An ARROW-B Surface Plasmon Resonance Sensor in Aqueous Environment

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Abstract – An ARROW-B (antiresonant reflecting optical waveguide, type B) surface plasmon resonance (SPR) sensor operating in aqueous environment is proposed. The characteristics and optimization of the Au-coated ARROW-B SPR sensor are discussed. The detectable changes of the refractive index down to the order of $10^{-5}$ can be achieved.

Index Terms – Waveguide sensors, surface plasmon resonance, antiresonant reflecting optical waveguides.

I. INTRODUCTION

Surface plasmon resonance for use in chemical and biochemical sensing has been receiving growing research efforts for the past two decades. 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 [1]. 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 [2] was adopted as the wave-guiding structure.

In this study, characteristics and design of ARROW-B SPR sensors were investigated. A dielectric overlay added onto the metal layer can be used to shift the operating range into the desired environment. A design example and the optimization of Au-coated ARROW-B SPR sensors are also presented.

II. CHARACTERISTICS AND DESIGN OF ARROW-B SPR SENSORS

The basic structure of an ARROW-B SPR sensor shown in Fig. 1 consists of three sections. Sections $F_1$ and $F_2$ are the input and output effective single-mode ARROW-B waveguides, and $S$ is the sensing section which supports surface plasmon waves. On top of the waveguide core is a layer of gold thin film. The length of the sensing region is assumed to be 2 mm.

![Figure 1 – Basic structure of an ARROW-B SPR sensor.](image)

When there is a variation in the refractive index of the environment (superstrate), the field...
profile of the quasi-guided mode will change, and the output power through the sensor will be different. The relative output power through the ARROW-B SPR sensor can be expressed as:

\[ p(L) = \left| a_0(L)/a_0(0) \right|^2, \quad (1) \]

where \( a_0(0) \) and \( a_0(L) \) are the complex amplitudes of the fundamental modes at the input and output of the sensor, respectively. Fig. 2 shows the relative output powers versus superstrate index \( n_a \) for different thickness of gold layer \( d_m \). The minimum relative output powers corresponds to the best resonant coupling between the surface plasmon mode and the fundamental mode of the waveguide. Since the sensitivity of the sensor is proportional to the slope of the relative output power curve, the one which has a steeper slope is more suitable for sensing. By a further comparison (not shown), we found that the curve for \( d_m = 35 \) nm has the steepest slope on both sides of the valley. As a result, the thickness of the gold layer of the ARROW-B SPR sensors was set to be 35 nm.

\[ \begin{align*}
\epsilon_{mr} n_{SPR,0}^2 & = \epsilon_{mr} n_{SPR,1}^2 \\
& + \frac{2\pi}{\lambda} n_{SPR,1} \left( n_f^2 - n_{SPR,1}^2 \right) d_f, \quad (2)
\end{align*} \]

where \( n_{SPR,0} \) and \( n_{SPR,1} \) denote the superstrate indices without and with the dielectric overlay, respectively. \( \epsilon_{mr} \) 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 overlay, respectively.

Recall that the superstrate index at the minimum output power for \( d_m = 35 \) nm is \( n_a = 1.370 \). By specifying \( n_f = 1.650 \) (the refractive index of \( \text{Al}_2\text{O}_3 \) at \( \lambda = 0.6328 \) \( \mu \)m) and replacing \( n_{SPR,0} \) with 1.370 into (2), it can be found that the thickness of the \( \text{Al}_2\text{O}_3 \) overlay \( d_f \) corresponding to \( n_{SPR,1} = 1.320 \) and 1.340 are 18 and 12 nm, respectively. The effect of overlay tuning could be seen from Fig. 4.
To optimize the Au-coated ARROW-B SPR sensor in aqueous environment, the sensing resolution or minimum detectable change in the superstrate index \( n_a \) defined as (3) could be used as a measure: [4]

\[
|\delta n_{\text{min}}| = \left. \frac{M}{\Delta p(L)} \right|_{n=n_a}, \tag{3}
\]

where \( p(L) \) is the relative output power defined as (1), and \( M \) is the measurement precision of \( p(L) \) as a percentage (typically, 1% [3]).

Fig. 5 shows the relative output power versus superstrate index for different overlay thickness. Based on the result, the minimum detectable changes can be calculated and are \( 8.50 \times 10^{-5} \), \( 5.56 \times 10^{-5} \), \( 6.53 \times 10^{-5} \), and \( 9.73 \times 10^{-5} \) for \( d_f = 12, 14, 16, \) and \( 18 \) nm, respectively.

IV. Conclusion

An Au-coated ARROW-B SPR sensor operating in aqueous environment has been investigated. The characteristics, design methodology, and optimization are presented. The minimum detectable change in environment index is of the order of \( 10^{-5} \), which is better than or comparable to existed conventional waveguide, prism, and grating SPR sensors.

REFERENCES


