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Performance Analysis of Nanomaterials Based Cubodical Dipole Antenna for Terahertz Communications

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***Abstract*— In this study, a simple dipole antenna is designed and analyzed using finite element method. The new design consists of two elements with cubodical shape and air gap. The dipole antenna is operating at 0.6 THz. The performance of the cubodical nanorod is measured in terms of Return loss, Radiation efficiency, Directivity and Realized Gain of the dipole antenna. A comparative analysis is done for various materials – Gold (Au), Silver (Ag), Titanium (Ti) in terms of the above mentioned parameters. The antenna is designed and simulated using FEM based electromagnetic solver, Ansys -HFSS.**

Keywords*—: Dipole Antenna, Realized Gain of the Antenna, Directivity, Return Loss (S11), Radiation Efficiency, Ansys-HFSS

I. INTRODUCTION

In radio and telecommunications, a dipole antenna is the simplest and most widely used class of antenna. It consists of two identical conductive elements such as metal wires or rods, which are usually bilaterally symmetrical. So the length of the dipole elements is determined by the wavelength of the radio waves used. The most common form is the half-wave dipole, in which each of the two rod elements is approximately $1/4^{th}$ of wavelength long, so the whole antenna is a half wavelength long. The radiation pattern of a vertical dipole is omnidirectional, it radiates equal power in all azimuthal directions perpendicular to the axis of the antenna.

The performance of a dipole depends on resonant frequency, good construction and efficient power transfer from source to antenna i.e., better impedance matching. There are many class of antennas. Still the reason to choose dipole is that, medium and high frequency operation of dipole antennas are easy to construct and have good flexibility that can be installed in an wide range of configurations other than the classical flat top arrangement.

In Fig.1, a simple dipole antenna structure is shown such that the feed is given at the center. The antenna elements have a length of quarter of the wavelength with total length becomes half of the wave length. As mentioned, antenna is designed for THz range such that it has a wide range of applications in fields like time domain spectroscopy and imaging since THz waves has high penetrating ability to penetrate dielectric materials and they are reflected by metals.

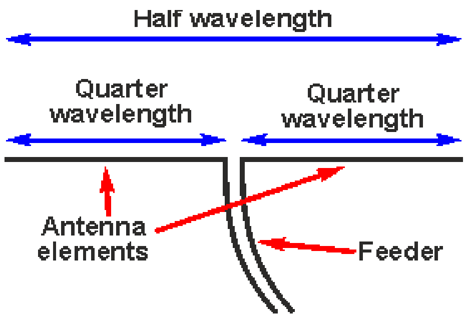

Fig. 1. A dipole wire

In this paper, a simple cubodical antenna is designed to resonate at terahertz frequency with resonating frequency of 0.6 THz. Also the performance of the dipole is measured with parameters like Return loss, Radiation efficiency, Realized Gain of the antenna, Directivity. Then these parameters are measured for different materials like Gold, Silver, Titanium and a comparative study is done.

This paper is divided into six parts such that section 1 is introduction followed by related works, preliminaries, antenna design, results, conclusion in their respective section.

II. RELATED WORK

Similar works have been done earlier using dipole antenna for various frequency for various purposes. Michael Hamid et al.[1], designed a dipole antenna of arbitrary length and its equivalent circuit is derived .From the derived equivalent circuit, the input impedance is found out and it is compared with the analytical and experimental data. In this, a center fed cubodical dipole antenna is designed and Zin versus frequency is found out using graphical procedure and the same is compared with their proposed equivalent circuit.

Truong khang Ngyuyen et al. [2] designed a strip line based dipole antenna and the antenna performance were analyzed in a frequency range up to 5 THz. Here two different substrate schemes were presented i.e., two radiation environments-a semi infinite gallium arsenide substrate and a gallium arsenide substrate backed by a silicon lens. The input impedance and radiation characteristics were found out for this dipole antenna. Here a comparative study was done between the two substrate schemes. The former approach had a good computational time than the latter. Also, lens substrate case exhibits frequency dependent gain profile which is not there in semi infinite substrate. In this study, a good guidelines for the design of terahertz antenna is provided and the lens effect also considered.

Mohamed Hussein et al.[3] proposed a novel design of nano antenna for energy harvesting .The new design consists of three nano elements with air gap in between them. He focused on improving the radiation efficiency of the nano antenna with in the wavelength range from 400 to 1400 nm. The dipole antenna designed for an average of 500 nm i.e., in the mid of visible range so that it can harvest high energy and deliver high radiation efficiency. Here the total harvesting efficiency is enhanced by 32.7 %. Also the suggested nano antenna has better efficiency of 74.6 % compared with the conventional solar cells at wavelength of 500 nm at which the sun irradiance is maximum. The dipole antenna is designed using gold material.

Fahan Shamshad et al.[4] designed a dipole antenna and went for a comparative study between the electromagnetic solver available like Ansys, CST Microwave studio and Wires Plates and Dielectrics(WIPL-D) .He concluded that CST transient solver is suitable for wide band antenna simulations and electrically large structures but need more time and memory. Also, WIPL-D is well suited for electrically large structures like parabolic dish and Ansys best suits for narrow band design.

II. PRELIMINARIES

Before going into the proposed system and measuring all antenna parameters as mentioned above, we need to know what does these antenna parameters like Directivity, Realized Gain, Radiation efficiency, Return Loss(S_{11}).

A. Return Loss

Return loss is the loss of power in the signal returned/reflected by a discontinuity in a transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

$$RL=10\log(Pi/Pr) \text{ in (dB)} \tag{1}$$

Where P_i is the incident power and P_r is the reflected power.

B. Radiation Efficiency

Radiation Efficiency of an antenna relates the power delivered to the antenna and the power radiated or dissipated within the antenna. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

The antenna efficiency (or radiation efficiency) can be written as the ratio of the radiated power to the input power of the antenna:

$$Radiation\ Efficiency=P_{radiated}\,/\,P_{input} \tag{2}$$

C. Realized Gain

Realized gain is the gain taking into account the reflection losses at the input of the antenna. In other words, we can say that realized gain doesn’t take into account the reflection losses at the antenna input. And it is the ratio of power radiated to the power accepted by the antenna. Obviously, the realized gain will be less than the gain of the antenna.

D. Directivity

Directivity is a figure of merit for an antenna. It measures the power density the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal isotropic radiator (which emits uniformly in all directions) radiating the same total power.

With these knowledge ,a dipole antenna is designed for THz region and these antenna parameters are computed and compared for different materials Gold(Au), Silver(Ag), Titanium (Ti) .

III. ANTENNA DESIGN

Simple and inexpensive antenna whose radiation characteristics are frequency dependent is a cubodical dipole (i.e., a wire of finite diameter and length) . Thick dipoles are considered broadband while thin dipoles are more narrowband. This geometry can be considered to be a special form of the biconical antenna when $\alpha = 0^{\circ}$,where ‘α’ is the angle of the cone . A thorough analysis of the current, impedance, pattern, and other radiation characteristics can be performed using the Moment Method. Antenna used at the frequency where its driving point impedance is purely resistive is called a resonant antenna.

Now we are going to design the cubodical nanorod (dipole antenna) for terahertz operation using Ansys-HFSS. The cubodical elements are separated with a air gap and these antenna elements have radius and height, where the height determines the operating frequency. In Fig.2,the cubodical nanorod structure is shown with a centre feed.

Now there is an important factor to be considered while calculating the length of the antenna. In general for a dipole antenna we say that the length ‘L’ can be (0.5*λ) half wavelength. But in real time cases it won’t be exactly half wavelength. In viewing the impedance as a function of the dipole length , it can be noted that by reducing the length slightly the antenna can become resonant. If the dipole's length is . reduced to 0.48λ, the input impedance of the antenna becomes Zin =70 Ohms, with no reactive component. This is a desirable property, and hence it is used here.

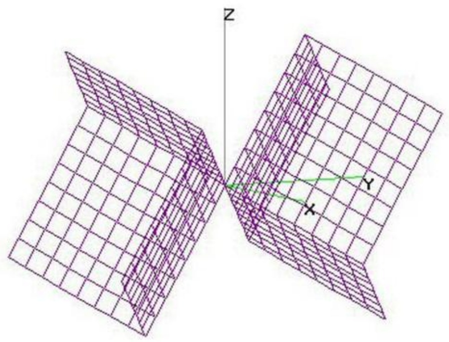

Fig. 2. A Rough sketch of Cubodical nano rod.

Here,

L=Total length of the antenna.

L1=Length of the antenna element.

L2=Length of the antenna element.

g=Air gap between the element.

a=radius of the cubodical.

Parameter of the antenna	Values in mm
L	0.35
L1,L2	0.23
a	0.005
g	0.017

TABLE I. DIMENSIONS OF THE ANTENNA

The antenna structure in Ansys software is as shown in Fig.3, which is designed with the dimensions specified in TABLE I. As said earlier ,the material used for constructing the dipole antenna is Gold. Then the Gold nanorod is analyzed and compared with other conducting materials Silver, Titanium.

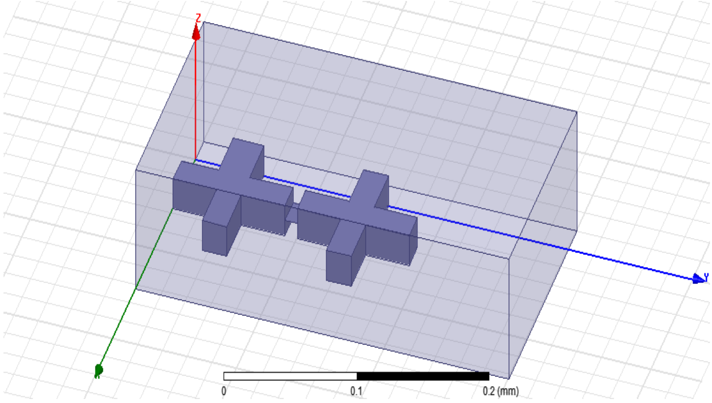

Fig. 3. HFSS layout for the Cubodical nano rod.

IV. SIMULATION RESULTS

Now we see the antenna parameters Return loss, Radiation efficiency, Realized gain, Directivity for the cubodical nanorod. First the dipole antenna is constructed using Gold material then in the section 5.1, we for a comparative analysis of different nanorods.

In Fig.4, the return loss (S11) of the gold nanorod is seen. We see that the dipole resonate at 0.6 THz. The loss is -22 dB which specifies that the incurred loss due to mismatch between the source and the antenna is at reasonable level and very well the antenna can be designed for real time applications. In Fig.5, the radiation pattern is shown. From the plot we can say or conclude that the antenna designed has a good directivity and the lobe pattern obtained almost covers most part of the region. The radiation pattern obtained almost resembles the ideal dipole antenna.

In TABLE II, the realized gain for the gold nanorod is tabulated. We can see that at 0.6 THz (resonating frequency), the realized gain is -11 dB, which is the gain that takes into account the losses incurred and the source. As mentioned earlier the antenna gain is different from the realized gain. In Fig.6, the radiation efficiency is plotted. It is of approximately 92 % which tells us that the antenna efficiency radiates the input signal without maximum loss.

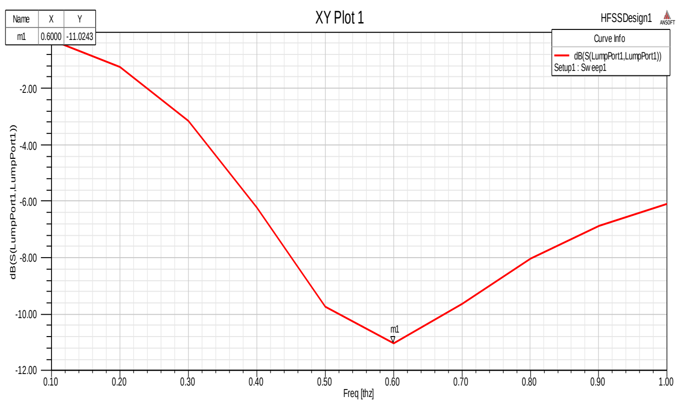

Fig. 4. Return loss of the cubodical gold nano rod

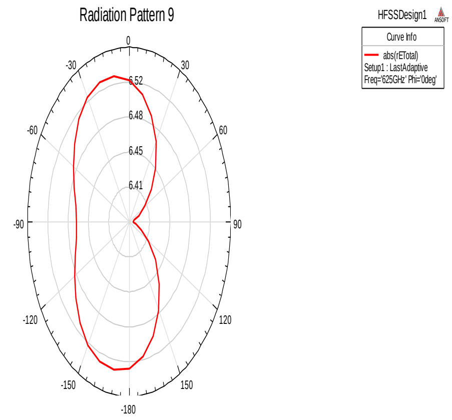

Fig. 5. Radiation pattern of the cubodical gold nano rod

Frequency in THz	Realized Gain in dB
0.1	-69.84643192
0.2	-65.39003241
0.3	-72.09445878
0.4	-72.57103647
0.5	-68.72621316
0.6	-62.23483467
0.7	-50.60348565
0.8	-43.42065799
0.9	-39.81070761
1	-36.20256774

TABLE II. REALIZED GAIN OF THE CUBODICAL GOLD NANO ROD

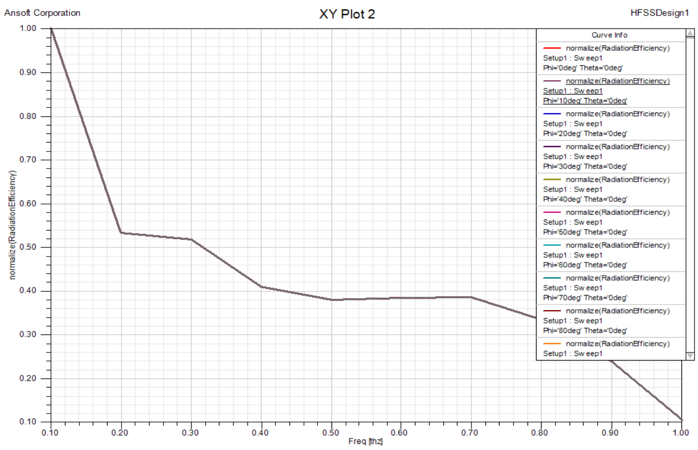

Fig. 6. Radiation efficiency of the cubodical nano rod.

A. *Comparative analysis*

Till now gold cubodical nanorod is discussed. Now, a comparative study of Gold, Silver, Titanium nanorods are done. TABLE III tells the realized gain value and the radiation efficiency of different nanorods. From this table we can easily come to conclusion. The same is shown as graphs in Fig. 7,8,9 for our convenience and easy visualization.Fig.7 shows the return loss for different nanorods followed by radiation efficiency and realized gain in the subsequent figures respectively

Material	Return loss	Gain	efficiency
GOLD	-12.67 db	-33 db	38 %
SILVER	-12.50 db	-33.2 db	35%
TITANIUM	-12.57 db	-33.93	45.1 %

TABLE III. COMPARATIVE VALUES FOR DIFFERENT NANORODS

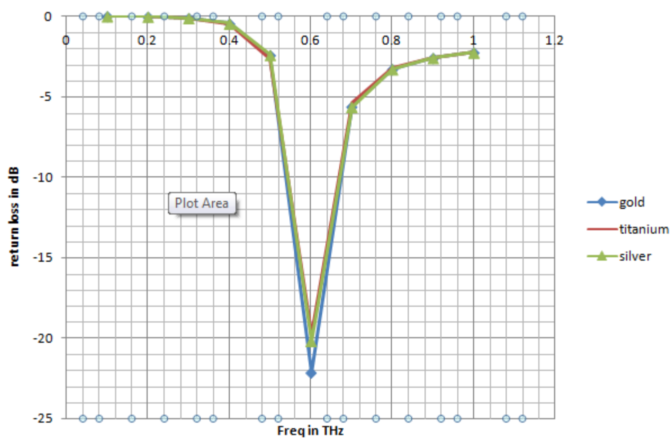

Fig. 7. Return loss of Au, Ag, Ti Nanorods.

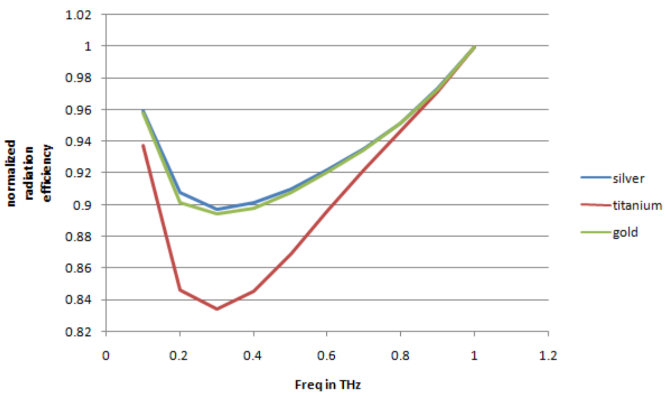

Fig. 8. Normalized Radiation Efficiency of Au, Ag, Ti Nanorods

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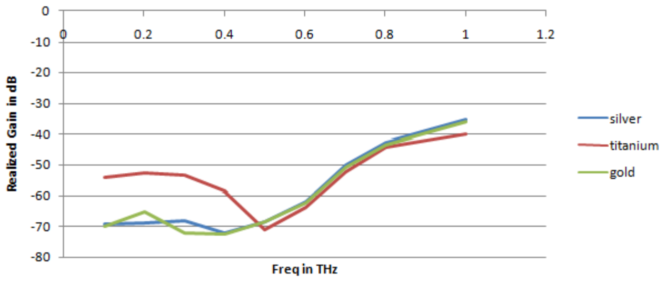

Fig. 9. Realized Gain in dB for Au, Ag, Ti Nanorods

From the above analysis,(i) Antenna made of Gold has good return loss,(ii) In terms of radiation efficiency , antenna with silver material has good percentage compared to other two nanorods. Where gold material has its percentage closer to the antenna made of silver than titanium and (iii)In terms of realized gain, again silver has better gain value followed by gold and titanium. In terms of material Gold is reasonable .Also it varies as per the need.

V. Conclusion

A simple cubodical dipole antenna is designed and analyzed using finite element method. The dipole antenna is operating at 0.6 THz. The performance measures of the cubodical nanorod like terms of Return loss, Radiation efficiency, Directivity and Realized Gain of the dipole antenna is studied and a comparative analysis is done for various materials –Gold (Au), Silver (Ag), Titanium (Ti) .The antenna is designed and simulated using FEM based electromagnetic solver, Ansys –HFSS. We see that the antenna designed with titanium has a good radiation efficiency and silver better return loss in our study. In terms of realized gain Titanium nanorod is best suited.

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