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DESIGN AND FABRICATION OF AN ARROW-B SPR BIOCHEMICAL SENSOR CHIP WITH A LIQUID-FLOWING CHANNEL

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Abstract — *An ARROW-B SPR biochemical sensor chip with a liquid-flowing channel has been designed and fabricated. Optical measurement system and liquid-flowing system have been established. Preliminary measurement results of glucose and $C_9H_{20}S$ have also been discussed.*

Keywords: integrated optics; surface plasmon resonance; biosensor; waveguide sensors.

INTRODUCTION

Surface plasmon resonance (SPR) is a quantum optical-electrical phenomenon based on the fact that the energy carried by photons can be coupled or transferred to electrons in metal and cause a charge-density oscillation at the interface of two media with dielectric constants of opposite signs [3]. Owing to its interface excitation characteristic, the SPR phenomenon is considered as one of the most promising optical techniques for study of biological and chemical reactions in thin films and monolayers.

The use of integrated optical waveguides for biosensing offers numerous advantageous features such as miniaturization, ruggedness, potential for realizing multiple channels and various functions on a single chip, etc [1]. Optical waveguide sensors using the SPR phenomenon are the most promising one in recent years because of its high sensitivity to the environment changes. Today, integrated optical SPR sensors have been employed not only in numerous environment sensing applications, in which small refractive index changes need to be distinguished, but also in biochemical and biological detecting fields because of its attractive features: ultrahigh sensitivity and real-time diagnostics [2]. These features could provide us a way to detect the molecule-level conjugate-disconjugate kinetic reaction properties.

SPR SENSOR CHIP BASED ON ARROW-B STRUCTURES

The basic structure of an antiresonant reflecting optical waveguide (ARROW) is composed of a core and interference claddings, consisting of the first cladding and the second cladding layers, on a high-index substrate. The interference claddings can form Fabry-Perot cavities as reflectors; therefore, in comparison with conventional waveguides, it has some great features [4]: wave propagating in a low-index core and with a relatively large core size suitable for efficient connection to single-mode fibers, flexible structure design rules, easy fabrication process, effective single-mode propagation, and low loss with good light confinement. In addition to conventional ARROW structures, which support only TE-polarized waves, the ARROW-B structure, which is similar to an ARROW but only the refractive-index profiles are different, can support low-loss propagation not only for TE but also for TM waves. Because the surface plasmon wave is TM-polarized, an ARROW-B is adopted for SPR sensors.

The ARROW-B structure with a thick guiding core provides efficient coupling with a single-mode fiber. In the design of our sensor chip, ARROW-B channels in front and rear of the SPR sensing region have a symmetric cladding structure, and therefore can support the liquid-flowing channel which is fabricated on it but has no effect on light propagation characteristics in the ARROW-B waveguide, as shown in Fig. 1. All structure parameters in the design have been studied systematically for obtaining the optimum sensitivity in an aqueous environment.

DESIGN AND FABRICATION OF THE SPR SENSOR CHIP

The sketch diagram of the SPR sensor chip with a liquid-flowing channel is shown in Fig. 1. The dash line indicates the underlying waveguide which is covered with upper cladding layers or protecting layers. The pure-white region in the center of the figure represents the etched space, forming a liquid-flowing channel for injecting/releasing the biochemical liquid samples.

Figure 2 shows the cross section of one complete sensing channel on our chip. The front and rear symmetric waveguides with upper claddings can prevent the light leaking out when we add a high-index O-ring or an additional liquid-flowing channel structure on it. The recess structure in the sensing region can provide liquid-flowing channels for injecting the sample solutions in it. We set four pairs of channels with different channel widths of $W_c = 20, 60, 100, 140$ μm, and eight channels were designed in total.

In the lateral y direction, the light is confined by the ridge structure, which can avoid the scattering loss caused by the rough sidewall of the channels after etching process of the core layer. The threshold channel width for supporting the lateral single-mode propagation also can be increased. Based on the effective-index method, the channel width needs to be narrower than 35 μm to support single-mode propagation.

In the fabrication process of the sensor chip, we used the PECVD to grow SiO_2 and Si_3N_4 layers, the e-gun evaporation to coat MgF_2 layers, and the sputtering to coat Au metal layer.

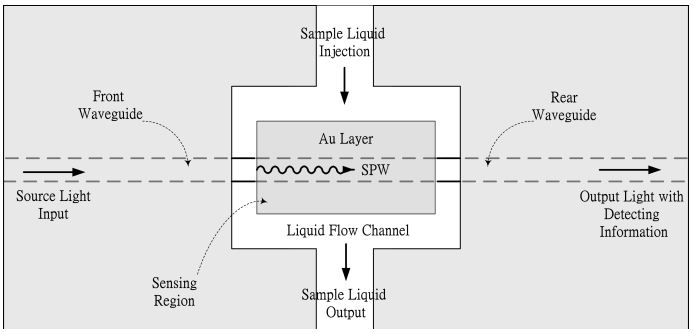

Figure 1: Sketch diagram of the SPR sensor chip with a liquid-flowing channel.

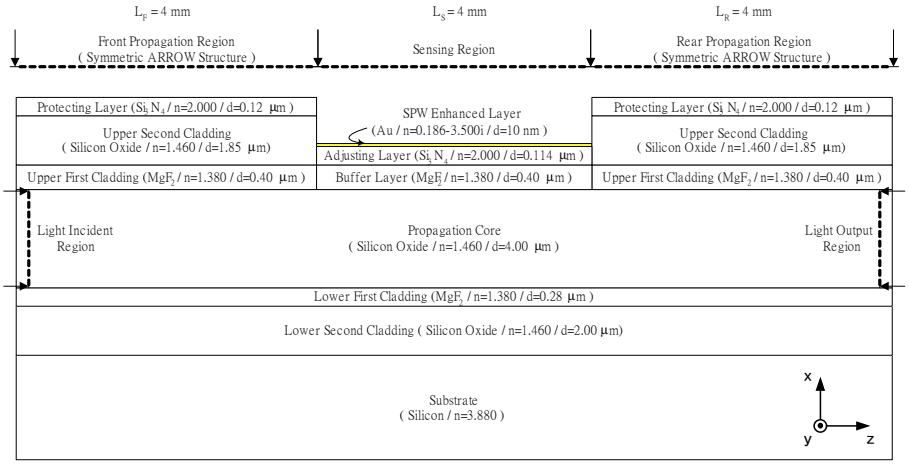

Figure 2: Cross section of an ARROW-B SPR sensing channel on the sensor chip.

CHARACTERIZATION OF THE SENSOR CHIP

The setup of the optical measurement system and liquid-flowing system for testing the ARROW-B SPR sensor chip is shown in Fig. 3, and Fig. 4 presents the real-time measurement results of the sensor chip.

In the optical system, we used a He-Ne laser with the wavelength $\lambda = 0.633$ μm as the light source. The system first filtered out the TE-polarized wave by a polarizer, then the remaining TM-polarized light beam was focused to the input port of the waveguide channel by an objective lens (20X). At the output port, the output beam was focused by another objective lens (10X). Then a polarizer was introduced to guarantee the pure TM-polarized light, and an iris diaphragm was used to filter out the scattered light noise. The value of light power detected by the optical power meter was transmitted to the computer, recorded and processed by the LabVIEW program.

In the liquid-flowing system, we used a micropump as the pumping source of the liquid samples. The pumping liquid flowed to the SPR sensor chip through a plastic tube with a 1-mm internal diameter. For getting an airtight liquid-flowing channel on the sensor chip, we added an O-ring on it and sandwiched them with a plastic slice. The biochemical liquid samples can be injected into the plastic tube by using syringes at a sample injection window made of rubber. Therefore, this liquid-flowing system can satisfy the requirement of real-time measurements.

From Fig. 4, we can see that the H_2O_2 solution with a proper concentration can clean Au surface. The 10-mM glucose solution added at 42 min. has an apparent physical absorption effect on the Au film, and can not be removed by a 7.5% H_2O_2 solution. The 1-mM $C_9H_{20}S$ solution added at 56 min. has a significant S-Au binding reaction occurring on the Au film. But at 56-min. point, even though we add a $C_9H_{20}S$ solution with a higher concentration (5 mM), there has relatively small power variation because of the spacial saturation effect. In the meantime, we can see that the power starts to increase slowly as time passing. This is because the Au film with a thickness of 10 nm becomes hard to afford the pull force which comes from the molecule layer that binds on the Au surface on one side and moves with the liquid on the other side.

As the SDS (sodium dodecyl sulfate) solution was injected at 72 min. after the experiment started, the power increased significantly to the value about 1530 nW. This is because the SDS is a strong detergent which can remove the $C_9H_{20}S$ molecular layer binding on the Au film in the sensing region. When $C_9H_{20}S$ molecules were removed by the SDS, the Au film was also pulled off from the sensing region. Therefore, the power consumption caused by the SPR effect approached zero.

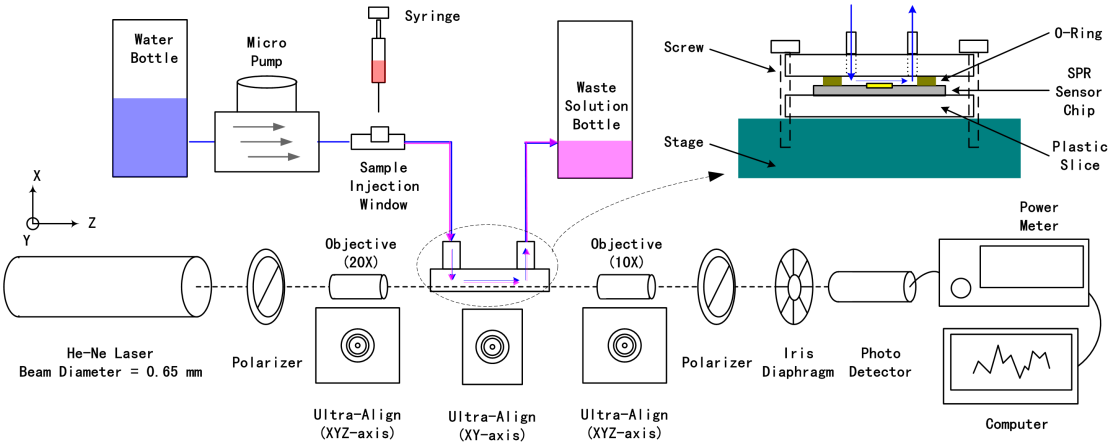

Figure 3: The setup of the optical measurement system and liquid-flowing system.

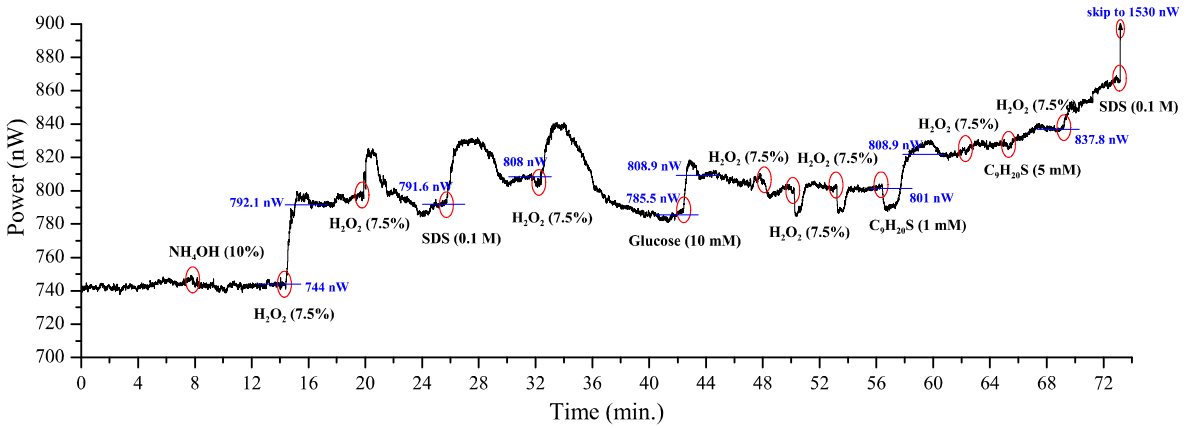

Figure 4: Real-time measurement results of the ARROW-B SPR sensor chip in an aqueous environment.

SUMMARY

The design and fabrication of an ARROW-B SPR biochemical sensor chip with a liquid-flowing channel has been presented. The waveguide channels in front and rear of the SPR sensing region have a symmetric cladding structure, and therefore can support the liquid-flowing channel fabricated on it without any influence on light propagation characteristics in the ARROW-B waveguide. The complete design of the sensor chip is discussed, and the fabrication process is also provided. The setup of the optical measurement system and a liquid-flowing system has been described. Preliminary measurement results show the real-time detection ability of the fabricated ARROW-B SPR sensor chip, and more experiments will be performed.

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