Nanoplasmonic ring resonator for biosensing applications

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We present a design of plasmonic resonator-based sensors for detecting a change in refractive index of sensed samples. It is theoretically demonstrated that the possibility of realizing of highly sensitive biosensors at nanoscale of 1000 nm/RIU is feasible.

Introduction

Surface plasmon resonance (SPR) sensors, which use surface plasmon polariton (SPP) waves to probe interactions between biomolecules and sensor surfaces, have attracted tremendous interest in the past decade for optical detection of small biological or chemical entities in liquids [1].

Recently we have proposed a highly sensitive SP interference sensor based on silicon-on-insulator technology. The basic element of the sensor is a surface plasmon interferometer consisting of a thin layer of gold 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 1×10^{-6} RIU with regards to wavelength interrogation [2]. Besides SP interference sensors, highly sensitive and integrated label-free biosensors based on ring resonators on silicon-on-insulator platform have been demonstrated [3].

However, all of those integrated sensors were made in dielectric materials and typical dimensions of waveguides and optical components were too large to be miniaturized leading to not well-suitable for lab-on-chip applications. In this contribution, we propose novel nanoscale sensing structures based on plasmonic ring resonators (PRR). It results in very compact sensors in terms of high integration in dimension of a few hundred nanometers associated with a high sensitivity.

Device structure and sensing principle

The cross section of the sensor is shown in Fig. 1. It consists of one plasmonic ring with an outer radius of R and a ring waveguide coupling with a guiding bus through a gap of *g*. The width of the ring waveguide of *d* is the same as the guiding bus. The sensed sample is filled inside the ring.

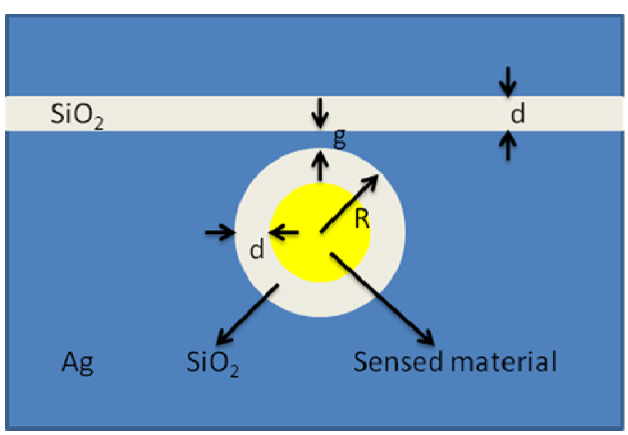

Fig. 1. Cross-section of the plasmonic ring resonator-based sensor

We believe that it is feasible to fabricate such nanoscale devices thanked to recent advances in nanofabrication and thin-film nanotechnology. The structure with the width of *d* larger than 20 nm can be fabricated by various techniques such as focused-ion-beam milling, electron-beam lithography, or template stripping [4-6]. Liquid sensed materials can be filled up into the ring by using nanofilling techniques based on capillarity attraction [7-9].

When TM polarized light is excited into the guiding bus from the left-hand side, part of the incident wave is coupled into the ring while other parts of the wave are coupled back into the guiding bus. Lost parts of the incident wave make the transmission characteristics of the entire system observed for variation of the refractive index of sensed materials. At a certain wavelength those parts of the incident wave are almost completely reflected on the guiding bus or confined in the ring waveguide. It results in a dip in the transmission spectrum where the resonant wavelength appears. So, a change of the refractive index of sensed materials can be detected by the shift of the resonant wavelength.

For example, the transmittance spectrum of the PRR sensor is depicted in Fig. 2. The gap between the guiding bus and the ring, the width of the ring waveguide, and the outer ring radius are set to be g=20 nm, d=50 nm and R=475 nm, respectively. The refractive index of silver (Ag) is described by the Lorentz-Drude model [10]. It is seen that dips in the transmittance spectrum where resonant wavelengths appear are obtained. At the resonance wavelength λ=1.448 μm of the sensor, a part of the incident wave is coupled back to the guiding bus, other part is confined in the waveguide ring and other parts are transmitted along the guiding bus as seen in Fig. 3.

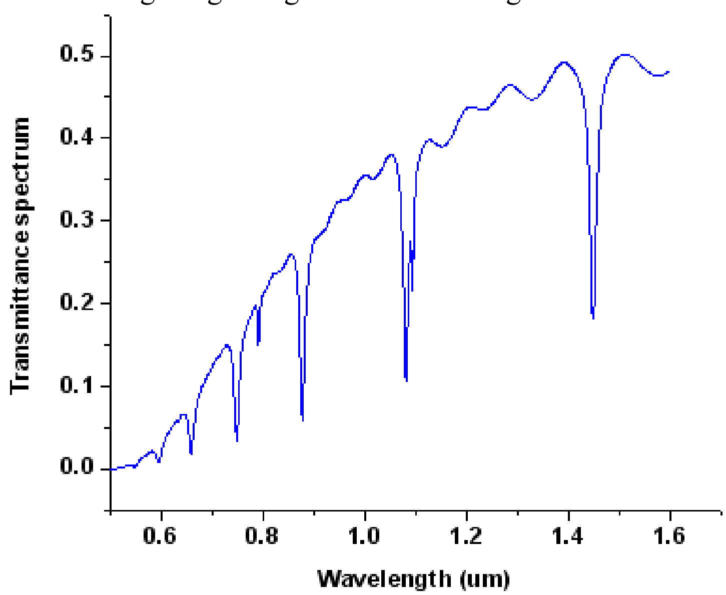

Fig. 2. Transmittance spectrum of the sensor with a refractive index of liquid of 1.33.

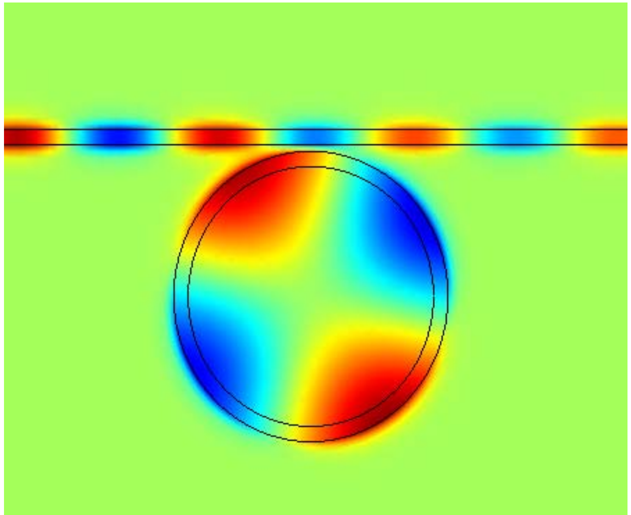

Fig. 3. Field distribution in the plasmonic ring resonator based sensor C at the resonance wavelength λ=1.448 μm.

Results

Simulations were done by the finite element method in the commercial multiphysics modeling and simulation software-COMSOL [11]. The fundamental TM mode of the plasmonic waveguide based on Silver-Insulator-Silver is excited from the left-hand side. The transmitted power P_{tr} is monitored on the right-hand side of the guiding bus. So, the transmittance of the device is defined as the ratio of the transmitted power and the incident power (P_{in}) as $T= P_{tr} / P_{in}$.

We now pay attention on applications of the PRR structures in biosensing. The performance of PRR sensors can be characterized by two main parameters including sensitivity and full-width at half maximum (FWHM) power. The sensitivity (S_n) of the PRR sensor with spectral interrogation is defined as

$$S_n = \frac{\delta\lambda_{res}}{\delta n_{analyte}}$$

where $\delta\lambda_{res}$ is a shift in the resonance wavelength corresponding to the change $\delta_{analyte}$ in the refractive index of analyte. The FWHM determines how accurately $\delta\lambda_{res}$ can be measured. The larger FWHM value, the less accuracy in the measurement of the resonance wavelength is obtained.

Subsequently, performance of the PRR sensor is investigated with respect to key device parameters such as the coupling gap g, the waveguide width d, and the outer radius R of the ring. Through simulations it is found that the highest sensitivity and the FWHM of the sensor are 1000 nm/RIU (refractive index unit) and 22 nm, respectively. The sensor consists of g=20 nm, d=50 nm and R=475 nm, respectively.

Conclusion

In this contribution, a nanoplasmonic ring resonator has been designed for application in biosensing. It was found that the plasmonic ring resonator response of the sensor is sensitive to the changes in the refractive index of the analyte leading to the possibility of realizing highly integrated and highly sensitive nanoscale biosensors.

Acknowledgments

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