Physics Letters A ••• (••••) •••–•••

Contents lists available at ScienceDirect

Physics Letters A

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Investigation of novel fractal shape of the nano-aperture as a metasurface for bio sensing application

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ARTICLE INFO

Article history:
Received 17 July 2016
Received in revised form 2 October 2016
Accepted 15 October 2016
Available online xxxx
Communicated by R. Wu

Keywords:
Plasmonic
Nano-aperture
Metasurface
FOM

ABSTRACT

Recently, nano-aperture is noticed due to its good transmission in the optical regime. Also, the nano-apertures are developed at the metasurface design for circular polarization; for this aim, various shapes of the nano-aperture are suggested. To reach this objective, we have developed a novel Jerusalem cross fractal shape for a mid-infrared application. We have simulated various formations of the nano-fractal Jerusalem cross based on a simple cross to show the effect of nano-aperture shape on electrical field enhancement in the near-field which is important in spectroscopy and optical imaging. In addition, we have used a single layer graphene over the aperture as a coat for making reconfigurable characteristic also creating a membrane for placement of nano-particle over the aperture. Implementation of the graphene is an amendment to the transfer of the nano-apertures. The biological materials with a thickness of 80 nm have been placed over the graphene layer and the Figures of Merits (FOM) have been obtained. Additionally, the prototype of nano-antenna is independent from incident wave polarization. The Finite Difference Time Domain (FDTD) calculations have been implemented in the simulation and modeling the nano-apertures.

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1. Introduction

During the last decade, nano-antenna has received significant attention due to the strong enhancement of energy for the interaction of light with a metal structure at visible or infrared regime [1]. The applications of plasmonic technology based on periodic metallic nano-structure have emerged as a hot research topic due to their extraordinary optical properties [2]. These unique properties have made them a focus of research in various applications such as optical circuit [3], cancer treatment and drug delivery [4], solar cells based on Ag and Au particles [5] and optical imaging by using a pair of two-dimensional arrays of metal nano-spheres [6]. A plasmonic structure includes a metal layer (silver or gold) mounting on a dielectric substrate. Recent advancements in nano-manufacturing technology have demonstrated that plasmonic nano-particles exhibit interesting scattering, absorbance and coupling properties based on their different shapes and sizes [7]. In recent years, many researchers have focused on subwavelength apertures. Subwavelength apertures have gained tremendous interest because of their ability to create near-field enhancements and light confinement in nanometer scale with various formations such as bow-tie slot or hole [8–10]. Subwavelength apertures display unusual high transmissions in the optical [11], infrared [12] and terahertz waveguide [13] frequency ranges. There are important factors which the optical characteristics of the apertures are mainly dependent on them such as the refractive index of the adjacent medium [14], the shape and orientation of the apertures [15,16], metal film thickness [17], and lattice geometry [18,19]. In this regard, several shapes and orientations of the aperture such as simple cross [20], Jerusalem cross [21], H shapes cross [22], and bow-tie aperture [23] was reported and investigated. H-shaped apertures are noticed for dual resonances. However, these apertures suffer from weak near-field intensities; therefore, the bow-tie-shaped nano-apertures are suggested. H-shaped apertures don't have the incident wave Independence. In order to address this issue, the cross and Jerusalem for single and dual resonance with polarization Independence have been introduced. Graphene is a monolayer of hexagonally arranged carbon atoms that with voltage excitation can be used for tuneable Plasmonic material [24]. The Kubo formula performances are implemented for graphene in these studies and graphene conductivity has different terms of the σ_{inter} and σ_{intra} and therefore $\sigma_G(\omega) = \sigma_{inter}(\omega) + \sigma_{intra}(\omega)$ [25].

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http://dx.doi.org/10.1016/j.physleta.2016.10.028
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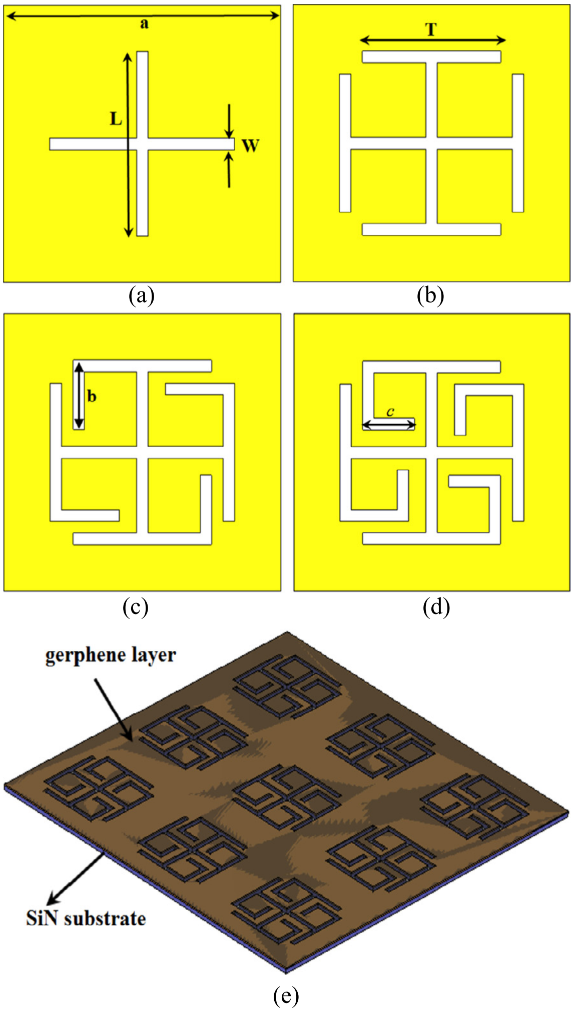

Fig. 1. Nano cross aperture antenna unit cells and arrays (a) simple aperture cross nano-antenna (b) Jerusalem cross nano-antenna (c) first step of the fractal nano-antenna (d) second step of the fractal nano-antenna (e) prototype array nano-antenna with graphene layer.

In addition, fractal patterns are irregular pieces and complex form families which have self-similarity or self-analogy with various formations such as a snowflake, ferns, coastlines, a tree and bow-tie [26]. These geometrical structures can improve the radiation quality in nano-particles [27].

The self-similar geometries in antenna applications are comparatively small. Therefore, designing fractal or self-similar fragments in nano-antenna creates multi-band characteristics. The H-shape aperture is a conventional model of fractional form that uses optical imaging [28,29]. In addition, Bow-Tie Dipole Antenna with Sierpinski shape Fractal has been examined for multi-band and Miniaturization [30]. In addition, recently, refractive index sensing characteristics of dual resonances in rectangular fractal nano-apertures is reported for bio-medical or gas sensing in a mid-infrared range at 10–140 THz [31]. The implementation of the graphene with fractal is noticed for field enhancement and making a reconfigurable device [32].

In this paper, we have modeled novel deformed cross shape nano-antenna with polarization independence for solar cell and the bio-application in mid-infrared.

At the first step, we developed the array of new shape and compared results with the conventional cross and then we are placed graphene layer to improve the antenna transmittance and electric field enhancement. Finally, the results are checked for implementation of the chain and we show the benefits of the coat and chain. FOM factor is studied to show the quality of the particle in detection of the bio particle.

2. Nano-antenna design

Recently, the cross junction nano antenna and nano aperture have been developed in various shapes by Wang et al. [33–36]. They have debated on tunable structures at THz regime with broken cross junction [33] and developed cross junction nano aperture as a metasurface for manipulating the polarization based on Babinet's theory [34,35] and phase variation for this metasurfaces are noticed.

In this current work, we are proposed a novel fractal nano-antenna based on cross-shaped nano-aperture for bio-sensing applications. Simulations are performed by the finite difference time domain (FDTD) method using CST Microwave Studio. For substrate, we have selected SiN with a refractive index of 1.98 and a thickness of 80 nm. The Palik model is used for the gold layer with the thickness of 30 nm in the design of the proposed nano-antenna. Fig. 1 illustrates fourth steps of the process of nano-antenna designing. The prototype cross nano-antenna is presented at Fig. 1(a) and then at second step as shown in Fig. 1(b), we have implemented the Jerusalem cross. In the third and fourth step, we have added an L shape element to nano-antenna and made meandered form as shown in Fig. 1(c) and Fig. 1(d). In addition, all dimensions are $a = 2400$ nm, $L = 1600$ nm, $W = 100$ nm, $T = 1200$ nm,

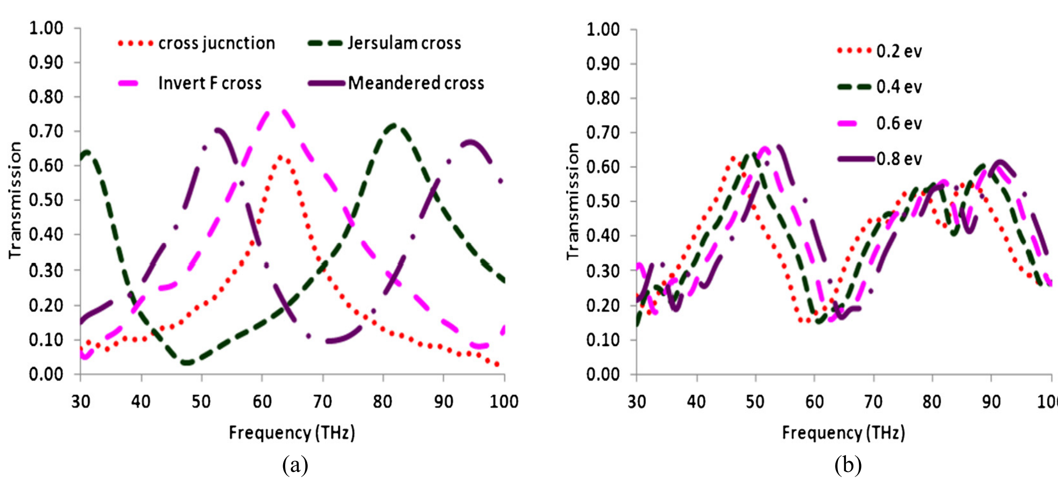

Fig. 2. The transmission of nano-antenna (a) for step of the design (b) with various graphene chemical potential biasing.

Please cite this article in press as: S. Heydari et al., Investigation of novel fractal shape of the nano-aperture as a metasurface for bio sensing application, Phys. Lett. A (2016), http://dx.doi.org/10.1016/j.physleta.2016.10.028

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