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Sub wavelength plasmonic nano-antenna with modified SRR structure for Fano resonance

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ABSTRACT

The optical electric field enhancement in the normal direction is noticed for Plasmonic and Fano mode at Nano antenna, therefore, we have modeled four various designs for Sub-wavelength Plasmonic and Nano-antenna with modified Split Ring Resonator (SRR) by adding new capacitors and SRR element to achieve the Fano resonance mode in various incident wave angles. Here, for all structures, the E-field enhancements at resonances are compared and design parameters effect on Fano resonance is debated. The incident wave direction is studied for making multi Fano resonance in all prototype structures and the extinction cross section comparison for 0°, 45° and 90° is revealed that the FANO resonances are related to the polarization angle of the incident wave and size of the gaps in Nano particles. SiN Substrate is selected with refractive index of 1.98 and silver with Johnson optical characteristic has been used for modeling of the metal layer. It has been observed that the $|E^2|/|Eint^2|$ increased to 200 000 at Fano resonances and the parametric studies showed that the gap size controls the Fano resonance frequency.

1. Introduction

Metamaterials have been the focus of many researches nowadays because of their unusual electromagnetic properties such as negative refractive indices, extraordinary near field enhancement, high frequency magnetism, electromagnetic cloaks, absorbers and nonlinear optics [1,2]. Due to these peculiar properties, they are considered as one of the best candidates in designing Nano structures and antennas.

By progress in the metamaterial and the plasmonic techniques, Surface Plasmon Polaritons (SPP) has been defined. SPPs have made vast development in the Nano-antenna and optical devices for biomedical application especially in imaging and spectrometry [3].

Different shapes of Nano antennas have been developed to improve the radiation field, Absorption Cross Section (ACS) and Reflection Cross Section (RCS) and achieving multi resonance structures in the mid-infrared and Bio-sensing applications [4].

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Table 1
dimensions of the antenna structures.

Parameter	nm
a	400
b	170
c	40
d	60
e	40
f	130
h	320
i	40
W	500

The coupled Plasmonic spiral with circularly polarized for unidirectional emission has been developed on a glass substrate (n = 1.5) [5]. Bowtie Nano-antenna for Localized radiative energy transfer and metal-dielectric-metal dipole antenna with quantum cascade laser feed with optimum SiO2 substrate thickness is known as the new conventional formations for Nano-antennas based on plasmonic method [6,7]. For designing Nano antennas with high Electric-field enhancement, bowtie and bowtie aperture plasmonic antennas are suggested in [8] which are operating at optical frequencies and are useful for different applications such as bio-sensing, THz detector including near-field scanning optical microscopy (NSOM), surface enhanced Raman scattering (SERS), sub-wavelength resolution, and Nano scale optical lithography scanning probes [9,10]. The scanning near-field optical microscope (SNOM) is enabled the performance of Nano spectrometric experiments at wavelengths in the visible range and microwave electromagnetic spectroscopy [11]. By the appearance of Nano shell and interaction of light with metallic surfaces or nanostructures, the new definition has been modeled for spectroscopy of bio sensing. Enhancement of electromagnetic field on a metal surface is noticed for sensitivity enhancement. The quality of the spectroscopic signal of molecule's absorption called surface enhanced Raman scattering (SERS) [12].

Split ring resonator (SRR) is a famous type of metamaterial, which is used in microwave devices or absorbers to improve the bandwidth and the gain of the antenna. It can produce the negative permeability and positive permittivity around its resonance frequency. The main feature of SRR is the quasi-static resonance at a larger wavelength in spite of its small size. This leads to use SRR in designing small antennas structures [13,14]. Gold dipole Nano antenna has been considered recently as one of the simplest models, which produces similar radiation pattern and lithography to Nano rod structures. Enhanced integrated scattering properties have noticed for dipole Nano-antenna in comparison to Nano rod structures [15,16]. Therefore, the gaps in Nano antenna are known as the best way for improving scattering and absorption in Nano antenna such as a dipole and bowtie Nano-antenna [17–19].

Combinations of the Split ring resonator (SRR) are studied for Nano application as a plasmonic planer split ring trimer [20] and THz absorber as a single and dual band application [21]. In addition, the gap in metamaterial, SRR and Nano antenna are known as the best candidate for controlling the resonance and polarization [22–24].

In this article, at first, we introduced a simple SRR Nano antenna (Ant. 1) and the structure changed to a loop formation (Ant.2). For third antenna (Ant. 3), a simple dipole structure is combined with the second model and at last, inner SRR elements are added to the loop antenna as the fourth antenna (Ant.4). In this structure gaps act as capacitor and the metal line has been used for making inductor. Therefore, by controlling capacitance and inductance properties, we are able to control the resonance frequencies. On the other hand, we investigated that we can add some new inductor and capacitor to our structure by adding dipole and SRR structure as shown in the third and fourth antenna (Ant.3 and Ant.4). The Fano resonance for all prototype structures and the Extinction cross section comparison for 0°, 45° and 90° revealed that the Fano resonances related to the polarization angle of the incident wave and the gap size in Nano particles.

2. Antenna design

Fig. 1 reveals various formations of the plasmonic Nano-antenna. Fig. 1(a) shows a parallel silver SRR structure with dimension 'a' = 400 nm and 'b' = 170 nm. The two parallel structures are placed 20 nm apart from each other. In this figure, 'c' is the gap in the SRR structure, which is equal to 40 nm. The silver trace width is 10 nm. In Fig. 1(b) both of SRRs are joined by junction to make a loop structure. Fig. 1(c) shows the third Nano-antenna. In this structure, a simple dipole structure is combined with the second model, and the new gap (e = 40 nm) structure will help us to improve the concentration of E-field at the gap. At last, for the fourth model two SRR structures have combined with the second structure, which is shown in Fig. 1 d). The Nano structures is placed on a SiN layer with refractive index of 1.98 and excited with incident 1 V/m electrical field. All the simulations are performed using CST microwave studio full wave simulation software. All the gaps are exhibited as capacitors as shown in Fig. 1(a). Table 1 presents all the dimensions related to the structures.

3. Simulation results

Because of the importance of scattering quality of Nano-antenna in different applications such as Surface Enhance Raman Scattering (SERS), the ECS is obtained for all presented structures and results are compared together.