Comparative study of DR Nanoantenna Array For Optical Frequencies

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***Abstract*—**The frequency dependent complex permittivity of plasmonic materials is one of the most decisive parameters in their resonant characteristics. This work shows how the optical responses of gold (Au),and silver(Ag) optical nanoantennas are affected by their size, shape and their frequency dependent optical functions. The optical functions of these metals are described by the Drude-Lorentz model in which both the free electrons contributions and harmonic oscillator (SPRs) acivities are considered. The change of material in the nanostrip and the ground plane results in the change in different parameters like return loss, VSWR , etc.
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Keyword- *optical antennas, nanoplasmonics, plasmonic metals,optical energy.*

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I. INTRODUCTION

Optical antennas stand for a class of novel optical detectors that have the potential to revolutionize optical inter-connections, image sensing andrelated fields by adapting radio wave techniques to the optical regime. Optical antennas couples up with electromagnetic radiation in the visible and infrared wavelengths in the same way that radio electric antennas do at the corresponding wavelengths [1]. The optical antennas size is in the range of the detected wavelength from a few hundred nanometers to a few microns. Optical antennas are advantageous in the detection of light showing polarization dependence, tunability, and a potential rapid time response. They also can be assumed as point detectors and directionally sensitive.

Nanoplasmonics is a branch of optical material science devoted on the phenomena of nanoscale nanostructured metal systems. A unique property of such systems is their ability to keep the optical energy concentrated on the nanoscale because of modes called surface plasmons (SPs). The existence of SPs depends entirely on the fact that dielectric function ε_m has a negative real part, Re ε_m <0 [2]. The SPs are well pronounced as resonances when the losses are quite small, i.e., Imε_m <<– Re ε_m . This is a known property of a good plasmonic metal, valid, e.g., for silver in the most of the visible region.A substance is a good plasmonic metal if these two properties are satisfied simultaneously.

Reε_m <0 ,Imε_m <<−Reε_m …….(1)

There is an extent to which an electromagnetic wave can be concentrated. The nanoplasmonics is about concentration of electromechanical energy at optical frequencies on the nanoscale.The scale of the concentration of electromagnetic energy can be determined by the wavelength that can be understood from Fig. 1 (a).

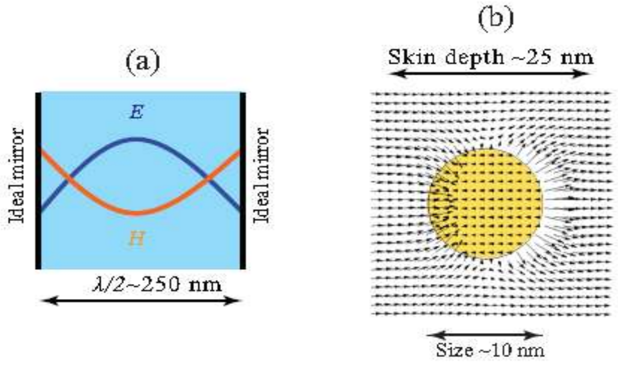

Fig. 1(a) localisation of optical fields by ideal mirror (b) by a gold nano particle.

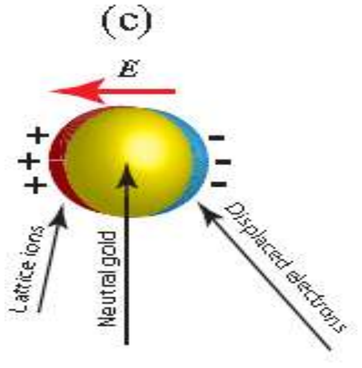

Fig.1(c) schematic of charge seperation.

It is difficult to achieve a localization of the optical energy to smaller volume than $\lambda^3/8$ apart from the ideal mirrors gives the best confinement of electromagnetic waves. There are two implied assumptions: (i) The optical energy is electromagnetic energy, (ii) The best confinement is brought through ideal mirrors. Both these assumptions must be removed to get nanolocalization of optical energy. Consider a nanoplasmonic system whose size is less than or comparable to the skin depth.

$$l_s = \lambda \left[Re \left(\frac{-\varepsilon_m^2}{\varepsilon_m+\varepsilon_d}\right)^{\frac{1}{2}}\right]^{-1} \text{ .... (2)}$$

Where λ = ω / cis the reduced vacuum wavelength. For single-valence plasmonic metals (silver, gold, copper, alkaline metals) $l_s \approx 25$ nm covering the entire optical region. In this paper we are analysing the effect of the two metals i.e. gold and silver respectively on the optical DR nanoantenna array.[3]

For such a plasmonicnanosystem with $R \leq l_s$, the optical electric field penetrates the entire system and drives oscillations of the metal electrons. The total energy of the system in this case is a sum of the potential energy of the electrons in the electric field and their mechanical kinetic energy. While the magnetic field is present, non-relativistic electrons' interaction with itis weak proportional to a small parameter $\frac{v_F}{c} \sim \alpha \sim 10^{-2}$, where$v_F$is the electron speed atthe Fermi surface, c is speed of light, and $\alpha = e^2/hc$is the fine structure constant. Thus in thislimit, which is conventionally called quasistatic, the effects of the magnetic component of thetotal energy is relatively small. Hence, this total energy is mostly *electromechanical* (and notelectromagnetic) energy.

At optical frequencies, electrons in metals have considerable inertia and cannot respond instantaneously to the driving fields. Typically, the skin depth is on theorder of tens of nanometers, comparable to the dimensionsof the antenna. Traditional design rules that prescribeantenna parameters only in terms of an externalwavelength are thus no longer valid. The metal must berigorously treated as a strongly coupled plasma, whichleads to the antenna "seeing" a reduced effective wavelength. This effective wavelength,λeff, is related to the external (incident) wavelength, λ,by a surprisingly simple relation

$$\lambda_{eff} = n_1 + n_2 \left[\frac{\lambda}{\lambda_p}\right] \text{ .... (3)}$$

whereλ_p is the plasma wavelength of the metal, and $n_1$and n_2 are constants that depend on the geometry anddielectric parameters of the antenna. λ_{eff} is shorter, bya factor of 2 to 6, than the free space, λ, for typical metals(e.g., gold, silver) and realistic antennathicknesses.The shortening of wavelength from λ to λ_{eff} hasinteresting implications. For example, it implies thatthe radiation resistance of an optical half-wave antennais on the order of just a few Ohms.

II. DESIGN

The proposed antenna design is classified with the help of two material of the nanostrip as well as the ground plane. Initially the material assigned for the nanostrip and the ground plane was silver. The optical dielectric nanoantenna array have four radiating element of cylindrical shape and is composed of silicon with the height (h) =325nm and diameter (d) =510nm.

A DRA can be analysed in terms of its shape and modes of excitation. The electromagneticnear fields inside the resonating body are the prime sources of interpreting the far fieldradiation patterns and thus help to understand the overall characteristics of the antenna.Though many design shapes are available, however the best one is thatwhich is either readily available or that is simple to cut, grind and mould. It is for this reasonthat a circular cylindrical shape has been chosen for the proposed designs.The geometry shape of the DRA is analysed in terms of its resonant modes, near-field distributioninside the resonator, far-field radiation into the space, resonant frequency and impedancebandwidth.The overall performance of an array can be evaluated in terms of the followingparameters;

i. Geometry and dimensions of DRA elements.
ii. The spacing among elements.
iii. The number of elements used.
iv. The feed mechanism.[9]

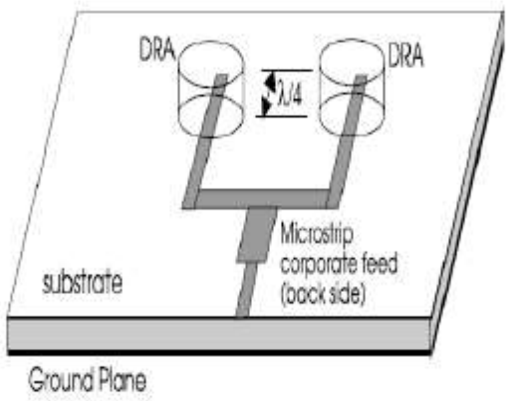

Fig. 2: feed structure to construct arrays

The resonators are above the nanostrip and positioned to obtain a maximum wideband. The antenna substrate is composed by SiO_2 and the ground plane is composed by silver. The thickness of the SiO_2 layer between the nanostrip and the ground plane is h_1=145nm. There is a layer of thickness h_3=10nm made of SiO_2 between the nanostrip and the DR. The nanostrip has w=340nm of width and h_2=20nm of height. The metallic regions of the nanostrip are composed by silver. Whose dispersive properties were described by the Drude's model assuming ε_{inf} =5, fp=2175THz, and γ=4.35THz [4][5]

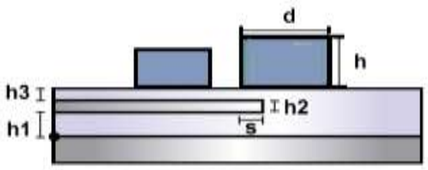

Fig 3: side view of the DR antenna array.

The DRA was investigated in nanoscale and operating at optical frequencies.The resonators are composed of silicon

(ε_r= 11.56).The resonance frequency of DR's H$E_{11\delta}$ mode in free space, can be estimated from [6]

$$f = \frac{6.324\,c}{(2\pi a\sqrt{\varepsilon_r}+2)}\left[0.27 + 0.36\left(\frac{d}{2h}\right) + 0.002\left(\frac{d}{2h}\right)^2\right] \ldots\ldots..(4)$$

According to this equation the mode can resonate at 193.5 THz when d and h are assumed proportionally. The length of nanostrip which is assumed to be under the resonator is taken as "s", which plays a very crucial role in the variation of the results. [7]

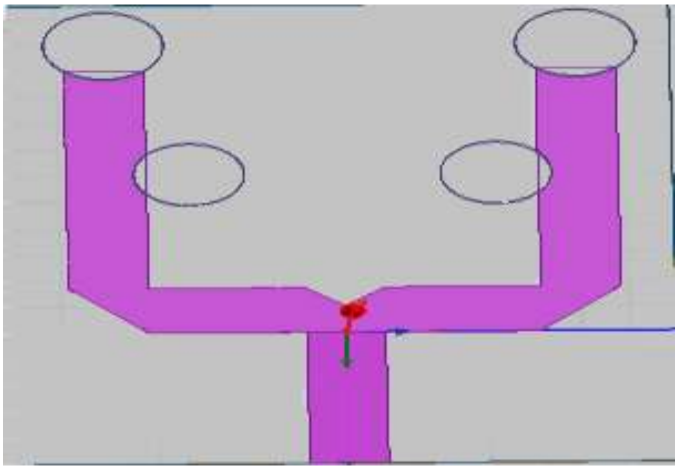

Fig 4: Top view of the nanostrip and ground plane is composed of silver

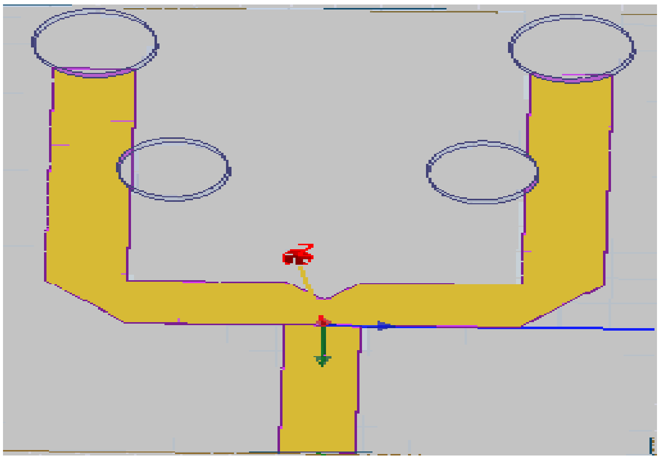

Fig 5: Top view of the nanostrip and the ground plane is composed of gold

The antenna design considered, has four cylindrical resonator elements, each of equal height and diameter, one pair is kept near the ends of nanostrip and another pair is kept at the midpoint of the length of nanostrip.

III. RESULTS

The results are simulated on HFSS14.0 software licensed version which is a FEM (Finite Element Method) based simulator. It is used to calculate various Electromagnetic behavior of the structure such as basic EM field quantities, S-parameters, resonance of the structure, etc. The return loss of the optical DR nanoantenna of material silver and gold at the optical frequency 193.5THz are -18.26db and -23.5db.

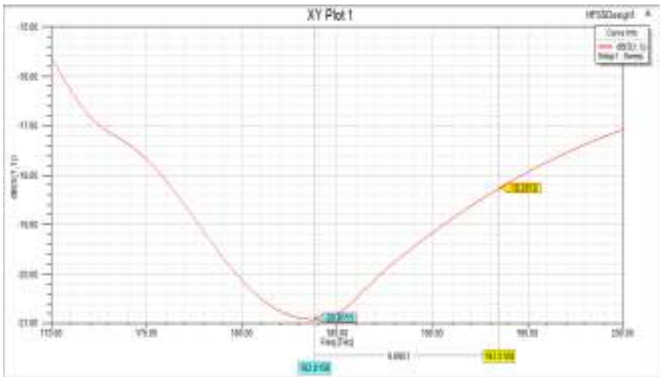

Fig 6(a): return loss for silver nanostrip and ground plane

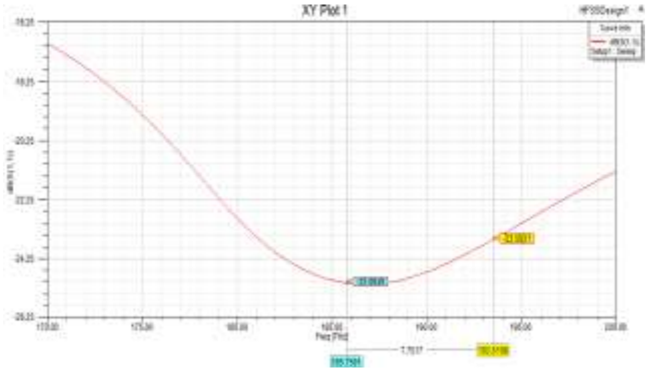

Fig. 6(b):return loss for gold nanostrip and ground plane

The voltage standing wave ratio (VSWR) is ameasurement of the impedance mismatch between thetransmitter and the antenna. Large value of VSWRcorresponds to the high mismatch.Minimum value of VSWR corresponds to a perfect match that is unity. The VSWR v/s frequency plot for the proposedantenna is shown in Fig.7. The VSWR for silver nanostrip and ground plane is 1.19 and for gold nanostrip and ground plane is1.11.It may be observed that thevalues of the VSWR are less than 2 for the whole bandwhich is within the required limits .

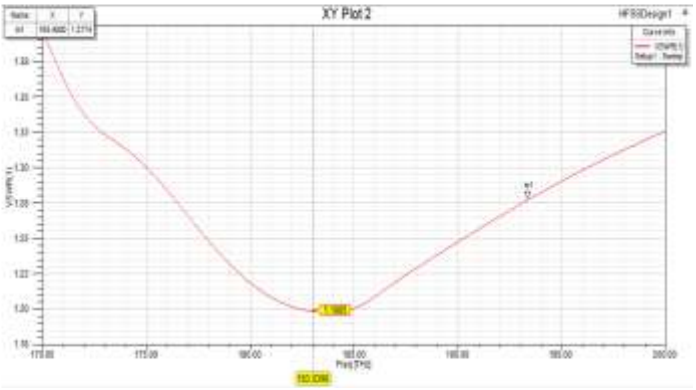

Fig 7(a) : VSWR for silver nanostrip and ground plane

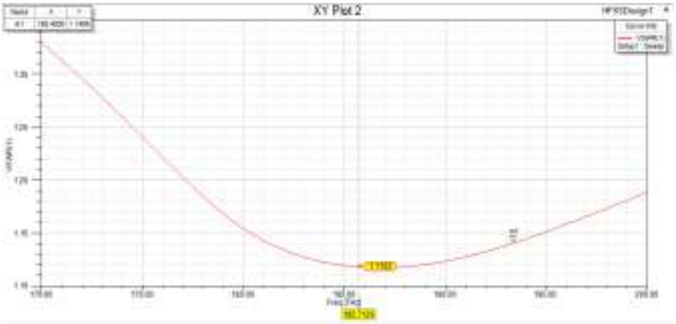

Fig. 7(b): VSWR for gold nanostrip and ground plane

IV. CONCLUSION

The optical DR nanoantenna array having four dielectric resonator elements has been compared separately by assigning materials like silver and gold on the nanostrip and the ground plane. The design having gold as nanostrip and the ground plane have better results than the silver one. This design can be used for many applications in the field of medicine, photovoltaic, spectroscopy and near field microscopy. [8]New ideas and developments are emerging at a rapidpace, and it is now clear that the optical antenna conceptwill provide new opportunities for optoelectronicarchitectures and devices. Today, the building blocksfor optical antennas are plasmonic nanostructures thatcan be fabricated either from the bottom up by colloidalchemistry or from the top down with establishednanofabrication techniques, such as electron-beamlithography and focused ion-beam milling. It is alsoconceivable that future optical antenna designs willdraw inspiration from biological systems, such as light harvestingproteins in photosynthesis.

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