by using the capillary permeation method.

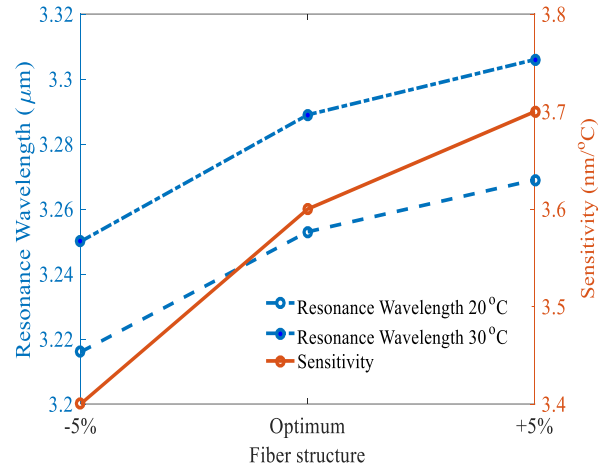


Fig. 11. Resonance wavelength and sensitivity of our designed sensor with a variation of $\pm 5\%$ for all structure parameters at $T=20, 30^\circ\text{C}$ (colour online)

4. Conclusion

In summary, a new SPR sensor is proposed utilizing a soft-glass PCF with two liquid cores. This non-silica design represents the first demonstration of ultra-broadband and highly sensitive temperature sensing in the MIR region. The sensing characteristics are meticulously studied employing the FEM method. The simulation outputs demonstrate that a single non-liquid gold-coated channel structure with two liquid cores significantly enlarges the temperature detection range. This design delivers outstanding sensing performance, achieving a high sensitivity of $6.30\ \text{nm}/^\circ\text{C}$ and an excellent linearity coefficient of 0.9963 across the -50 – 40°C temperature range. Therefore, our work opens a way for the application of PCF-based SPR sensor in MIR temperature sensing.

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References

- [1] G. An, P. Jia, T. Liang, Y. Hong, H. Wang, A. Ghaffar, J. Xiong, *Plasmonics*, **15**(5), 1471 (2020).
- [2] J. F. Liao, H. Lei, C. Y. Xu, *Appl. Opt.*, **60**(17), 5161 (2021).
- [3] J. Roether, K. Y. Chu, N. Willenbacher, A. Q. Shen, N. Bhalla, *Biosensors and Bioelectronics* **142**,

- 111528 (2019).
- [4] S. C. Jena, S. Shrivastava, S. Saxena, N. Kumar, S. K. Maiti, B. P. Mishra, R. K. Singh, *Scientific Reports* **9**, 13485 (2019).
- [5] W. W. Lam, L. H. Chu, C. L. Wong, Y. T. Zhang, *Sensors and Actuators B: Chemical* **105**(2), 138(2005).
- [6] T. Vo, A. Paul, A. Kumar, D. W. Boykin, W. D. Wilson, *Methods* **167**, 15 (2019).
- [7] Y. Q. Dai, H. M. Xu, H. Y. Wang, Y. H. Lu, P. Wang, *Optics Communications* **416**, 66 (2018).
- [8] M. H. Jodaylami, J. F. Masson, A. Badia, *Nature Reviews Methods Primers* **5**, 47 (2025).
- [9] A. Hosoki, M. Nishiyama, K. Watanabe, N. Sakurai, *Optics Express* **30**(20), 35348 (2022).
- [10] N. A. Aljbar, B. R. Mahdi, A. H. Khalid, A. H. Attallah, F. S. Abdulwahid, A. J. Haider, *Plasmonics* **20**, 605 (2025).
- [11] Y. Zhao, Z. Q. Deng, H. F. Hu, *IEEE Transactions on Instrumentation and Measurement* **64** (11), 3099(2015).
- [12] Z. Zhu, L. Liu, Z. Liu, Y. Zhang, Y. Zhang, *Optics Letters* **42**, 2948 (2017).
- [13] L. Lu, Z. Jiang, Y. Hu, H. Zhou, G. Liu, Y. Chen, Y. Luo, Z. Chen, *Optics Express* **27**, 25420 (2019).
- [14] X. Wang, H. Deng, Libo Yuan, *Optics Express* **29**, 22417 (2021).
- [15] X. Zhang, Y. Xu, X. Zhu, Y. Shi, *Optics Express* **30**, 48091 (2022).
- [16] X. Zhang, Y. Xu, X. Zhu, Y. Shi, *Optics Express* **31**, 26398 (2023).
- [17] E. Nahid, M. R. Kaysir, M. J. Islam, S. S. Hossain, M. S. Rahman, *Plasmonics* **20**, 6553 (2025).
- [18] H. Liang, T. Shen, Y. Feng, Z. Xia, H. Liu, *IEEE Photonics Journal* **12**(3), 7201811 (2020).
- [19] A. B. Siddik, S. Hossain, A. K. Paul, M. Rahman, A. Mollah, *Sensing Bio-Sensing Research* **29**, 100350 (2020).
- [20] J. N. Jabir, *Plasmonics* **17**, 2245 (2022).
- [21] C. Mei, Y. Wu, S. Qiu, J. Yuan, X. Zhou, K. Long, *Optics Communications* **508**, 127838 (2022).
- [22] H. P. Li, J. Ruan, X. Li, G. Wei, T. He, *Progress in Electromagnetic Research (PIER) M*, **116**, 11 (2023).
- [23] C. T. C. Chao, S. H. Chen, H. J. Huang, M. R. R. Kooh, C. M. Lim, R. Thotagamuge, A. H. Mahadi, Y. F. C. Chau, *Crystals*, **13**(5), 813(2023).
- [24] Q. You, H. Pan, Z. Zhao, Y. Zhu, Y. Li, B. Li, *IEEE Sensors Journal* **24**(16), 25785 (2024).
- [25] J. H. V. Price, T. M. Monro, H. Ebendorff-Heidepriem, F. Poletti, P. Horak, V. Finazzi, J. Y. Y. Leong, P. Petropoulos, J. C. Flanagan, G. Brambilla, X. Feng, D. J. Richardson. *IEEE Journal of Selected Topics in Quantum Electronics*, **13**(3), 738 (2007).
- [26] Z. Chen, S. Ma, N. K. Dutta, *Optics Communications* **283**, 3076 (2010).
- [27] H. Hu, W. Li, N. K. Dutta, *Applied Optics* **52**(30), 7336(2013).
- [28] H. Hu, W. Li, N. K. Dutta, *Optics Communications* **324**, 252 (2014).
- [29] F. Saleha, A. Rubaya, I. R. Mohammad, A. Jobaida, *Journal of Optical Communications* **41**(4), 371 (2020).
- [30] M. N. Polyanskiy. *Scientific Data* **11**, 94 (2024).
- [31] S. Chu, K. Nakkeeran, A. M. Abobaker, S. S. Aphale, S. Sivabalan, P. R. Babu, K. Senthilnathan, *IEEE Sensors Journal* **21**(1), 76 (2021).
- [32] N. Nallusamy, R. V. J. Raja, G. J. Raj, *IEEE Sensors Journal* **17**(12), 3720 (2017).

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