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Nanoscale plasmonic antenna difference formation implementation effect on field enhancement

Ferdows B. Zarrabi [a], Zahra Mansouri [b], Rahele Ahmadian [c], Hamed Kuhestani [b,*], Maryam Rahimi [c]

[a] Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
[b] Department of Electrical Engineering, Khodabandeh Branch, Islamic Azad University, Khodabandeh, Iran
[c] Department of Electrical Engineering, Imam Khomeini International University, Qazvin, Iran

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ABSTRACT

In this article, different implementation of plasmonic nano-antenna for optical range is presented. Nano antennas are designed based on I, U, dual I and dual U metamaterial structures. Different models of nano-antenna are studied for E field density, transmission coefficient, ACS (absorption cross section) parameter and E^2 enhancement for different wavelengths when linear polarization wave incident to nano antenna as a source field. Also, field enhancement and its relation with dual structure and comparison with single model are noticed. As shown here, single arrangement gives better field enhancement in comparison to dual structures but here we try to modify the result of dual U shape structure and enhancement of E field. On the other hand, benefits of U shape structure in nano-antenna design such as dual band characteristic and higher field enhancement are shown. At last different metamaterial formations to improve filed enhancement in this nano antenna is noticed here. The nano structures are based on deposition of silver layers on silicon-nitride substrate.

1. Introduction

Recently, by progress of micro and nano technology at THz and optical regime, many new devices and THz or optical sensors have been designed by these novel methods for detection of small partial such as biological and chemical materials that are important in medical, genetic analysis, and the pharmaceutical and food industries [1,2]. THz and optical systems are noticed for high efficiency and high quality imaging systems that are important for bio-sensing and ingredient detection by different methods such as Time domain spectroscopy (TDS), Resonant tunneling diode (RTD) oscillator, Schottky barrier diode (SBD) detector, surface enhanced Raman scattering (SERS) [3]. Recently, different models and methods have been presented for infrared bio-sensing such as a bowtie antenna operating with antiresonant mode by loaded InGaAsSb low-bandgap [4], diffusion approximation theory used for tissue optical properties [5], spectroscopy of Bragg scattered surface plasmons (BSSPs) generated by diffraction-coupling of counterpropagating surface plasmons and refractive index (n) of dielectric on phase parameter where $n = \sqrt{\varepsilon/2}$ [6] and polyethylene glycol (PEG) protected gold nanorods (NR) for higher X-ray absorption than a clinical iodine contrast agent in cancer detection [7].

Different forms of Antennas such as dipole for $\lambda = 814$ nm with each branch 20 nm × 200 nm base on Green function for scattering field [8], bowtie have been studied for 500–1600 nm with size of 100 nm × 120 nm [9], also photoemission electron microscope (PEEM) feeding for $f = 300$–450 THz (corresponding to $\lambda = 1000$–660 nm) has been used for field enhancement [10] and ring structure is noticed for multi resonance application [11] have become conventional for bio sensing with nano antenna because of easy feeding with laser [12] and array arrangement [13,14]. Near-field scanning optical microscopy (NSOM) subwavelength aperture probe is one of the earliest methods for optical imaging and recently gold gap nano antennas with picoseconds laser pulses are applied for higher accuracy in detection [15].

Multi-resonant metamaterials such as U and T shape structures have been noticed for nano aperture [16] and also UT-shaped metamaterial antennas with different dielectric loads, $MgFl_2$ ($n = 1.37$),

* Corresponding author at: Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. Tel.: +98 9381511367.
E-mail address: h.kuhestani@srbiau.ac.ir (H. Kuhestani).

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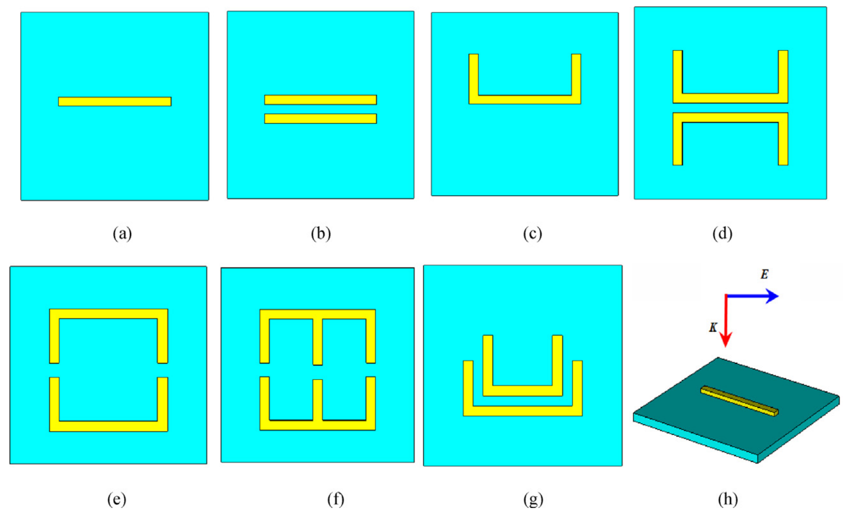

Fig. 1. Nano antenna structure (a) I shape, (b) dual I shape, (c) U shape, (d) dual U shape, (e) parallel U shape, (f) parallel E shape, (g) dual inside U shape and (h) linear polarization.

SiO_2 (n = 1.46) and Al_2O_3 (n = 1.76) are fabricated with gold deposition and joining to SiN with Ti for multi resonance at 40–110 THz [17].

Plasmonic resonant nano-focusing-antenna (RNFA) has been presented and compared with plasmonic disk [18], but Altug et al. have studied the absorption enhancement in gap structure in coupled Molecular based on plasmonic resonator by transmission (T), reflection (R), absorption can be calculated by ($A = 1 - R - T$) with wave number of 1000–3500 nm^{-1} [19,20]. MgF_2 is implemented for substrate and λ is defined by $(2n_{\text{eff}}/m)(2L)$ where m is mode number and L is length of antenna [20]. In other researches, improvement of the effect of gap antennas is compared to single cut-wire antenna elements. On this comparison, scattering and FOM (Factor of Merit) parameters have been noticed [21]. CMOS (Complementary Metal–Oxide–Semiconductor) imager chips are used by Altug et al. for protein detection in LED spectrometry and the effect of covering plasmonic layer by protein have been studied [22]. On the other hand, nanoarray biochips were developed based on wavelength-dependent single plasmonic nanoparticles by differential interference contrast (DIC) microscopy for protein detection [23]. Also, they have done researches about the effect of different shapes of nano antenna on multi band or improve reflection for NSOM spectrometry system [24–26].

Connecting metals to the dielectric causes $\varepsilon(\omega)$ frequency dependency and also negative characteristic at imaginary part of ε [27,28]. The general and simplified form of $\varepsilon(\omega)$ is given by Eq. (1) which is obtained from Drude Equations. Plasmonic nano loop array antenna is used in Yagi-Uda formation to improve far field enhancement and direct optical energy to achieve high gain radiation pattern. Gain is increased from 2 to 8.2 dBi [29,30]. By deposition of silver or gold layer on dielectric substrate, plasmonic structure will be achieved. For the aim of dielectric characteristic modeling, the Drude model is suggested to calculate real and imaginary part of the permittivity [29,30]:

$$\varepsilon(\omega) = \varepsilon_0\left(1 - \frac{\omega_p^2}{\omega(\omega + i\Gamma_p)}\right) = \varepsilon_0\left(1 - \frac{\omega_p^2}{\omega^2 + \Gamma_p^2} + i\frac{\omega_p^2\Gamma_p}{\omega(\omega^2 + \Gamma_p^2)}\right) \quad (1)$$

where ωp is the plasma frequency of the material and $\omega p = 2\pi \times 2175$ THz for silver. Damping factor Γp represents the losses present and $\Gamma p = 2\pi \times 4.35$ THz [29]. In this article, field enhancement and its relation with dual structure and comparison with single model are noticed and based on metamaterial techniques structures have been improved. On the other hand, benefits of U shape in nano-antenna design such as dual band characteristic and higher frequency field enhancement are shown. Finally, comparison between different model and arrangement of dual U shape is presented. The nano structures are based on deposition of silver layer on silicon-nitride substrate.

2. Antenna design

Fig. 1 shows seven different models of nano-antenna and different placement of dual U shape antenna have been studied. Here, I shape and dual I shape are compared with U and dual U shapes in different aspects such as E field density, transmission coefficient, and ACS (absorption cross section) parameter. E filed for different wavelengths has been studied and in Fig. 1h shows the incident field with linear polarization. The nano structure designing's are based on deposition of silver layer with thickness of 10 nm on silicon-nitride substrate with thickness of 30 nm and permittivity of 7. Gap is assumed 20 nm at dual structure and it is compared with 10 nm and 30 nm for studying the gap effect on E field enhancement. Metamaterial structures are noticed for field enhancement in different forms for THz and optic applications [31,32]. By Bakker et al. [33] metamaterial is reported the implementation for Near-field and broadband optical spectroscopy. Here assume I, U and E shape as metamaterial and nano-antenna for our studies and their effect on E-field have been noticed. Fig. 1a shows simple antenna with only contain I shape plasmonic and the silver layer size is 240 nm. Fig. 1b shows dual I shape plasmonic and the gap is 20 nm. Third nano antenna is the U shape form and total length is 420 nm as shows in Fig. 1c. Fig. 1d shows dual U-shape with 20 nm gap. Parallel U shape is presented in Fig. 1e, in this structure the gap is 28 nm and Also E shape is studied in this condition as shows in Fig. 1f. At last a combination of inserted U structure is noticed and presented in Fig. 1g with 20 nm gaps. In this article, linear polarization is used and incident to antenna as shows Fig. 1h.

3. Simulation result

Here, FIT and Time domain method is used by CST microwave studio with full wave simulation for nano antennas. E field density, transmission coefficient, ACS parameter and E-filed are extracted and compared for all models. By incident of 1 V/m E-field and linear polarization to plasmonic layer, the effect of this field is studied on enhancement of E^2. Fig. 2 shows the transmission intensity of