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Performances of different metals in optical fibre-based surface plasmon resonance sensor

NAVNEET K SHARMA
Department of Physics, Jaypee Institute of Information Technology, A-10, Sector-62, Noida 201 307, India
E-mail: navneetk.sharma@jiit.ac.in

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Abstract. The capability of various metals used in optical fibre-based surface plasmon resonance (SPR) sensing is studied theoretically. Four metals, gold (Au), silver (Ag), copper (Cu) and aluminium (Al) are considered for the present study. The performance of the optical fibre-based SPR sensor with four different metals is obtained numerically and compared in detail. The performance of optical fibre-based SPR sensor has been analysed in terms of sensitivity, signal-to-noise (SNR) ratio and quality parameter. It is found that the performance of optical fibre-based SPR sensor with Au metal is better than that of the other three metals. The sensitivity of the optical fibre-based SPR sensor with 50 nm thick and 10 mm long Au metal film of exposed sensing region is 2.373 μm/RIU with good linearity, SNR is 0.724 and quality parameter is 48.281 RIU^{-1}. The thickness of the metal film and the length of the exposed sensing region of the optical fibre-based SPR sensor for each metal are also optimized.

Keywords. Optical fibre; surface plasmon resonance; sensor.

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1. Introduction

For the past few years, intense investigations were done on various sensing techniques, which may be employed for quick and accurate measurements of several physical, chemical and biochemical parameters. Liedberg *et al* [1] were the first to exploite surface plasmon resonance (SPR) for chemical sensing. Since then, the principle of SPR sensing has been studied intensively [2–4]. Collective resonating oscillation of free electrons may exist on the plasma surface (like, metal), giving rise to a charge density wave propagating along the plasma surface. This transverse wave is known as the surface plasmon wave. When the wave vector and the frequency of the incident p-polarized light (electric field vector parallel to the incident plane) coincide with those of the surface plasmon wave, this light resonantly excites the surface plasmon wave, propagating along the metal–dielectric

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interface. The resonance condition depends on the incident angle, wavelength of the light and the dielectric constants of both the metal and the dielectric. A sharp dip appears in the spectrum of the output signal at the resonance angle (angular interrogation) or at the resonance wavelength (spectral interrogation). The angle or the wavelength at which the resonant excitation of the surface plasmon occurs is very sensitive to variations in the refractive index of the dielectric adjacent to the metal. Hence, the variations in the refractive index of the sensed (dielectric) medium can be detected by measuring the resonance angle or the resonance wavelength. For observing SPR, Kretschmann's configuration is most widely used over other SPR sensing structures [5–7]. In the Kretschmann's configuration, a high refractive index prism is coated with a thin metal film (such as silver or gold) touching the sample (sensing medium). Surface plasmon waves are excited by evanescent waves from a high refractive index prism at the total reflection condition. The optical fibre-based SPR sensing has many advantages such as simplified and flexible optical design, development of remote sensing, continuous analysis and *in situ* monitoring [8–10] over the prism-based SPR sensing. Many researchers have demonstrated the optical fibre-based SPR sensing experimentally. Mitsushio *et al* have shown the aluminium deposited SPR-based optical fibre sensor [11]. Recently a SPR-based fibre optic sensor has been proposed for detecting the low water content in ethanol [12].

In this paper, optical fibre-based SPR phenomenon has been theoretically investigated for four metals: gold (Au), silver (Ag), copper (Cu) and aluminium (Al). The spectral interrogation method is used for the analysis of SPR-based fibre-optic sensor. In this method, the wavelength of the light from the polychromatic source is varied and the corresponding transmitted power through the optical fibre is measured. At resonance wavelength, a sharp dip in transmitted power occurs. The resonance wavelength depends on the refractive index of the sensing medium. The detailed analysis is carried out separately for all the four metals. Each metal-based SPR sensor is evaluated theoretically in terms of its sensitivity, signal-to-noise ratio and quality parameter. The performance of the SPR sensor based on four different metals has been compared to predict the proper metal suitable for best sensing conditions. The present study reveals that the optical fibre-based SPR sensor with Au metal shows better performance than that of the other three metals-based SPR sensors. The thickness of metal film and the length of the exposed sensing region of the optical fibre-based SPR sensor for each metal are also optimized.

2. Theory

The SPR sensing is based on the principle of attenuated total reflection (ATR) with Kretschmann's configuration. In the optical fibre-based SPR sensor, a sensing system consisting of a fibre core–metal film–sensing medium is considered as shown in figure 1.

The plastic cladding around the core from the middle portion of a step index multimode PCS fibre is removed and is then coated with a thin metal (Au, Ag, Cu or Al) film of thickness d. This film is finally surrounded by the sensing medium. The light from a broadband (polychromatic) source is launched into one end of the fibre with proper optics and the transmitted light is detected at the other end of the fibre.

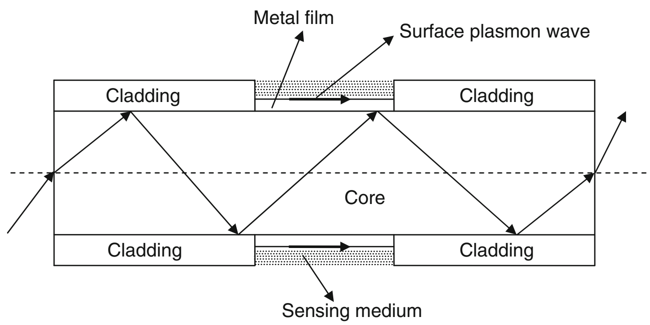

Figure 1. Schematic diagram of an SPR sensor based on optical fibre.

2.1 *Layer I (fibre core)*

This layer is made of the core of the optical fibre which is assumed to be made of fused silica. The refractive index of the fused silica varies with wavelength according to Sellmeier dispersion relation as

$$n_1(\lambda) = \sqrt{1 + \frac{a_1\lambda^2}{\lambda^2 - b_1^2} + \frac{a_2\lambda^2}{\lambda^2 - b_2^2} + \frac{a_3\lambda^2}{\lambda^2 - b_3^2}}, \tag{1}$$

where λ is the wavelength in μm and a_1, a_2, a_3, b_1, b_2 and b_3 are Sellmeier coefficients. The values of these coefficients are given as: $a_1 = 0.6961663$, $a_2 = 0.4079426$, $a_3 = 0.8974794$, $b_1 = 0.0684043\ \mu$m, $b_2 = 0.1162414\ \mu$m and $b_3 = 9.896161\ \mu$m [13].

2.2 *Layer II (metal film)*

This layer is made of metal. The dielectric constant of any metal can be calculated according to the Drude model as

$$\varepsilon_{\mathrm{m}}(\lambda) = \varepsilon_{mr} + i\varepsilon_{mi} = 1 - \frac{\lambda^2\lambda_{\mathrm{c}}}{\lambda_{\mathrm{p}}^2(\lambda_{\mathrm{c}} + i\lambda)}. \tag{2}$$

Here, λ_{p} and λ_{c} are the plasma wavelength and the collision wavelength of the metal, respectively. $\lambda_{\mathrm{p}} = 1.6826 \times 10^{-7}$ m, 1.4541×10^{-7} m, 1.3617×10^{-7} m, 1.0657×10^{-7} m and $\lambda_{\mathrm{c}} = 8.9342 \times 10^{-6}$ m, 1.7614×10^{-5} m, 4.0852×10^{-5} m, 2.4511×10^{-5} m for Au, Ag, Cu, Al metals respectively [14].

2.3 *Layer III (sensing medium)*

This layer is made of the sensing medium. The dielectric constant of the sensing medium is ε_{s}. If n_{s} is the refractive index of the sensing medium, then $\varepsilon_{\mathrm{s}} = n_{\mathrm{s}}^2$. The resonance condition for the excitation of surface plasmon wave is given as

$$\frac{2\pi}{\lambda} n_1 \sin\theta = \mathrm{Re}\left\{K_{\mathrm{sp}}\right\}, \tag{3}$$

where

$$K_{\mathrm{sp}} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_{\mathrm{m}}\varepsilon_{\mathrm{s}}}{\varepsilon_{\mathrm{m}}+\varepsilon_{\mathrm{s}}}} = \frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon_{\mathrm{m}}n_{\mathrm{s}}^2}{\varepsilon_{\mathrm{m}}+n_{\mathrm{s}}^2}}$$

is the propagation constant of the surface plasmon and c is the speed of light in vacuum. The left-hand side of eq. (3) denotes the propagation constant of the light incident at an angle θ and the right-hand side shows the real part of the propagation constant of the surface plasmon.

2.4 *Reflection coefficient*

The expression for the amplitude reflection coefficient of the p-polarized incident light can be obtained by using the matrix method for N-layer model [15]. The matrix method is very easy and accurate due to absence of approximations and can be applied to a system containing any number of layers. The layers are considered to be stacked along the z-axis. For an arbitrary medium layer, the thickness is d_k; dielectric constant is ε_k; permeability is μ_k and refractive index is n_k. The tangential fields at the first boundary $z = z_1 = 0$ are related to those at the final boundary $z = z_{N-1}$ by

$$\begin{bmatrix} U_1 \\ V_1 \end{bmatrix} = M \begin{bmatrix} U_{N-1} \\ V_{N-1} \end{bmatrix}. \tag{4}$$

Here, U_1 and V_1 are the tangential components of the electric and magnetic fields respectively at the boundary of the first layer. U_{N-1} and V_{N-1} are the corresponding fields at the boundary of Nth layer. M is the characteristic matrix of the combined structure and is given as

$$M = \prod_{k=2}^{N-1} M_k = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \tag{5}$$

with

$$M_k = \begin{bmatrix} \cos\beta_k & (-i\sin\beta_k)/q_k \\ -iq_k\sin\beta_k & \cos\beta_k \end{bmatrix}, \tag{6}$$

where

$$q_k = \sqrt{\frac{\mu_k}{\varepsilon_k}}\cos\theta_k = \frac{\sqrt{(\varepsilon_k - n_1^2\sin^2\theta_1)}}{\varepsilon_k} \tag{7}$$

and

$$\beta_k = \frac{2\pi}{\lambda}n_k\cos\theta_k(z_k - z_{k-1}) = \frac{2\pi d_k}{\lambda}\sqrt{(\varepsilon_k - n_1^2\sin^2\theta_1)}. \tag{8}$$

The amplitude reflection coefficient of the p-polarized incident light is given as

$$r_p = \frac{(M_{11} + M_{12}q_N)\,q_1 - (M_{21} + M_{22}q_N)}{(M_{11} + M_{12}q_N)\,q_1 + (M_{21} + M_{22}q_N)}. \tag{9}$$

Finally, the reflection coefficient (reflectance) of the p-polarized incident light is given by

$$R_{\mathrm{p}} = \left|r_{\mathrm{p}}\right|^2 . \tag{10}$$

2.5 *Transmitted power*

Considering that all the guided rays are launched in the fibre using a collimated source and a microscope objective, the angular power distribution of rays guided in the fibre is given as [16]

$$\mathrm{d}P \propto \frac{n_1^2 \sin\theta \cos\theta}{\left(1 - n_1^2 \cos^2\theta\right)^2} \mathrm{d}\theta, \tag{11}$$

where θ is the angle of the ray with the normal to the core-cladding interface and n_1 is the refractive index of the core of the fibre. To calculate the effective transmitted power, the reflectance (R_{p}) for a single reflection is raised to the power of the number of reflections the specific propagating angle undergoes with the sensor interface. Hence, for p-polarized light, the generalized expression for the normalized transmitted power in an optical fibre-based SPR sensor will be given as

$$P_{\mathrm{trans}} = \frac{\int_{\theta_{\mathrm{cr}}}^{\pi/2} R_{\mathrm{p}}^{N_{\mathrm{ref}}(\theta)} [n_1^2 \sin\theta \cos\theta / \left(1 - n_1^2 \cos^2\theta\right)^2] \mathrm{d}\theta}{\int_{\theta_{\mathrm{cr}}}^{\pi/2} [n_1^2 \sin\theta \cos\theta / \left(1 - n_1^2 \cos^2\theta\right)^2] \mathrm{d}\theta}, \tag{12}$$

where

$$N_{\mathrm{ref}}(\theta) = \frac{L}{D \tan\theta} \tag{13}$$

and

$$\theta_{\mathrm{cr}} = \sin^{-1}\left(\frac{n_{\mathrm{cl}}}{n_1}\right). \tag{14}$$

Here, $N_{\mathrm{ref}}(\theta)$ is the total number of reflections performed by a ray making an angle θ with the normal to the core–metal layer interface in the sensing region. L and D are the length of the exposed sensing region and the fibre core diameter respectively and θ_{cr} is the critical angle of the fibre and n_{cl} is the refractive index of the cladding of the fibre.

2.6 *Sensitivity, signal-to-noise ratio and quality parameter*

Resonance wavelength (λ_{res}) is determined corresponding to the refractive index of the sensing medium (n_{s}) in the SPR sensor based on spectral interrogation. If the refractive index of the sensing medium is altered by δn_{s}, the resonance wavelength shifts by $\delta\lambda_{\mathrm{res}}$. The sensitivity ($S_n$) of a SPR sensor with spectral interrogation is defined as [17]

$$S_n = \frac{\delta\lambda_{\mathrm{res}}}{\delta n_{\mathrm{s}}}. \tag{15}$$

The signal-to-noise ratio (SNR) or resolution of the SPR sensor is inversely proportional to the width of the SPR response curve. If $\delta\lambda_{0.5}$ is the spectral width of the SPR response curve corresponding to 50% reflectivity, the signal-to-noise ratio of a SPR sensor with spectral interrogation is defined as [17]

$$\mathrm{SNR} = \frac{\delta\lambda_{\mathrm{res}}}{\delta\lambda_{0.5}}. \tag{16}$$

To denote the overall performance of the sensor, a quality parameter is introduced. If $\delta\lambda_{0.5}$ is the spectral width of the SPR response curve corresponding to 50% reflectivity (full-width at half-maximum of the SPR dip), the quality parameter (χ) is defined as [18]

$$\chi = \frac{S_n}{\delta\lambda_{0.5}}. \tag{17}$$

3. Results and discussion

For numerical calculations, different solutions of glycerine in water with concentrations that provide refractive indices of 1.320, 1.325, 1.330 and 1.335 are considered using the following values of the parameters: Numerical aperture of the fibre = 0.18, fibre core diameter $D = 600$ μm, length of the exposed sensing region $L = 10$ mm and thickness of the metal film $d = 50$ nm.

Figure 2 shows the SPR transmittance curves for all the four metals as the refractive index of the sensing medium changes from 1.320 to 1.335 in steps of 0.005. From figure 2a, it is clear that the resonance wavelength shifts from 0.54 μm to 0.5756 μm for Au metal as the refractive index of the sensing medium varies from 1.320 to 1.335. Similarly, from figure 2b, it is obvious that the resonance wavelength shifts from 0.4659 μm to 0.50 μm for Ag metal as the refractive index of the sensing medium changes from 1.320 to 1.335. Also, figures 2c and 2d reveal that the resonance wavelength shifts from 0.435 μm to 0.465 μm for Cu metal and 0.335 μm to 0.36 μm for Al metal respectively, as the refractive index of the sensing medium changes from 1.320 to 1.335. Thus the shift in the resonance wavelength is different for different metals and it is maximum for Au metal and minimum for Al metal. Also, these figures reveal that Al metal exhibits the sharpest SPR dip while Au metal has the broadest SPR curve among all the four metals.

Figure 3 shows the variation of resonance wavelength with refractive index of the sensing medium (slope of the resonance wavelength over the refractive index, i.e. sensitivity) for all the four metals. The resonance wavelength for each metal increases linearly with the increase in refractive index of the sensing medium. The variation of resonance wavelength with the refractive index of the sensing medium for all the four metals follows the same pattern. The slope of the resonance wavelength over the refractive index for the Au metal is highest among all the four metals while the slope of resonance wavelength over the refractive index for Al metal is the lowest. However, the slope of the resonance wavelength over the refractive index for Ag metal is larger than that of Cu metal but is smaller than that of Au metal. Thus, the shifts in resonance wavelength for all the four metals are nearly linear over the whole range of refractive indices, i.e. 1.320 to 1.335, of the sensing

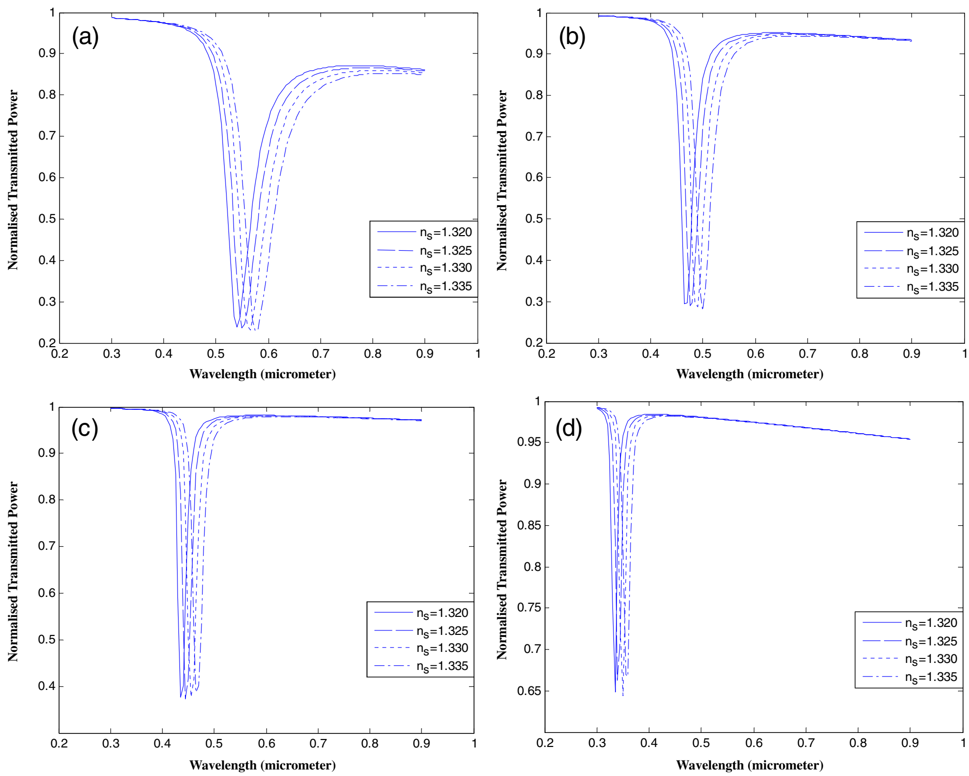

Figure 2. Transmittance curves of optical fibre-based SPR sensor with (**a**) Au, (**b**) Ag, (**c**) Cu, (**d**) Al metals.

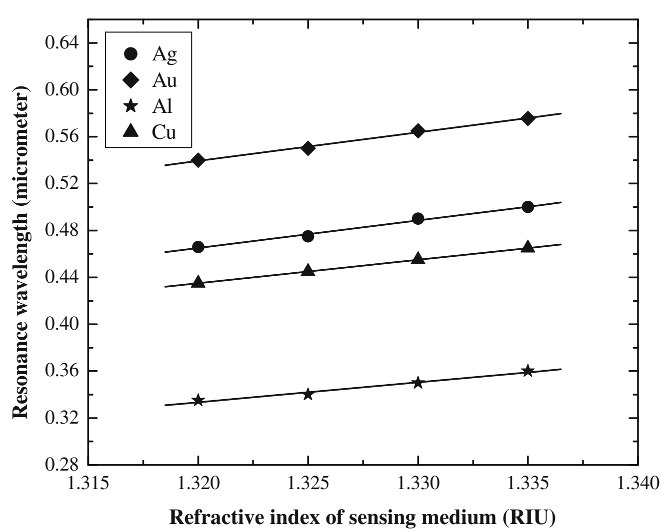

Figure 3. Variation of resonance wavelength with refractive index of the sensing medium for the four metals.

Table 1. Comparison of sensitivity of the optical fibre-based SPR sensor with different metals.

Metal layer	Sensitivity S_n (μm/RIU)
Gold (Au)	2.373
Silver (Ag)	2.273
Copper (Cu)	2
Aluminium (Al)	1.667

medium. The sensitivity of the optical fibre-based SPR sensor with four different metals is compared in table 1.

It can be seen from table 1, that the sensitivity for Au metal-based SPR sensor is the largest (2.373 μm/RIU) among all the metals-based SPR sensors. Also, Al metal-based SPR sensor has the least sensitivity (1.667 μm/RIU). Therefore, the sensitivity, i.e. the shift in resonance wavelength per unit change in refractive index of the sensing medium, is maximum for Au metal and minimum for Al metal. However, the sensitivity of Ag metal is greater than that of Cu metal but less than that of Au metal. Also, the sensitivity of Cu metal is greater than that of Al metal.

To see the effect of other two performance parameters (SNR and quality parameter), only three metals (Au, Ag and Cu) have been considered as Al metal provides the least sensitivity. The SNR and quality parameter of the optical fibre-based SPR sensor with three different metals are compared in table 2.

From table 2, it is obvious that the SPR sensor with Cu metal has the maximum SNR (2.5) and the maximum quality parameter (166.667 RIU^{-1}) and the SPR sensor with Au metal has the minimum SNR (0.724) and the minimum quality parameter (48.281 RIU^{-1}). However, the SPR sensor with Ag metal finds the values of SNR and quality parameter between those of Au and Cu metal-based SPR sensors.

Thus, from tables 1 and 2, it is clearly observed that the sensitivity of SPR sensor with Au metal is large but its SNR and quality parameter values are small. The sensitivity of Au metal-based SPR sensor is large because the shift in resonance wavelength for Au metal is large as the refractive index of the sensing medium is altered from 1.320 to 1.335. However, the smaller values of SNR and quality parameter for Au metal-based SPR sensor are due to the small value of FWHM for Au metal. Also the sensitivity of SPR sensor with Cu metal is small but its SNR and quality parameter values are large. Hence, in designing an optical fibre-based SPR sensor, the proper metal should be chosen

Table 2. Comparison of SNR and quality parameter of the optical fibre-based SPR sensor with different metals.

Metal layer	FWHM $\delta\lambda_{0.5}$ (μm)	SNR	Quality parameter χ (RIU^{-1})
Gold (Au)	0.04915	0.724	48.281
Silver (Ag)	0.02205	1.546	103.084
Copper (Cu)	0.012	2.5	166.667

depending upon the performance parameter of interest, i.e. either sensitivity or SNR along with quality parameter, because Au metal provides high sensitivity but smaller values of SNR and quality parameter while Cu metal provides small sensitivity but higher values of SNR and quality parameter.

Therefore, taking all the three parameters (sensitivity, SNR and quality parameter) into consideration, it can be concluded that the performance of optical fibre-based SPR sensor with Au metal is better than that of Ag, Cu and Al metals-based SPR sensors. However, it is also important to note that Ag and Cu metals should be avoided in designing an optical fibre-based SPR sensor because these metals are prone to oxidation and are not chemically much stable.

To obtain maximum values of performance parameters (sensitivity, signal-to-noise ratio and quality parameter), it will be better to identify appropriate values of thickness of metal film and the length of the exposed sensing region of the optical fibre-based SPR sensor for each metal. Metal film thickness of the optical fibre-based SPR sensor with four different metals is optimized in table 3.

In table 3, the sensitivity, SNR and quality parameter of the optical fibre-based SPR sensor with four different metals are evaluated for 20, 30, 40, 50, 60 and 70 nm metal film thicknesses. It is clear from the table that for 60 nm thickness of Au metal, the sensitivity, SNR and quality parameter of the optical fibre-based SPR sensor with Au metal are maximum (2.667 μm/RIU, 1.966 and 131.057 RIU^{-1} respectively) compared to that of other film thicknesses of Au metal. Similarly, these three parameters are maximum for 20 nm thickness of Ag metal (1.333 μm/RIU, 2.247 and 149.775 RIU^{-1} respectively), 30 nm thickness of Cu metal (1.667 μm/RIU, 3.030 and 202.060 RIU^{-1} respectively) and 40 nm thickness of Al metal (1.667 μm/RIU, 2.809 and 187.303 RIU^{-1} respectively). Therefore, the optimized metal film thicknesses of the optical fibre-based SPR sensor with Au, Ag, Cu and Al metals are 60, 20, 30 and 40 nm respectively.

Table 3. Optimization of the metal film thickness for the optical fibre-based SPR sensor with different metals.

Metal		Metal film thickness					
		$d = 20$ nm	$d = 30$ nm	$d = 40$ nm	$d = 50$ nm	$d = 60$ nm	$d = 70$ nm
Gold	S_n (μm/RIU)	1.653	1.667	2	2.333	2.667	2.427
(Au)	SNR	0.514	0.341	0.425	0.711	1.966	Negligible
	χ (RIU^{-1})	34.259	22.742	28.349	47.419	131.057	Negligible
Silver	S_n (μm/RIU)	1.333	2	2	2.333	2	2.333
(Ag)	SNR	2.247	0.849	0.901	1.584	Negligible	Negligible
	χ (RIU^{-1})	149.775	56.577	60.060	105.566	Negligible	Negligible
Copper	S_n (μm/RIU)	1	1.667	2	2	2.333	2
(Cu)	SNR	Negligible	3.030	1.699	2.489	Negligible	Negligible
	χ (RIU^{-1})	Negligible	202.060	113.314	165.975	Negligible	Negligible
Aluminum	S_n (μm/RIU)	Negligible	1.333	1.667	1.667	1.667	1.667
(Al)	SNR	Negligible	1.223	2.809	Negligible	Negligible	Negligible
	χ (RIU^{-1})	Negligible	81.529	187.303	Negligible	Negligible	Negligible

Table 4. Optimization of the length of the exposed sensing region for the optical fibre-based SPR sensor with different metals.

Metal		Length of the exposed sensing region				
		$L = 10$ mm	$L = 20$ mm	$L = 30$ mm	$L = 40$ mm	$L = 50$ mm
Gold (Au)	S_n (μm/RIU)	2.667	2.333	2.333	2.667	2.333
(Film thickness	SNR	2.030	0.666	0.465	0.409	0.281
$d = 60$ nm)	χ (RIU^{-1})	135.381	44.396	30.983	27.256	18.716
Silver (Ag)	S_n (μm/RIU)	1.333	1.333	1.333	1.333	1.333
(Film thickness	SNR	2.484	0.448	0.306	0.241	0.201
$d = 20$ nm)	χ (RIU^{-1})	165.590	29.854	20.367	16.060	13.390
Copper (Cu)	S_n (μm/RIU)	1.667	1.667	2	1.667	1.667
(Film thickness	SNR	3.086	0.859	0.756	0.517	0.446
$d = 30$ nm)	χ (RIU^{-1})	205.802	57.285	50.378	34.442	29.741
Aluminum (Al)	S_n (μm/RIU)	1.667	1.333	1.333	1.333	1.333
(Film thickness	SNR	2.874	1.294	1.026	0.889	0.795
$d = 40$ nm)	χ (RIU^{-1})	191.609	86.278	68.359	59.244	53.002

The length of the exposed sensing region of the optical fibre-based SPR sensor with four different metals is optimized in table 4.

In table 4, the sensitivity, SNR and quality parameter of the optical fibre-based SPR sensor with Au, Ag, Cu and Al metals of film thicknesses 60, 20, 30 and 40 nm respectively are evaluated for 10, 20, 30, 40 and 50 mm lengths of the exposed sensing region. It is obvious from the table that for 60 nm thick film of Au metal and 10 mm length of exposed sensing region, the sensitivity, SNR and quality parameter of the optical fibre-based SPR sensor are maximum (2.667 μm/RIU, 2.030 and 135.381 RIU^{-1} respectively) compared to that of other lengths of exposed sensing region. Similarly, these three parameters are maximum for 20 nm thick film of Ag metal and 10 mm length of exposed sensing region (1.333 μm/RIU, 2.484 and 165.590 RIU^{-1} respectively), 30 nm thick film of Cu metal and 10 mm length of exposed sensing region (1.667 μm/RIU, 3.086 and 205.802 RIU^{-1} respectively) and 40 nm thick film of Al metal and 10 mm length of exposed sensing region (1.667 μm/RIU, 2.874 and 191.609 RIU^{-1} respectively). Thus, the sensitivity, SNR and quality parameter of the optical fibre-based SPR sensor are largest for 10 mm length of exposed sensing region for each metal. Therefore, the optimized length of the exposed sensing region of the optical fibre-based SPR sensor with Au, Ag, Cu and Al metals is 10 mm.

4. Conclusions

An optical fibre-based SPR sensor with four different metals (Au, Ag, Cu and Al) has been studied theoretically. The SPR sensor based on Au metal provides the largest sensitivity but the least values of SNR and quality parameter while the SPR sensor based on Cu metal provides the smallest sensitivity but the largest values of SNR and quality parameter.

Thus, among these four metals, no metal is capable to provide the highest values of all the three performance parameters (sensitivity, SNR and quality parameter) simultaneously. The Al metal-based SPR sensor is not recommended as the Al metal provides the least sensitivity. However, keeping all the three performance parameters into account, it can be concluded that the performance of the optical fibre-based SPR sensor with Au metal is better than that of Ag, Cu and Al metals-based SPR sensors. From the results, it is obvious that for the optical fibre-based SPR sensor with 50 nm thick film of Au metal and 10 mm length of exposed sensing region, the sensitivity approaches 2.373 μm/RIU with good linearity, SNR is 0.724 and quality parameter is 48.281 RIU^{-1}, which are better than that of other three metals-based SPR sensors. However, the optimized metal film thicknesses of optical fibre-based SPR sensor with Au, Ag, Cu and Al metals are found to be 60, 20, 30 and 40 nm respectively while the optimized length of exposed sensing region of optical fibre-based SPR sensor with each metal is 10 mm.

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References

[1] B Liedberg *et al*, *Sensors Actuat.* **B4**, 299 (1983)
[2] R D Harris and J S Wilkinson, *Sensors Actuat.* **B29**, 261 (1995)
[3] J Homola, *Sensors Actuat.* **B41**, 207 (1997)
[4] Z Salamon *et al*, *Biochim. Biophys. Acta* **1331**, 131 (1997)
[5] E Kretschmann and H Reather, *Z. Naturforsch.* **23**, 2135 (1968)
[6] A Otto, *Z. Phys.* **216**, 398 (1968)
[7] E Kretschmann, *Z. Phys.* **241**, 313 (1971)
[8] J Homola, *Sensors Actuat.* **B29**, 401 (1995)
[9] W B Lin *et al*, *Sensors Actuat.* **A84**, 198 (2000)
[10] A K Sharma and B D Gupta, *Sensors Actuat.* **B100**, 423 (2004)
[11] M Mitsushio *et al*, *Sensors Actuat.* **A163**, 1 (2010)
[12] S K Srivastava *et al*, *Sensors Actuat.* **B153**, 194 (2011)
[13] A K Ghatak and K Thyagarajan, *An introduction to fiber optics*, 1st ed (Cambridge, University Press, 1999) pp. 82–83
[14] M A Ordal *et al*, *Appl. Opt.* **22**, 1099 (1983)
[15] E Hecht, *Optics*, 4th ed (Pearson Education Inc., 2002) pp. 431–436
[16] B D Gupta *et al*, *Int. J. Optoelectron.* **8**, 409 (1993)
[17] A K Sharma and B D Gupta, *Opt. Commun.* **245**, 159 (2005)
[18] C Hu and D Liu, *Mod. Appl. Sci.* **4(6)**, 8 (2010)