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Enhancement of electric field of bowtie nanoantenna

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ABSTRACT
A nanoantenna is designed to transform high frequency into energy. The proposed antenna is made of aluminuim. are shaped with a pair of nanoparticles brought in close nearness. Antennas separated by small gaps printed on a Si layer, which is designed as a flat-edge bowtie, with a ground plane at the under most of the substrate with a feeding putting in the gap of the bowtie antenna. The proposed antenna is designed using 3D-electromagnetic solver (CST) programs and analysed for the optimisation of metal thickness, gap size, and geometrical length. Simulations are conducted to investigate the behaviour of the nanoantenna illuminated by the linearly polarized plane wave. The nanoantenna parameters such as substrate thickness, feeding size, feeding type, and feeding material were changed to select the most efficient nanoantenna with a large directivity in our reaserch find the nanoantenna make a high electric field enhancement in their gap region. This specialty can be employed for SERS or biosensing to improve the detection limit and measure the presence of single molecules. For this, it is necessary to create antennas with enough small gaps, to be capable to recompense for the defects created during the fabrication process and reach antenna characteristics that are close to the ones presage by simulations.

The numerical simulations are studied to improve the best E-field of the antenna within the 250–700 THz frequency range. The proposed antenna offers multiple-resonance frequencies and good return loss in the frequency band of 310 THz, as well as an output electric field of 5.48 v/m to 7.8 v/m. Upon changing the type of feeding in the gap (without feeding, air feeding, dielectric silicon, or feeding),and we find that when using the air between the gap, the S-parameter is (-12.9) dB at the resonance frequency of (531.3) THz and the directivity is 7.41 dB at 666 THz incident frequency.

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Introduction

An antenna is a tool for receiving or radiating electromagnetic energy. When incoming radiation effects a dynamic current distribution to happen on an antenna, it is said to be a receiver, when an externally actuated dynamic current distribution on the antenna causes radiation it is said to be a transmitter. Most antennas are reciprocal meaning that they both receive or transmit. Furthermore, some antennas focus incoming electromagnetic waves, receiving and transmitting concurrently. When an electric charge accelerates it radiates energy in the form of electromagnetic waves [1].

Antennas are usually represented with specific performance parameters: radiation pattern, radiation power density, radiation intensity, beamwidth, directivity, gain, bandwidth, polarization, input impedance [1].

An optical antenna may be considered as devices that efficiently transform free propagating optical radiation to limited energy, and vice versa [2].

Guglielmo Marconi was the first who use the term “antenna” in radio context in 1895. Now, it is common to relate to electromagnetic transmitters or receivers as an antenna. They have been developed at the start of electromagnetism theory and the need for enhancing the bandwidth of communication link has fed this development. Though, the development for antennas using shorter and shorter wavelengths did not touch the optical regime. One of the reasons for designing and improving optical frequencies, optical fibers is the increasable need for using optical fibers and optical antenna in telecommunication applications [3].

Although the antennas are a key element for lots of tools at radio wave or microwave regime, their optical analog is almost nonexistent in today’s technology. Rather, optical radiation is manipulated by redirecting the wavefronts with lenses and mirrors. This kind of manipulation relies on the wave nature of the electromagnetic waves and since it is not proper to control the field on the subwavelength scale (the diffraction limit).

Optical antennas and their radio wave and microwave counterparts are alike, but there are crucial differences in their physical features and scaling behavior since, at optical frequencies, metals are not ideal conductors, but heavily correlated plasmas characterized as a free electron gas [3]. So, the penetration of radiation into metals can not be ignored.

The electromagnetic reply is prescribed by collective electron oscillations (surface plasmons, SP) quality of heavily coupled plasma [4]. These collective excitations produce a direct downscaling of traditional antenna designs impossible. So, at optical frequencies, an antenna no large responds to external wavelength but to a shorter effective wavelength, which depends on material features [5].

In (2015) Haque, Ahasanul, Ahmed Wasif Reza, and Narendra Kumar.published a paper study a Novel circular-edge bowtie nanoantenna was designed for energy harvesting. Frequenz [6] noticed that circular-shaped bowtie nanoantenna presents resonant frequency at 25.3 THz and show the best return loss within the frequency band of 23.2 THz to 27 THz. and from (31-35.9) THz. the bandwidth of 4.9 THz This antenna provides an utmost electric field intensity at 25.3 THz with a 50 nm gap between the nanoantennas where the thickness of the substrate is 1.2 µm. A flat-edged bowtie nanoantenna with different parameters was designed, and the effect of these parameters on the nanoantenna response was studied.

In 2017, Victor Pacheco-Peña, et.al; [7]: was said The design consists of a nanoantenna with two arms of angle θ, total length L=L1+L2 and the arms illuminated by a line dipole with arbitrary polarization. the gap between the two arms of 1 nm. He notices that high values of electric field are obtained close to 35 Db. And the coupling between the dipole nano-emitter and the bowtie nanoantenna. The non-radiative Purcell improvement spectrum is estimated both analytically and numerically for various lengths, arm angles, and metals, demonstrating a good agreement between both procedures. The method here displayed fills the gap of the design techniques for optical nanoantennas

Optical nanoantennas have been utilized for several unique applications, including optical imaging [8], energy harvesting [9] and diverse other near-infrared and visible applications [10-11]. An important aspect of optical antennas in our research is field enhancement in subwavelength regions that finds applications in fluorescence and Raman spectroscopy with capabilities of single-molecule sensing [12]

- **Plasmonic nanoparticles:**

The plasmonic nanoparticle is defined as particles with electron density sufficient to couple with the electromagnetic radiation of incident wavelengths. These nanoparticles are considerably large because of the nature of the dielectric-metal mediator between the medium and particles. Different in a pure metal where there is an utmost limit on what size wavelength can be effectively coupled rooted in the material size.[13]

These particles are distinguished from standard surface plasmons in that plasmonic nanoparticles exhibit attractive absorbance, scattering, and coupling properties depending on their geometries and comparative positions. [14] These singular properties have made these particles a focus of research in several applications, including spectroscopy, cancer treatment, solar cells and indicator of enhancement for imaging. [15] They are also good candidates for designing mecha-optical instrumentation given their high sensitivity. [16]

Plasmons are oscillations of free electrons as a result of the formation of a dipole in the material caused by electromagnetic waves. The electrons move into the material to return to its initial state; however, the light waves oscillate, leading to the constant shift in the dipole, which results in the oscillation of the electrons at a frequency similar to that in light. This coupling occurs only when the frequency of the light is the same as or less than the plasma frequency and is utmost at the plasma frequency that is so-called the resonant frequency. Cross-section scattering and absorbance explain the density of a particular frequency to be scattered or absorbed. A number of fabrication processes or chemical synthesis methods that rely on controllable size and geometry exist for the preparation of such nanoparticles. [17]

The equations that characterize the absorbance and scattering cross-sections for very small nanoparticles are

$$\boldsymbol{\sigma_{scatt}}=\frac{8\pi}{3}\,\boldsymbol{k^4\,R^6}\left|\frac{\boldsymbol{\varepsilon_{particle}}-\boldsymbol{\varepsilon_{medium}}}{\boldsymbol{\varepsilon_{particle}}+2\boldsymbol{\varepsilon_{medium}}}\right|^2\cdots(\mathbf{1})$$

$$\boldsymbol{\sigma_{scatt}}=\frac{8\pi}{3}\,\boldsymbol{k^4\,R^6\,Im}\left|\frac{\boldsymbol{\varepsilon_{particle}}-\boldsymbol{\varepsilon_{medium}}}{\boldsymbol{\varepsilon_{particle}}+2\boldsymbol{\varepsilon_{medium}}}\right|^2\cdots(\mathbf{2})$$

where (κ) is the wavenumber, R is the radius of the particle,($\varepsilon_{particle}$) is the relative permittivity of the particle described by equation (3) [17]

, and ε_{medium} is a relative permittivity of a dielectric substrate,

$$\boldsymbol{\varepsilon_{particle}}=\mathbf{1}-\frac{\omega_p^2}{\omega^2+i\omega\gamma}\cdots(\mathbf{3})$$

As we know as the Drude model for free electrons where ω_p^2 is the plasma frequency,γ is the relaxation frequency of the charge carriers and ω is a frequency of electromagnetic radiation. This equation is the consequence of solving the differential equation for a harmonic oscillator with a driving force proportionate to the electric field to the particle is exposed to.

It logically followed that the resonance case for these equations is reached as the denominator is at zero.

$$\boldsymbol{\varepsilon_{particle}}+2\boldsymbol{\varepsilon_{medium}}\approx\mathbf{0}$$

As this state is satisfied, the cross-sections are at their highest, These cross-sections are for single, spherical particles. The equations change when particles are nonspherical or are coupled to one or more other nanoparticles, for example when their geometry changes. This principle is important for several applications, Rigorous electrodynamics investigation of plasma oscillations in a nanoparticle spherical metal of a finite size was performed in. [17].

Design of nanoantenna

The proposed antenna has a flat-edged bowtie aluminum structure; and the other side is also flat with length (L) = 141.42 nm, width (W) = 280 nm, thickness (T) = 50 nm, $\alpha = 90°$ and gap distance (g) = 50 nm.

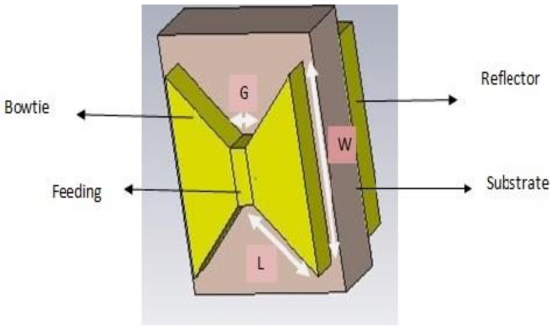
Printed on a substrate, the substrate (silicon lossy material): L = 280 nm; W= 360 nm; T = 100 nm.

Reflector (aluminium) (lossy metal): L = 280 nm; W = 280 nm; T = 50 nm; and placed a feeding (aluminum) (lossy metal) in the gap of nanoantenna with L = 50 nm; W = 80 nm; T = 50 nm, as shown in Figure 1.

used of Electromagnetic simulators for designing the antenna structure and performing numerical analysis. The proposed antenna is capable of concentrating the electric field in the side of metal of the bowtie with incident frequency:

f = (250–700) THz a substrate silicon (normal) Material Set as a Default Type Normal Epsilon= 11.9, Mu = 1, Electric cond= 0.00025 [S/m], Rho = 2330 [kg/m^3] , Thermal conductivity = 148 [W/K/m], Thermal expansion = 5.1 [1e-6/K].

This antenna is designed to study electromagnetic radiation (far-field directivity) which is analysis with a linear polarised plane wave in this simulation, (hexahedral) mesh grid is considered where the density of the mesh is determined by cells per wavelength are given as 20 and the cell size. The overall number of mesh cells is 18,879. surface plasmon oscillation Excitation occurs because of the impinging of infrared light or visible on the antenna surface, which makes hot spots where the field intensity becomes enhanced and drives the current towards the feeding point of the antenna. [18] By using these features, the antenna can be designed for many potential applications, for example, spectroscopy and nanoscale imaging [19], beneficent solar cell efficiency [20] and coherent control [21].



(Figure 1: A flat-edged bowtie nanoantenna)

Result and discussion

1- Gap effect

In this work, a flat-edged bowtie nanoantenna with a rectangular aluminum feeding gap is proposed. The simulated S-parameter (reflection coefficient) and the resonance frequency of the flat-edged bowtie nanoantenna Figure at different distance gaps are shown in Figure (2). The proposed antenna provides better performance around the frequency of (303.4–600) THz with a distance gap of 5 nm Figure (2)(a, b, c, d, e, f)] with gaps of 30, 25, 20, 15, 10 and 5 nm.

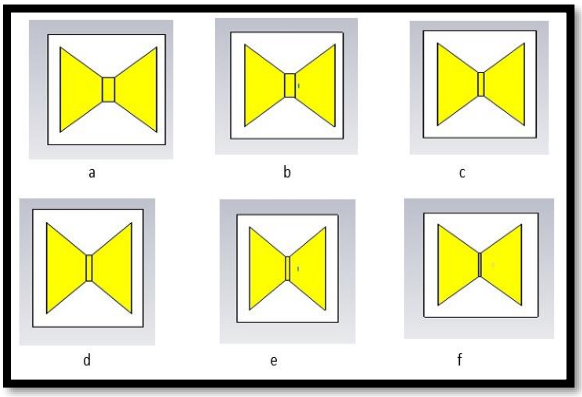
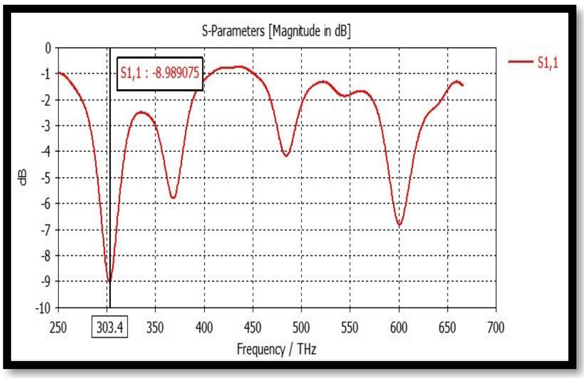
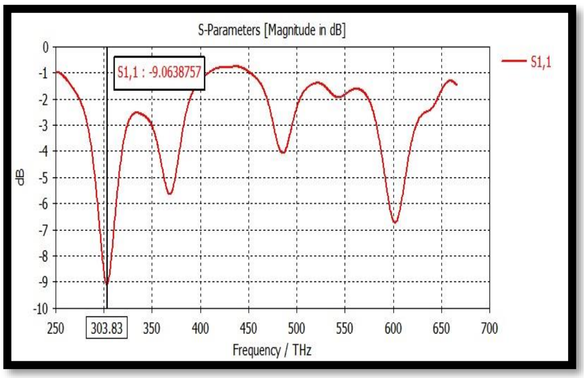


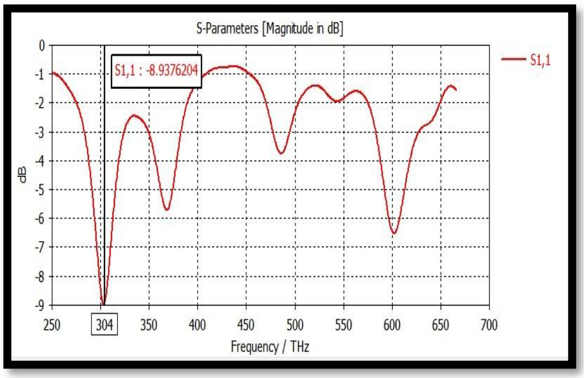
Figure 2 : Bowtie with different gap (a ,b ,c ,d ,e ,f) gap =(30,25,20,15,10,5)nm



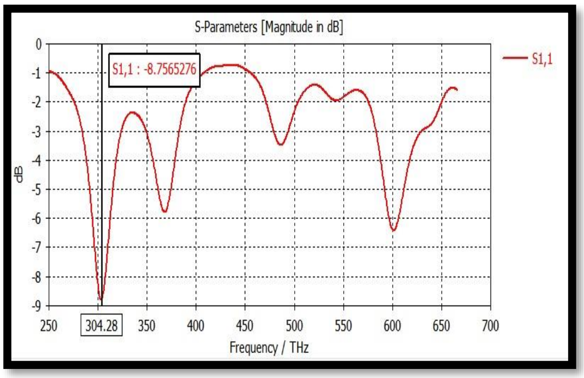
(a)



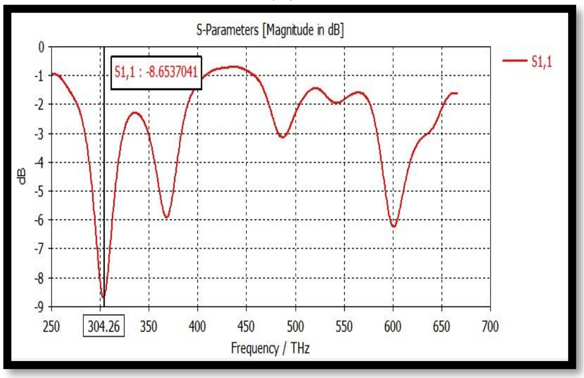
(b)



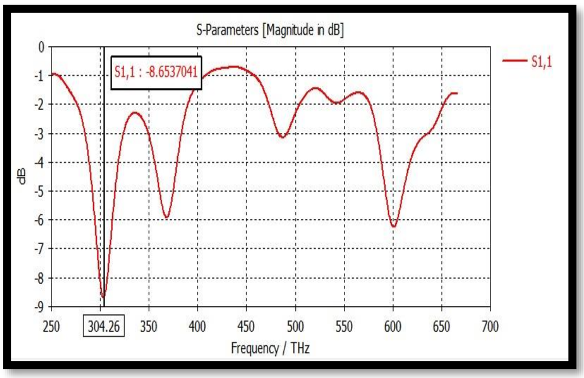
(c)



(d)



(e)



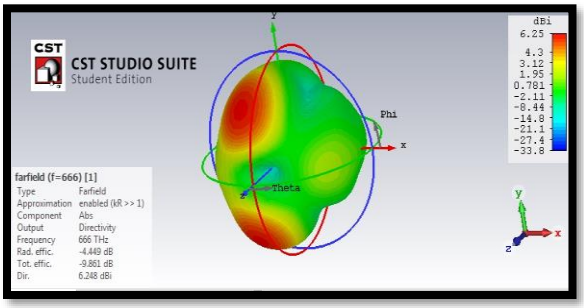
(f)

Figure:(a,b,c,d,e,f) result of s-parameter and resonance frequency for bowtie nanoantenna with feeding when changed the gap distance from(30-5)nm

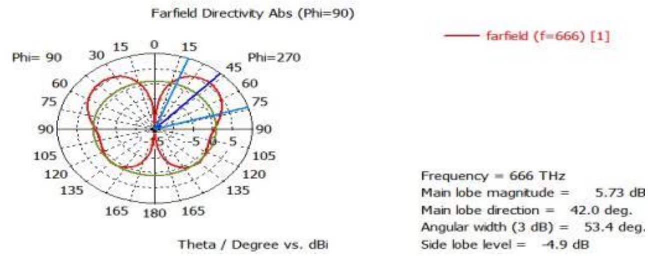
So, when fabricated two a nanoscale of metallic with a little distance gap between them this is a bowtie nanoantenna that supplies high electric field energy in the Gap [22, 23]. Because of a localized surface Plasmon excitation [54]. So, by varying the gap distance between the two nanostructures as shown in figure (2) we can be controlling the improvement of the electric field around the gap.

The electromagnetic investigation is accomplished from 250 THz to 700 THz. The performance of the flat-edged bowtie nanoantenna is calculated in terms of the captured electric field from the gap that is transferred through the end of the feeding. As shown, the utmost electric field intensity is found at the centre of the bowtie gap, and this electric field is transferred by the feeding. Along with the antenna formation, the free electron of the aluminium flows towards the feed point and is concentrated at the gap.

Figure 4 shows the radiation patterns at a frequency of 666 THz. From Figure 4(a), the radiation patterns exhibit a maximum directivity value of 6.25 dB, a (Half- power) beamwidth is also a significant matter to retain the energy, and Figure 4(b) shows the polar of (far-field directivity). A number of numerical electromagnetic analyses are complete to optimize and discover the most excellent fitted gap size at the feeding point of the antenna. After the greatest electric field is captured at the gap of the antenna, it is transferred through the feeding line. The red curve stands for $E\theta$ *pattern*, the blue lines represent the half-power bandwidth, and the green curve is a magnitude of the back loop. In this study, the gap size acting a significant function in the captured electric field. As observed in Figure4 (a b), the highest amount of electric field is obtained with a higher gap size provided that the electric field decreases with a decreased gap because of the feeding. When the distance gap is changed (30, 25, 20, 15, 10 and 5 nm, the directivity increased with increased gap, where the directivity at g = 30 nm is 6.25 dB; as shown in fig (4)(a,b) however, that at g = 5 nm the directivity is 3.82 dB, as shown in Figure(5) (a)(b).

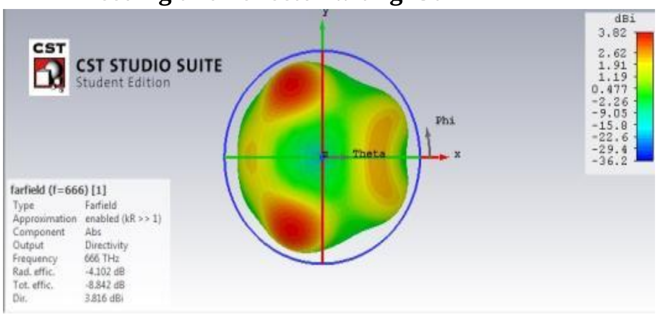


(a): **3D radiation pattern**

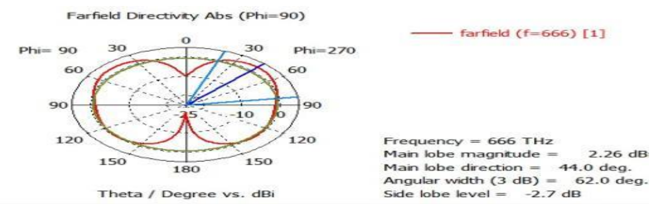


(b) Polar

Figure 4: the 3-d radiation patterns and polar of the flat-edged bowtie nanoantenna with feeding and reflector with g=30nm



(a) 3D radiation pattern



(b)polar

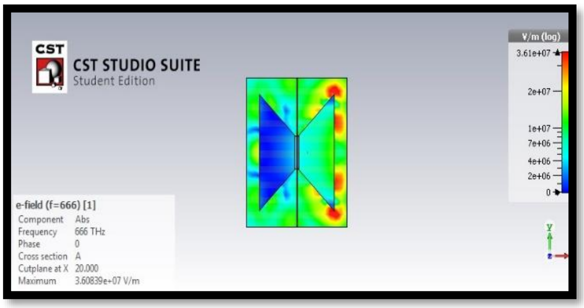
Figure 5: the 3-d radiation patterns and polar of the flat-edged bowtie nanoantenna with feeding and reflector with g=5nm

2- Effect of substrate thickness

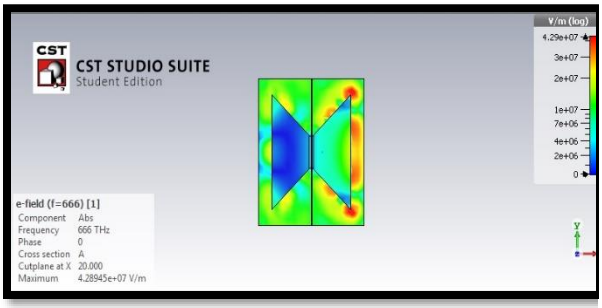
The effects of substrate thickness on the current density, electric field, VSWR and reflection coefficient of the flat-edged bowtie nanoantenna are investigated for the projected design. The numerical electromagnetic analysis of the antenna is performed by varying the substrate thickness. As shown in Table 1 and Figure (6)(a, b, c, d, e), the lower the substrate thickness, the higher the electric field. The optical frequency here checks at T = 80, 60, 40, 20 nm; hence, the wavelength of these frequencies are 518.93, 509.81 and 495.21 nm

Table 1 the result of s-parameter and resonance frequency when changed the Dielectric substrate thickness

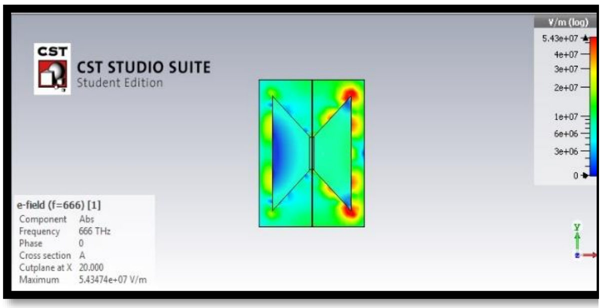
Dielectric substrate thickness	S-parameter (dB)	Resonance frequency (THz)
80	-1.298	577.71
60	-1.208	588.05
40	-1.088	605.38
20	-6.989	927.4



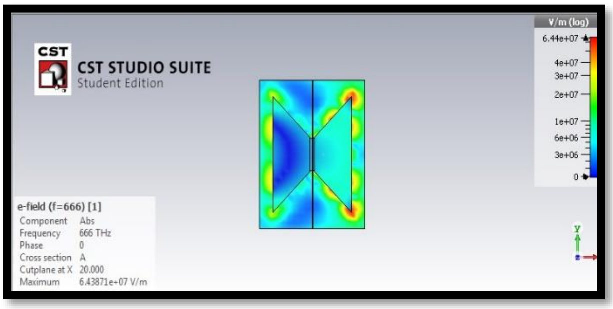
(a) T = 80 nm



(b) T = 60 nm



(c) T =40 nm



(d) T = 20 nm

Figure 1 (a,b,c,d): The result of directivity when changing the thickness of the dielectric substrate

The electric field at a substrate thickness of 80 nm is 3.61×10^7 v/m; however, that at a thickness of 20 nm is 6.44×10^7 v/m as shown in the figure above.

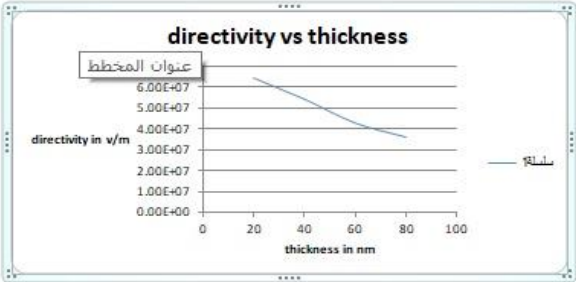


Figure (7): The relation between directivity and thickness when changing the dielectric substrate thickness

The x-axis shows the thickness in nm of a substrate and the y-axis shows the output directivity in v/m

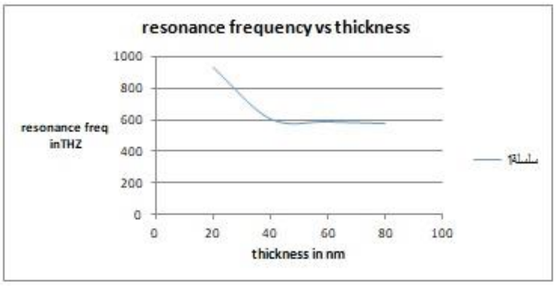


Figure (8): The relation between the resonance frequency and thickness when changed the dielectric substrate thickness

The x-axis shows the thickness of the substrate in nm and the y-axis shows the output resonance in THz frequency.

In our case, its peak position is mainly driven by substrate properties by increasing the substrate thickness, a red-shift of resonance frequency and decreasing in energy based on transmission spectrum is obtained,

3-Effect of reflector thickness

Only the reflector thickness T = 50, 40, 30, 20, 10 nm was changed in this step. The effect of change these on the s11and resonance frequency and how were changed according to changed reflector thickness the results in Table (2), and how the directivity changed, as shown in Figure (9)(a, b, c, d, e).

Bowtie nanoantenna (aluminium) material with L = 141.4 nm; W = 200 nm; $\alpha = 90°$.

Dielectric Substrate silicon material L = 200 nm; W = 360 nm; T = 100, 80, 60, 40, 20 nm

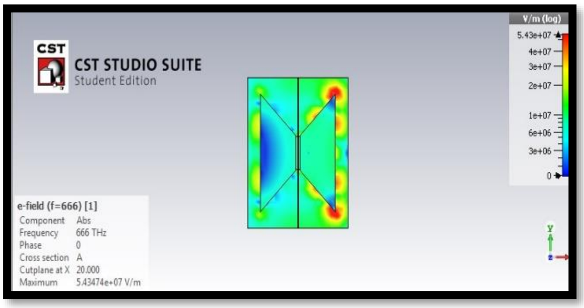
Reflector L = 280 nm; W = 280 nm; T = 50 nm,

Feeding aluminium material L = 20 nm; W = 80 nm; T = 50 nm;

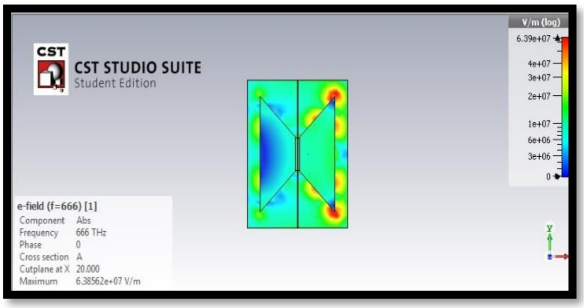
f = 666 THz.

Table (2)results of s-parameter and resonance frequency when changed the Reflector thickness

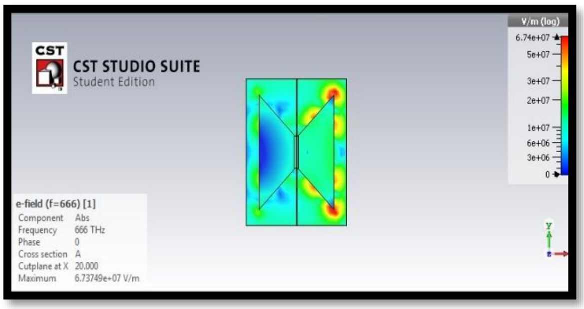
Reflector thickness (nm)	s-parameter (dB)	Resonance frequency (THz)
50	-1.0088	605.38
40	-1.443	603.9
30	-1.663	602.42
20	-2.2276	600.9
10	-2.60	599.47



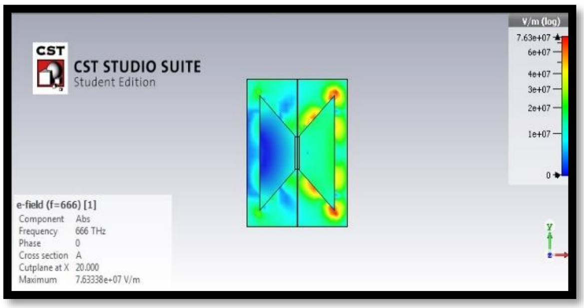
(a) T = 50 nm



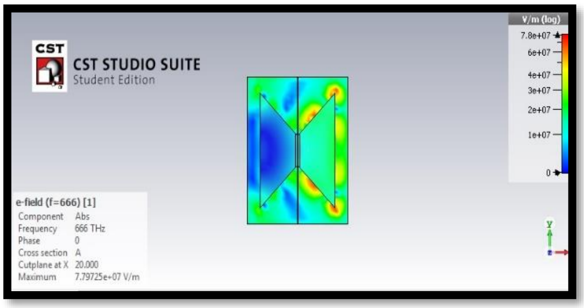
(b) T = 40 nm



(c) T = 30 nm



(d) T = 20 nm



(e) T = 10 nm

Figure 2 (a,b,c,d): The result of directivity when changing the reflector thickness

The electric field at T = 50, 40, 30, 20, 10 nm is calculated as 5.43×10^7, 6.39×10^7, 6.74×10^7, 7.63×10^7 and 7.8×10^7 v/m, respectively. Hence, at the maximum electric field at T = 10 nm, the electric-field directivity increases with decreased reflector thickness.

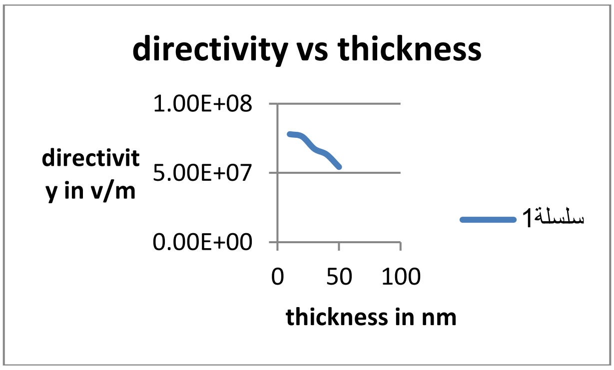


Figure (10) The relation between the directivity of nanoantenna and reflector thickness

The x-axis shows the thickness in nm of a substrate and the y-axis shows the output directivity in v/m

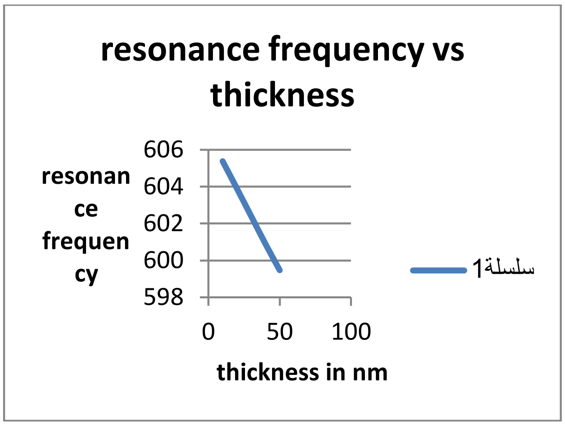


Figure (11) The relation between the resonance frequency and reflector thickness
The x-axis shows the thickness in nm of the substrate and the y-axis shows the output resonance frequency in THz.

From the curves we notice that the decreasing the thickness of reflector leads to the resonance frequency increased, the wavelength decreased, and the directivity increased

4-Effect of different feeding materials

Only the feeding material (gold, silver, and iron) was changed in this step. The effect of change of these materials on the s11and resonance frequency and how discrete port current was changed according to the change in the material of the bowtie nanoantenna were studied, as shown in Table (3). Bowtie nanoantenna (aluminum) material: L = 146.9 nm; W = 280 nm; $\boldsymbol{\alpha} = \mathbf{90°}$.
Substrate silicone material: L = 280 nm; W = 360 nm; T = 100 nm
Reflector material (aluminum): L = 280 nm; W = 280 nm; T = 50 nm
Feeding: L = 40 nm; W = 80 nm; T = 50 nm

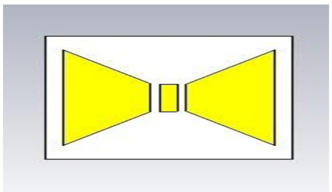
Table (3)results of s-parameter, discreet port current and resonance frequency when changed the feeding material

Material (feeding)	S-parameter (dB)	Discreet port current (dB)	Resonane frequency (THz)
Gold	-8.839	-19.77	302.09
Silver	-8.84	-19.76	302.1
Iron	-8.78	-19.8	302.1

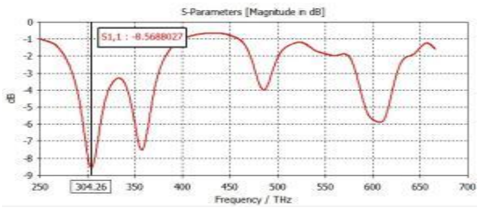
Selecting the best material is very important because of the effect of the optical properties of materials on the response of the antenna.

5-Effect of different feeding sizes

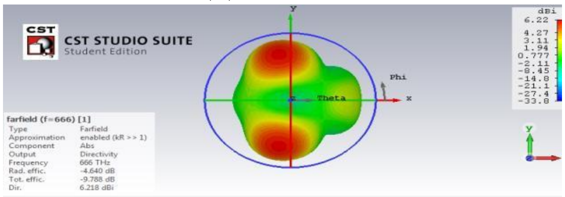
In this step, only the feeding size was changed as shown in Figure (12) (a, b, c), and the effect of changing these sizes on the response of nanoantennas was studied.
Bowtie nanoantenna (gold) material: L = 146.9 nm; W = 280 nm; $\alpha = 90°$, gap = 40 nm; T = 50 nm,
Substrate silicon material: L = 280 nm; W = 360 nm; T = 100 nm
Reflector (aluminium): L = 280 nm; W = 280 nm; T = 50 nm
Feeding gold material: L = 20 nm; W = 80 nm; T = 50 nm



(a) Bowtie nanoantenna



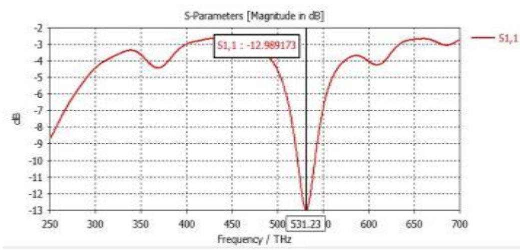
(b) S-parameter



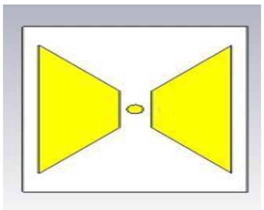
(c) 3D pattern directivity

Figure (12)(a,b,c) the result of using a rectangle feeding ,s-parameter,resonance frequency, and 3D pattern directivity

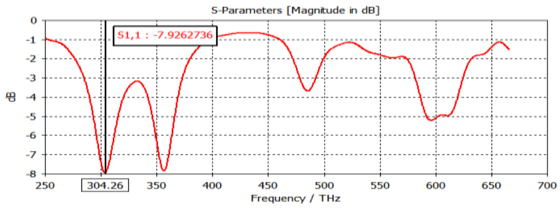
From Figure (12) (a, b, c), the S-parameter is found to be -8.6 dB at a resonance frequency of 304.3 THz, and the directivity is 6.215 dB at an incident frequency of 666 THz.



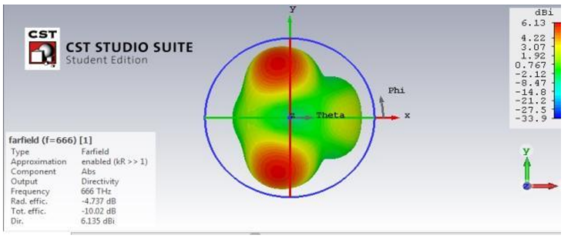
When changing the feeding to circular feeding with a radius of 20 nm as shown in Figure (13)(a). for the nanoantenna with the same parameter above and study the effect of this on the response of the antenna as shown in Figure 13 (b.c).



(a) Bowtie nanoantenna



(b) S-parameter



(c) 3D pattern directivity

Figure (13)(a,b,c) the result of using circular feeding ,s-parameter,resonance frequency, and 3D pattern directivity

From Figure (13) (a, b, c), the S-parameter is found to be -7.9 dB at a resonance frequency of 304.3 THz, and the directivity is 6.1 dB at an incident frequency of 666 THz.

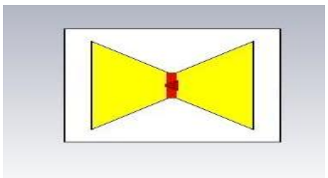
6-Effect of change type of feeding

1- Bowtie nanoantenna (aluminium) material: L = 141.4 nm; W = 200 nm.

α = 90°; T = 50 nm.

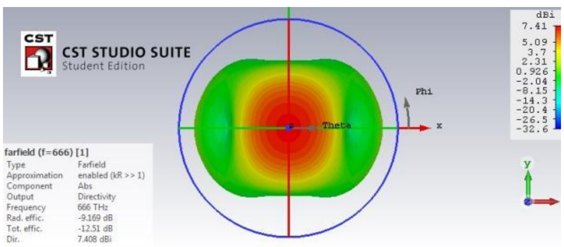
Dielectric substrate silicone material: L = 200 nm; W = 360 nm; and T = 40 nm.

Reflector aluminium material: L = 280 nm; W = 280 nm; T = 50 nm Gap L = 10 nm without feeding. The S-parameter, resonance frequency and directivity were changed as shown in Figure (14)(a, b, c).



(a) Bowtie nanoantennae

(b) S-parameter



(c) 3D pattern directivity

Figure (14)(a,b,c) the result of bowtie with out feeding ,s-parameter,resonance frequency, and 3D pattern directivity

From Figure (14)(a,b,c), the S-parameter is found to be -12.9 dB at the resonance frequency of 531 THz. The optical wavelength is found to be 564.26 nm, and the directivity is 7.41 dB at an incident frequency of 666 THz.

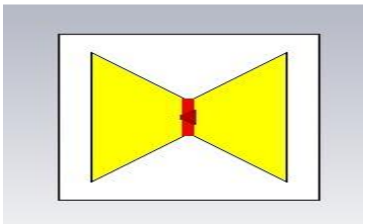
2. Bowtie nanoantenna (aluminum) material: L = 141.4 nm; W = (200) nm;

α = 90°; T= 50 nm

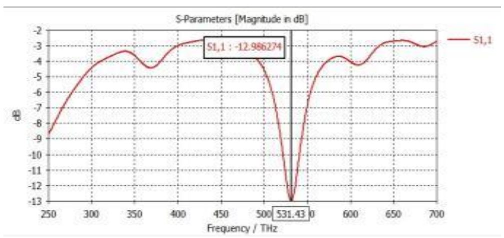
Dielectric Substrate silicon material: L = 200 nm; W = 360 nm; T = 40 nm

Reflector aluminium: L = 280 nm; W = 280 nm; T = 50 nm Gap is air: L = 10 nm

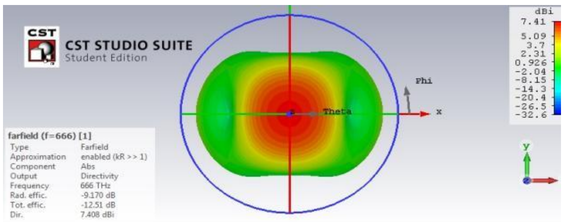
The S-parameter, resonance frequency and directivity were changed, as shown in Figure (15) (a, b, c).



(a) Bowtie nanoantenna



(b) S-parameter



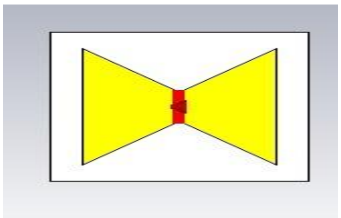
(c) 3D pattern directivity

Figure (15)(a,b,c) the result of bowtie with air feeding ,s-parameter,resonance frequency, and 3D pattern directivity

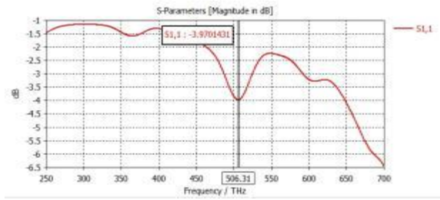
From Figure (15) (a, b, c), S-parameter is found to be -12.9 dB at a resonance frequency of 531.3 THz, and the directivity is 7.41 dB at an incident frequency of 666 THz. The optical wavelength is 564.26 nm at a frequency of 531.3 THz.

3- Bowtie nanoantenna (aluminium) material: L = 141.4 nm; W = 200 nm;

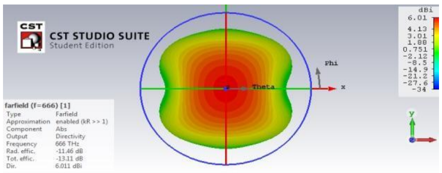
$\alpha = 90°$; T = 50 nm
Dielectric Substrate silicon material: L = 200 nm; W = 360 nm; T = 40 nm
Reflector aluminium: L = 280 nm; W = 280 nm; T = 50 nm
The gap is dielectric: L = 10 nm
The S-parameter, resonance frequency, and directivity were changed, as shown in Figure (16)(a, b, c).



(a) Bowtie nanoantenna



(b) S-parameter



(c) 3D pattern directivity

Figure (16)(a,b,c) the result of bowtie with dielectric feeding ,s-parameter,resonance frequency, and 3D pattern directivity

From Figure (16) (a, b, c), the S-parameter is -3.9 dB at a resonance frequency of 506.3 THz. The optical wavelength is 592.12 nm and the directivity is 6.01 dB at an incident frequency of 666 THz.
The electric fields for bowtie without feeding, air feeding and dielectric feeding are **3.78** $\times 10^8$, 3.78×10^8 and 3.58×10^8 v/m, respectively**.**

Conclusion

Optical nanoantenna fabrication is discussed. The first approach involved samples fabricated using bowtie with a flat edge and printed on the silicon substrate and metal reflector with a feeding placed in the gap size. With decreased gap distance from 30 nm to 5 nm, the s-parameter increased and the directivity decreased. With increased substrate and reflector thickness, the directivity and reflection coefficient increased. Selecting the best material is important because of the effects of such materials on the response of antenna, for example, s-parameter, current, VSWR, and directivity. The feeding size and type effect too on the response of the nanoantenna by using feeding size less than the gap size we notice that s-parameter -8.6 dB and the directivity is 6.215 dB, but when using the circular feeding the S-parameter -7.1 dB and the directivity is 6 dB, and then change the type of feeding (without, air and dielectric). The electric fields for the bowtie without feeding, with air feeding and with dielectric feeding are 3.78×10^8, 3.78×10^8 and 3.58×10^8 v/m, respectively; the S-parameter values are -12.9, -12.9 and -3.9; and the directivity values are 7.41, 7.41 and 6.1 dB. The design of bowtie nanoantenna without feeding and with air feeding exhibited the same effect and result; however, with dielectric feeding exhibited different effects and results.

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