

On-chip Localized Surface Plasmon Resonance (LSPR) Sensing

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Abstract: We experimentally demonstrate on-chip efficient LSPR sensing in a device consisting of plasmonic nanoresonators integrated with silicon nitride photonic waveguides. A sensitivity of 168nm/RIU and a coupling efficiency of 8% to individual nanoresonators are demonstrated.

Localized surface Plasmon resonance (LSPR) sensing works based on the resonance spectral shift of plasmonic nanoresonators when the refractive index of the medium surrounding these nanoresonators is changed. It has been shown that plasmonic nanoresonators in different forms and shapes are very sensitive to the refractive index of the surrounding medium [1]. Sensitivities on the order of 150-285nm/RIU have been reported for gold nanorods. Also, novel plasmonic nanoresonators such as nanocages and nanoframes, with hollow core structures, have been shown to have spectral sensitivities as high as 600nm/RIU [2]. Since the physical size and the mode volume of these nanoresonators are extremely small, the required amount of analyte to observe a shift of resonance is very small. LSPR sensing has shown a promise for the label-free detection of a few molecules [3, 4]. To take advantage of the small size and the small required amount of analyte, individual plasmonic nanoresonators need to be efficiently interrogated. Some recent efforts have been dedicated to the excitation and measurement of the LSPR modes of individual plasmonic nanoresonators immobilized on a substrate. To interrogate individual plasmonic nanoparticles, scattering spectroscopy is used, where a darkfield microscope is used to excite the LSPR mode of nanoresonators, and the scattered field is collected and is directed to a spectrograph equipped with a sensitive detector array such as a cooled CCD [3, 4]. In such cases, the extinction spectroscopy is not practical, since the absorbed power by each individual nanoresonator is at the shot noise level, and the signal to noise ratio (SNR) is very low [3]. This originates from the fact that only a small fraction of the input power is coupled to each individual nanoresonator. Although single nanoparticle LSPR sensing has shown a promise for biological detection, the bulky alignment-sensitive interrogation mechanism, and the low SNR limit its application for practical sensing and biological detection.

Here, we demonstrate an on-chip hybrid photonic-plasmonic sensor that can address the issues in conventional LSPR sensing systems. The proposed device consists of a silicon nitride (SiN) photonic ridge waveguide integrated with plasmonic nanoresonators. We have previously shown that by properly designing the hybrid structure, the coupling of the photonic mode to the plasmonic LSPR modes of the plasmonic nanoresonators can be optimized [5]. In this paper, we show that this hybrid structure can be used for on-chip LSPR sensing. The schematic of the hybrid sensor is shown in Fig. 1(a). It consists of a gold nanorod integrated on top of a SiN ridge waveguide. The analyte of interest is introduced to the top surface of the hybrid structure, and the resulting resonance shift is monitored at the output of the waveguide. This architecture can provide a very efficient way of exciting each individual plasmonic nanoresonator. Also, the interrogation mechanism does not involve a microscope system and is not very alignment sensitive. Once the lightwave is coupled to the waveguide input, the LSPR mode of the nanoresonator is excited, and the extinction can be monitored at the waveguide output. Since the coupling efficiency is high; the SNR is high, and the extinction can be measured at the output even with a simple spectrometer at room temperature. Figure 1(b) shows the scanning electron micrograph (SEM) of such a sensor consisting of a 958nm×200nm SiN waveguide integrated with gold nanorods of dimensions 106nm×56nm×27nm. The measured absorbance at the output of the waveguide integrated with 19 plasmonic nanorods is shown in Fig.1(c).

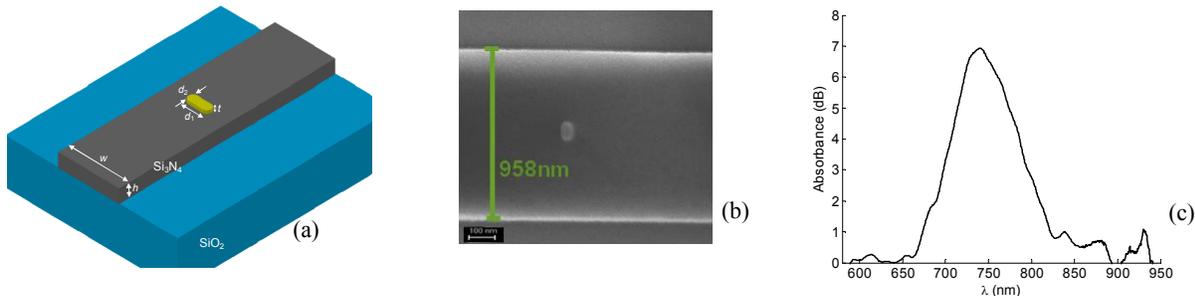


Fig. 1 a) Schematic of the on-chip LSPR sensor consisting of gold nanorods integrated with a SiN waveguide. b) Scanning electron micrograph (SEM) of a 958nm×200nm SiN waveguide integrated with plasmonic gold nanorods with dimensions 106nm×56nm×27nm. c) The absorbance measured at the output of the waveguide in (b) for an array of 19 gold nanorods.

The absorbance is defined here as

$$Absorbance = \frac{Trans(Sample) - BKGND}{Trans(ref) - BKGND}, \quad (1)$$

where $Trans(sample)$ is the transmission of the waveguide integrated with nanoresonators, and $Trans(ref)$ is the transmission of a reference waveguide with the same dimensions and with no nanoparticle on top, and $BKGND$ is the background. The measurement was carried out by using a superluminescent broadband laser source that was attenuated to deliver a power density of -54dBm/nm to the waveguide input. The output transmission spectrum was measured using an Ocean Optics USB2000+ spectrometer with a detector at room temperature and only 1sec integration time. The experimental results in Fig. 1(c) suggest that the coupling efficiency from the waveguide to each nanoresonator is 8%. The large coupling efficiency helps measuring the extinction without the need to use very sensitive detectors and high input powers.

To characterize the sensitivity of the proposed sensor, we have used certified refractive index liquids from Gargille Labs as analytes. Each time the extinction is measured with a different analyte. The dimensions of the waveguide and the gold nanoresonators are the same as the ones introduced in Fig.1. First, the measurement is carried out with air cladding. Then, the analyte of known refractive index is drop coated on the sample, and the extinction spectrum is measured. Finally, the sample is washed with trichloroethylene, acetone, methanol, IPA, and DI water to make sure that the analyte is completely washed off the surface and the extinction returns to that of an air-cladding structure before introducing the next analyte. In Fig. 2(a), the normalized absorbance is shown for the two cases of air cladding and an analyte with a refractive index of 1.3. It can be seen that a shift of $\sim 47\text{nm}$ can be observed. In Fig. 2b the experimental results for the resonance shift versus the index change of the analyte is plotted. The linear fit to these measurement results suggests a sensitivity of 168nm/RIU .

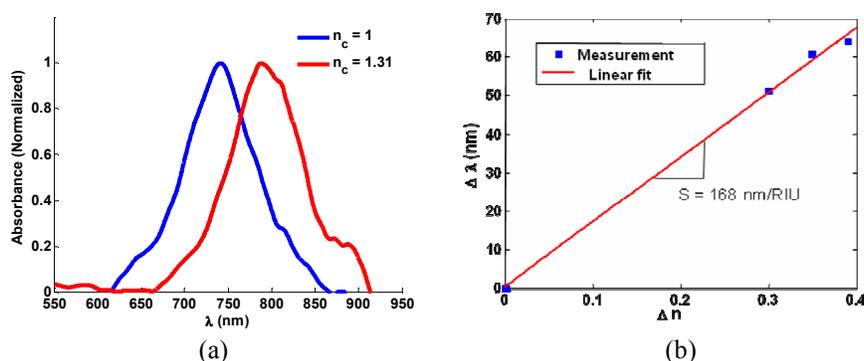


Fig. 2 a) Normalized absorbance measured at the output of the sensor introduced in Fig. 1 for the two cases of air cladding and an analyte of refractive index 1.3. b) The resonance shift of the sensor measured for different analytes. The linear fit suggests a sensitivity of 168nm/RIU .

Because of the large sensitivity and the large coupling efficiency (and therefore the large SNR), the proposed structure can be used for the detection of biological analytes of low concentrations. Also, since the sensor is realized on a chip and does not require complicated and bulky interrogation systems, it is well suited for lab-on-chip point of care diagnostics. Several of these proposed structures can be integrated on the same chip with plasmonic nanoresonators of different sizes and shapes to realize multiplex, multianalyte sensing for several different target analytes. Further details of the design, fabrication, and characterization of the proposed sensors for biological detection will be discussed in the presentation.

References

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