D-shaped Photonic Crystal Fiber Based on Surface Plasmon Resonance Sensor with Metal Nanodimers Array

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Abstract

A D-shaped photonic crystal fiber (PCF) sensor with metal nanodimers array is presented and demonstrated for analyte detection with refractive index (RI) ranging from 1.28 to 1.37. In contrast to previous D-shaped PCF sensors, the coupling system is composed of Au-Ag nanodimers array, Silver (Ag) nanowires are arranged under the Gold (Au) array on the D-shaped surface, which cause the electric field within a confined volume is strongly enhanced, and the sensitivity of the surface plasmon resonance to dielectric environment of this volume to be promoted by near-field coupling. The finite element method (FEM) is adopted to numerical investigate the coupling characteristics and sensing performance of the PCF sensor in the near-infrared region. An average wavelength sensitivity (WS) of 14021 nm/RIU is attained, and a maximum WS of 16380 nm/RIU is acquired with a supernal RI resolution of 6.11×10^{-6} RIU, which has an excellent application prospect in the fields of biological, biochemical and environmental detection.

Full Text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the latest manuscript can be downloaded and [accessed as a PDF](#).

Tables

Table 1 Values of the experimental data of bulk **Au, Ag**

Symbol	ϵ_m	$\omega_D/2\pi(\text{THz})$	$\gamma_D/2\pi(\text{THz})$	$\Gamma_L/2\pi(\text{THz})$	$\Omega_L/2\pi(\text{THz})$	$\Delta\epsilon$
Au	5.9673	2113.6	15.92	104.86	650.07	1.09
Ag	2.4064	2214.6	4.8	620.7	1330.1	1.664

Table 2 Effect of width (l_{Au}) and thickness (t_{Au}) on loss, λ_{peak} , SW, and R

Thickness (t_{Au} , nm)	Width (l_{Au} , nm)	Peak loss (dB/cm)		Resonance wavelength (λ_{peak} , nm)		SW (nm/RIU)	R (RIU ⁻¹)
		$n_a=1.33$	$n_a=1.34$	$n_a=1.33$	$n_a=1.34$		
60	80	755.89	716.43	1681.4	1542.5	13890	$7.20 \cdot 10^{-6}$
60	100	872.24	839.17	1699.3	1560.9	13840	$7.23 \cdot 10^{-6}$
60	120	841.71	817.12	1743.3	1605.2	13810	$7.24 \cdot 10^{-6}$
60	140	814.23	792.16	1761.3	1623.4	13790	$7.25 \cdot 10^{-6}$
40	120	798.28	769.54	1593.0	1456.9	13610	$7.35 \cdot 10^{-6}$
60	120	841.71	817.12	1743.3	1605.3	13810	$7.24 \cdot 10^{-6}$
80	120	793.81	773.16	1819.4	1678.2	14120	$7.08 \cdot 10^{-6}$

Table 3 Effect of d_3 on λ_{peak} , SW, and R

d_{Ag} (μm)	λ_{peak} (nm)		SW (nm/RIU)	R(RIU ⁻¹)
	1.33	1.34		
1.6	1785.5	1643.2	14230	$7.03 \cdot 10^{-6}$
2.0	1743.3	1605.2	13810	$7.24 \cdot 10^{-6}$
2.4	1682.1	1548.0	13410	$7.46 \cdot 10^{-6}$

Table 4 Effect of Au nanoarray lattice spacing (Λ_2) and Au-Ag dimer gap (Λ_3) on loss, λ_{peak} , S_W , and R

		Peak loss (dB/cm)		λ_{peak} (nm)		SW (nm/RIU)	R (RIU ⁻¹)
Λ_2 (μm)	Λ_3 (nm)	$n_a=1.33$	$n_a=1.34$	$n_a=1.33$	$n_a=1.34$		
0.7	80	363.52	344.66	1670.1	1528.6	14150	7.07×10^{-6}
0.8	80	841.71	817.12	1743.3	1605.2	13810	7.24×10^{-6}
0.9	80	750.21	729.13	1818.2	1682.7	13550	7.38×10^{-6}
0.8	60	737.78	714.32	1688.2	1553.8	13440	7.44×10^{-6}
0.8	80	841.71	817.12	1743.3	1605.1	13820	7.24×10^{-6}
0.8	100	917.17	895.96	1825.4	1684.3	14110	7.08×10^{-6}

Table 5 Performance analysis comparison of the proposed sensor with different analyte refractive index.

n_a (RIU)	λ_{peak} (nm)	α_{Loss} (dB/cm)	$\Delta\lambda_{\text{peak}}$ (nm)	SW (nm/RIU)	R (RIU)
1.28	2427.5	918.17	139.5	13950	7.17×10^{-6}
1.29	2288.0	908.61	137.3	13730	7.28×10^{-6}
1.30	2150.7	896.47	136.0	13600	7.35×10^{-6}
1.31	2014.7	881.19	135.4	13540	7.39×10^{-6}
1.32	1879.3	863.25	136.0	13600	7.35×10^{-6}
1.33	1743.3	841.71	138.2	13820	7.24×10^{-6}
1.34	1605.1	816.87	142.3	14230	7.02×10^{-6}
1.35	1462.8	789.10	149.9	14990	7.04×10^{-6}
1.36	1312.9	757.82	163.8	16380	6.11×10^{-6}
1.37	1149.1	589.62	N/A	N/A	N/A

Table 6 Performance Comparison Between the Proposed Sensor and the Existing SPR Sensors

Optical Structure and Refs.	WS (nm/RIU)	R (RIU)	R ²	Detection range (RIU)
D-shaped with metal array [30]	7000	1.43×10^{-6}	0.988	1.32-1.38
D-shaped with film [44]	10200 11000(max)	-	-	1.33-1.39
Dual-side polished with film [45]	10650 12400(max)	9.39×10^{-6}	0.99692	1.39-1.42
Air-Core [46]	11700	8.66×10^{-6}	-	1.33-1.41
D-shaped [47]	11500	8.7×10^{-6}	0.99519	1.37-1.37
Big open rings [48]	12400	8.06×10^{-6}	0.9992	1.22-1.36
Present work	14021 16380(max)	7.13×10^{-6}	0.9994	1.28-1.37

Figures

Figure 1

Cross schematic of the proposed D-shaped PCF sensor

Figure 2

(a) The wavelength dependence dispersion relation of core mode and SPP modes, and loss spectra when the RI of the analyte $n_a=1.33$, (b) the losses of core mode and SPP mode in X- polarization and Y- polarization

Figure 3

At $n_a= 1.33$, electric field distributions of (a) x-pol core mode, (b) x-pol SPP mode, (c) y-pol core mode and (d) y-pol SPP mode at wavelength of 1300 nm, (e) x-pol core mode and (f) x-pol SPP mode at wavelength of 1743.3 nm, (g) y-pol core mode and (h) y-pol SPP mode at wavelength of 2050.0 nm.

Figure 4

The effect of hole spacing change on loss spectra of the core mode

Figure 5

The corresponding confinement losses spectra of core mode with different quantities of metal nanodimers

Figure 6

The effect of hole spacing change on loss spectra of the core mode

Figure 7

(a) Variation of confinement loss spectra for different d_1 ($d_2=0.80 \mu\text{m}$). (b) Variation of confinement loss spectra for different d_2 ($d_1=1.0 \mu\text{m}$).

Figure 8

(a) Confinement loss spectra for different l_{Au} ($t_{Au}=120\text{nm}$). (b) Confinement loss spectra for different t_{Au} ($l_{Au}=60\text{nm}$).

Figure 9

Variation of confinement loss spectra for the diameter of dag

Figure 10

(a) The corresponding losses spectra of core mode with different Au arrays lattice spacing (Λ_2), (b) The corresponding losses spectra of core mode with different dimers gap (Λ_3)

Figure 11

The corresponding confinement losses spectra of core mode with different pitch between metal wires dag

Figure 12

(a) Confinement loss spectra of the proposed sensor when RI increases from 1.28 to 1.37, (b) the linear fitting curve of resonant wavelength with respect to n_a