An ARROW-B Surface Plasmon Resonance Sensor in Aqueous Environment

Wei-Zung Chang and Yang-Tung Huang*

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.

*Manuscript received on Sept. 26, 2001. This work was supported in part by the National Science Council of the Republic of China under contract NSC 89-2215-E-009-079. Wei-Zung Chang and Yang-Tung Huang, Department of Electronics Engineering and Institute of Electronics, National Chiao Tung University, Hsinchu, Taiwan, ROC, TEL: 886-3-5712121 Ext. 54138, FAX: 886-3-5724361, E-mail: huangyt@cc.nctu.edu.tw.

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.

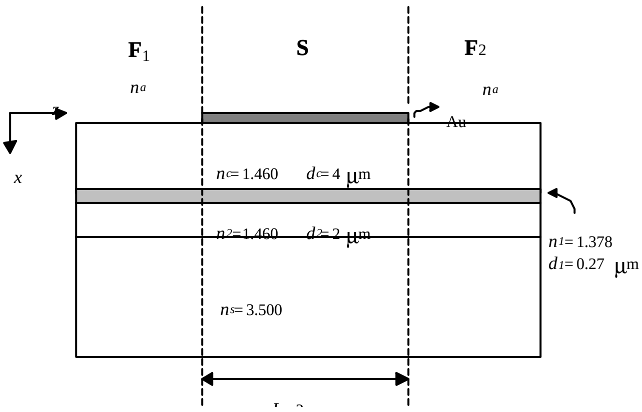

Figure 1 – Basic structure of an ARROW-B SPR sensor.

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:

$$p(L) = |a_0(L)/a_0(0)|^2 , \qquad (1)$$

where $a_0(0)$ and $a_0(L)$ are the complex amplitudes of the fundamental modes at the input and output of the aensor, 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.

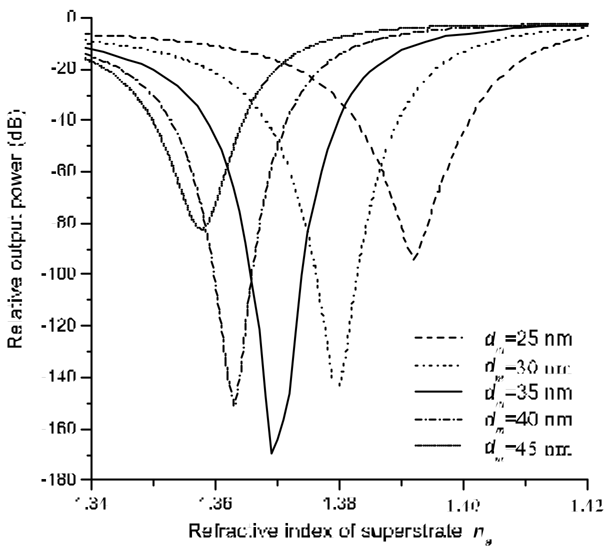

Figure 2 – Dependence of the relative output power on the superstrate index.

III. Overlay Tuning and Optimization

Although the ARROW-B SPR sensor presented in the previous section is highly sensitive to superstrate index changes, the operating range is somewhat away from the desired aqueous environment. In order to shift the location of the minimum relative output power, a dielectric overlay was added on the top of the Au-coated ARROW-B SPR sensor as shown in Fig. 3. 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]:

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

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 overlay, respectively.

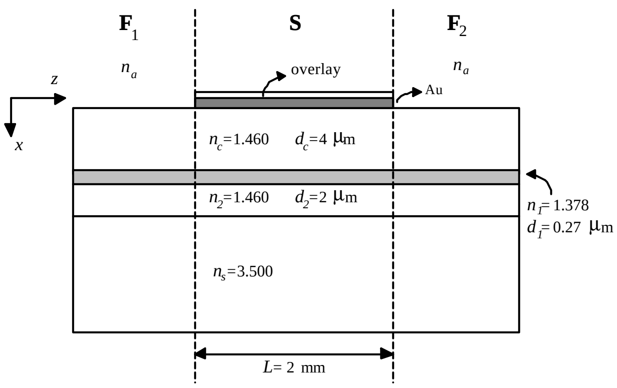

Figure 3 – An Au-coated ARROW-B SPR sensor with an overlay.

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 Al_2O_3 at $\lambda = 0.6328$ μm) and replacing $n_{\mathrm{SPR},0}$ with 1.370 into (2), it can be found that the thickness of the Al_2O_3 overlay d_f corresponding to $n_{\mathrm{SPR},1} = 1.320$ and 1.340 are 18 and 12 nm, respectively. The effect of overlay tuning could be seen from Fig. 4.

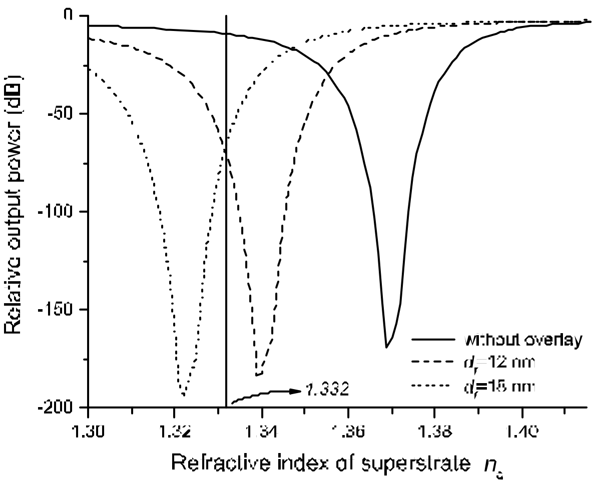

Figure 4 – Relative output power versus superstrate index for the sensors with and without overlay.

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]

$$|\delta n_{min}| = \left| \frac{M\ p(L)}{\frac{\partial\, p(L)}{\partial\, n}} \right|_{n=n_a}, \qquad (3)$$

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 8.50×10^{-5}, 5.56×10^{-5}, 6.53×10^{-5}, and 9.73×10^{-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.

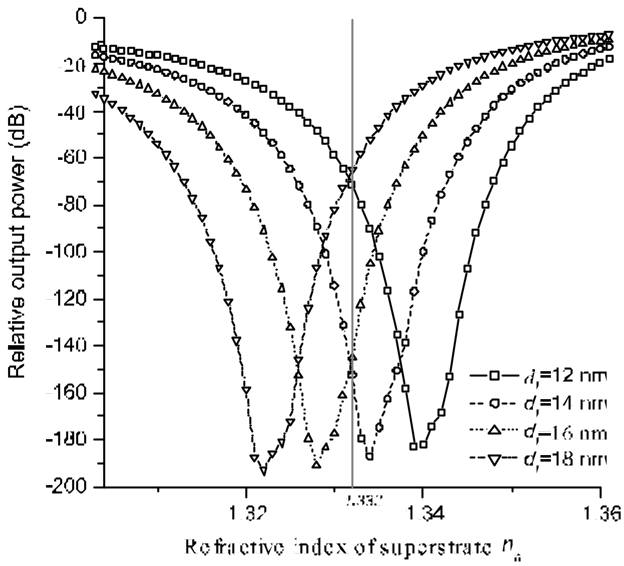

Figure 5 – Relative output power versus superstrate index for $d_f = 12$, 14, 16, and 18 nm.

References

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