Study the Effect of Change the Antenna Length on the Performance of Optical Nano-Antenna Using Plasmonic Surfaces

دراسة تأثير تغيير طول الهوائي على أداء هوائي بصري نانوي باستخدام السطوح البلازمية

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Abstract:

This study aims to find out the effect of increasing the length of the arm of the antenna on the amount of electric and magnetic fields generated between the ends of optical nano antenna and choose the best values, We have been using optiFDTD program to test the effect of change the length of the arms of the antenna on the electric and magnetic fields generated , The results show that the electric and magnetic fields inside the antenna have increased when the length of the arm of the antenna decreased, while the penetration and reflection fields have an increased when the length of the antenna arm increased. Therefore, we can concluded that the decrease in the length of the antenna arm enhancement the reflection and dispersion field generated between the antenna on both ends of the domain account.

الخلاصة :

يهدف هذا البحث الى معرفة مقدار تأثير زيادة طول ذراع الهوائي على مقدار المجالات الكهربائية والمغناطيسية المتولدة بين طرفي هوائي بصري نانوي واختيار القيم الأفضل لها ,وقد تم استخدام برنامج OptiFDTD لاختبار تأثير تغيير طول ذراعي الهوائي على المجالات الكهربائية والمغناطيسية المتولدة , وأظهرت النتائج أن المجالين الكهربائي والمغناطيسي داخل الهوائي يزدادان بنقصان طول ذراع الهوائي أما المجال النافذ والمنعكس فيزداد بزيادة طول ذراع الهوائي ,ومنها نستنتج أن نقصان طول ذراع الهوائي يعزز المجال المنعكس والمتشتت على حساب المجال المتولد بين طرفي الهوائي.

1.Introduction

An optical antenna can be defined as a visual combination of the two components is responsible for coupling electromagnetic field component and correct metal structure. The latter prevents the confined energy currents in the length of the antenna to the signal can be controlled [1]. In 2013 Yousif and Samra have used gold nanoparticles to design optical nano antenna. They show that the optical nano-antennas which have visible and infrared light to enhancement the interaction light with nanoparticles through its ability to improve areas and connecting optical fields that is generated spatially efficiently [2]. The plasmonic surfaces are collective of oscillation of the electronic density of the gas in the metals at the optical frequencies, these oscillations are importance to simulated of induce currents in the antenna, as well as the spread signals over wires. Therefore, Dunn (1999) have concluded that the combination of antenna and plasmonic surfaces resonant have reinforcement the fields at specific area was very large[3].

Muhlschlegel *et. al* (2005) show that the optical nano-antennas can produce high intensity in the near-field when they are optically excited with an appropriate suitable wavelengths which are properly with the size of the optical antenna because of the specific plasmonic surface resonance[4].

In 2004 Chen *et.al* have designed bowtie optical nano-antennas. They found astrong localization effect in the gap of the optical bowtie nano-antenna. Therefore, the enhanced intensity in the gap was due to the surface Plasmon resonance and the concentration of energy flow [5].

Bowtie plasmonic quantum cascade laser antenna have been suggested by Yu *et. al.* they observed when there are air gap between to side of metal optical bowtie antenna then the electric field an increased more than 100 times [6].

There are many applications of optical nano-antenna besides applications in the field of biological sensor imaging. Moreover, these optical nano-antennas can be used to manipulate nano-particles, which are attracted by high-intensive areas in which was creation in the gap between the metal areas [7-9].

In 2007 Nanfang Yu *et.al* antenna have designed optical bowtie and bipolar nano-antenna which each of it has air gap (100 nm), thickness (125 nm) and angle nano antenna Bowtie is (45 deg). They make a change in the length of each of the optical nano-antennas as well as the change wavelength 220 nm to 700 nm were measured improvement in the electric field as a function of the length of the antenna and wavelength [6].

Ming in 2010 in his doctoral thesis, he had studied the impact of the relationship between the wavelength and square field intensity for four metals and two length antenna 180 nm and 240 nm[10].

In 2012 Saba has studied the effect of some parameters of dipole optical nano antenna by using (optiFDTD) program. She concluded that resonance occurs when the length of the optical nano antenna is approximately half wavelength and the increasing in length lead to increased wavelength contrast to him [11].

To the best of knowledge there are few systematic studies of the effect of the change the antenna length on the performance of optical nano-antenna reported in the literature regarding the use three layer (gold, silicon dioxide, gold) in optical nano antenna.

In this paper, the design of optical nano-antenna (50 nm) using plasmonic surface was carried out by optiFDTD based on the theory of limited terms to the field of program time, because of this modern way of advantages in terms of the calculate the electric and magnetic fields at each point through the application of Maxwell's equations.

2- Methodology :

Numerical simulations play an important role for the design and modeling of optical structure. The finite difference time-domain method (FDTD) belongs in the general class of grid based differential time domain numerical modeling methods. The time-dependent Maxwell's equations in partial differential form are discredited using central-difference approximations to the space and time partial derivatives. The FDTD method has been established as a powerful engineering tool for integrated and diffractive optics device simulations. This is due to its unique combination of features, such as the ability to model light propagation, scattering and diffraction, and reflection and polarization effects. The basic of FDTD method starts with solving Maxwell equations in heterogeneous materials[12,13]. The procedure begins with two basic equations as described below.

$$\nabla \times E = -\mu \frac{\partial \vec{H}}{\partial t} \qquad (1)$$

$$\nabla \times \mathrm{H} = \sigma \overrightarrow{E} + \varepsilon \frac{\partial \vec{E}}{\partial t} \qquad (2)$$

Where $\varepsilon = \varepsilon_o \varepsilon_r$, Is the dielectric permittivity and is the magnetic permeability of the vacuum. The refractive index is, $n = \sqrt{\varepsilon_r}$ .Equation (1) represents the Ampere's law [12] and equation (2) represents the Faraday's law [12]. The first step is to convert the vector differential equations represented by (1) and (2) to the scalar differential equations. The next step is to convert the scalar differential equations to the difference equations and this is done by discrediting the 3-D FDTD grid. So the values of electric and magnetic fields are updated from their previous values to define a crystal lattice that contains a defined number of FDTD grids. The magnetic field and electric field difference equations are also known as FDTD equations in context to the FDTD method. Since these equations are defined for a single grid, we can use them to define 1D, 2D, 3D crystal consisting of the same grids. So in this project we have used 3D crystal dimensional approach. In 3D crystal, the lattice structure is a cubic box, the space steps are Dx, Dy and Dz in x, y and z directions respectively. Each field components is presented by a 3D array Ex(*i, j, k*), Ey(*i, j, k*) , Ez(*i, j, k*), Hx(*i, j, k*), Hy(*i, j, k*), Hz(*i, j, k*). The field algorithm components position in Yee's Cell are shown in Figure 1(f). These placements and the notation show that the E and H components are interleaved at intervals of 1/2Dh and 1 /2Dt in space and for the purpose of implementing a leapfrog algorithm. the maximum size for the time step Δ immediately follows the Courant-Friedrichs-Levy (CFL) condition [53]. For 3D FDTD simulation, the CFL condition is:

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \qquad (3)$$

Where c is the speed of the light in medium, Δx is the size in real units of a space step along the x direction, Δy is the size in real units of a space step along the y direction, Δz is the size in real units of a space step along the z direction and Δt is the size in real units of a time step .

The FDTD simulators have options to use Perfect Electrical Conductor (PEC) and Perfect Magnetic Conductor (PMC) boundary conditions. The boundaries that use the new conditions can be chosen, and Anisotropic PML can be used for the remaining boundaries. For a 3D simulation, the plane wave realization depends on the wave polarization and the boundary condition setup at different edges of the transverse plane. If the wave goes in z-direction, and the input wave is in y-direction polarization, then the y plane (x-z) edge should be set to the PEC and x-plane (y-z plane) edge set to the PMC boundary.

2.1 material of optical nano antenna:

The metal have been chosen for optical nano-antenna consists of three layers which are (gold, silicon dioxide, gold) of equal width and thickness of each of these layers which are corresponds to the theory (Lorentz-Drude), where the refraction index of gold transactions is (0.322) and silicon dioxide is (1.457).

The altitude of the optical nano antenna was 50 nm that shared by three layers where the altitude for each layer was 16.6 and the degree of slop surface optical nano antenna was (zero) degree. The diagram of optical nano antenna showed in Figure 1

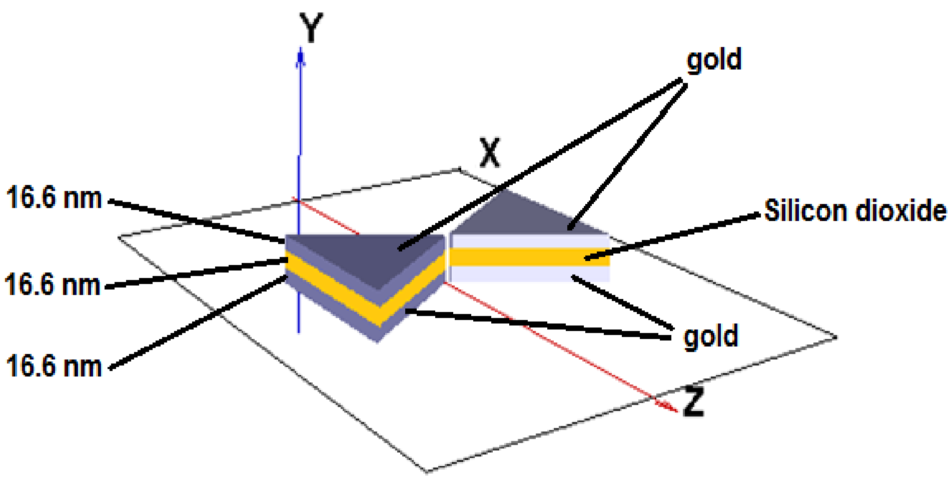


Figure (1) layer of optical nano antenna according to propagation field

2.2 Wavelength and Refractive Index:

When the light pass through the material which have a certain refractive index, these material will be deviation the light according to refractive index coefficient, these deviation have depended on the type of materials and the wavelength of the falling light since each wavelength has its own refractive index of the same material and this is the basis of the work of the prism where scatters light by own wavelength. In our model there are two materials(gold and silicon dioxide) where each of them has a different behavior with each wavelength. The relationship between the wavelength and the refractive index have shown in Figure 2. Where the wavelength which has used more than 300 nm.

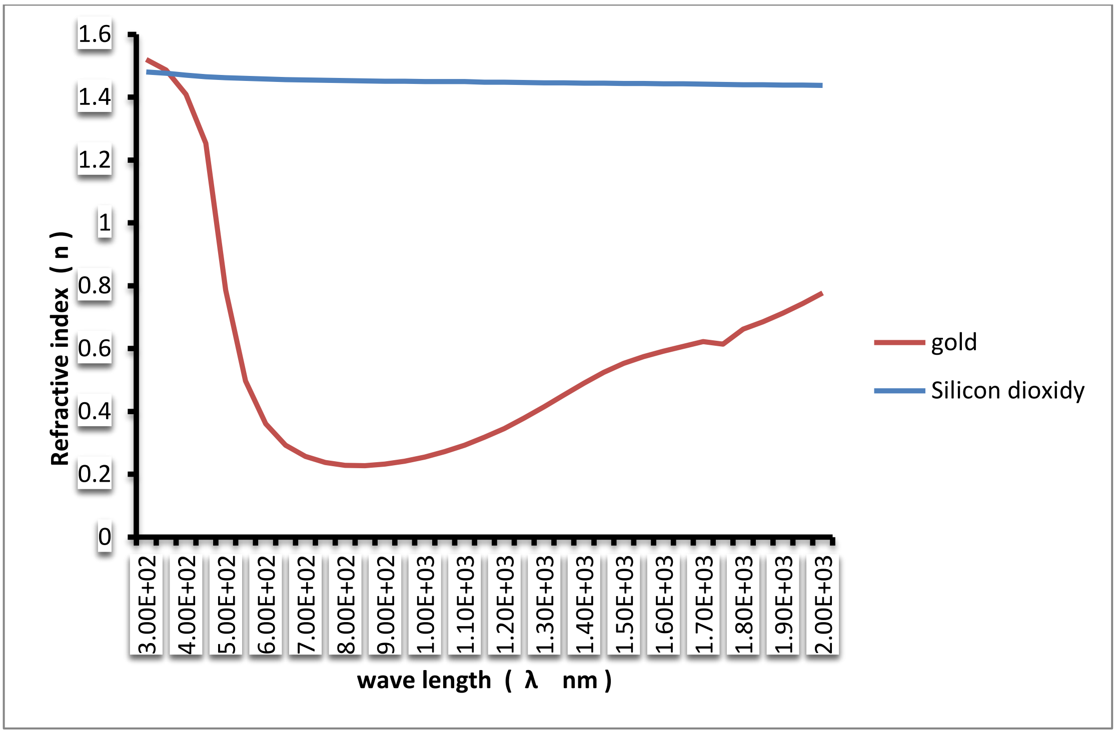


Figure (2) The relationship between the refractive index and the largest wavelength of 300 nm

3.3 Design of The Optical Nano Antenna:

Before start to design optical nano antenna, we should have be calculated the length of the optical nano antenna, we have needed to know the optical nanoantenna sites in the coordinate plane of OptiFDTD program, where is set optical nano antennasite by two points located on the antenna axis which are in both ends of the optical nano antenna (for each part). However, these two points located at the top of the triangle and middle triangle base, where between the two points will be the axis of symmetry of the triangle as shown in Figure 3.

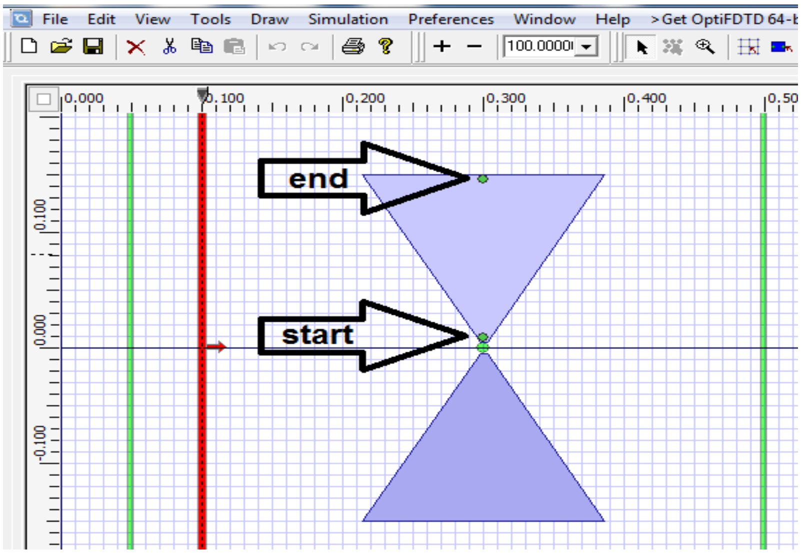


Figure (3) start and end points of the optical nano antenna site in the models

So, to drawing a triangle that should set the site these two points (end and start) as show in Figure (4) which are contains both the horizontal and vertical coordinates. the difference between two Coordinates points is determined by the length of the rectum, which is draws a triangle, and When one of the coordinates for the two points are equal, this means that:

1. vertically (if the horizontal coordinates)
2. horizontally (if the vertical coordinates are equal) as in Figure 5
3.

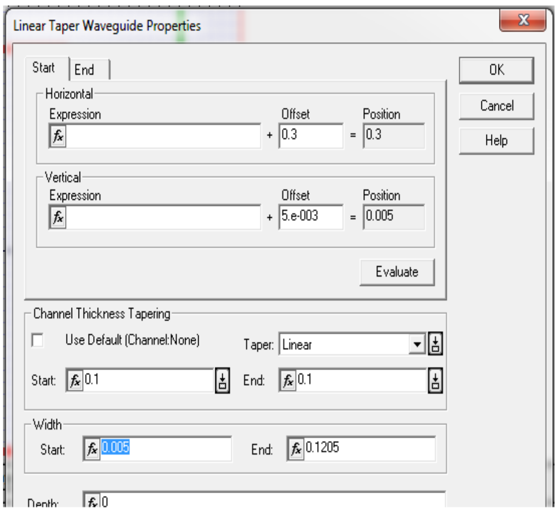


Figure (4)Triangle shaped window properties

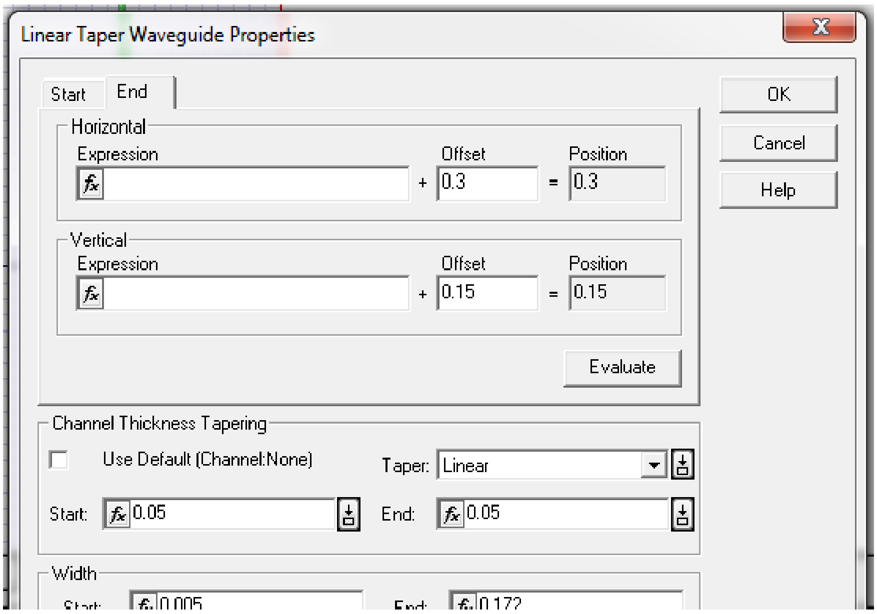


Figure (5) Coordinates the starting and end points

Since each of the two triangles are parallel to the two axes, as well as the axes are identical. Therefore, each horizontal dots for both triangles are equals, thus the length of the optical nano antenna is the difference between the farthest points of the vertical points, which are determine the length of the antenna.

So, mathematically the optical nano antenna length is the difference between Coordinates (vertical > end) of the first triangle and (vertical > end) of the second triangle.

So, after calculated the length of optical nano antenna, we have designed the optical nano antenna with a thickness of 50 nm representing the total thickness of the constituent layers which are consists of three layers (gold Au - silicon dioxide SiO_2 - gold Au) as the thickness of these layers be equal. The wavelength has been used is 700 nm,the angle antenna arc is 60°, gap width in all models is 10 nm, and the length of the optical nano antenna has been selected five values are (200, 250, 300, 350, 400) nm as listed in table 1.There comparison between the outputs of these values in terms of the electric and magnetic fields have conducted.

Table 1 specification of optical nano antenna

λ(nm)	ϴ(deg)	Gap (nm)	L (nm)
700	60	10	200
			250
			300
			350
			400

Results and Discussion

Figures 6 and 7 shows the change of the electrical fields in the direction of propagation waves (x, y) respect to the length of optical nano antenna, that show approximately linear behavior, so, decreasing the electric field in the gap for two electric field in Y direction (Ey) and electric field in X direction (Ex) because of the increased surface area of the optical nano antenna to increase the length, which led to distribute charges over a larger area, and therefore lead to less concentration of charges points of convergence. In additions, the magnetic field have linear behavior as shown in

Figure 8, when the charges are distributed which are generated the currents that regards the source of magnetic field, so the currents will be less, therefore lead to minimize the magnetic field.

The penetration and reflection fields have increased with increasing the length of the optical nano antenna, where the reflection field depends on increasing the surface area of the optical nano antenna, while, and the penetration field depends on the regenerate antenna's power to greater power due to an increased size and increase the size of the area which are exposed to radiation. As shown if Figures 9 to 16.

Moreover, Figure 17 when has increased the length of the optical nano antenna, the impact zone have been expanded. As well as the minimized the field density which are distributed on the surface by less.

Figures 18 to 20 have illustrated the amounts of electric and magnetic fields in each position of the optical nano antenna according to color scale, while the Figure 21has illustrated the far field around the optical nano antenna.

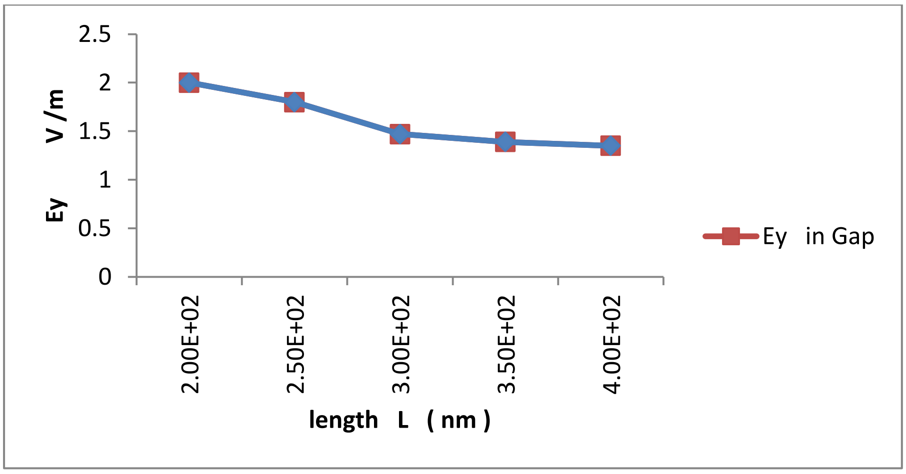


Fig (6) electric field Ey Respect to the antenna lengths

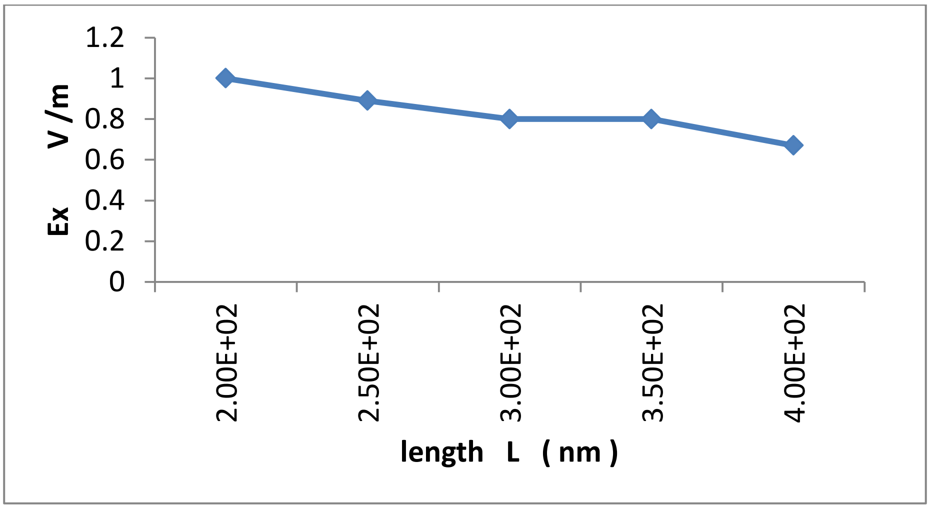


Fig (7) Electric field Ex Respect to the antenna lengths

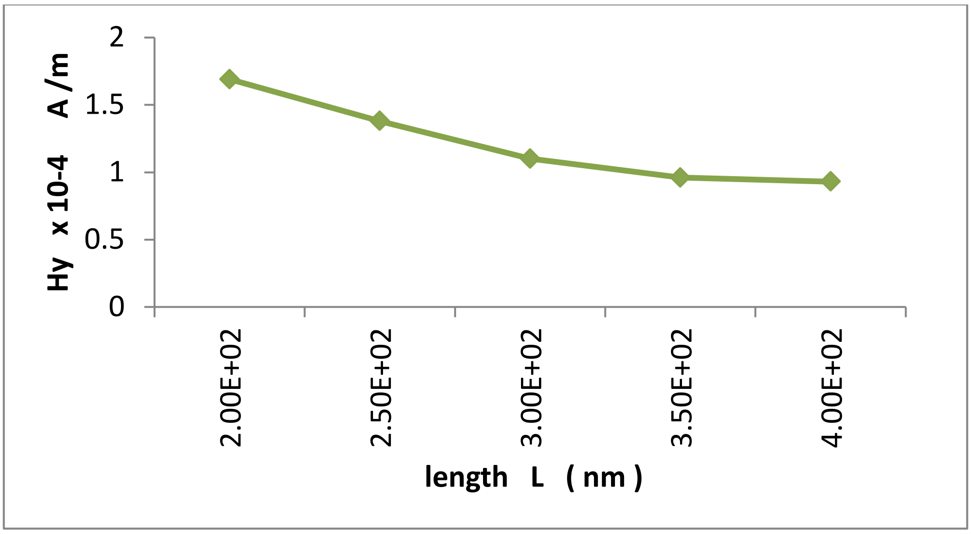
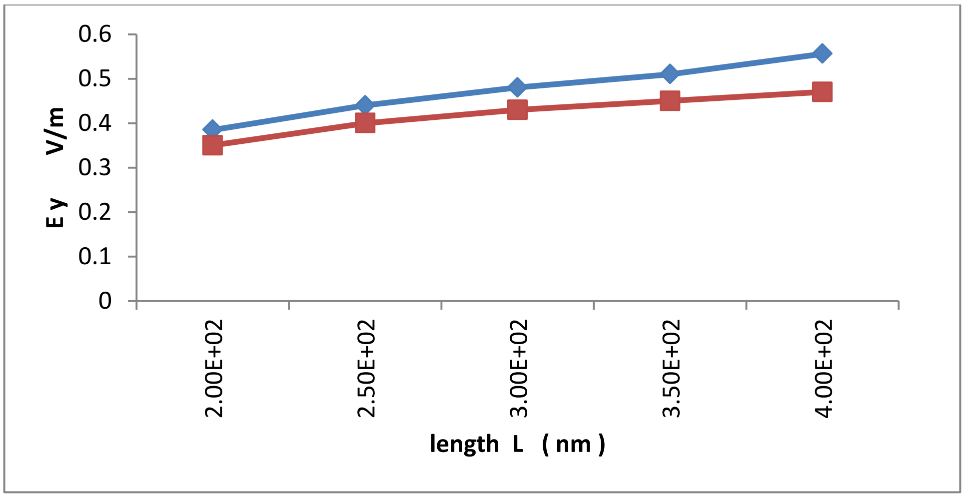
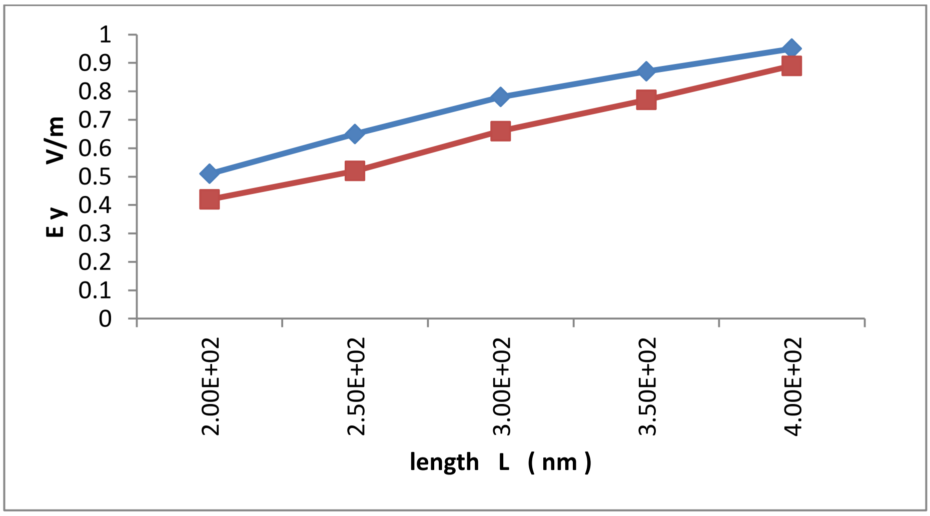


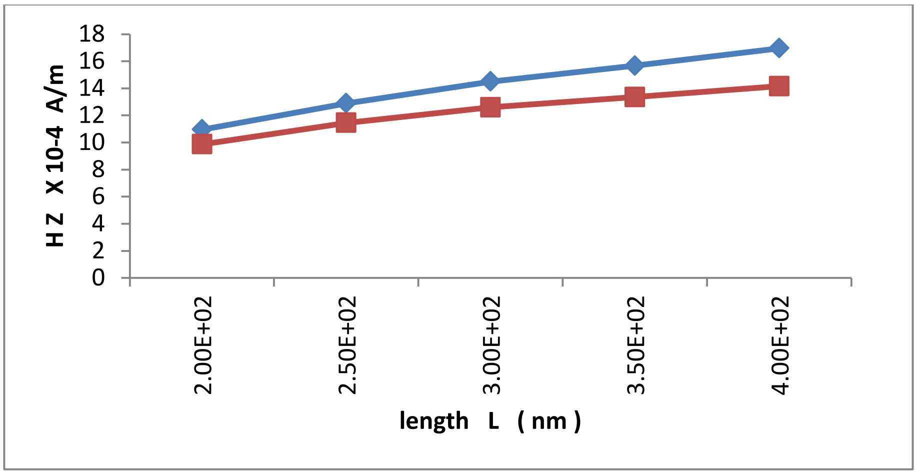
Fig (8) Magnetic field H_x Respect to the antenna lengths



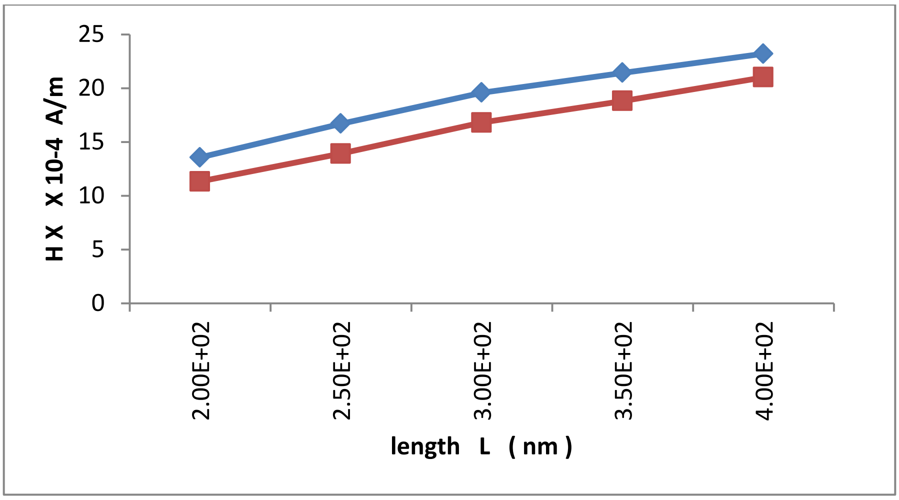
Fig(9) The penetration and reflection electric fields E_y respect to antenna lengths parallel to The X axis



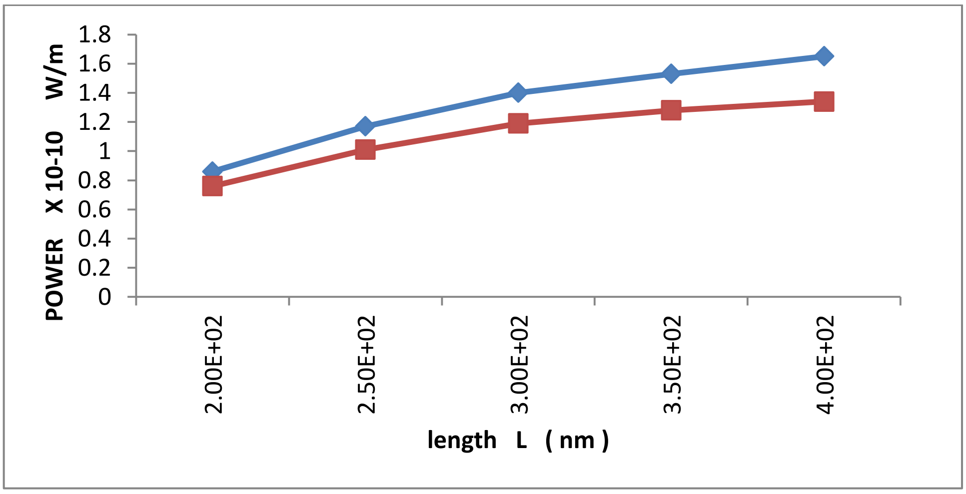
Fig(10) The penetration and reflection electric fields E_y respect to antenna lengths parallel to The Z axis



Fig(11) The penetration and reflection Magnetic fields H_Z respect to antenna lengths parallel to The X axis



Fig(12) The penetration and reflection Magnetic fields H_X respect to antenna lengths parallel to the Z axis



Fig(13) The penetration and reflection Power respect to antenna lengths parallel to the X axis

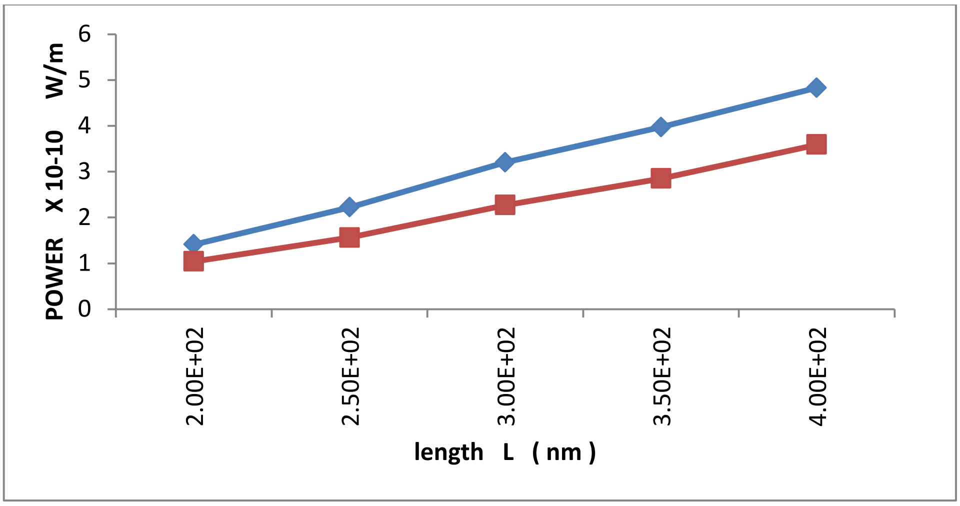


Fig (14) The penetration and reflection Power respect to antenna lengths parallel to the Z axis

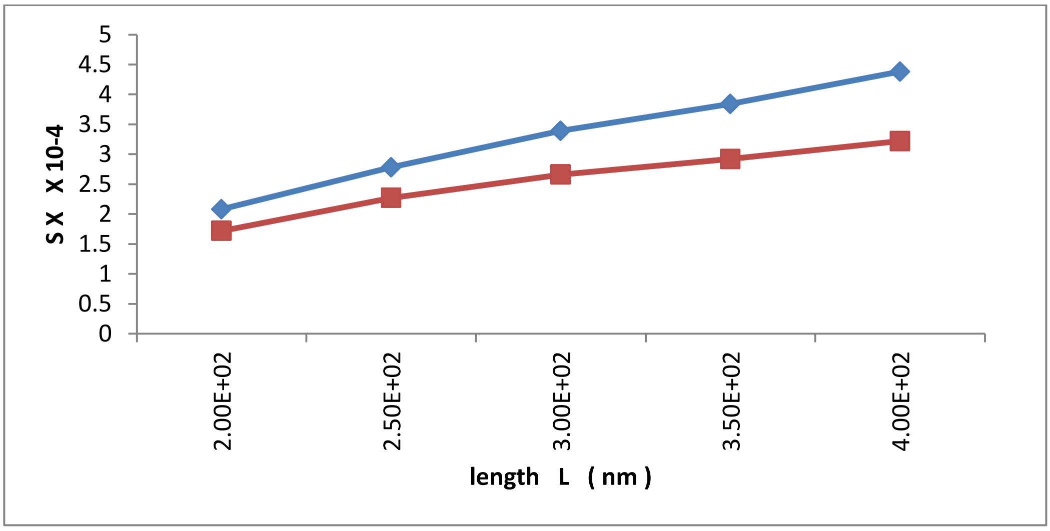


Fig (15) The penetration and reflection Pointing Vector respect to antenna lengths parallel to the X axis

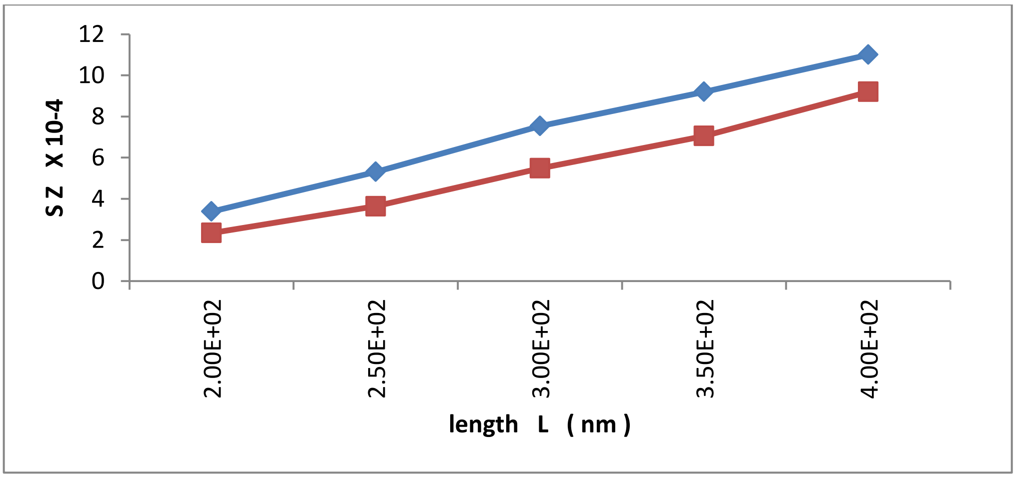


Fig (16) The penetration and reflection Pointing Vector respect to antenna lengths parallel to the X axis

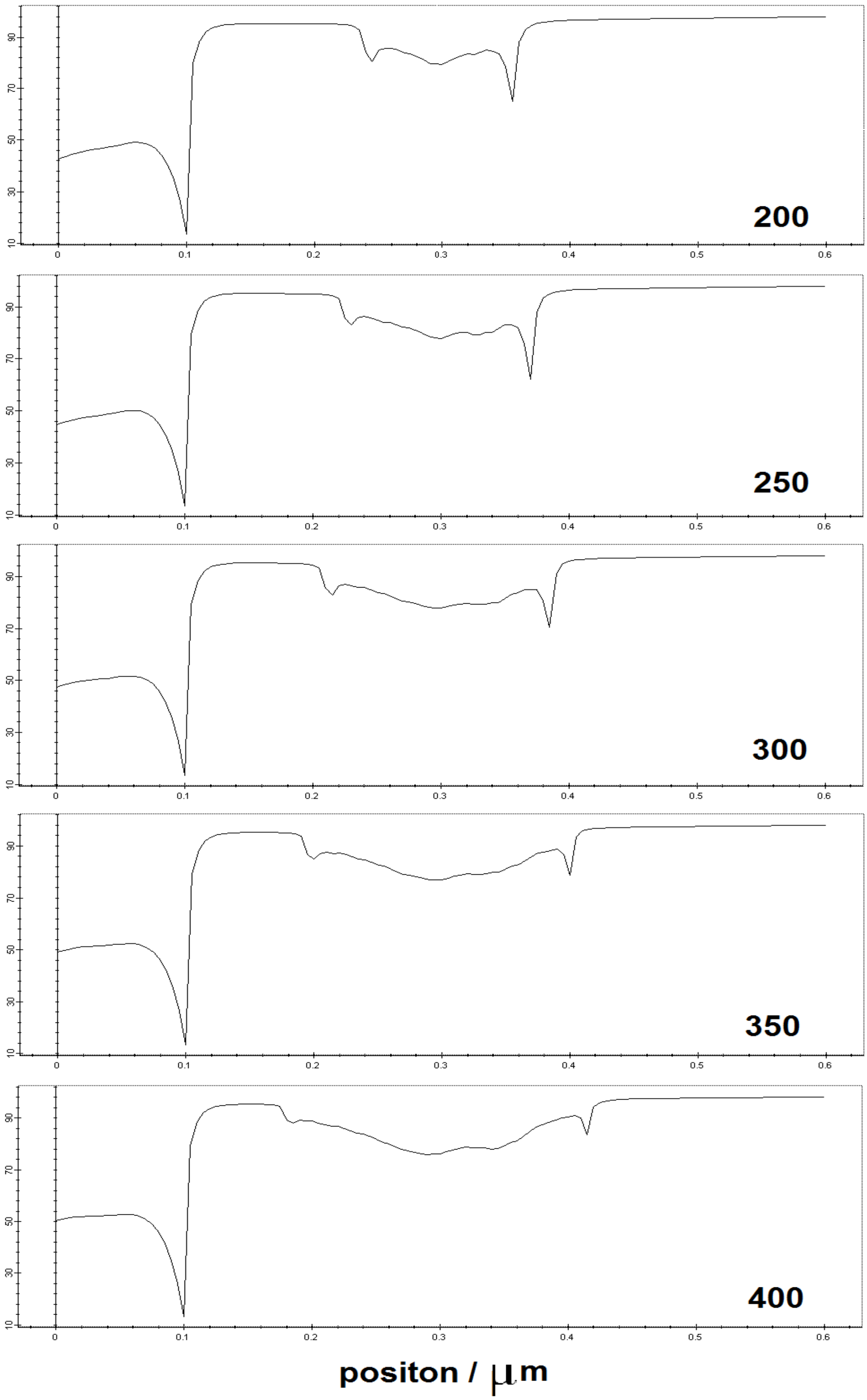
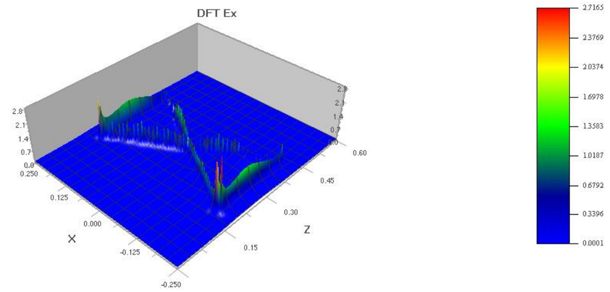
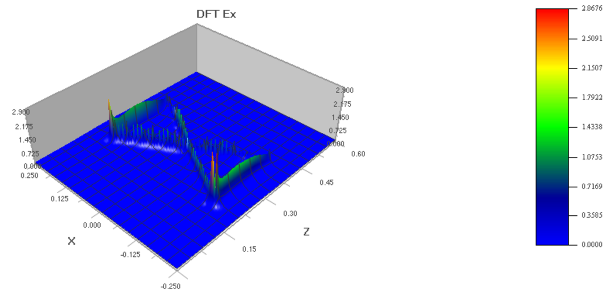


Fig (17) Position Overlap scan respect to antenna lengths parallel to the X axis



L =400 nm



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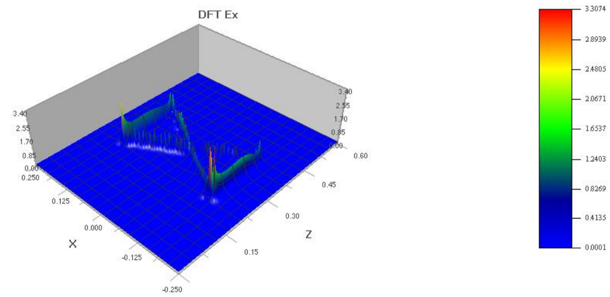

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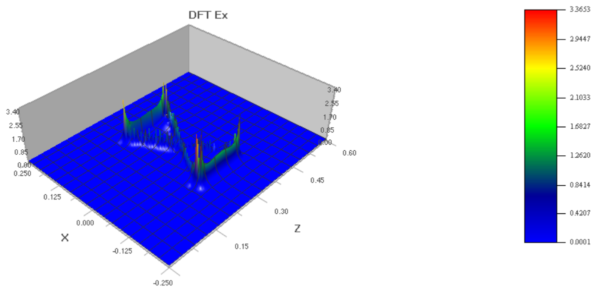

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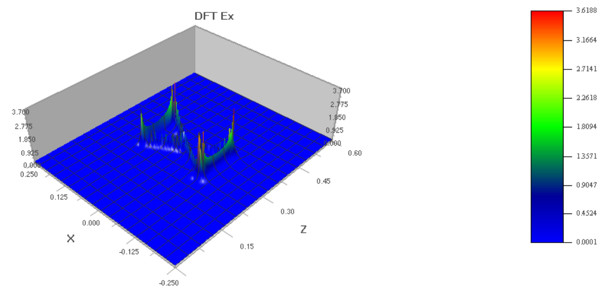
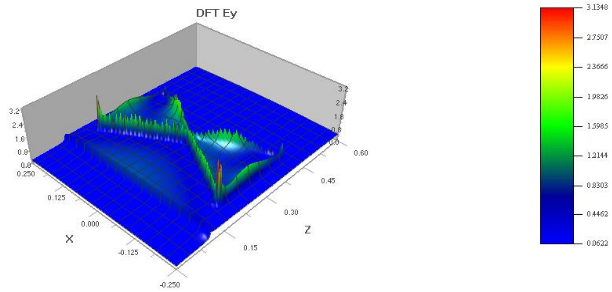


L = 200 nm

Fig (18) Distribution of electrical field E_x at the surface of optical nano antenna for different wavelength



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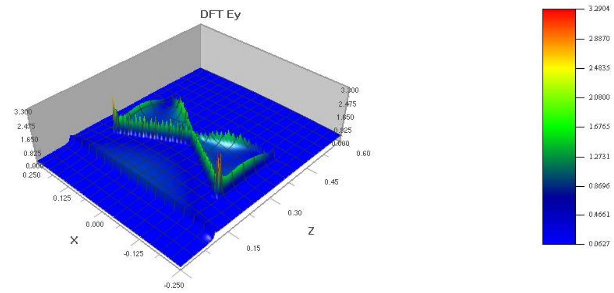

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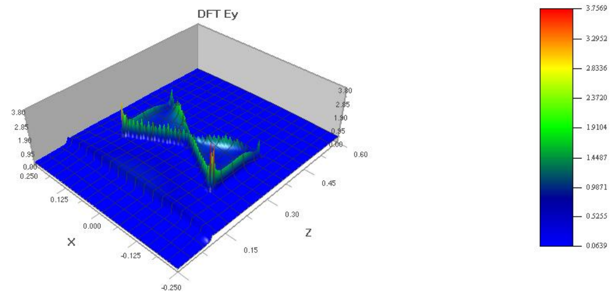

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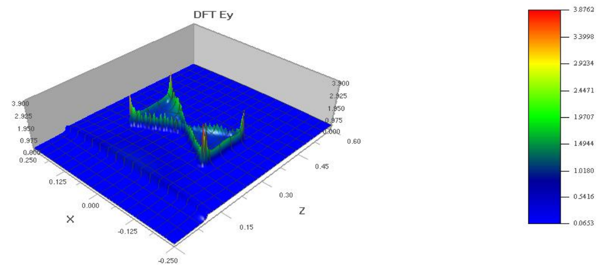

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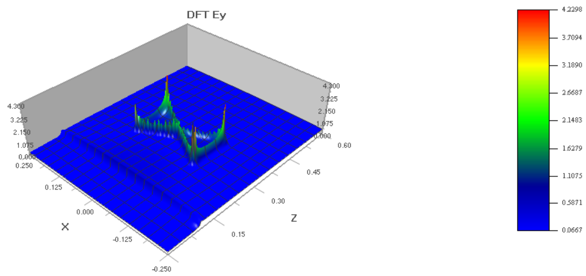


L = 200 nm

Fig (19) Distribution of electrical field E_y at the surface of optical nano antenna for different wavelength

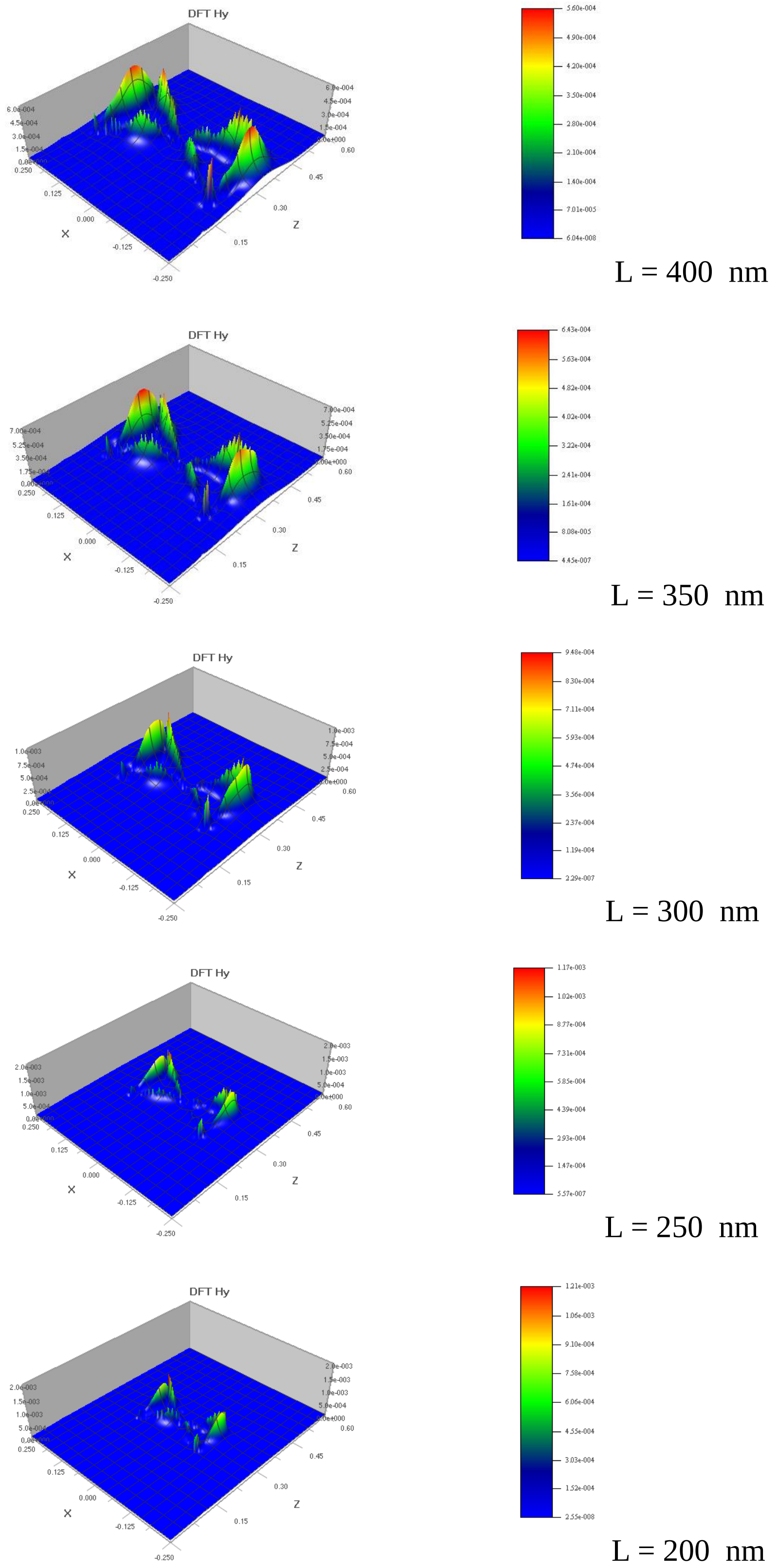
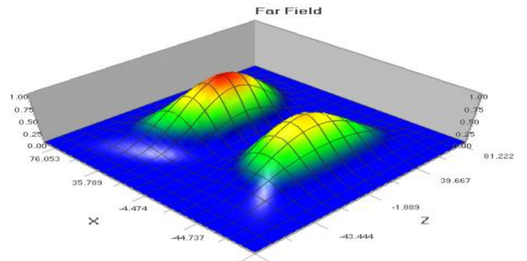
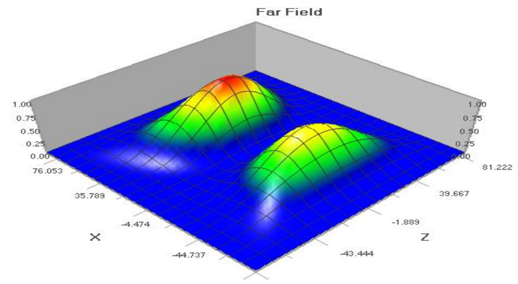


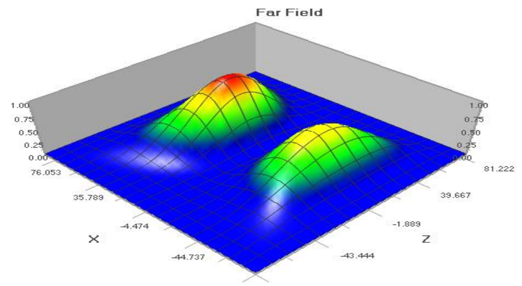
Fig (20) Distribution of Magnetic field H_y at the surface of optical nano antenna for different wavelength



L = 400 nm



L = 350 nm



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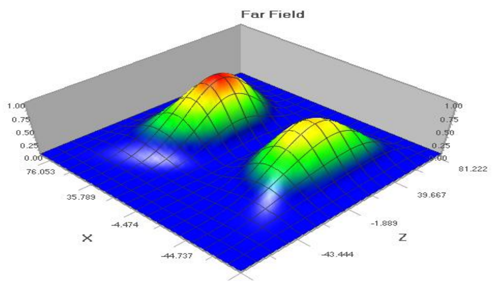

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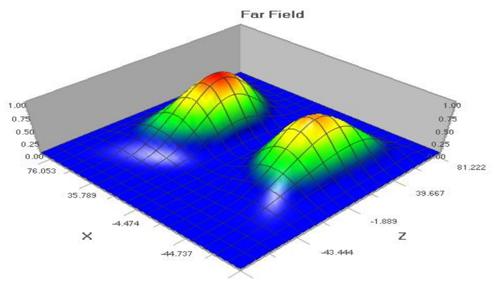

L = 200 nm

Fig (21) Distribution of Far field at the surface of optical nano antenna for different wavelength

Conclusions

We can conclude from results that the electric and magnetic fields in gap have been increased when the decrease length of the optical nano antenna. While, increasing electric and magnetic fields around optical nano antenna when increasing the length of the antenna. that means, the electric and magnetic fields have enhancement when increasing the arm length of the optical nano antenna.

Thus, optical nano antenna which has is a length of 200 nm is the better in the fields which are generated than other, in addition the responses of optical nano antenna change with wavelength according to match the antenna with wavelengths which receives. Therefore, the best length of the optical nano antenna when the wavelength is complications of half wavelength.

As well as, use of multilayer optical nano antenna has enhanced electrical and magnetic fields due to the interaction the layer with each other which lead to increasing the value of those fields.

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