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ARROW-B SURFACE PLASMON RESONANCE SENSORS IN AQUEOUS ENVIRONMENT

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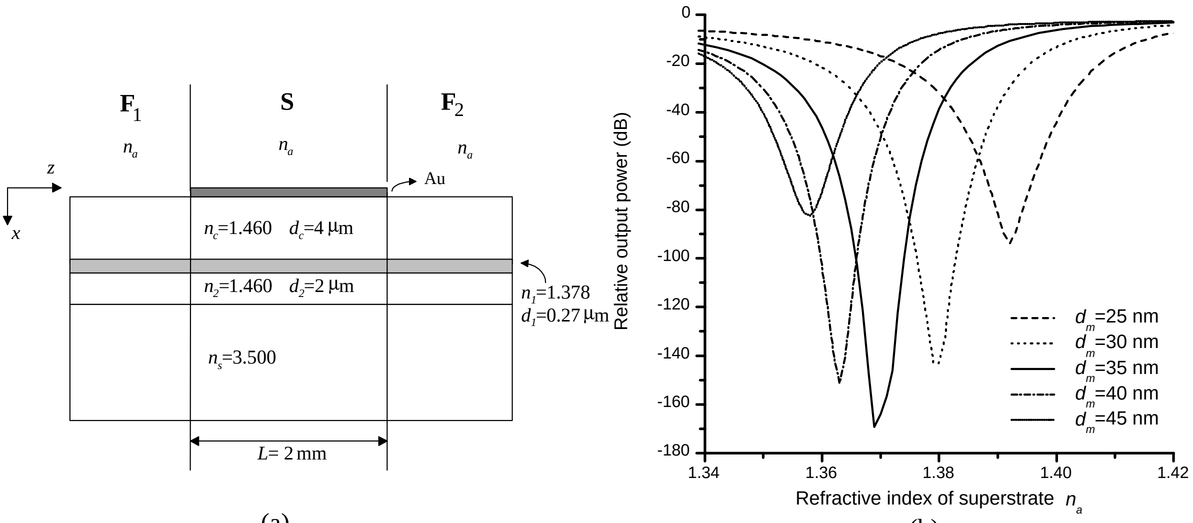
Abstract: ARROW-B surface plasmon resonance sensors operating in aqueous environment for biomolecular interaction analysis are investigated. The detectable changes of the refractive index down to the order of 10^{-5} can be achieved.

1. INTRODUCTION

Surface plasmon resonance (SPR) for use in biochemical sensing has been receiving growing research efforts [1]. Among several SPR sensor configurations, waveguide SPR sensors have many attractive features such as compact size, ruggedness, prospect of fabrication of multiple/multichannel sensors on a single chip [2], [3]. In contrast to conventional waveguides, antiresonant reflecting optical waveguides (ARROW's) utilizing antiresonant reflection as guiding mechanism instead of total internal reflection can perform low-loss single mode propagation with relatively large core size. Moreover, to support surface plasmon waves which are TM-polarized, polarization-insensitive ARROW-B [4] was adopted as the wave-guiding structure. In this presentation, design and characteristics of Au-coated ARROW-B SPR sensors will be discussed. An adhesion buffer layer of Cr is added between ARROW-B structure and the Au layer to enhance the adhesion. Furthermore, a dielectric overlay added onto the Au-metal layer is used to shift the operating range to the desired aqueous environment for biomolecular interaction analysis [5]. The issue of fabricating the devices will also be addressed.

2. DESIGN AND CHARACTERISTICS OF AN Au-COATED ARROW-B SPR SENSOR WITH A Cr BUFFER LAYER

The basic structure of an ARROW-B SPR sensor shown in Fig. 1(a) consists of three sections. Sections F_1 and F_2 are the input and output single-mode ARROW-B waveguides, and S is the sensing section which supports surface plasmon waves. Atop the waveguide core is a layer of Au thin film. The length of the sensing region is set to be 2 mm and the operating light wavelength is 0.6328 μm.



(a)

(b)

Figure 1: SPR sensor. (b) Dependence of the relative output power on the superstrate index.

When there is a variation in the refractive index of the environment (superstrate), the field profile of quasi-guided mode will change, and the output power through the sensor will be different. Fig. 1(b) shows the relative output powers versus superstrate index n_a for different thickness d_m of the gold layer. The minimum relative output powers corresponds to the best resonant coupling between the guided mode of the waveguide and the surface plasmon mode. Since the sensitivity of the sensor is proportional to the slope of the relative output power curve and $d_m = 35$ nm has the steepest slope on both sides of the valley, this thickness was chosen.

To enhance the adhesion of the Au layer to the waveguide core an adhesion buffer layer of Cr is added between them. The thickness of this layer ranging from 1 to 10 nm has been investigated. After adding an ultra-thin Cr layer, the device characteristics are nearly the same.

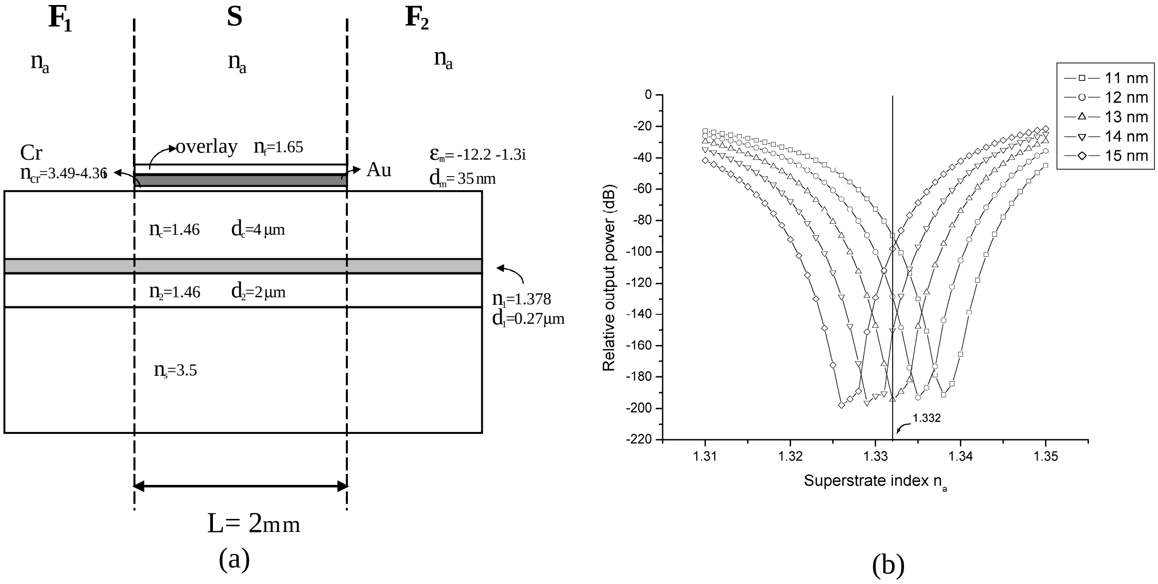
3. OVERLAY TUNING AND OPTIMIZATION

Although the presented ARROW-B SPR sensor is highly sensitive to superstrate index changes, the operating range for n_a around 1.370 is somewhat away from the desired aqueous environment for $n_a =$ 1.332. In order to shift the location of the minimum relative output power, a dielectric overlay was added atop the Au layer as shown in Fig. 2(a). The resonant refractive indices of the superstrate when the resonant coupling occurs with and without the dielectric overlay are governed by the following equation [3]:

$$\sqrt{\frac{\epsilon_{mr}\, n_{\mathrm{SPR},0}^2}{\epsilon_{mr} + n_{\mathrm{SPR},0}^2}} = \sqrt{\frac{\epsilon_{mr}\, n_{\mathrm{SPR},1}^2}{\epsilon_{mr} + n_{\mathrm{SPR},1}^2}} + \frac{2\pi}{\lambda}\frac{n_{\mathrm{SPR},1}}{\sqrt{-\epsilon_{mr}}}\left(n_f^2 - n_{\mathrm{SPR},1}^2\right) d_f, \tag{1}$$

where $n_{\mathrm{SPR},0}$ and $n_{\mathrm{SPR},1}$ denote the superstrate indices without and with the dielectric overlay, respectively. ϵ_{mr} is the real part of the relative permittivity of the metal, and n_f and d_f are the refractive index and the thickness of the dielectric overlay, respectively.

Based on Eq. (1), the overlay thickness d_f, as a function of the overlay index n_f, can be calculated. According to experimental investigations, materials like Al_2O_3, Y_2O_3 [3], Ta_2O_5 [7], etc., which have been successfully formed on the gold film, are proper candidates for the overlay. Here, Al_2O_3 ($n_f = 1.650$) was selected. Fig. 2(b) shows relative output powers as functions of the superstrate index for $d_f = 11$ to 15 nm.



(a)

(b)

Figure 2: (a) An ARROW-B SPR sensor with an adhesion layer and an overlay. (b) Relative output power vs. the superstrate index for $d_m = 35$ nm and $d_{Cr} = 3$ nm.

The sensing resolution or minimum detectable change in the superstrate index n_a defined as (2) is used as a measure [6]:

$$|\delta n_{min}| = \left|\frac{Mp(L)}{\frac{\partial p(L)}{\partial n}}\right|_{n=n_a}, \tag{2}$$

where $p(L)$ is the relative output , and M is the measurement precision of $p(L)$ as a percentage (typically, 1% [3]). A smaller $\mid \delta n_{min} \mid$ value stands for a better resolution.

Table 1 lists some sensing resolution values $|\delta n_{min}|$ at $n_a = 1.332$ for several Cr-thickness and overlay-thickness. When $d_{cr} = 3$ nm and $d_f = 14$ nm, the device has the best resolution as $|\delta n_{min}| = 3.7 \times 10^{-5}$. Compared with a conventional waveguide SPR sensor, which also works in aqueous environment but uses "wavelength" measurement, having resolution $\sim 6 \times 10^{-5}$ [7], it seems that our ARROW-B SPR sensor is quite competitive with the conventional waveguide. As for the prism SPR sensor and the grating SPR sensor with optical power resolution of 0.2% have resolutions of 5×10^{-5} and 2×10^{-4}, respectively [1]. To change our 1% optical power resolution into 0.2%, our device resolution becomes 7.4×10^{-6}, which shows better sensing ability than these two configurations.

Table 1: The sensing resolution $|\delta n_{min}|$ at $n_a = 1.332$ of Cr thicknesses ranging from 2 to 4 nm combined with the overlay thicknesses ranging from 12 to 15 nm.

Cr (nm) \ overlay (nm)	12	13	14	15		
2	8.77×10^{-5}	6.97×10^{-5}	-2.87×10^{-4}	-5.88×10^{-5}		
3	8.19×10^{-5}	8.60×10^{-5}	-3.70×10^{-5}	-7.01×10^{-5}		
4	8.00×10^{-5}	-2.85×10^{-4}	-6.69×10^{-5}	-8.12×10^{-5}		

4. SUMMARY

Au-coated ARROW-B SPR sensors operating in aqueous environment have been investigated. An ARROW-B SPR sensor with an adhesion buffer layer of Cr is more stable. This new layer is so thin that the characteristics of SPW hardly change. The resolution of $|\delta n_{min}| = 3.70 \times 10^{-5}$ can be achieved. The devices are suitable for bimolecular interaction analysis. In addition, the tolerances to each film thickness and index of the device have been investigated and will be discussed in the presentation. The issue of fabricating the devices will also be addressed.

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