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Research paper

Fractal cross aperture nano-antenna with graphene coat for bio-sensing application

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ABSTRACT

In this paper, we presented a novel shape for nano-aperture for biomedical and spectroscopy application. In addition, when the graphene coat layer is added to structure, we are achieving a reconfigurable particle with more transmittance and the impedance parameters can describe the effect of the graphene layer. The prototype structure is simulated with the FDTD method by the CST microwave studio and for the substrate, the SiN layer with refractive index of 1.98 and thickness of 80 nm is selected. The Palik model is implemented for the gold layer with thickness of 30 nm, and single graphene layer is selected for a coat with 1 nm thickness. The prototype antenna has the dual band characteristic at 46 and 86 THz for biomedical sensing at mid infrared application. The graphene coat is improving the transmittance in the prototype nano-particle. Here we show that the graphene layer implementation is useful for making biosensor with more accuracy and sensitivity. The prototype structure shows orthogonal characteristic that made it useful for solar cell application and energy harvesting in by enhancement of electrical field in both X and Y directions.

1. Introduction

Nowadays, developments of micro and nano technology at THz and optical regime are resulted many new devices at THz or optical sensors for detection of small partial such as biological and chemical materials that are important in medicine, genetic analysis and the pharmaceutical and food industries [1–2].

Surface plasmon polaritons (SPPs) are indicated of the electromagnetic excitations with the metal-dielectric layer and are appearing at the interface between dielectric and metallic layers, and SPPs are used for different application such as field enhancement [3], subwavelength propagation [4], subwavelength waveguide [5], molecule detection [6], surface Raman scatters enhancement [7] and near-field coupling effects [8].

Various shapes of the aperture nano-antenna are studied by Altug et al. for the spectroscopy and bio-sensing for infrared domain (IR) such as an H-shape with sensitivity to polarization [9] Jerusalem cross [10] Multi-resonant Metamaterials based on UT-shaped nano-aperture [11].

Graphene is used as an optical application from THz to the optical regime for achieving reconfigurable characteristic at tunable dipole nano-antenna and absorber [12–13]. The σ_{intra} formation is used as the surface conductivity of the graphene for THz application for less than 10 THz [14] and the σ_{inter} formation is implemented for the surface conductivity of the graphene at optical application for more than 150 THz [15]. However, for the mid infrared application, the Kubo formula performances are implemented for graphene in these studies and graphene's conductivity has two various terms of the σ_{inter} and the σ_{intra} and therefore $\sigma_G(\omega) = \sigma_{inter}(\omega) + \sigma_{intra}(\omega)$ [16].

Recently, graphene has been noticed with single or multilayer structures to enhance the transmittance and the absorption cross section in nano-antenna and nano-particle [17–18].

By Altug et al. debated about the fabrication process of the nano-aperture in six photolithography steps with UV-light, dry etching by SF6 and He, wet etching by KOH, E-beam lithography with PMMA, dry etching by SF6 and Ar and at last metal deposition by using gold and Titanium for bonding of gold to SiN layer [19–20].

In addition, fractal geometry is made by mathematical abstraction of self-similar or self-off-line that are improving the radiation quality in nano particle or absorber with various formations such as a snowflake, a tree and bowtie [21].

Sierpinski fractal plasmonic nanoantennas are conventional models of fractional form for bowtie or rectangular structure as a fractal carpet in optical regime [22–23]. In addition, the fractal carpets are used in plasmonic absorber for enhancement in the surface absorption of solar cell application [24].

Furthermore, the fractal formation is noticed in nano aperture for optical imaging [25].

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In this article, the final modeled nano-antenna has the dual band characteristic at 46 and 86 THz, and it is implemented for biomedical sensing at mid-infrared application. We have used commercial FDTD software by using two-port analyzing for transmittance studies, and results are compared with simple cross-junction model, and we show that the prototype nano-antenna has the independence to incident polarization. Here we show that with the implementation of the fractal formation the electrical field in both X and Y directions is increased drastically and structure shows orthogonal polarization.

2. Design particles

Fig. 1(a) shows the novel cross-loop shaped nano-aperture and graphene layer over the gold layer at Fig. 1(c). The structure contains a gold layer with cross-loop shape aperture with length of 2400 nm and width of 2400 nm with a thickness of 30 nm. In Fig. 1(b) we show the fractional nano-antenna design process in 3 steps and result of these antennas is compared together. The gold layers are placed on the SiN layer with n = 1.98 that is selected as a substrate with a thickness of 80 nm and Palik's model of gold is selected for the gold parts in our structure.

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 (perfectly match layer) is selected. Accordingly, we are covering the gold layer with a multilayer graphene with a thickness of 1 nm as shown in Fig. 1(c).

We should have noticed that the single-layer graphene cannot bond to gold layer and therefore. For bonding of the Au with a single layer, graphene (SLG) by Electron-beam lithography a thin layer of Cr + should be deposited over the gold layer before deposition of the graphene [26]. Here, in simulation, because of little thickness [around 5 nm] of the Cr, we are neglecting the effect on our simulation. In addition, all dimensions are a = b = 2400 nm, c = 600 nm, d = 100 nm.

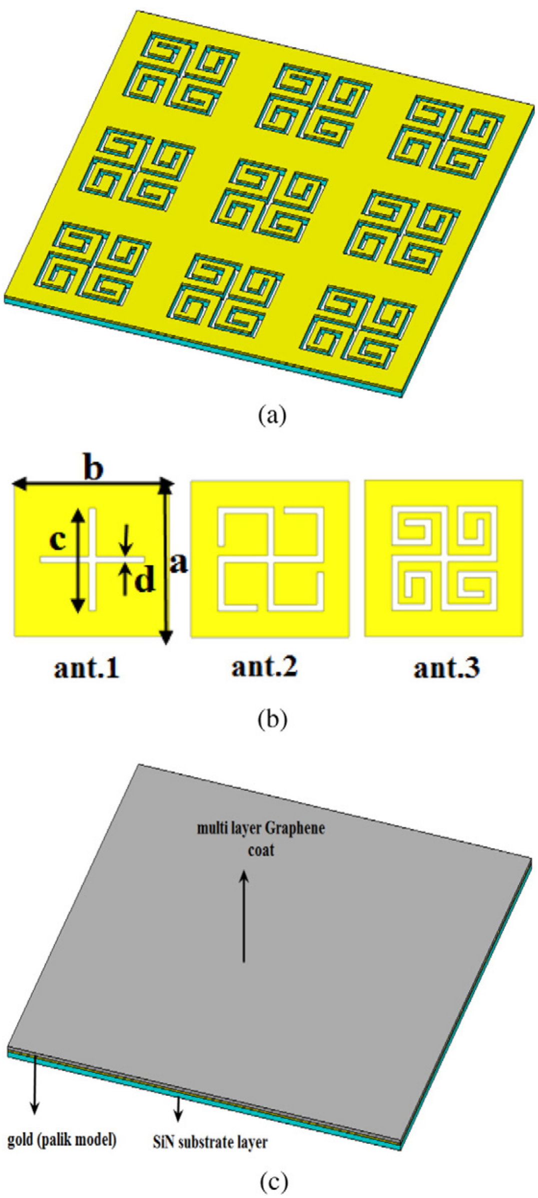

Fig. 1. The geometric of the nano-antenna (a) final prototype nano-antenna (b) three types of the designing of the nano-antenna and the dimensions are a = b = 2400 nm, c = 600 nm, d = 100 nm (c) final prototype antenna with multilayer graphene

3. Simulation result and discussions

For numerically analyze, the aperture system, we use FDTD by using two-port analyzing where the ports are placed in front of the array structure. The boundary condition is selected open for sidewalls and open with space in Z and -Z directions. The Fig. 2(a) shows the transmission of a three step of nano-antenna without the graphene layer.

In the first antenna, the nano-antenna has a resonance at 62 THz (λ = 4830 nm) and the resonance pick is about 0.63 for transmission.

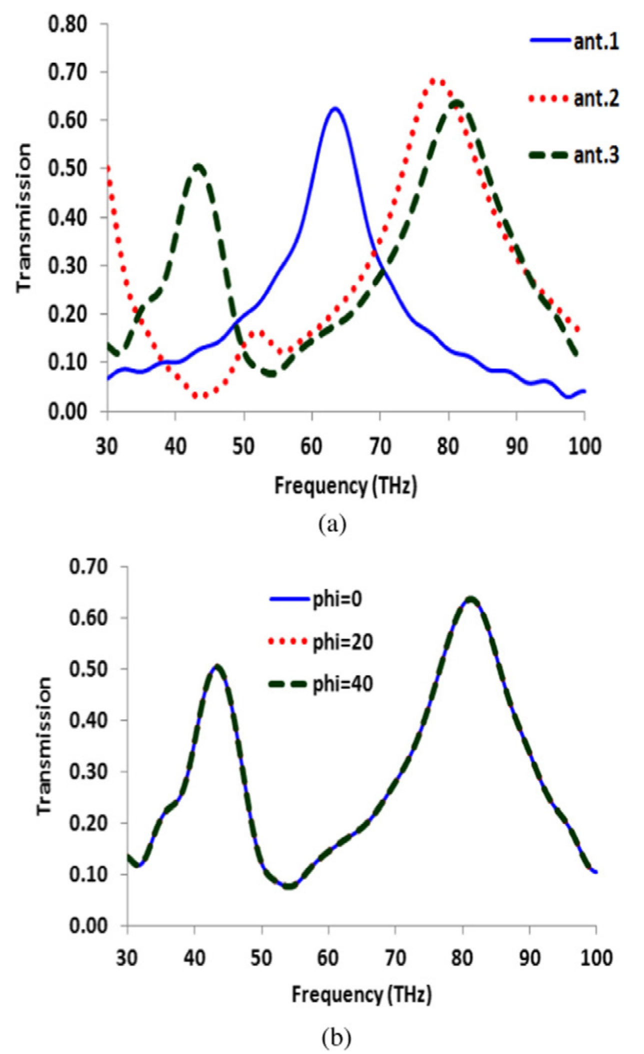

Fig. 2. The transmission of nano-antenna (a) three type of nano-antenna (b) various polarization angle for phi = 0°, 20° and 40°.