Enhanced Sensitivity of Absorption-Based Surface Plasmon Interference Sensors in Silicon-On-Insulator by Adsorbed Layer

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***Abstract*—We present an numerical investigation of a planar waveguide surface plasmon resonance (SPR) sensor in silicon-on-insulator (SOI) for detecting a change in the imaginary part of the refractive index. By adding a thin adsorbed layer between the metal-analyte boundary it is found that an enhanced sensitivity of the sensor is obtained, suggesting the possibility of realizing a highly integrated and highly sensitive absorption-based SPR sensor in SOI.**

Keywords-component: SPR biosensors; silicon-on-insulator

I. Introduction

Surface plasmon resonance sensors have attracted tremendous interest in the past decade for optical detection of small biological or chemical entities in liquids [1]. Furthermore, the SPR sensors can detect changes in not only the real but also the imaginary parts of the refractive index resulting in the so-called absorption-based SPR sensor [2-3]. In general, the conventional absorption-based SPR sensors have been restricted to the cases with the conventional Kretschmann configuration. Unfortunately, the conventional configuration is not suitable for the integration into optical circuits, because of the bulk structure composed of a prism coated with a thin metal [4]. To integrate the traditional absorption-based sensor into optical circuits, input/output parts were replaced with optical waveguides. There has been a growing interest in the development of robust, portable and highly sensitive SPR sensing devices capable of out-of-laboratory measurements. Recent progress in sensitive fiber and waveguide SPR provide options for miniaturization and integration of SPR sensor systems. However, the integration of fiber-SPR to other biosensor components raises some design issues. Among those include the high precision requirement for the insertion of the fiber in to a planar substrate containing fluidic circuit and chambers and the requirement of additional optical components to achieve efficient coupling of light in and out of the fiber [5]. The proposed alternative approach to fiber-based SPR has been the planar optical waveguide structure.

Recently we proposed a highly integrated and sensitive SPR interferometer sensor based on silicon-on-insulator technology. The basic element of the sensor was a surface plasmon interferometer consisting of a thin layer of gold

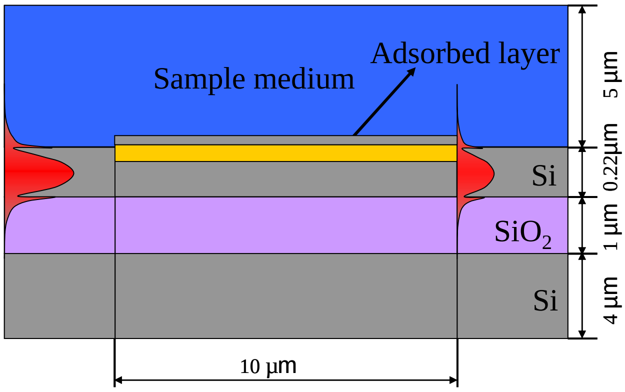

Fig. 1. Cross section of the planar waveguide SPR sensor with a 20 nm-thick adsorbed layer.

embedded in a silicon membrane. It was demonstrated that the device could achieve a sensitivity of 463.5 nm/ RIU (refractive index unit) and a resolution of $1x10^{-6}$ RIU with regards to wavelength interrogation [6]. That sensor, however, treats only the real part of the refractive index and no literature has examined so far the potential applicability of the planar waveguide sensor in SOI for the use as an absorption-based SPR sensor in SOI.

In this paper, we apply the SPR interferometer sensor in SOI to detect a change in the imaginary part of the refractive index. The resulting sensitivity of the sensor calculated by an in house-developed eigenmode expansion solver [7] is relatively low. This can be improved, however, by adding a nanoscaled adsorbed layer. Numerical results show a sensitivity enhanced by a factor 5 in comparison to the SPR interferometer without the adsorbed layer. This leads to the possibility of realizing a compact and highly sensitive absorption-based SPR sensing device in SOI.

II. Simulation Results and Discussions

The cross section of the SPR interferometer sensor is shown in Fig. 1. The interferometer consists of a gold layer (refractive index calculated by the well-known Lorentz-Drude model [8]) embedded into the silicon membrane (n=3.47) on top of a supporting silica layer (n=1.45), all dimensions and

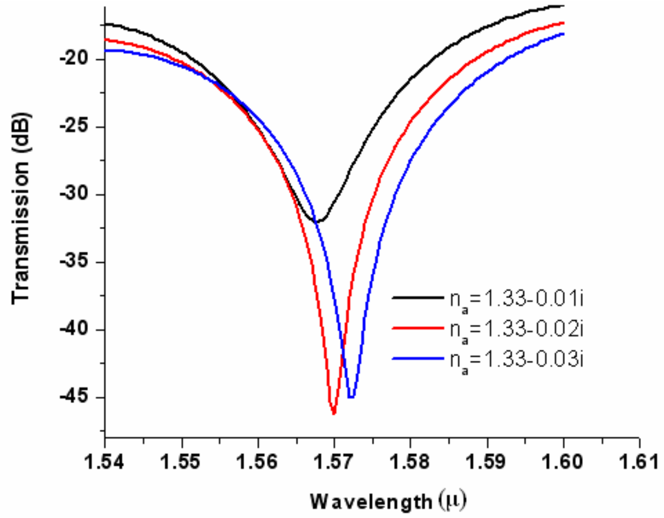

Fig. 2. Shift in resonance wavelength with respect to refractive index of analyte for the sensor without adsorbed layer.

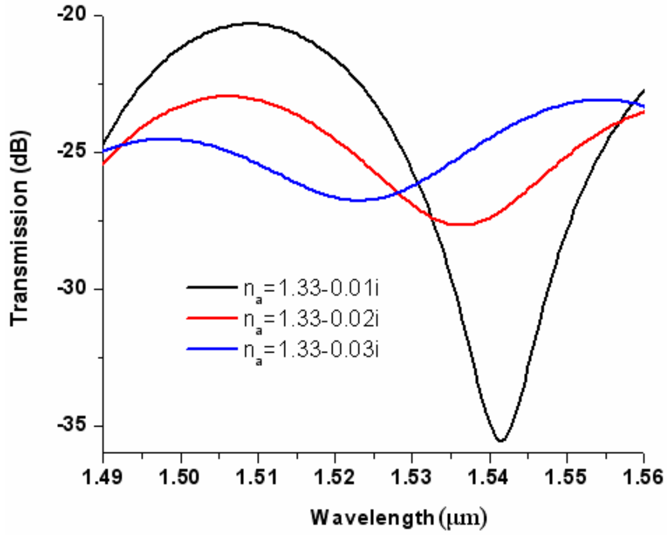

Fig. 3. Shift in resonance wavelength with respect to refractive index of analyte for the sensor with 20 nm-thick adsorbed layer.

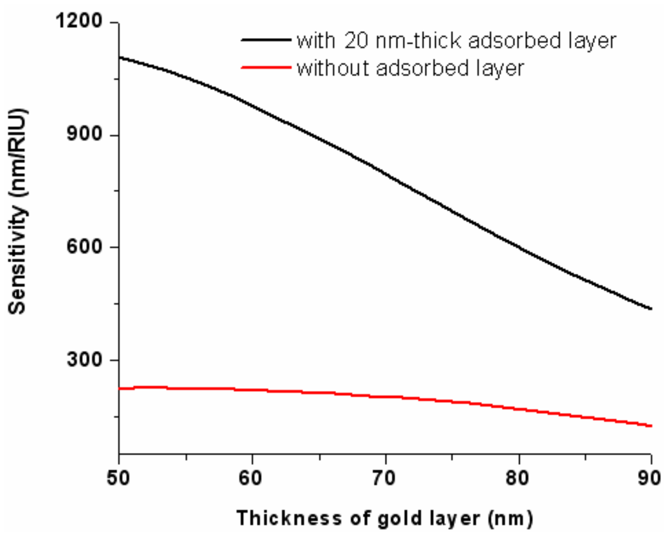

Fig. 4. Enhanced sensitivity of the sensor by a 20 nm-thick adsorbed layer for various thickness of gold layer.

length scales are depicted in the figure. TM polarized light is coupled into the waveguide and the transmission characteristics of the entire system are observed for variation of the imaginary part of the refractive index of analyte. We here define the refractive index of the analyte by n_a-k_ai.

The absorption-based SPR sensor can observe changes in both real and imaginary parts of the refractive index. To investigate the basic performance of the sensor, however, we deliberately vary only the value of the imaginary part k_a, whereas the real part is fixed to be n_a=1.33 [9,10]. By varying the imaginary part of the analyte k_a from 0.01 to 0.03 the transmission spectrum of the entire sensor with a 60 nm-thick gold layer is shown in Fig. 2. For each analyte the resonance wavelength has been observed. However, the small shift in resonance wavelength demonstrated the low sensitivity of the sensor. To improve the sensitivity, we propose to add a nanoscaled adsorbed layer with high refractive index between the metal-analyte boundary. In fact, using the adsorbed layer as a means to enhance the sensitivity of biosensors is not new, and SPR sensors using this approach have been realized in Kretschmann-type SPR sensors [11]. Figure 3 shows the transmission spectrum of the sensor with respect to the refractive index of the analyte. From the figure it is clearly seen that there is a large shift in resonance wavelength leading to the high sensitivity of the sensor. Furthermore, to demonstrate an enhancement of the sensitivity of the sensor by adding adsorbed layer we investigate the sensitivity of the sensor with various thickness of the gold layer. Numerical results show that by adding a 20 nm-thick silicon layer with refractive index of 3.47 the enhanced sensitivity is observed and depicted in Fig. 4. Indeed, with 50 nm-thick gold layer the sensitivity of the sensor without adsorbed layer is 225 nm/RIU whereas those of the sensor with the 20 nm-thick adsorbed layer is 1125 nm/RIU.

III. Conclusions

The absorption-based SPR interferometer sensor in SOI has numerically been investigated. By adding an adsorbed layer an enhanced sensitivity of the sensor was obtained. It is worth mentioning that the SPR response of the sensor is quite sensitive to the changes in the imaginary part of the refractive index of the analyte leading to the possibility of realizing the highly integrated and highly sensitive absorption-based SPR interferometer sensor in SOI.

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