High-sensitivity temperature sensor based on photonic crystal fiber fully coated with gold and PDMS films.

yuhi feng (✉ 1355181057@qq.com)
Yanshan University  https://orcid.org/0000-0002-5888-0640

shuguang li (✉ shuguangli@ysu.edu.cn)
Yanshan University

hongyu li
Yanshan University

xiaojian meng
Yanshan University

mengqiang li
Yanshan University

Research Article

Keywords: Photonic Crystal Fibers, Surface Plasmon Resonance, Temperature Sensing, High-sensitivity

DOI: https://doi.org/10.21203/rs.3.rs-358753/v1

License: © This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
High-sensitivity temperature sensor based on photonic crystal fiber fully coated with gold and PDMS films

YUHUI FENG, SHUGUANG LI*, HONGYU LI, XIAOJIAN MENG, MENGQIANG LI

State Key Laboratory of Metastable Materials Science & Technology and Key Laboratory for Microstructural Material Physics of Hebei Province, School of Science, Yanshan University, Qinhuangdao, 066004, PR China

*Corresponding author: shuguangli@ysu.edu.cn

Abstracts

This paper presented a high-sensitivity temperature sensor based on photonic crystal fiber fully coated with gold and PDMS films. For the convenience of production, gold film is coated outside the fiber cladding, and it is used to excite the surface plasmon resonance (SPR) effect. In addition, the temperature response has been effectively improved by depositing poly-dimethylsiloxane (PDMS) layer outside the gold film. This fully coated structure on the outside of PCF enables temperature-sensitive medium to be in direct contact with the environment, which reduces the difficulty of internal coating and filling. The influences of the parameters on the sensing characteristics are investigated by using the finite element method (FEM). Simulation results show that the average temperature sensitivity is up to 9.287nm/℃ in the range of -20℃-40℃. Moreover, compared with other designs, the optimized process of structure in this study provides an effective method, which shows a wide application prospect to overcome the difficulty of filling liquid in the air holes.

Keywords: Photonic Crystal Fibers; Surface Plasmon Resonance; Temperature Sensing; High-sensitivity

Introduction

Photonic crystal fibers (PCFs), also known as microstructured fibers that have various air holes extending along the fiber in its cross section [1-3]. PCFs have been extensively applied to sensors [4], filters [5], lasers [6], and other optical devices due to the flexible structural design and many distinctive characteristics [2]. Since the distinguished performance of surface plasmon resonance (SPR) technology in the sensing domain, SPR technology has been combined with PCFs to increase the function of this fiber [7]. Compared to conventional fiber sensors, SPR-PCF sensors are obviously optimized in terms of cross-sensitivity and coupling loss. In addition, it has qualities of wide operating wavelength range, high sensitivity, and multi-parameter measurement [8-10]. Owing to surface plasmon polaritons are sensitive to the external environment and easily changing transmission constants of sensor, SPR-PCF sensors have aroused tremendous interest in temperature measurement, medical diagnostics and more [10].
Temperature measurement plays an indispensable role in industrial production, environmental monitoring and other fields. At present, electrical temperature sensor has been developed and matured. But as technology advances, fiber temperature sensor based on combination of fiber and metal has attracted people's attention. Fiber temperature sensors have gradually substituted electrical temperature sensors because of its preponderance of long-distance transmission and design flexibility. In 2014, Yang et al. [11] proposed and experimentally demonstrated a PCF temperature sensor based on SPR, which achieves temperature sensing by filling PCF with silver nanowires and liquid. Experimental results show that the sensitivity was -2.08 nm/°C, whereas the operation procedure for filling in PCF was cumbersome. In 2015, Zhao et al. [12] presented a PCF-SPR sensor for temperature detection by using a temperature-sensitive liquid as an intermediate and combined with fiber SPR structure. The sensing element is fabricated by packaging a silver-coated fiber probe into a capillary filled with thermosensitive anhydrous ethanol. This proposed sensor achieves the sensitivity of 1.5745 nm/°C between 35-70°C. In 2016, Luan et al. [13] presented a SPR sensor, which can simultaneously realize refractive index (RI) and temperature sensing in an exposed-core microstructured fiber. Two orthogonal passageways coated with silver layers are designed in cladding air holes, one of which is filled with thermosensitive liquid to distinguish the variation of analyte RI and temperature. The corresponding sensitivity was 6.18 nm/°C as the temperature changed from 26 to 43°C. The same year, Lu et al. [14] accomplished sensing by filling liquid crystals into a hollow-core fiber which was coated with a gold film on the inner wall. The sensitivity was 4.72 nm/°C in the range of 20 to 34.5°C. Subsequently, Zhu et al. [15] proposed a novel PCF sensor by combining SPR principle with defect coupling mechanism. Two air holes are determined in cladding, metal films are deposited on one of inner surfaces while the diameter of the other air hole is changed. Magnetic fluid material is filled in these two air holes. By analyzing the relationship between RI of magnetic fluid with its temperature and magnetic field, simultaneous sensing of temperature and magnetic field are realized. Liu [16] presented a new core-cladding symmetrical structure PCF in 2019, which fills all air holes of a group of core-cladding with ethanol. Temperature measurement is achieved due to RI of ethanol changes with temperature. Simulation results show that the sensitivity of 1cm fiber meets 3.21 nm/°C in the area from 20 to 25°C. According to previous studies, most existing fiber temperature sensors selected to be filled with temperature-sensitive materials in PCF. Since infiltrating liquid into air holes or coating metal on the inner wall is comparatively inconvenient in practical approach, fabrication of sensors described above is rather complicated. In addition, filling media are mainly alcohol, benzene or liquid crystal. These materials respond significantly to changes in temperature but poisonous and volatility, which is not conducive to preservation and recycle of sensors. In order to surmount the above problems, this study chooses to wrap the double-layer membrane immediately outside PCF, which reduces complexity of the structure and is more sensitive to external surroundings.

This paper numerically reports a high-sensitivity temperature sensor by using commercial software COMSOL Multiphysics, finite element method (FEM), with anisotropic perfectly matched layers (PML). First of all, SPR material gold is deposited outside PCF cladding with chemical vapor deposition (CVD), owing to its chemical stability and is less likely to be oxidized in presence of temperature sensing medium. Then, PDMS is wrapped outside the gold film through the curing process, which makes it in direct contact with the environment to be measured and reduce the manufacturing difficulty. By optimizing the parameters, results show that the identification ability of sensor for temperature changes is improved effectively. It's found that the average sensitivity of sensor is 9.287 nm/°C, and the maximum can reach 13 nm/°C. Finally, the influences of diameters d1, Λ, t1 and t2 on resonance wavelength, loss value and sensitivity are analyzed. Owing to the simple structure and stable performance, the proposed sensor has a chance of actually being manufactured with current technology.

Structural design and theoretical analysis
The two-dimensional cross-sectional of the proposed PCF is depicted in Fig. 1(a). It consists of twelve air holes arranged in a hexagonal grid. In order to promote the surface plasmons propagate effectively on metal dielectric surface, air holes with two different diameters are designed. The large air holes are placed on both sides parallel to the fiber core while the small air holes are arranged on the upper and lower sides. Consequently, evanescent wave is transferred to gold film through passageways as shown by arrows in Fig. 1(a), which passageways radius is \( r = 7.5 \mu m \). The diameters of air holes are represented by \( d_1 \) and \( d_2 \), where \( d_1 = 1.2 \mu m \), \( d_2 = 3 \mu m \); \( \Lambda \) represents the horizontal distance between adjacent small air holes, which was determined to be \( 2.5 \mu m \); A gold layer with diameter of \( t_1 = 35nm \) is used as plasmonic material, which is deposited outside the PCF cladding by CVD method; Symbol \( t_2 \) expresses the thickness of sensing medium PDMS, which is wrapped on top of the gold surface and it is considered to be \( t_2 = 1.1 \mu m \); The proposed PCF is practically realizable through stack-and-draw fabrication means because of its simple structure. By commercial software COMSOL Multiphysics to investigate sensing properties of the proposed PCF. Fig. 1(b) indicates the meshing of the calculation region for optimized structure. To guarantee the computational accuracy, PML and scattering boundary condition are increased.

Pure silica is the background material of PCF whose dispersion coefficient is calculated by the Sellmeier equation [17]:

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

Here, \( n \) is the refractive index of fused silica, which is decided by incident light wavelength \( \lambda \) in vacuum. \( B_1, C_1, B_2, C_2, B_3, C_3 \) are known as Sellmeier constants.

The dielectric constant of gold is described by the Drude-Lorentz formula [18]:

\[
e_m = e_\infty - \frac{\omega_0^2}{\omega(\omega + i\gamma_0)} - \frac{\Delta e \cdot \Omega_L^2}{(\omega^2 - \Omega_L^2)^2 + i\Gamma_L \omega} \quad (2)
\]

where \( e_m \) expresses the permittivity of gold, and \( \epsilon_e = 5.9673 \) is the permittivity at high frequency. \( \omega = 2\pi c/\lambda \) indicates angular frequency of guided light where \( c \) is the velocity of light, \( \omega_D = 2\pi \times 2113.6 \) THz refers to plasmon frequency, and \( \gamma_0 = 2\pi \times 15.92 \) THz represents the damping frequency. \( \Delta e = 1.09 \) can be interpreted as a weighting factor, \( \Omega_L = 2\pi \times 650.07 \) THz and \( \Gamma_L = 2\pi \times 104.86 \) THz are frequency and spectral width of the Lorentz oscillator, respectively.

PDMS is silicone material with unique optical properties extensively applied to optical field, which has excellent qualities of wide operating range, non-toxic and chemically stable [19]. It has high thermo-optic coefficients and is sensitive to temperature change. At the same time, the extraordinary optical characteristics of PDMS are not affected after curing. Its effective refractive index varies with temperature as determined by the equation [20-22]:

\[
n_{PDMS} = n_0 - \gamma \Delta T \quad (3)
\]

In this expression, \( n_0 = 1.421332 \) is the effective refractive index of PDMS at \( 20^\circ C \), \( \gamma = -4.66 \times 10^{-5}/^\circ C \) is thermo-optical coefficient, \( \Delta T \) refers to temperature variation.

Confinement loss is an indispensable parameter while investigating PCF, which can be defined by the following equation [23]:

\[
\alpha = 8.868 \times \frac{2\pi}{\lambda} \text{Im}(n_{\text{eff}}) \times 10^{-4}
\]  

(4)

where the units of \(\alpha\) are dB/cm, \(\lambda\) is wavelength in vacuum and \(\text{Im}(n_{\text{eff}})\) represents virtual part of the effective refractive index.

The capability of sensor can also be reflected by sensitivity, which can be calculated by wavelength interrogation method as follows [24]:

\[
S(\lambda) = \frac{\Delta \lambda_{\text{peak}}}{\Delta T} (\text{nm/}^\circ\text{C})
\]

(5)

Here, \(\Delta \lambda_{\text{peak}}\) represents the distance of resonance peak shift and \(\Delta T\) indicates the amount of temperature change.

As shown in Fig. 2, experimental setup for realize temperature sensing mainly includes the following three parts: broadband light source (BBS), temperature control chamber and optical spectral analyzer (OSA). BBS is used to transmit light into single mode fiber (SMF) and couple with PCF-SPR sensor. Then the sensor responds to temperature by changing the temperature of surroundings with temperature control chamber. Finally, transmission spectrum is tracked and displayed by OSA. Temperature changes will lead to variations in RIs of PDMS. Since different RIs will change the phase matching condition of fundamental mode and SPR mode result in loss peak shift. Therefore, temperature measurement is achieved by analyzing the relationship between temperature variation and resonance wavelengths drift.

Fig. 2. Schematic diagram of the experimental setup for the proposed PCF temperature sensor.

**Results and discussions**

A. Influences of different parameters on sensing characteristics

In this segment, the influences of structural parameters \(d_1\), \(\Lambda\), \(t_1\), and \(t_2\) on loss values, sensitivity and resonance wavelengths are discussed.

![Graph showing loss spectrum variation with different \(d_1\).](image)

**Fig. 3.** (a) Variation of loss spectrum at 20°C with different \(d_1\); (b) Variation of the resonance wavelengths with different \(d_1\) in the range -20–40°C.

Fig. 3(a) shows that the confinement loss relies on the operable wavelength by changing diameter of \(d_1\). It can be seen that with increases of \(d_1\), the confinement loss decreases and resonance wavelength red-shifts, which is owing to the enhanced limitation of light. The energy transferred to gold surface decreases due to the enhancement of the bound light ability, which weakens the SPR phenomenon and reduces the loss value. Variations of the resonance wavelengths with different \(d_1\) over the temperature ranges from -20°C to 40°C as depicted in Fig. 3(b). It can be seen from Fig. 3(b) that when \(d_1\) is fixed, resonance wavelength blue-shifts with increase of temperature. Average sensitivity is obtained about 8.291nm/°C, 8.807nm/°C, 9.568nm/°C, 10.354nm/°C, 11.507nm/°C, respectively, with the \(d_1\) increased from 0.8µm to 1.6µm. Increasing \(d_1\) is instrumental in improving sensitivity, while
half-peak width tends to wider and the shape of spectrum is too smooth. Therefore, \( d_1 = 1.2 \mu m \) is the optimal value by considering the confinement loss and wavelength sensitivity.

**Fig. 4.** (a) Variation of loss spectrum at 20°C with different \( \Lambda \); (b) Variation of the resonance wavelengths with different \( \Lambda \) in the range -20~40°C.

Fig. 4(a) describes the variation of confinement loss spectrum for different \( \Lambda \) at 20°C. From Fig. 4(a), it can be concluded that the resonance wavelength blue-shifts when \( \Lambda \) changes from 2.3\( \mu m \) to 2.4\( \mu m \) while peak loss decreases. The large \( \Lambda \) narrows the transmission route of energy to the metal layer, which results in a weakened coupling between fundamental mode and SPP mode. Variations of the resonance wavelengths with different \( \Lambda \) over the sensing range are shown in Fig. 4(b). The maximum wavelength sensitivity of 10.781nm/°C is obtained at \( \Lambda = 2.3 \mu m \), while the corresponding confinement loss is not conducive to practical application. All in all, by considering the peak loss and sensitivity \( \Lambda \) is determined to be 2.5\( \mu m \).

As observed in Fig. 5(a), the confinement loss depends on operable wavelength by changing \( t_1 \). The confinement loss decreases and the resonance wavelength red-shifts as \( t_1 \) increases. Since the effective refractive index of fiber core remains invariant, while the effective refractive index of SPP mode varies with \( t_1 \), which results in the shift of coupling position between two modes. The thickness of metal film will influence the decay rate of evanescent wave and SPP mode. Thicker gold layer is responsible for loss value decreases and half-peak width increases. With the increase of gold layer, the energy of evanescent field decreases and confinement loss increases. The thickness of the gold layer also affects sensitivity of sensor, as depicted in Fig. 5(b). As seen in Fig. 5(b), sensitivity increases from 10.452 to 11.093nm/°C with the gold layer increases from 32nm to 38nm. Taking into account sensitivity and confinement loss, \( t_1 = 35nm \) is determined as the optimum gold layer thickness of the sensor.
The effect of varying sensor parameter $t_2$ on loss spectrum and sensitivity is illustrated in Fig. 6. Fig. 6(a) indicates that confinement loss increases significantly and blue-shifts as $t_2$ increases. In addition, the half-peak width greatly decreases and the spectral appears sharper. That is because the RIs of PDMS decreases with increase of temperature, which leads to the variation of phase matching wavelength. According to Fig. 6(b), sensitivities decreased from 11.094 to 10.116 nm/°C, when the $t_2$ increased from 1.0 µm to 1.4 µm. In order to improve the sensing performance and meet practical applications, $t_2 = 1.1$ µm was chosen as the optimum PDMS layer thickness. Finally the influence of each parameter on sensor performance is summarized, which is illustrated in Table 1.

### Table 1: The effects of different parameters on spectra and sensitivity.

| Parameters | Variation | Loss | Spectrum | Sensitivity |
|------------|-----------|------|----------|-------------|
| $d_1$      | 0.8–1.6   | Decrease | Red-shift | Increase    |
| $\Lambda$  | 2.3–2.7   | Decrease | Blue-shift | Decrease    |
| $t_1$      | 0.032–0.038 | Decrease | Red-shift | Increase    |
| $t_2$      | 1.0–1.4   | Increase | Blue-shift | Decrease    |

### B. Sensing Performances of the Proposed Temperature Sensor

From the above discussion, optimal parameters for this sensor were determined, which are observed in Table 2. Fig. 7(a) shows the confinement loss dependence on operable wavelength as temperature varies from -20°C to 40°C and the temperature interval is 10°C. At the resonance wavelength of 1380, 1280, 1150, 1030, 950, 890, and 840 nm, the corresponding losses are 405.45, 328.57, 267.46, 229.97, 201.7, 175.35, and 152.77 dB/cm. The changes of resonance wavelength at different temperatures and fit curves are depicted in Fig. 7(b). The equation of the linear fitting is determined as $y=1168.28-9.287x$, where $y$ and $x$ represent the resonance wavelength and temperature, respectively. The slope $K$ represents the average sensitivity of the sensor from -20°C to 40°C, which is 9.287 nm/°C. Linearity $R^2$ is equal to 0.99114. The maximum sensitivity of the sensor reaches 13 nm/°C in the range of -10°C ~ 0°C.
Fig. 7. (a) Variation of loss spectrum, (b) Resonance wavelengths and its fit curve.

Table 2. The value of the optimized parameters.

| Parameters | $d_1$ | $\Lambda$ | $t_1$ | $t_2$ |
|------------|-------|-----------|-------|-------|
| value(µm)  | 1.2   | 2.5       | 0.035 | 1.1   |

In addition to the criterion of sensitivity, measurement accuracy can also be regarded as intuitive reflection of sensor performance. The measurement accuracy determines the minimum temperature change sensed by sensor, which can be defined by the following expression [25]:

$$ R = \frac{\Delta T \Delta \lambda_{\text{min}}}{\Delta \lambda_{\text{peak}}} \; \text{(°C)} \quad (6) $$

where $\Delta T$ refers to the temperature variation. The minimum detection accuracy of the spectrometer is $\Delta \lambda_{\text{min}}$, which is generally taken as 0.1nm. $\Delta \lambda_{\text{peak}}$ expresses the wavelength shift. The proposed sensor is capable of detecting extremely small temperature changes with an accuracy of 0.01077°C. A detailed comparison of the performance of our work with previous studies based on sensing range and wavelength sensitivity, which is illustrated in Table 3.

Table 3. Comparison of the proposed temperature sensor with previous studies.

| Reference | Sensing Type | Detection range(°C) | $\Delta T$(°C) | Sensitivity(nm/°C) |
|-----------|--------------|---------------------|----------------|--------------------|
| [26]      | SPR          | 0–50                | 50             | 0.72               |
| [27]      | Sagnac       | 25–33               | 8              | 1.65               |
| [13]      | SPR          | 26–43               | 17             | 6.18               |
| [28]      | Mach–Zehnder | 23.2–58.2           | 35             | 1.83               |
| [29]      | WGM          | 25–45               | 20             | 0.377              |
| This work | SPR          | -20–40              | 60             | 9.287              |

**Conclusion**

A high-sensitivity PCF temperature sensor is proposed in this paper. Both the gold and PDMS are deposited outer surface of PCF to minimize the fabrication complexity and achieve more efficient sensing. The FEM method is used to investigate sensing characteristics of the temperature sensor. At optimized sensor parameters, simulation results show that average sensitivity of the proposed sensor is 9.287 nm/°C as temperature changes from -20°C to 40°C, and the maximum sensitivity reaching 13nm/°C. Owing to its high sensitivity and wide sensing range, the proposed sensor supports temperature detection in intelligent monitoring and industrial production. Meanwhile, the design of forming an annular sensing channel outside the PCF effectively overcomes the problem, which is the difficulty of filling air holes in the PCF.

**Funding** This work is supported by National Key Research and Development Project (Grant No. 2019YFB2204001), National Natural Science Foundation of China (12074331), the Program of the Natural Science Foundation of Hebei Province (Grant No. F2017203193, F2020203050) and the Postdoctoral preferred funding research project of Hebei Province (Grant No. B2018003008).

**Disclosures** The authors declare no conflicts of interest.

**Ethical Approval** Approval was obtained from the ethics committee of YanShan University. The procedures used in this
study adhere to the tenets of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The participant has consented to the submission of the case report to the journal.

Availability of data and materials Data are available on request to the authors.

Code availability Not applicable

Authors Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Yuhui Feng, Shuguang Li, Hongyu Li, Xiaojian Meng, and Mengqiang Li. The first draft of the manuscript was written by Yuhui Feng and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgements Authors are thankful to the group members of modeling and simulation laboratory for the fruitful discussions.

Compliance with Ethical Standards

Conflict of interests The authors declare that they have no conflicts of interest.

References

1. Guo J, Zhong Y, Liu Y, et al. (2017) A novel high birefringence equal diameter circular-hole photonic crystal fiber. Optoelectronics Letters (05):34-38.

2. Gao F, Song N, Xu X, et al. (2019) Low-loss hollow-core photonic bandgap fiber with isolated anti-resonance layer. Optics Communications 441:208-211.

3. Yadav T K, Narayanaswamy R, Bakar M H A, et al. (2014) Single mode tapered fiber-optic interferometer based refractive index sensor and its application to protein sensing. Optics Express 22(19):22802-22807.

4. Yu X, Zhang Y, Pan S, et al. (2009) A selectively coated photonic crystal fiber based surface plasmon resonance sensor. Journal of Optics 12(1):015005.

5. Xue J, Li S, Xiao Y, et al. (2013) Polarization filter characters of the gold-coated and the liquid filled photonic crystal fiber based on surface plasmon resonance. Optics Express 21(11):13733-13740.

6. Yao W, Zhu Y, Wang S, et al. (2015) Flat-topped hollow laser beams can be obtained by using the multi-core photonic crystal fiber mixed with GeO2. Optik International Journal for Light & Electron Optics 126(23):3761-3766.

7. Hautakorpi M, Mattinen M, Ludvigsen H. (2008) Surface-plasmon-resonance sensor based on three-hole microstructured optical fiber. Optics Express 16(12):8427-8432.

8. Shuai B, Xia L, Zhang Y, et al. (2012) A multi-core holey fiber based plasmonic sensor with large detection range and high linearity. Optics Express 20(6):5974-5986.

9. Wang W, Xiong Z, Shi W, et al. (2017) Fiber-Optic Surface Plasmon Resonance Sensing Technology. Laser & Optoelectronics Progress 54(9):090008.

10. Wang X, Hong X, Zhan S, et al. (2014) Surface Plasmon Resonance Sensing Technology and Bioanalytical Instrument. Progress in Chemistry -Beijing- 26(7):1143-1159.

11. Yang X, Lu Y, Liu B, Yao J. (2016) Temperature Sensor Based on Photonic Crystal Fiber Filled With Liquid and Silver Nanowires. IEEE Photonics Journal 8(3):1-1.

12. Zhao Y, Deng Z, Hu H. (2015) Fiber-Optic SPR Sensor for Temperature Measurement. IEEE Transactions on Instrumentation & Measurement 64(11):3099-3104.

13. Luan N, Ding C, Yao J. (2016) A Refractive Index and Temperature Sensor Based on Surface Plasmon Resonance in an
Exposed-Core Microstructured Optical Fiber. IEEE Photonics Journal 8(2):1-1.

14. Lu M, Zhang X, Liang Y, et al. (2016) Liquid crystal filled surface plasmon resonance thermometer. Optics Express 24(10):10904.

15. Zhu C, Tan C, Wang Y, et al. (2017) Photonic Crystal Fiber High Sensitivity Magnetic Field and Temperature Sensor Based on Surface Plasma Resonance Effect and Defect Coupling. Chinese Journal of Lasers (03):253-261.

16. Liu X, Cheng H, Jiao Z, et al. (2019) Temperature sensing characteristics of symmetric structured photonic crystals in optical fibers. Laser & Infrared 49(04):477-481.

17. Samoc A. (2003) Dispersion of refractive properties of solvents: Chloroform, toluene, benzene, and carbon disulfide in ultraviolet, visible, and near-infrared. Journal of Applied Physics 94(9):6167-6174.

18. Vial A, Grimault A S, Macias D, et al. (2005) Improved analytical fit of gold dispersion: Application to the modeling of extinction spectra with a finite-difference time-domain method. Physical Review B Condensed Matter 71(8):85416.

19. Fainman Y, Lee L, Psaltis D, et al. (2009) Optofluidics: Fundamentals, Devices, and Applications. McGraw-Hill, Inc.

20. Zhang X, Yu Y, Zhu C, et al. (2013) Miniature End-Capped Fiber Sensor for Refractive Index and Temperature Measurement. IEEE Photonics Technology Letters 26(1):7-10.

21. Park C S, Joo K I, Kang S W, et al. (2011) A PDMS-Coated Optical Fiber Bragg Grating Sensor for Enhancing Temperature Sensitivity. Journal of the Optical Society of Korea 15(4):329-334.

22. Hernández-Romano, Iván, Cruz-Garcia M A, Moreno-Hernández, Carlos, et al. (2016) Optical fiber temperature sensor based on a microcavity with polymer overlay. Optics Express 24(5):5654.

23. Dash J N, Jha R. (2015) On the Performance of Graphene-Based D-Shaped Photonic Crystal Fibre Biosensor Using Surface Plasmon Resonance. Plasmonics 10(5):1123-1131.

24. Wang X, Li S, Chen H, et al. (2016) Compatibility of Temperature Sensor and Polarization Filter Based on Au Film and Glycerin Selectively Infilling Photonic Crystal Fibers. Plasmonics 11(5):1-7.

25. Liu H, Bai B, Zhang Y, et al. (2020) High-sensitivity temperature measurement of gold-PDMS-coated photonic crystal fiber based on SPR effect. Chinese Journal of Lasers (04):210-216.

26. Peng Y, Hou J, Huang Z, et al. (2012) Temperature sensor based on surface plasmon resonance within selectively coated photonic crystal fiber. Applied Optics 51(26):6361-6367.

27. Li X, Zhao Y, Zhou X, et al. (2018) High sensitivity all-fiber Sagnac interferometer temperature sensor using a selective ethanolfilled photonic crystal fiber. Instrumentation Science & Technology 46(3).

28. Geng Y, Li X, Tan X, et al. (2013) Compact and Ultrasensitive Temperature Sensor With a Fully Liquid-Filled Photonic Crystal Fiber Mach-Zehnder Interferometer. IEEE Sensors Journal 14(1):167-170.

29. Liu Z, Liu L, Zhu Z, et al. (2016) Whispering gallery mode temperature sensor of liquid microresonastor. Optics Letters 41(20):4649.