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Student Paper

Plasmonic Antennas based Gas sensor using Graphene

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Plasmonics based sensors have been a prominent area of research. Plasmonics based sensors are widely used in bio sensing and many other applications. The basic mechanism in which these sensors operate is that there are metal nano particles that are separated by a very small distance between them. The dimensions of these nano particles is much smaller than the incident light [1]. For sensing purposes, we use the light in the visible spectrum. The dimension of those nano particles is in the range of 20-200nm [2]. When light is incident on these nano particles, it generates a very high electric field in the gap between the two nano particles. This generated electric field is dependent on the size, shape and material of the nano particles and also the properties of the environment surrounding the nano particles.

In this paper, the dipole nano antenna structure are used for chemical gas sensing. The structure is as shown in figure 1. The dipole arms are made of gold. The length, width, gap and thickness is 150, 60, 50 and 30 nm respectively. Different dimensions of plasmonic antennas for dipole structure have been simulated. These structures are fabricated on a SiO_2 substrate and they are illumined from top. All the simulations for these structure were carried out using commercially available FDTD tool [3].

Graphene is one atom thick sheet of Carbon. Graphene has been widely researched in recent years [4]. Due to its one atom thickness, researchers have proposed to use it widely in different sensor applications. It has a high surface-to-volume ratio and is very sensitive material. Chemical gas sensors have been built using Graphene where conductivity change in Graphene is measured upon exposure to different gases [5, 6]. A single layer of Graphene is transferred on top of the dipole structure as shown in figure 2. Graphene then acts as the adsorbing layer for the gas molecules on top. Because Graphene is conducting by nature, it should short the dipole arms as Graphene is transferred on top of the dipole antenna and there should be no electric field between the gap. But as seen in the figure 3, there is no shorting effect by Graphene and the electric field is not greatly affected. This happens because Graphene does not generate any plasmons in the visible spectrum, and therefore it acts as insulator for that dipole structure. The effective dielectric permittivity for Graphene to be used in the simulation is calculated using the formula mentioned in [7, 8].

Finally to check the sensitivity of the proposed sensor, the refractive index of the surrounding is changed from 1.0 to 1.4 in steps of 0.1. There are then changes in the absorption characteristics of the device; the wavelength at which resonance occurs and absorption intensity. The output is shown in figure 4a. The simulation with mono layer of Graphene on top of the dipole structure is also performed. The simulation output for the sensor with mono layer Graphene on top is shown in figure 4b. Traditionally, the sensitivity of the plasmonic sensor is calculated by the ratio of the shift in resonant wavelength to the change in the refractive index of the surrounding. This sensitivity for only dipole structure without a monolayer of Graphene is 500nm/RIU (Refractive Index Unit). From figure 4b it can be observed that Graphene does not affect the shape of the waveform but the waveform is red shifted by 16nm. The sensitivity of the device with Graphene is 460nm/RIU. Though the sensitivity for the bulk refractive index has been reduced by introduction of Graphene, there are still some advantages. The gas sensing mechanism takes into consideration the local refractive index change in the vicinity of the antenna. Presence of Graphene on top of dipole nano antennas improves the sensor as it acts as a good adsorbing material as compared to bare gold nano antennas. Though, Graphene does not improve the sensitivity of the device it acts as a good adsorbing material, which can adsorb the gas molecules near the vicinity of the dipole nano antenna. These gas molecules adsorbed will affect the electric field near the dipole, resulting in a shift in the resonance wavelength. This shift won't be easy to observe for bare gold dipole antennas even though it has comparatively greater sensitive for bulk refractive index.

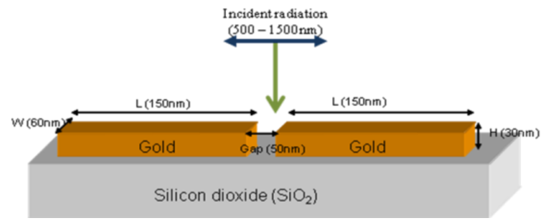

Figure 1: The dipole structure being used as sensor

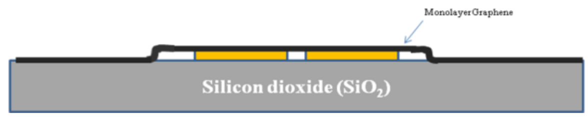

Figure 2: Dipole structure with a monolayer of Graphene on top

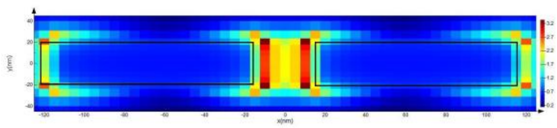

Figure 3a: Electric field distribution 2 nm above the top surface of the dipole structure being used as sensor

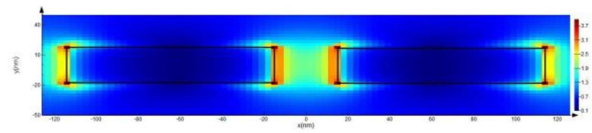

Figure 3b: Electric field distribution 2nm above the top surface of the dipole structure with monolayer of Graphene

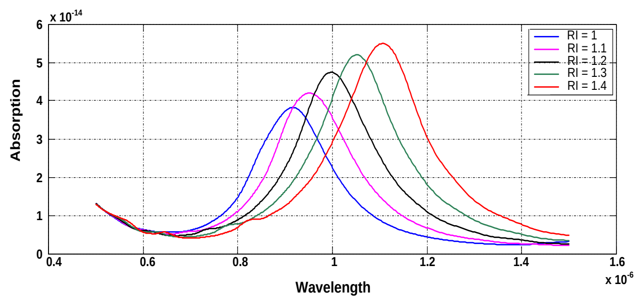

Figure 4a: Shift in the resonance wavelength by the change in the refractive index of the surrounding without Graphene

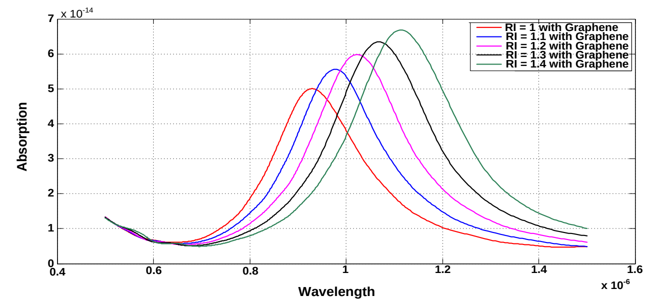

Figure 4b: Resonance shift by the change in the refractive index with monolayer of Graphene

$$\sigma_r = \sigma_0\left(\frac{18-\left(\hbar\omega/_t\right)^2}{12\pi\sqrt{3}}\right)\psi_r\kappa \quad (1) \qquad \sigma_i = \frac{\sigma_0}{\pi}\left\{\frac{4\mu_c}{\hbar\omega}\left[1-2\left(\frac{\mu_c}{3t}\right)^2\right]-\left[1-\left(\frac{\hbar\omega}{6t}\right)^2\right]\varphi\right\} \quad (2)$$

Where,

$$\psi_r = \tanh\left(\frac{(\hbar\omega+2\mu_c)}{4k_BT}\right)+\tanh\left(\frac{(\hbar\omega-2\mu_c)}{4k_BT}\right) \quad (3) \qquad \kappa = \begin{cases} 4.6936-2.897\tanh\left(|\hbar\omega-2t|^{.546}\right), & \hbar\omega < 2t \\ 4.6936\exp\left(-0.7714|\hbar\omega-2t|^{.4727}\right), & \hbar\omega > 2t \end{cases} \quad (4)$$

$$\varphi = log\left(\frac{|\hbar\omega+2\mu_c|-\psi_i}{|\hbar\omega-2\mu_c|+\psi_i}\right) \quad (5) \qquad \psi_i = 2k_BT\left\{\tanh\left(\frac{|\hbar\omega+2\mu_c|}{4k_BT}\right)-\tanh\left(\frac{|\hbar\omega-2\mu_c|}{4k_BT}\right)\right\} \quad (6)$$

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