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The sub-wavelength plasmonic nano-antenna based on cross structure

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ABSTRACT

In this article, a new combination of a loop and cross structure as a sub-wavelength plasmonic nano-antenna is presented. Loop antenna and a model of cross nano-antenna as well as their combination are studied in this paper. Three different models of plasmonic cross sections are employed in this article for absorption, as simple loop, simple cross junction and finally in combination of these two structures. To achieve high field enhancement and dual resonances, a bent cross-junction structure is combined with ring structure. New cross-junction ring structure represents two resonances at 45 THz and 86 THz. In the new model, E^2 increases extremely to more than 20,000 $(V/m)^2$ at 88 THz. Absorption cross section (ACS) shows great enhancement at 88 THz, where E^2 has the maximum rate.

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1. Introduction

Interaction of light with metal-dielectric materials leads in new characteristic, called Plasmon surface. The metal/dielectric interface is excited by an electromagnetic field at optical frequency. This propagation along the interface is known as surface plasmon polaritons (SPP) and the 300–1000 nm wavelength is selected for plasmonic application [1,2].

Metamaterial is a kind of structures with negative or zero permittivity and permeability, which cannot be found in nature and natural structures. Generally, metamaterials include double negative (DNG) and single negative (SNG) structures. In nature, plasmonic metamaterials are found in optical and infrared frequencies. However, plasmonic materials can be used in epsilon negative (ENG) structures that are a group of SNGs with negative ε in microwave frequencies [3–5].

In the last decade, with the progress of nano technology, various shapes of nano antennas are presented for different applications such as spectroscopy and nano imaging [6,7]. Nanorod is the simplest model of nano antenna, which radiation characteristic and fabrication process are the same as cavities for dipolar emitters that has been studied extensively [8,9]. Novotny studies effective wavelength scaling for optical application with full wave modeling [10].

The gold dipole nano antenna is known as one of the simplest models and is attractive because of the simple radiation pattern and lithography to the nanorod. Enhanced integrated scattering properties of dipole nano-antenna are noticed in comparison with nanorod [11,12]. Therefore, a gap is known as the best way to improve scattering and absorption characteristics of nano antenna such as dipole and bowtie models [13–15].

Loop nano antenna has a similar radiation pattern to nanorod and it has been studied in former researches because of its simple formation and multilayer as a Yagi antenna and has been compared with nano-disk antenna [16–18]. The resonance frequency of nano antennas with gap can be calculated by $\varepsilon = \left(1/\sqrt{L(C+C_g)}\right)$, where C_g is the gap capacitance [19]. By deposition of silver or gold layer on dielectric substrate, the plasmonic structure is achieved. The Drude model is suggested for simulating the dielectric characteristic. Following is the real and imaginary part of the permittivity [17]:

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

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The ring structure of nano-antenna is studied for optical applications in which the field is concentrated inside the ring [20]. The effect of multiple-Split on transition and field distribution of nano-photonic ring antenna is studied for different gap sizes [21]. To improve the absorption characteristic in metamaterial structure, split-coin resonator (SCR) structures are presented with similar shape of ring antenna [22].

In this article, nano-loop antenna is studied in basic formation, and on the other hand, L-shape strips are used to make a cross structure. Both structures have both productive and counter-productive specifications such as low absorption cross section, E-field enhancement and single band characteristic. Though, the combination of nano-loop and cross-junction are implemented in order to achieve higher absorption cross section and E-field enhancement with dual band characteristic.

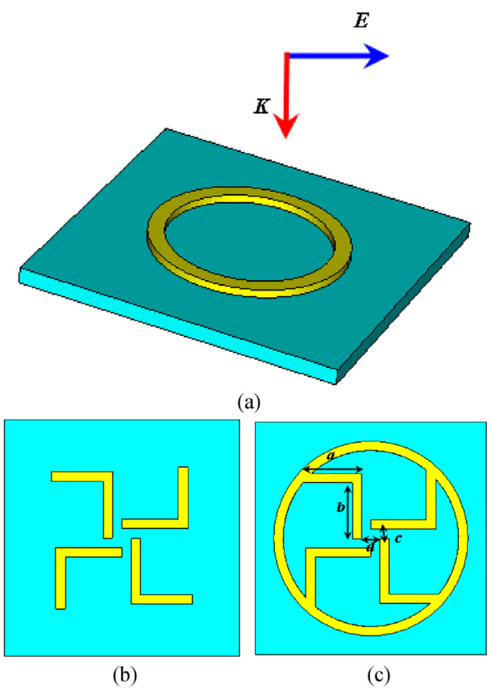

Fig. 1. Field encountering to Ring nano antenna (a) loop antenna, (b) cross antenna and (c) combination of loop and cross antenna.

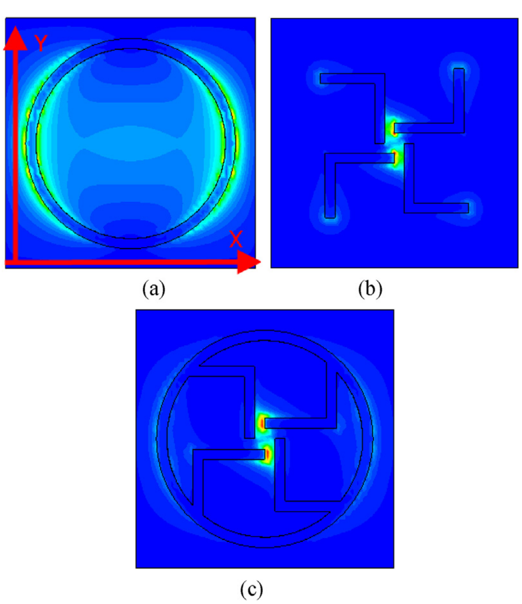

Fig. 2. The E field density in antenna (a) loop antenna, (b) cross antenna and (c) combination of loop and cross antenna.

2. Design particle

Fig. 1a shows a simple Ring nano-antenna with incident wave polarization and direction for Plasmonic structure. The structure contains gold ring with the thickness of 10 nm, outer and inner radius of 210 nm and 190 nm, respectively. The ring structure is placed on SiN layer by $n = 2$. Incident field is 1 V/m on the X direction. Commercial field solver CST Microwave Studio with its time domain option is used for simulation. Fig. 1b shows the simple cross structure that is made by four L shaped 250 nm long strips and dimension of $a = 130$ nm and $b = 120$ nm. The structure has two gaps, which behave as capacitance in this structure. The widths of

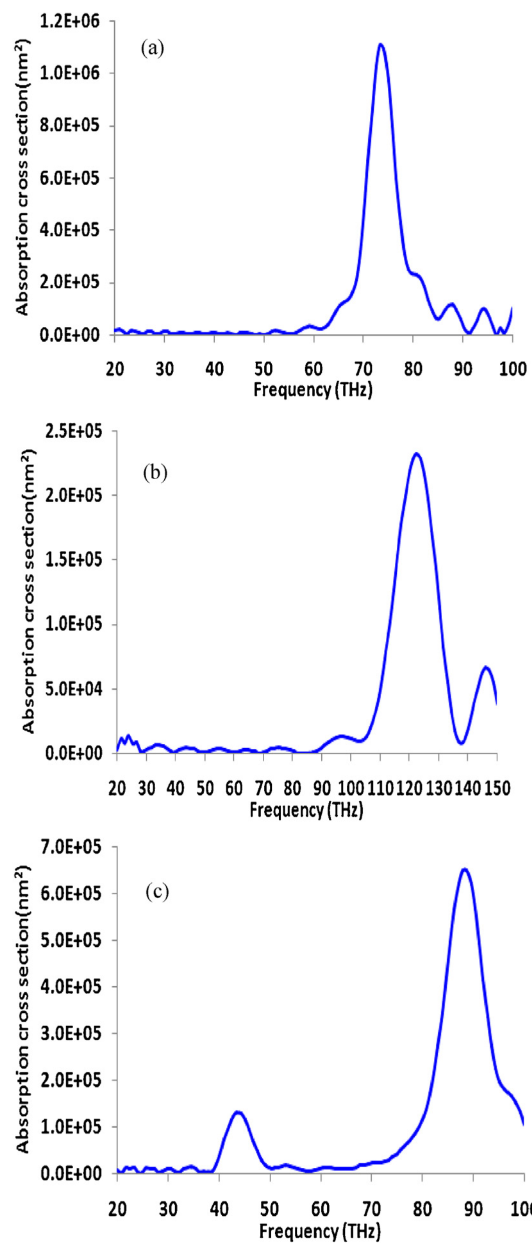

Fig. 3. Absorption cross section (a) loop antenna, (b) cross antenna and (c) combination of loop and cross antenna.

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