# Numerical Investigation of a Plasmonic Biosensor on Flexible Substrate

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***Abstract*—Surface plasmon resonance (SPR) based sensors are state of the art in bio-sensing. Here we numerically inspect a device that can induce SPR on the opposite side of planar metal films. The evanescent field of SPR can detect wide of refractive index with linear sensitivity. This device modeled on bendable PDMS substrate can launch SPR modes with perpendicularly incident light which enhances the robustness and practical feasibility of the whole system.**

***Keywords*— *Surface plasmon resonance, Biosensor, Flexible substrate.***

As currently a pandemic is wreaking havoc around the world, biosensors are in the spotlight of research. Optical biosensors mainly sense the refractive index (RI) of the analyte. By observing the change of RI, different biomolecules can be distinguished [1]. Food quality and purity can also be determined by detecting RI. Here we demonstrate a surface plasmon resonance-based label-free, real-time biosensor with high figure of merit (FOM) that can sense wide range of a RIs.

Surface Plasmon Resonance (SPR) is the combined resonant oscillation of conduction electrons and incoming photons at the interface between metal and dielectric. To induce SPR in the boundary between metal and dielectric, the momentum of photon must be matched with the momentum of the conduction band electrons. This matching of momentum can be done by different structural changes. Commercially available RI sensors use prism mechanism to meet the condition that induces SPR [2]. Resonance condition of SPR is largely depended on the dielectric traits of its surroundings. Hence slightest change of dielectric property of the surrounding medium can change the resonance condition. Typical plasmonic biosensors usually detect different biomolecules based on total internal reflection phenomena of incident light [3]. Recent research works on SPR based bio-sensing reported with higher sensitivity, but the range of sensing was not up to mark [4].

Here we studied a SPR based biosensor built on bendable (Polydimethylsiloxane) PDMS substrate which works with normally incident light. The sensitivity of the sensor is 900nm/RIU (Refractive Index Unit), most importantly the range of sensing is from 1 to 1.8 RIU. The sensitivity of this simulated device was found to be linear (coefficient of determination, $R^2 = 0.997$) throughout whole the range. In this paper FDTD (Finite-difference time-domain) analysis of SPR based biosensor is demonstrated.

The structure of the device is shown in the figure 1. As metal layer planar Silver (Ag) of 50nm thickness was used. Just underneath the silver layer Gallium Phosphide (GaP) grating layer was applied. GaP was used as dielectric material instead of typical Si. Because the RI of Si falls sharply when the wavelength of incident light is less than 0.3 microns, likewise RI decreases when the wavelength is more than 0.7 microns. The RI of GaP remains relatively constant with the wavelength of incident light than Si [5]. The grating layer replaces traditional prism mechanisms in SPR based biosensors. The width and height of the each di-electric block were chosen as 220nm and 270nm respectively. Each grating blocks were 200nm apart. Between the grating layer and metal layer an adhesion layer of $TiO_2$ having 5nm thickness was considered to enhance practicability of the whole structure. A 2D graphene layer is added above silver layer. This graphene coating escalates bi-molecular bindings with the metal layer as well as this layer reduces erosion of silver layer [6]. The whole structure was made on PDMS substrate. A p-polarized light source of varying frequency was used.

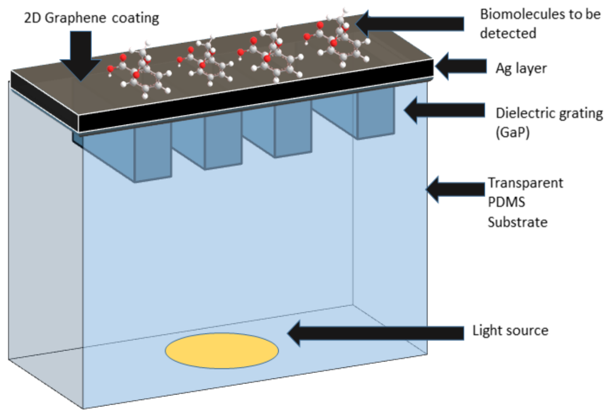


Figure 1: Structure of the biosensor.

Surface plasmons occurring at the interface between the metal film and di-electric grating layer contain both electromagnetic wave and surface charge properties. The combination of these characters affects the surface-perpendicular component of the electric field, causing enhancement near the surface, but exponential decay as one moves further away.

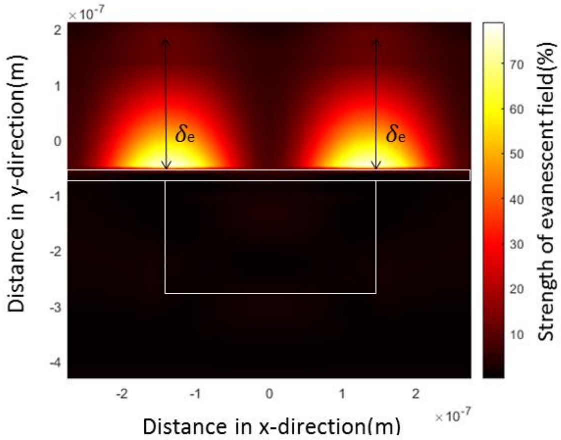


Figure 2: Strong evanescent field generated due to SPR. $\delta_e$ showing evanescent field length.

The field in the normal direction is evanescent and represents non-radiative nature of surface plasmon polaritons (SPP). Just above the metal in the specimen, the decay length of the evanescent field of SPP, is approximately half the wavelength of the light involved. As the resonance conditions approaches the evanescent field height increases which marks the existence of SPR in the vicinity of dielectric and metal interface. Figure 2 shows the evanescent field of sensor. Evanescent field is well inside that sensing medium, which confirms the viability of the sensing.

This device works based on normalized reflectance spectra of light. The light reflected from the back of the di-electric grating is normalized with the input light. At a certain wavelength when SPR was generated in the metal-dielectric interface, eventually a sharp dip was observed in the reflectance spectra. The Full-Width Half-Maximum (FWHM) of this minimum is very narrow (~5nm). The narrower FWHM, the better overall figure of merit of the sensor.

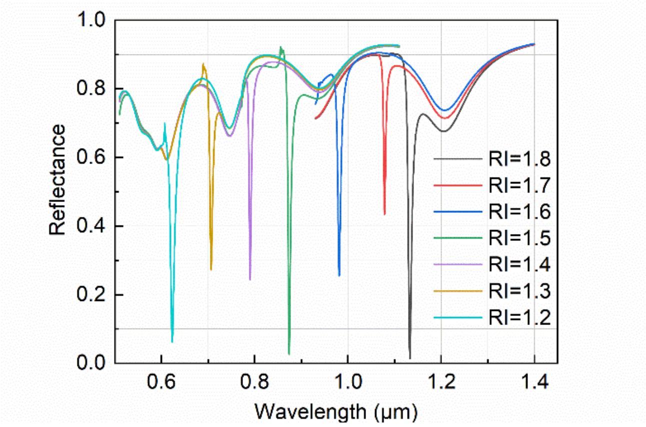


Figure 3: Reflectance spectra when different refractive index is being sensed.

When materials having different RI was sensed this sharp fall was observed at different wavelengths. This is the basic scheme of sensing. From figure 3 it is observed that as RI of speciman increase, the sharp fall of reflectance spectra occurs at higher wavelengths. Each collapse of spectra is well apart from each other (almost 1000nm). This can be explained from the following dispersion equation of Surface Plasmon [7], $k=\frac{\omega}{c}\sqrt{\frac{\varepsilon_m\varepsilon_d}{\varepsilon_m+\varepsilon_d}}$, where $\varepsilon_m$ and $\varepsilon_d$ are the permittivity of metal and surrounding dielectric medium, respectively. As $\varepsilon_d$ is related to the RI also changes eventually altering the wavevector k. When $\varepsilon_m$ and $\varepsilon_d$ are equal and opposite of each other wavevector is maximum which indicates resonance. $\varepsilon_m$ depends on the wavelength of incident light and $\varepsilon_d$ depends on the refractive index of the dielectric analyte environment which on the top of the metal film.

To find the sensitivity of the device a minimum point of the reflection spectra vs wavelength graph was plotted. Figure 4 displays the sensitivity graph. The sensitivity was found to be linear. Linearity can be determined by coefficient of determination, $R^2$. The equation is more linear if $R^2$ value is closer to 1. It was determined by the following equation.

$$R = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[(n\sum x^2)-(\sum x)^2][(n\sum y^2)-(\sum y)^2]}}$$

For this simulated device $R^2$ was 0.997. The slope of this line defines the sensitivity of the total system.

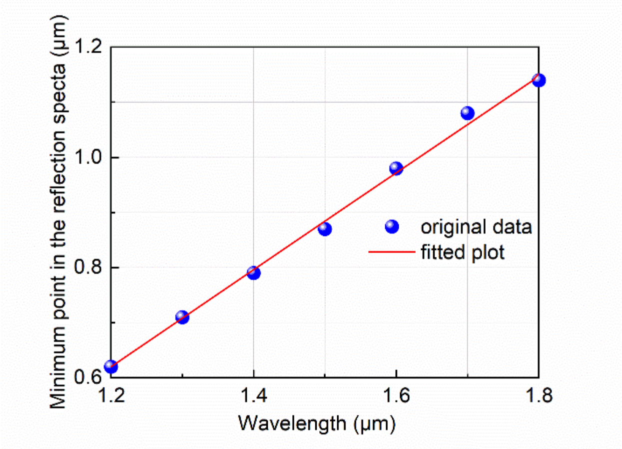


Figure 4: Sensitivity of the biosensor.

The figure of merit (FOM) is another important criterion that determines performance and viability of any sensor. For plasmonic biosensors FOM is defined as sensitivity divided by the resonance linewidth (FWHM) [8]. For this device FOM was 888.89/5≈178.

In conclusion a real time, label free biosensor design is proposed and numerically investigated on a transparent bendable PDMS substrate. The biosensor could detect a wide range of biomolecules having refractive index from 1 to 1.8. The sensitivity of the biosensor was almost 900nm/RIU. The sensitivity graph was linear all throughout the sensing range. The FOM of the sensor was also up to mark.

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