Double peak nanoplasmonic sensor for multiple biosensing

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ABSTRACT

This work is related to the development of nanoplasmonic methodologies in Surface Plasmon Resonance (SPR) biosensing. Developed concept of experimental device is based on angular properties of plasmonic nanogratings that allow fast and multiple analytes tests applied for bacteria detection. Proposed methodology can significantly facilitate the calibration of the system for multi-sample sensing and is promising for low-cost and portable nanoplasmonic multisensing applications.

Keywords: instrumentations, measurement and metrology, optics at surfaces, plasmonics, surface plasmon.

1 INTRODUCTION

The rapid detection of biological species and the identification of thermodynamic and kinetic parameters related to macromolecular interactions are key issues in many fields of biosciences and are very important for health issues related to food safety, water resources, medical diagnostics, hospital infection outbreaks and homeland security. Despite the importance of accurate and rapid diagnosis in biomedical, available techniques are expensive, have limited ability to differentiate between multiple pathogens, are slow, and have a poor detection threshold. The ideal diagnostic device would need to be a sensitive, accurate, cost-effective and portable point-of-care detection system. Since the conditions of plasmon excitation are extremely sensitive to the refractive index (RI) and the thickness of the thin surface films, Surface Plasmon Resonance (SPR) biosensing is now considered as a leading technology for real-time detection and studies of biological binding events [1]. Significant effort is now undertaken on the application of nanoplasmonic structures for biosensing where unique optical properties can allow the development of novel promising sensor designs and architectures, impossible to achieve with conventional SPR technology [2].

In this article we present the nanoplasmonic biosensing methodology and concept of cost-effective portable device based on nanograting photon-plasmon coupling. In this case, SPR is produced by a converging pumping beam, while a double peak pattern is extracted perpendicular to the angular sweep pattern by the linear CCD detector (Fig.1). Real time detection of two SPR peaks separation allows self-referencing noise elimination and calibration where tests of multiple samples with different analytes are required.

2 BASIC IDEA AND APPROACH

Coupling of photons into surface plasmon can be achieved using a grating as a coupling medium to match the photon and surface plasmon wave vectors. A grating coupler matches the wave vectors by increasing the parallel wave vector component by an amount related to the grating period. The angle θ that satisfies the condition of resonant excitation of the surface plasmon is given by [3]:

$$\sqrt{\varepsilon_d}\,\frac{2\pi}{\lambda_0}\sin(\theta)+p\,\frac{2\pi}{\Lambda}=\frac{2\pi}{\lambda_0}\sqrt{\frac{\varepsilon_M(\lambda)\cdot\varepsilon_d(\lambda)}{\varepsilon_M(\lambda)+\varepsilon_d(\lambda)}} \quad (1)$$

where p is integer relative to the diffraction order, Λ is the grating period, and ε_d and ε_m are the dielectric constant of the surrounding medium and of the metal, respectively, λ_0 is the monochromatic light source wavelength. This method, while less frequently utilized, is critical where plasmon excitation on the planar surface by free-space radiation with normal incidence is required. In this work we show that under a proper sensor design the symmetrical angular SPR pattern in transmitted light intensity produced by nanoplasmonic grating structure (Fig.1) can be employed to rapidly determine the SPR self-calibration point and thus adjust the system for maximal reproducibility and reliability of the SPR measurements in multi-sample and multi-channel sensing.

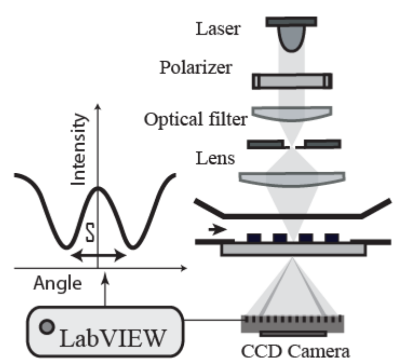

Figure 1: Schematics of the experimental setup for the determination of differential angular SPR position.

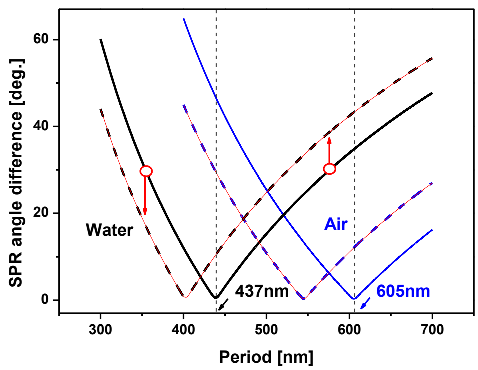

Figure 2: Differential angular SPR position curves for different grating periods. Red curves present shift due to the medium refractive index change (δn=0.1). The data are given for water and air ambient medium

First, using Eq.1, we performed a numerical simulation of angular SPR parameters in the grating coupling geometry using laser light 632.8nm. It is implied that the gold nanograting contacts either air (n = 1) or aqueous (n=1.33) medium, corresponding to conditions of gas sensing or biosensing, respectively. Fig.2 presents differential angular position (S in Fig.1) curves when the period of the SPR-supporting grating is changed. One can see that the grating period variation leads to the appearance of minima corresponding to the period equal to the surface plasmon wave vectors on the gold/medium interface. Characteristic value for air and water are found to be Λ_{Cwater} = 605nm and Λ_{Cair} = 437nm respectively.

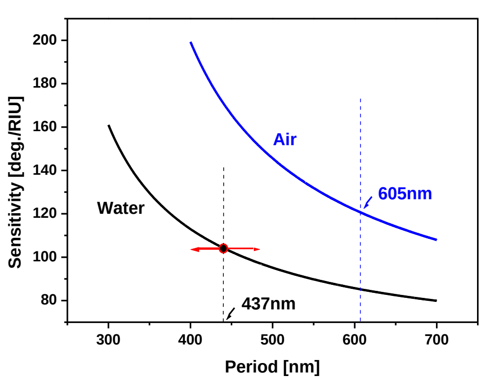

Figure 3: SPR sensitivity dependence for different grating periods in water and air ambient medium.

For the experimental application this value corresponds to the transfer from subwavelength grating to the over wavelength grating when grating period is compared to the surface plasmon propagating wave and, as shown on Fig.2 a change in the refractive index (red lines) causes an opposite shift of the angular position of the SPR dip on the left and right side of the minimum point. The estimated sensitivities for water and gas analysis are presented on the Fig.3. Smaller grating periods show higher angular sensitivity thus providing confirmation for efficiency of nanoplasmonic sensing. For example, the sensitivity can be doubled by using 300nm grating instead of 600nm for He-Ne 632.8nm probing light.

3 INSTRUMENTAL METHODOLOGY

Fig.1 illustrates a schematic diagram of the experimental setup. A He-Ne laser operating at a wavelength of 632.8 nm is used as the light source. A polarizer enables to set a linear light polarization. The beam is then filtered by an optical filter, consisting of a lens and a pinhole. After a focusing lens the convergent light is transmitted through the gold nanoplasmonic grating structure, thus exciting two symmetrical surface plasmons corresponding to the opposite angular direction. Detection with a linear CCD Camera (GARRY3000) and numerical treatment with LabView software allows to measure the angular position difference between two SPR peaks in the real time. Specially designed flow-injection measurement cell was used for tests in gases. Estimated experimental sensitivity is about one pixel shift for 10^{-5} RIU changes and depends on the distance between detector and sensor.

4 RESULTS AND DISCUSSION

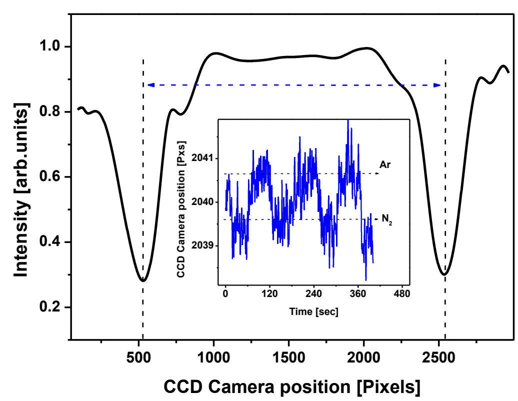

Figure 4: Experimental SPR differential angular position curve for 580nm grating period. Inset: Blue curve presents the sensor response under the replacement of pure N_2 by a Ar gas.

For experimental tests, nanograting array with period 580nm and overall size of 150x150µm were produced by Focused Ion Beam (FIB) fabrication method on the transparent substrate (glass BK7) with 50nm gold metal film. To examine the sensing response, we used a well-established gas methodology for small refractive index variations δn [4]. This method involves comparing the system response, while different inert gases with known refractive indices are brought in contact with the grating gold film. In our experiments, Ar and N_2 were used, for which the refractive indices differ by $\delta n \cong 1.5 \cdot 10^{-5}$ RIU under the normal conditions [5]. The gases were passed to the cell through a long spiral copper tube to equalize their temperatures with the room temperature and then brought in contact with the SPR-supporting gold film. Fig.4 demonstrates typical untreated differential angular signal under the replacement of pure N_2 by a Ar. Taking into account the level of residual noises and potential application of numerical smoothing methods, we can determine that the detection limit of our system is better than 10^{-5} RIU, which is comparable with conventional SPR devices. Further improvement of the detection limit can be achieved by eliminating thermal and other noises related to the sensing block. This can be done by a better thermoisolation or active thermostating.

Thus, using a simple scheme with nanoplasmonic grating we are able to determine the SPR responses to the medium refractive index changes without comparing with initial base line. We reason that the proposed self-calibration methodology can be used to simplify the adjustment procedure in real biosensing tests and to decrease the background noise from experimental set-up. More importantly, the proposed methodology can be advantageous for multiple SPR tests of the same nanoplasmonic sample after different surface modifications made in the separate locations or for the repeated investigation of the multiple samples for different analytes. Here, intrinsic self-referencing makes possible to eliminate steps of the sensors initial opto-mechanical alignment in high throughput automatic multisensor system.

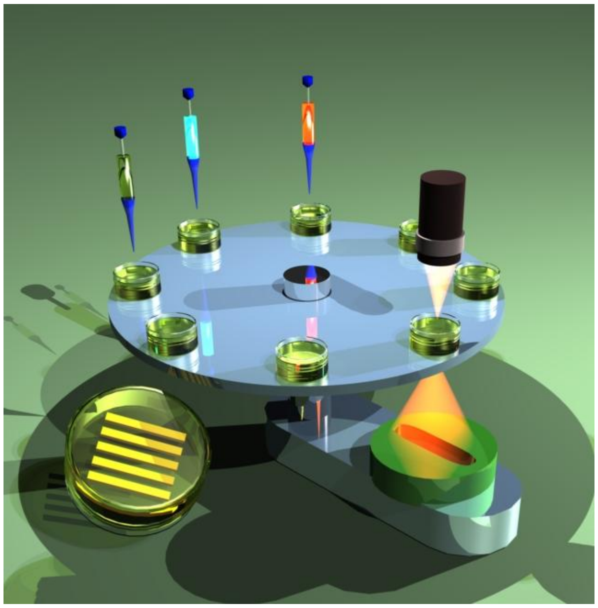

Figure 5: Schematics of a nanoplasmonic device for the multiple sensor detection.

In this work we propose the concept of multiwell devices for the rapid bacteria detection, which is shown on Fig.5. Here, several nanoplasmonic sensors are continually checked after repeated steps of washing, regeneration and modification by the simple rotation of samples holder plate. Measurement time for individual sensor can be adjusted by the rotation speed and sensor slight misalignment due to the mechanical vibration or initial installation will be eliminated by the proposed nanograting based double SPR peak measurements method. The proposed methodology opens opportunities for the implementation of low-cost nanoplasmonic sensor designs for field and multi-sensing applications.

5 CONCLUSIONS

We introduced a novel methodology and instrumentation to rapidly determine the SPR response in multiple sensing point measurements. The application of the nanoplasmonic grating sensor chips with optimized period enables to implement a reference calibration point that greatly facilitates reproducibility and reliability of the SPR measurements in field and multi-channel sensing. The concept of the low-cost and high throughput experimental device for the bacteria detection is proposed and procedure of real biosensing application is discussed.

6 ACKNOWLEDGEMENTS

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