Surface Plasmon and Nano-metallic layout simulation with OptiFDTD

1. Lorentz_Drude Model and Surface Plasma wave

Metallic photonic materials demonstrate unique properties due to the existence on metals of electromagnetic surface waves known as surface plasmons. Surface plasmons are set to become part of the photonics revolution in which the interaction between light and matter is controlled by producing patterned structures that are periodic on the scale of the wavelength of light. Surface plasmons open up a wealth of new possibilities for photonics because they allow the concentration and propagation of light below the usual resolution limit, thus opening up such possibilities as sub-wavelength optical components. OptiFDTD was the first software that employed the Lorentz_Drude model for the surface Plasmon and metallic layout simulation. The Frequency domain Lorentz_Drude model is discussed in reference [1]. Figure 1 is the permittivity [1] for the noble metal gold and silver, as we can see they are very dispersive. OptiFDTD used the time domain Lorentz_Drude model [2] (Please provide the link for our paper). Figure 2 shows the OptiFDTD simulated surface wave propagate along a Silver surface.

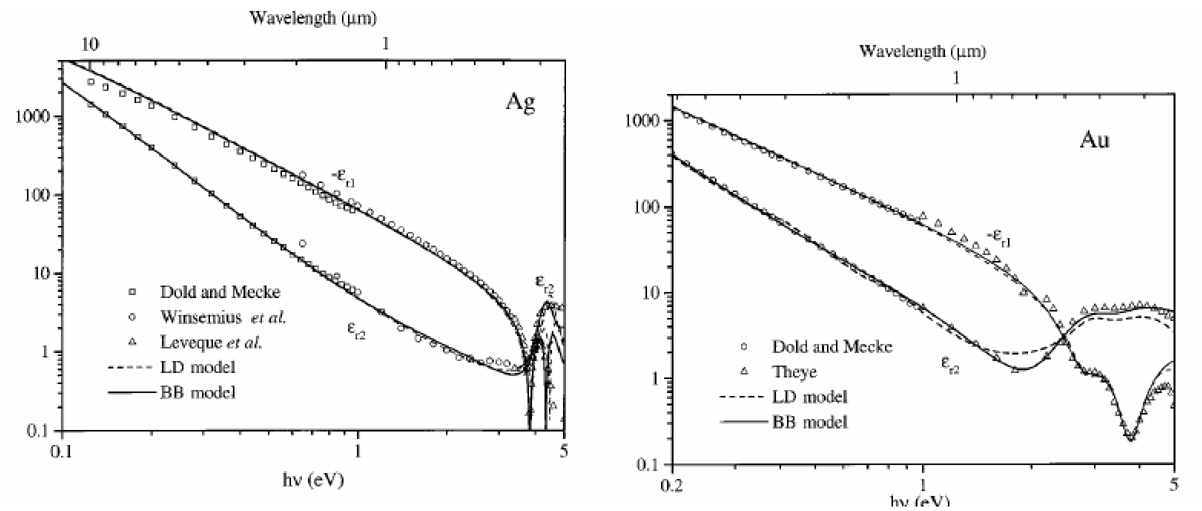

Figure 1 Permittivity of Gold and Silver [1]

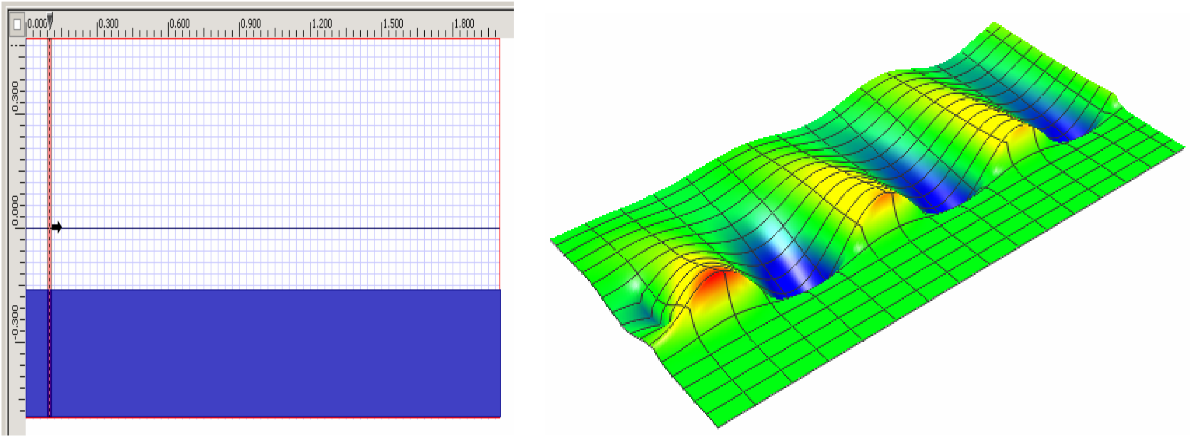

Figure 2   OptiFDTD simulated Surface Plasmon wave propagates along the silver surface

[1] A. D. Rakic, et al. “Optical Properties of metallic films for vertical-cavity optoelectronic devices”, Applied Optics, Vol. 22, No.22, Aug.1998, pp.5271

[2] Richard Zhang, et al. “Finite-difference time-Domain method guides optical design of metallic nanostrcutures”, LaserFocusWorld,2004,

2. Example 1:   Beaming light from metallic aperture

Original reference:

OptiFDTD simulation results can be compared with the following reference:

[3] H.J. lezec, et al. “Beaming light from a subwavelength Aperture”, Science, Vol. 297, August 2002, pp.820.

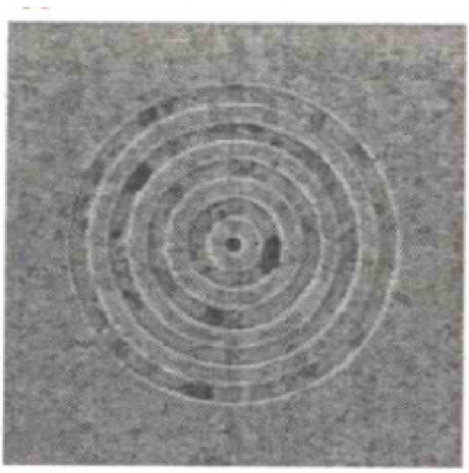

Figure 3   Bull’s eye structure of Ag film [3]

Layout in OptiFDTD

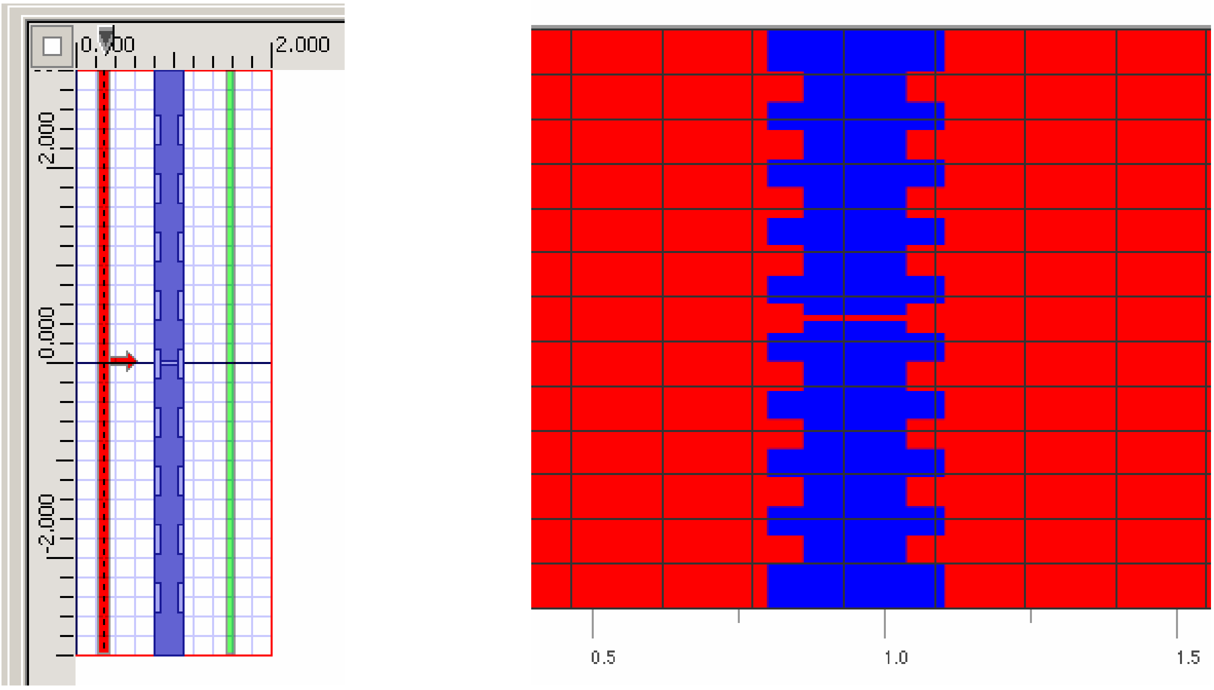

Figure 4 Side view of the layout.

Simulation results

Wave propagation effect can be observed in the simulator as shown in figure 5

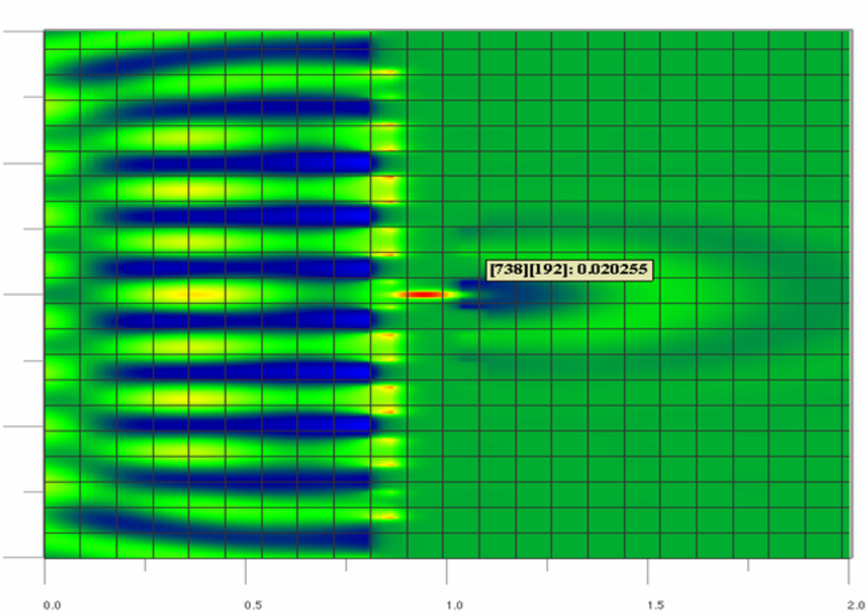

Figure 5 Beam propagation through the holes

Power transmission spectrum can be detected (See figure 6). Figure 7 is the optical image from the OptiFDTD for this bull's eyes Ag film.

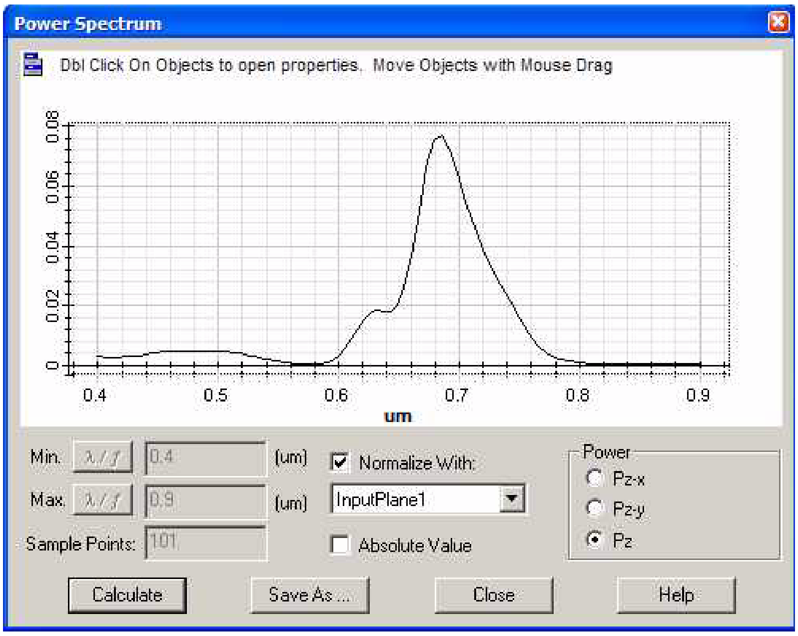

Figure 6 Power transmission for normal incident wave

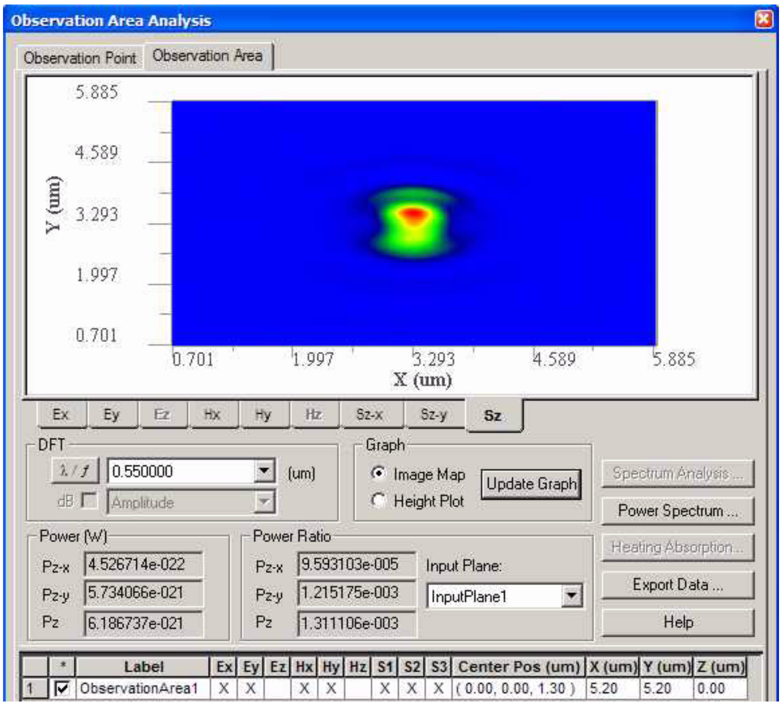

Figure 7 Optical images of the layout.

3. Example 2: Nano-scale image

Introduction

In this example, a subwavelength image system layout using the metallic nano-rods is simulated. The point sources under the nano rods compose a letter λ shape. The OptiFDTD simulation shows the silver nano-rods works as a mirror read successfully the shape λ. The original concept can be found in the following reference

[4] Atsuchi Ono, et al. “Subwavelength optical imaging through a metallic nanorod array”, *Physical review letters*, 31December, 2005.

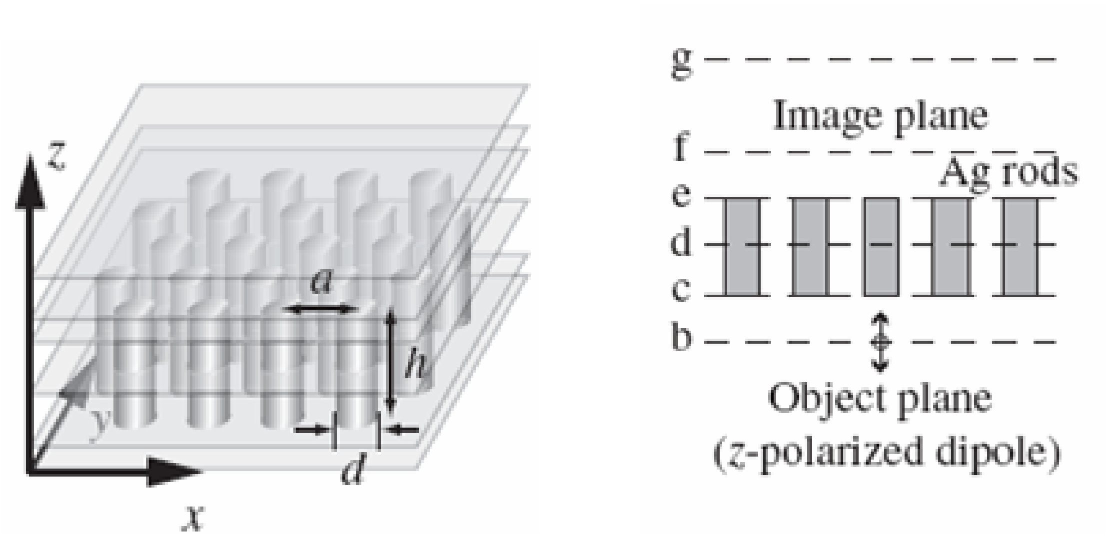

Figure 8 Nano-rod image system [4]

OptiFDTD Results

After the OptiFDTD simulation, the field patterns are recorded at the different transverse slice of the nano-silver-rod array. Figure 9 shows these images, as we can see that the image shape λ can be successfully repeated in the other end of the nano-rods.

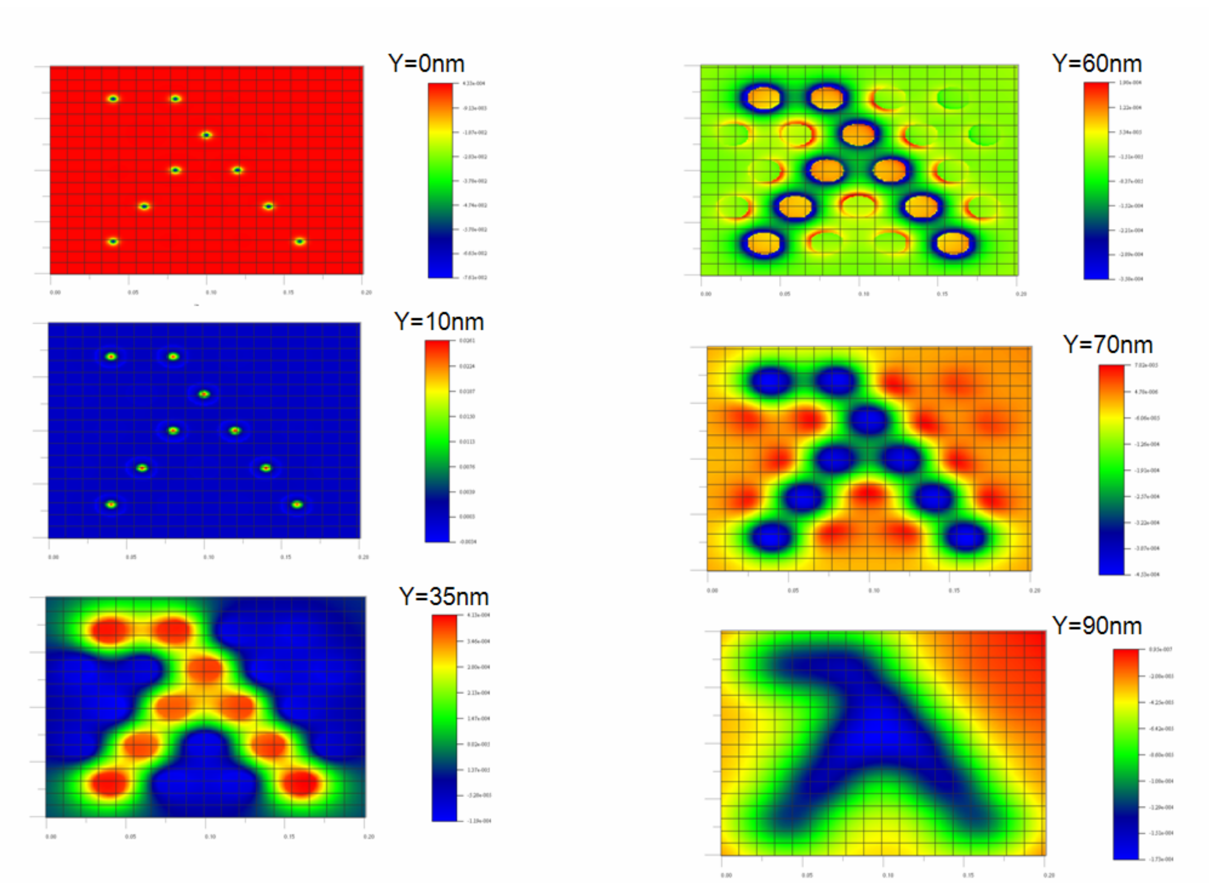

Figure 9 Read the image of shape λ by the OptiFDTD

4. Example 3: Field enhancement for Nano-bow-tie antenna

In the past several years, nano-antenna was being studied actively. As rewarded software, OptiFDTD did some contributions in this study. The following examples show the field enhancement effect for the nano-bow-tie antenna. The project took David P. Fromm, et al two published papers as reference[5-6]. The OptiFDTD project Layout is shown in Figure 10,

[5] David P. Fromm, et al. "Gap-Dependent Optical coupling of single "bowtie" nanoantennas resonant in Visible", Nano Letters, Vol. 4, No.5, 2004, pp. 957-961

[6] P. J. Schuck, David P. Fromm, et al. "Improving the mismatch between light and nanoscale objects with gold bowtie antennas", Physical review letters. 14 Jan. 2005,

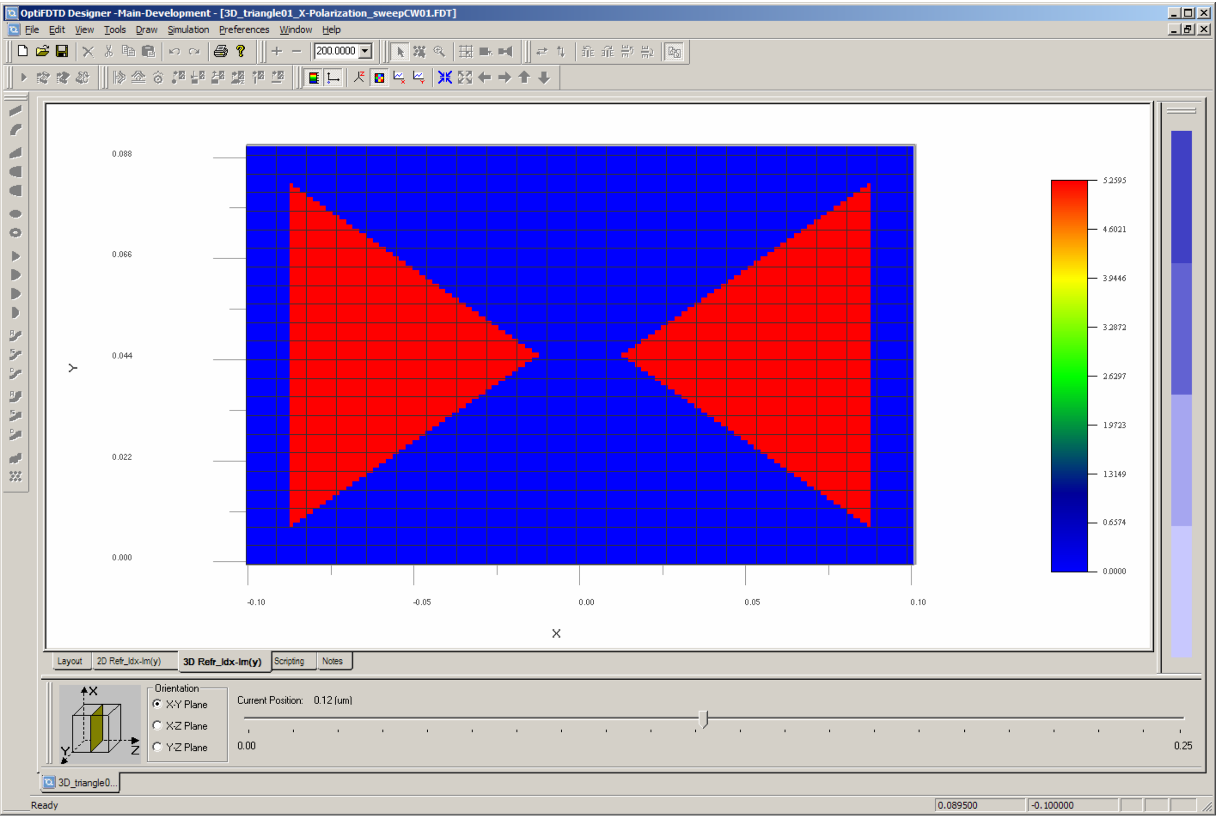

Figure 10, Gold Bowtie antenna in OptiFDTD

Simulation Notes

- Input wave is the plane wave in xy plane, propagate to direction
- X-direction polarization (parallel to the axis of bowtie)
- Input plane wave amplitude is 1.0 (Ex,inc=1.0)
- Use the VB to sweep the CW input wavelength or used pulse to cover a relative broad band
- Simulation resolution is 2nm
- Simulation used the periodic symmetric boundary condition for x-y boundary and PML for z direction boundary (negative x edge is mapped to positive x edge boundary---can save the memory

Simulation results

The Field enhancement effect (as shown in figure 11) in the bow tie surface can be observed. Field enhancement factor can also be extracted in from the field response (Figure 12)

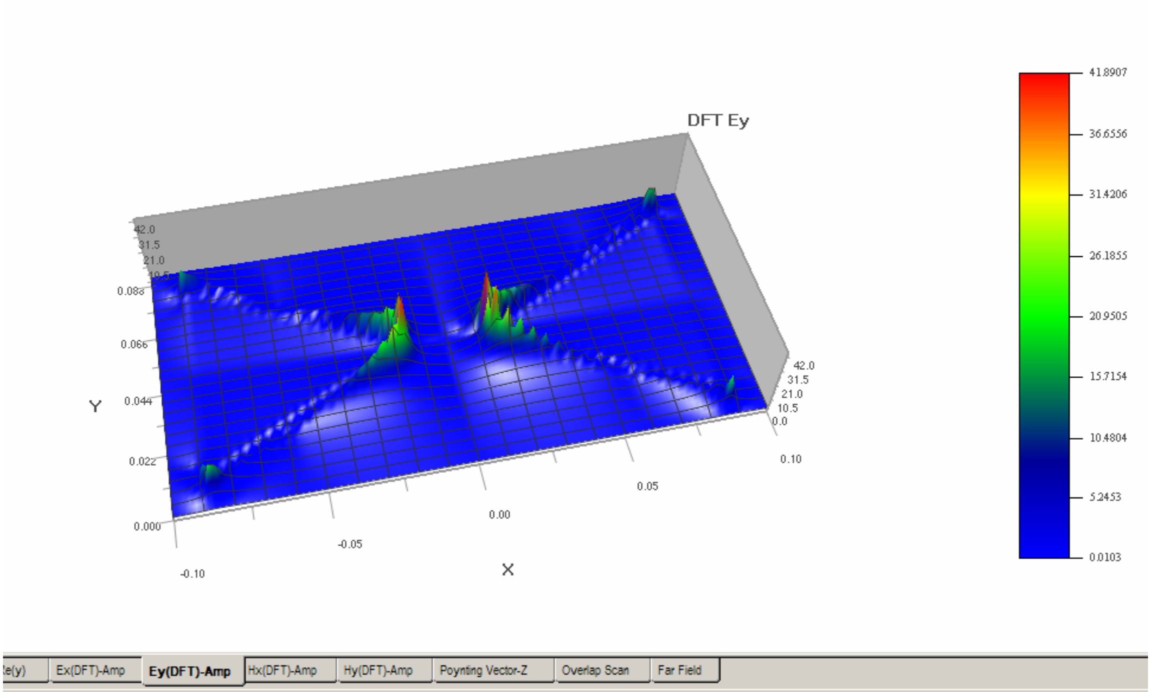

Figure 11 Field enhancements in the edge of the bow-tie antenna

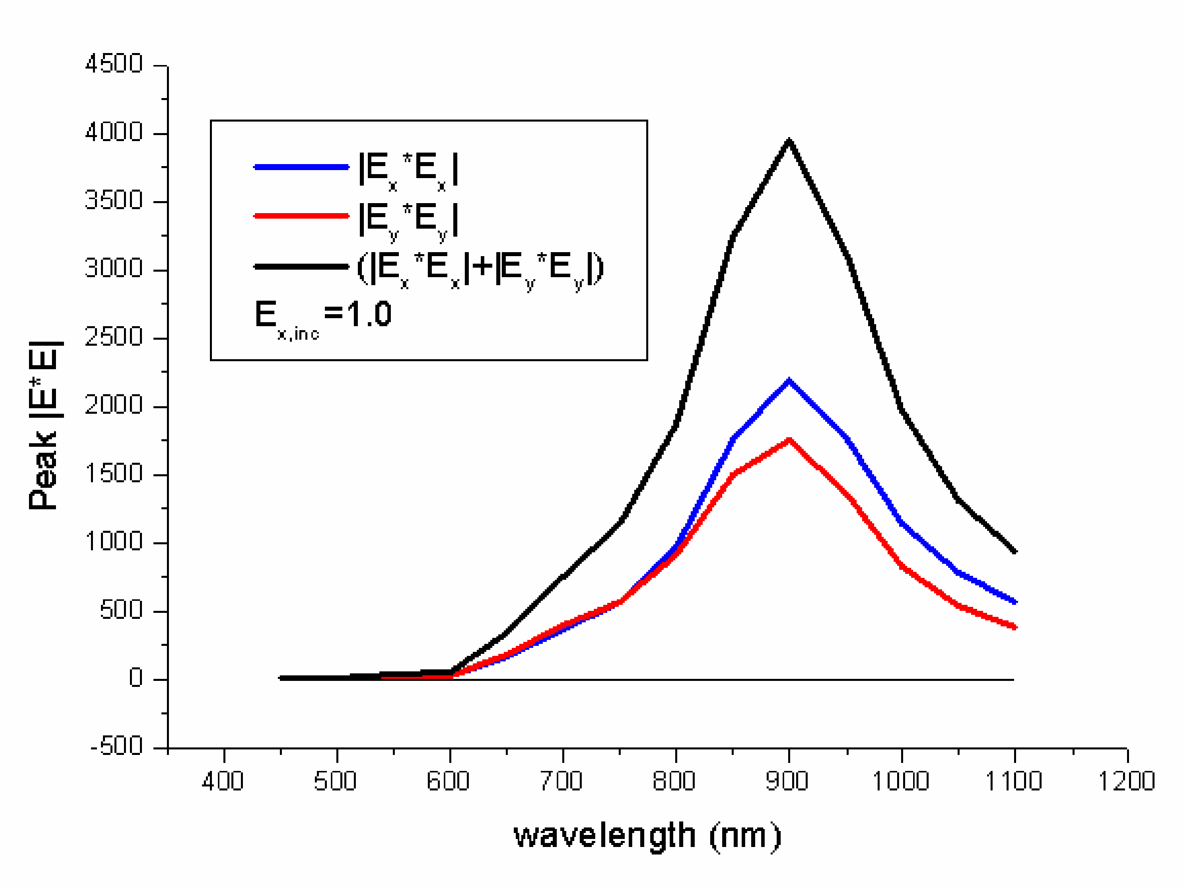

Figure 12 Field enhancement factor as a function of input wavelength