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Cross-slot nano-antenna with graphene coat for bio-sensing application

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ABSTRACT

we present a compact cross-shaped nano-aperture for biomedical and spectroscopy applications. Furthermore, by adding a graphene coat to structure, we achieved a reconfigurable particle with more transmittance. Finally, a cross shape chain of silicon dioxide is added to structure and it is placed on graphene layer and over the aperture slot. The structure is modeled with FDTD simulation by the CST microwave studio and for substrate, we selected SiN with $n = 1.98$ and thickness of 80 nm. The palik model is used for gold layer with thickness of 30 nm and the 2 nm graphene layer is selected for coat. The simulations emphasize that adding graphene coat and silicon dioxide chain is applicable in order to improve the transmittance at mid infrared (IR) frequency. In addition, here we show that the chain structure is useful for enhancement of the E-field in both X and Y direction and it is made useful this particle for energy harvesting. Figure of merit (FOM) is studied for different additional material effects on prototype structure and $\Delta(E)$ variation. Finally, we revealed that the current device is highly practical for making differential sensor for detecting nano-particle with more accuracy and sensitivity.

1. Introduction

Surface plasmon resonance (SPR) is important electromagnetic mode that occurs at optical wavelength band when the optical wave incident to metallic nanostructures. This optical resonator is developed for light absorption and great local field enhancement, which provides potential applications in different areas such as bio-sensing, optoelectronic nano-device and surface enhanced Raman scattering (SERS) [1–3]. Intensity in SERS systems is extremely sensitive to the optical efficiency of the plasmonic enhancer particle [4].

Recently by making progress in nano-manufacturing technologies, fabrication and utilizing sub-wavelength plasmonic structures in different shapes and sizes are become possible [5]. Different shapes of the aperture are studied for spectroscopy and bio-sensing at the infrared domain (IR) such as H-shape with sensitivity to polarization [5] Jerusalem cross [6] plasmonic microarrays coupled [7] Multi-resonant metamaterials based on UT-shaped nano-aperture [8]. Scanning probes make nanoscopy on a 100–10 nm achievable and these techniques are used for local material processing and manipulation. The scanning near-field optical microscope (SNOM) enables the performance of nano-spectrometry experiments at the wavelengths of visible range and microwave electromagnetic spectroscopy [9].

Newly, Altug et al. have designed and fabricated different model of nano-antenna for bio-sensing based on silicon nitride (SiN) membrane layer and for metal deposition a combination of gold with titanium implement [10].

Graphene is a special honeycomb carbon lattice based on a single atomic layer arrangement that exhibits unique and exceptional behaviors in electronics and Photonics [11]. Electronic band structure in graphene is the main reason of these extraordinary properties and it makes graphene more suitable for a wide range of applications in optical and photonic field such as optoelectronic applications [12], optical and THz antenna [13], photodetectors [14], broadband optical polarizers [15] high-speed optical modulators [16] and optical filter [17].

In addition, graphene coat is noticing for improving the Q-factor in nano-disk resonators for a wide range of integrated nanophotonic devices such as detectors, modulators, and emitters in the mid-infrared region [18].

However, for mid infra red and the Kubo formula performances, graphene is implemented in these studies and graphene's conductivity has two various terms of the σ_{inter} and σ_{intra} and therefore

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$\sigma_G(\omega)=\sigma_{inter}(\omega)+\sigma_{intra}(\omega)$, where [19]:

$$\sigma_{intra}(\omega)=\frac{e^2}{4\hbar}\frac{-8jk_BT}{\pi\hbar(\omega+j\tau^{-1})}\ln\left[2\cosh\left(\frac{E_F}{2k_BT}\right)\right]$$

$$\sigma_{inter}(\omega)=\frac{e^2}{4\hbar}\left[\frac{1}{2}+\frac{1}{\pi}\tan^{-1}\left(\frac{\hbar\omega-2E_F}{2k_BT}\right)-\frac{i}{2\pi}\ln\left(\frac{(\hbar\omega+2E_F)^2}{(\hbar\omega-2E_F)^2+(2k_BT)^2}\right)\right]$$

Surface conductivity of graphene depends on the radian frequency ω, charged particle scattering rate Γ, temperature T, and chemical potential (or Fermi Energy Level) μ_c where e is the charge of an electron, k_B is Boltzmann's constant, and $\hbar=h/2\pi$ is the reduced Planck's constant. Chemical potential μ_c is currently attainable involving charge-carrier densities $n=\mu_c/(\pi\hbar^2\nu_F^2)$, where ν_F is the Fermi velocity [19].

Linear chains of nanoparticles are one-dimensional periodic arrays that have been studied to miniaturize photonic devices [20] and energy transition [21] and energy harvesting at solar cell with linear and nonlinear array [22,23].

Recently, graphene layer has been noticed for fabricating gas sensor and bio-detector at THz regime [24,25].

In this article, we are designing a conventional cross-slot antenna for bio optical application and in addition we have used a graphene coat for improving the antenna transmittance. At last, the silicon dioxide chains are placed on the graphene layer at aperture placement. We improve antenna's quality factor by adding these new layers. The equivalent circuit is presented for a description of the prototype structure based on two-port analysing. We show that the chain structure is useful for enhancement of the E-field in both X and Y direction and it is made this particle useful for energy harvesting. Here, the biasing effect on transition is studied for 0–0.8 eV and extract that, by increasing the biasing to 0.8 eV the transmittance rise up to peak. Figure of merit (FOM) is studied for different additional materials effect on prototype structure and $\Delta(E)$ variation for four different materials. Exactly the cross junction is selected for aperture nano-antenna and because of its symmetrical shape shows independency to X and Y incident field and it is important material for some parallel applications such as solar cell. In addition implementation of the graphene and chain improved the field enhancement as debated in this paper.

2. Design particle

Fig. 1 shows a prototype cross-shaped nano-aperture and the placement of the spherical chain and graphene layer over the gold layer so the first main role of the graphene is placement of the spherical chain over the aperture. The structure contains a gold layer with cross shape aperture with length of 1200 nm and width of 1200 nm with a thickness of 30 nm and the dimensions are modified for mid infrared application.

The gold layer is placed on a SiN layer with $n=1.98$ that is selected as a substrate with a thickness of 80 nm and Palik model of gold is selected for the gold parts in our structure, typically SiN layer is joint to gold layer with a thin film of titanium with the thickness of 2–5 nm.

CST microwave studio full wave simulator has done the simulation with time domain method and the open boundary with 300 nm distance by conventional PML is selected to achieve true result at mid infrared frequency range. In the following, we coated the gold layer with a multilayer graphene with thickness of 2 nm as shown in Fig. 1(c). Here the multi layer graphene implemented

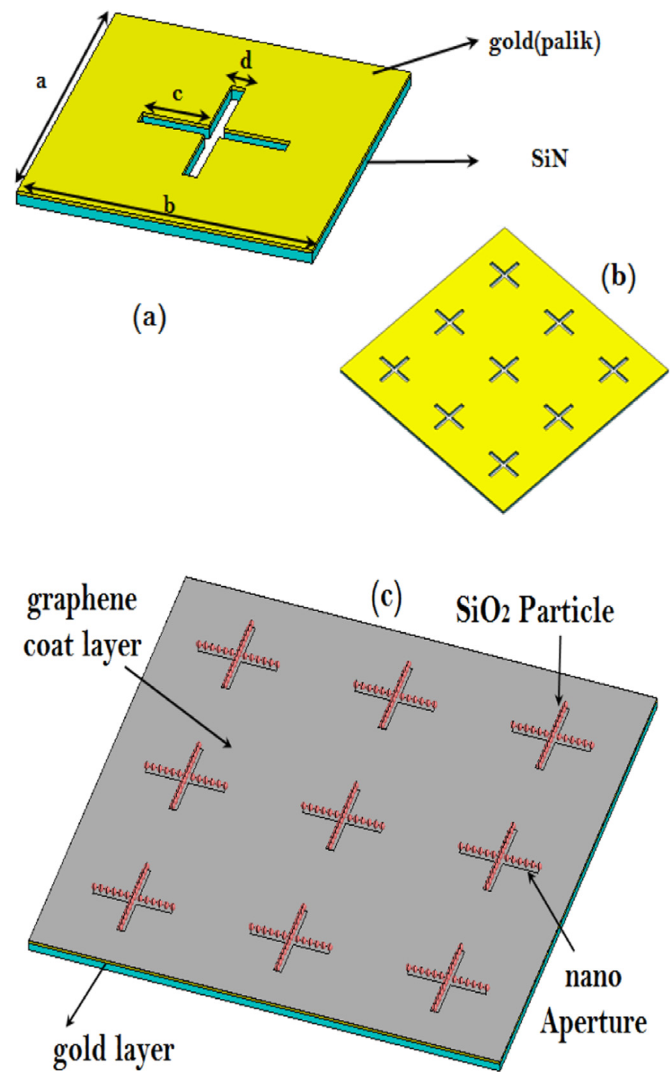

Fig. 1. The geometric of the nano-antenna.

for achieving more Q-factor in prototype nano-antenna. The cross-junctions of spherical chains are placing over the aperture on the top of the graphene layer for transmittance enhancement. For chain structure at here, we are assuming SiO_2 spherical structure with the radius of 40 nm and distance between two spheres are assumed 40 nm so at here we are exerted the distance between two spheres equal to $3r$ where the r is radius of each sphere as same as pervious researches [20]. SiO_2 spherical structures are used for prototype structure for possibility of deposition of SiO_2 on graphene layer without any other material implementation for junction.

In addition, all dimensions are $a=b=2400$ nm, $c=600$ nm, $d=100$ nm.

3. Simulation result

In order to, numerically analyze the aperture system we used FDTD commercial software (CST microwave studio 2014) by using two-port analyzing. Fig. 2 shows the transmission of a simple structure when the graphene coat layer and chain structure did not implemented to nano-aperture. In this case, the nano-antenna has a resonance at 88 THz ($\lambda=3400$ nm) and the resonance pick is about 0.45 for transmission. Because of the symmetrical structure that is used in this study, the effects of the polarization in y and x