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RESEARCH ARTICLE

NUMERICAL INVESTIGATION INTO A NEW SHAPE OF METAMATERIALS AT OPTICAL FREQUENCIES

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ABSTRACT

The development of metamaterials was driven by the desire to fulfill synthetic materials with optical properties beyond naturally available materials. Natural isotropic homogeneous materials are characterized by a frequency dependent permittivity $\varepsilon(\omega)$ and permeability $\mu(\omega)$. Both of $\varepsilon(\omega)$ and $\mu(\omega)$ describe the response of the media to an electromagnetic field, where $\varepsilon(\omega)$ describes the electric polarization induced by the electric field and $\mu(\omega)$ describes the magnetic polarization induced by the magnetic field. In the optical domain, where the magnetic response is vanishing, the permeability is a constant equal to unity. In this paper, a new shape of structure made of mercury metal was modeled and simulated. It shows that this structure acts as a double negative material at a specific ranges of the optical frequencies. The study cover numerical investigation on the reflectance, transmission and absorption behavior of this new structure, the parameters of the material including permittivity, permeability and refractive index. Then the study shows the effect of the different radius of the nanowires on the structure behavior. After that, I plot the E-Field, H-Field and surface current for some frequencies.

INTRODUCTION

The range of the electromagnetic responses presented by natural materials is quite limited. Lately, a new kind of artificial materials, named metamaterials, became a topic of great interests for its novel electromagnetic features, including the negative refractive index and the tunable permittivity and permeability (Veselago, 1986). Metamaterial was firstly proposed for the microwave domain (Pendry, 1999 and Yen, 2004) and then introduced into terahertz (Yen, 2004) and recently into optical frequencies. Simulations and experiments have showed the properties of metamaterials from radio frequencies to optical frequencies. Metamaterials can be single negative metamaterials with either $\varepsilon<0$ or $\mu<0$, or double negative metamaterials with both $\varepsilon<0$ and $\mu<0$. Due to the negative refraction index the direction of phase and group velocity is opposite. Potential applications of metamaterials are varied, and include: optical fibers, medical devices, remote aerospace applications, sensor detection and infrastructure monitoring, smart solar power management, high frequency battlefield communication and lenses for high gain antennas, et cetera (Brun, 2009; Rainsford, 2005; Cotton, 2009 and Alici, 2007). Metamaterial research is interdisciplinary and involves such fields like electrical engineering, electromagnetics, classical optics, microwave and antenna engineering, material science, solid state physics, optoelectronics, nanoscience and semiconductor engineering (Veselago, 1986).

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Modeling and Calculation

Transmission, Reflectance and Absorption characteristics

The design made of a box which is opened from the front and the back, inside it has arrays of nanowires, and the design is made of mercury (lossy metal) as shown in Figure 1. Each nanowire has a radius of 5nm and 100nm length. The structure is directed along z-axis. An electric field applied along x-axis and magnetic field applied along z-axis with open boundaries on y-axis. The range of frequency is between 300-700THz. Figure 1 below shows the structure with its dimensions. I plot reflectance diagram versus wavelength range in Figure 2, the diagram shows weak reflectance along the optical wavelength. While figure3 present the diagram of the transmission which shows weak transmission along the wavelength (465.75-590.54nm) which means weak transmission of the colors from blue to yellow then it continue with about 60% of transmission covering the orange and red light.

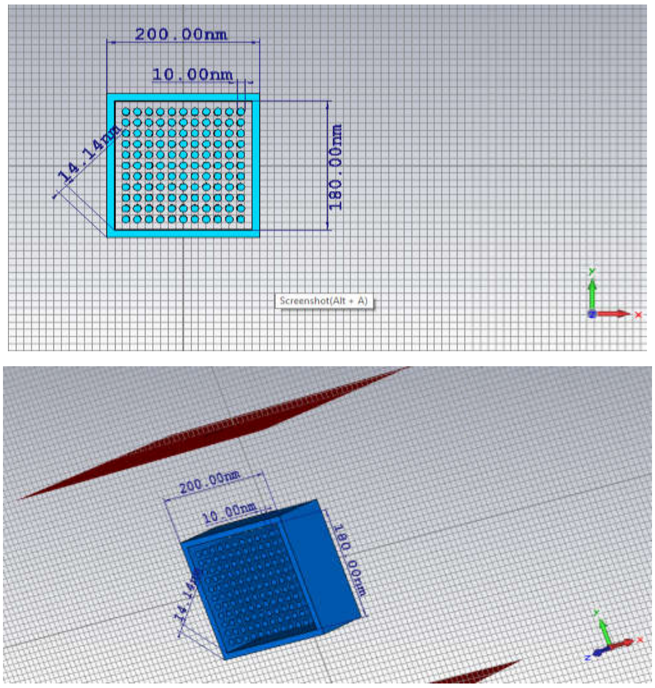


Figure 1. 3D full field electromagnetic simulation geometry with CST

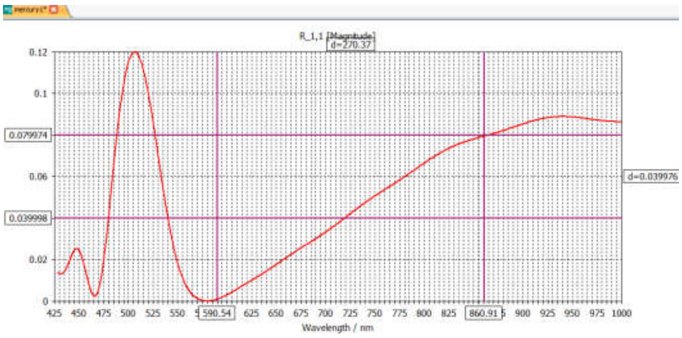


Figure 2. Magnitude of the reflected waves

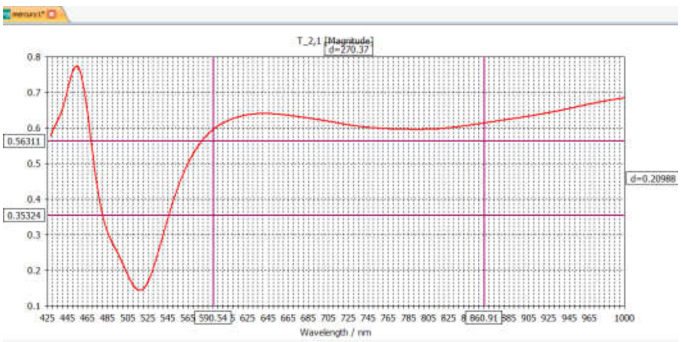


Figure 3. Magnitude of transmitted waves

The figure4 below present the reflected and transmitted waves in dB. Figure 5 shows the absorption behavior of the structure, 80% of the blue and green waves were absorbed by the material. I plot the linear and dB magnitude of the absorbed waves.

Permittivity, permeability and negative refractive index properties of the structure: In Diagram 6 below I plot the real and imaginary part of the permittivity after the simulation, it shows that this structure exhibit negative values of permittivity covering the frequency range (311.6-559.75THz), this frequency range is covering red, orange, yellow and green light.

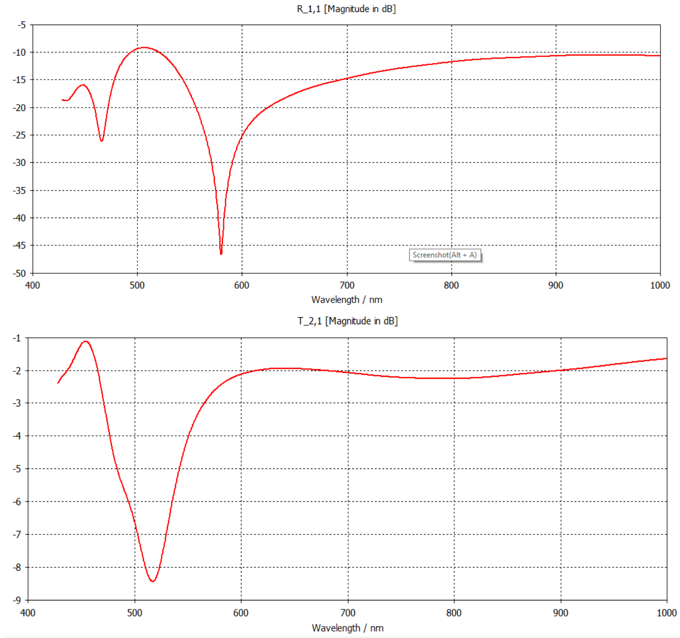


Figure 4. Reflected and Transmitted waves in dB

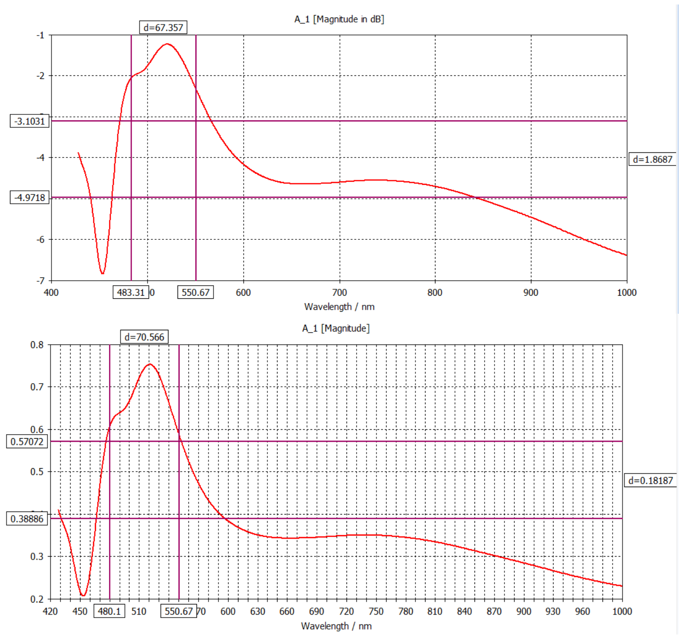


Figure 5. Magnitude of absorbed waves in both linear and dB

Figure 7 below indicates the real and imaginary part of permeability, the permeability exhibits negative values along the frequency range (311.6-541.21THz), covering the red, orange, yellow and green light of the visible light. As a result, we can describe this structure as a double negative material that exhibit negative values of both permittivity and permeability.

The final important parameter is refractive index *n*, the diagram below shows that the refractive index of refraction is negative along frequency range (300-552.95THz) as the permittivity and permeability. Figure 8 indicates the real and imaginary part of the refractive index.

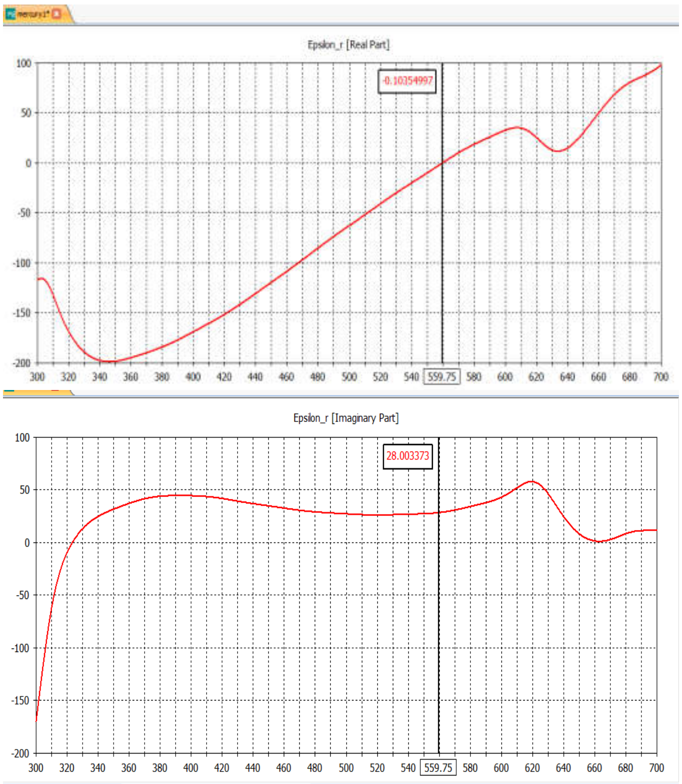


Figure 6. Real and imaginary part of the permittivity

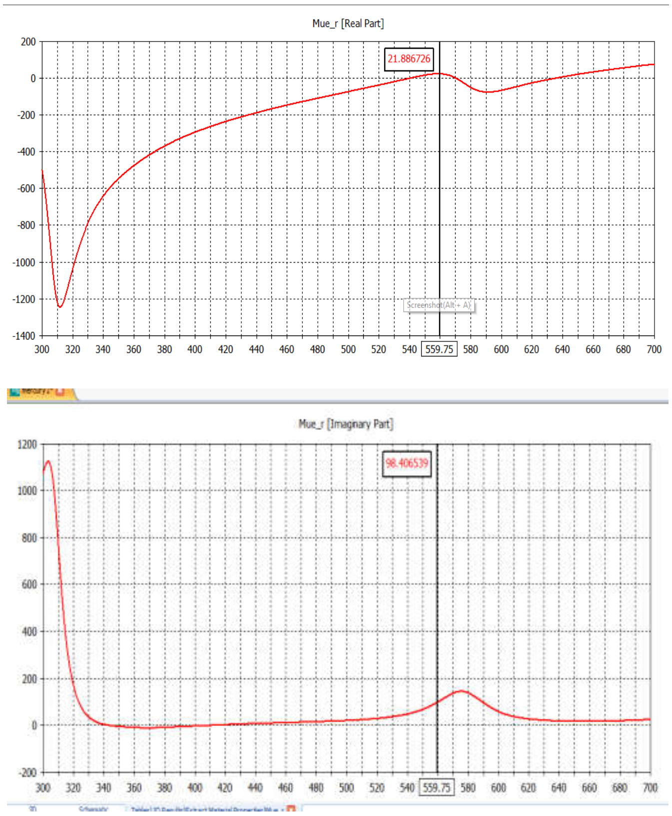


Figure 7. Real and imaginary part of the permeability

Effect of the nanowiers radius (r) on the behavior of the material

Increasing the radius of the wires lead to enhancing the absorption at a frequency resonant 520.11THz as shown in the Figure 9 below. Diagram 10 shows the reflected and transmitted waves with different values of the nanowires at the resonant frequency. Under here, I plot the parameters of the structure, Figure 11 shows the permittivity, permeability and refractive index for different radius of the wires.

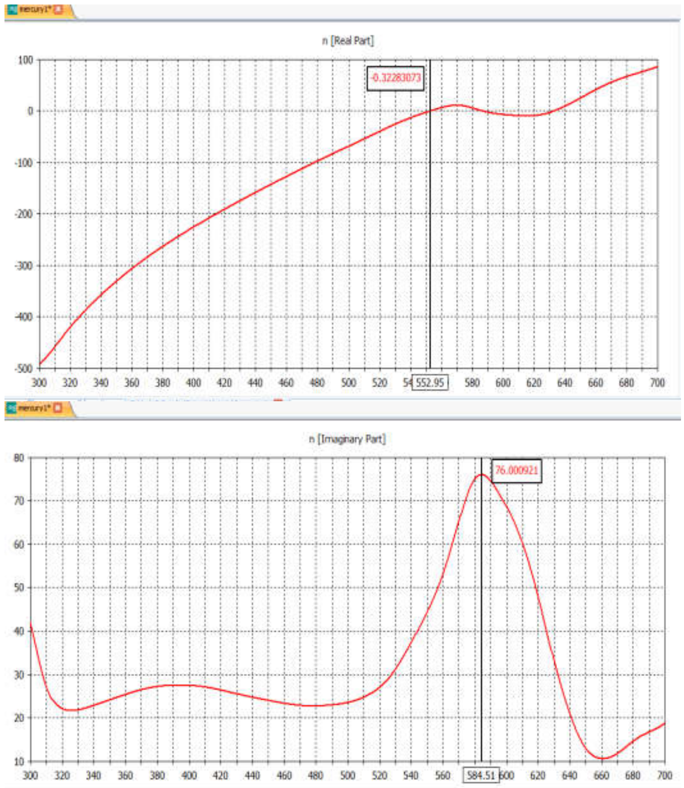


Figure 8. Refractive index

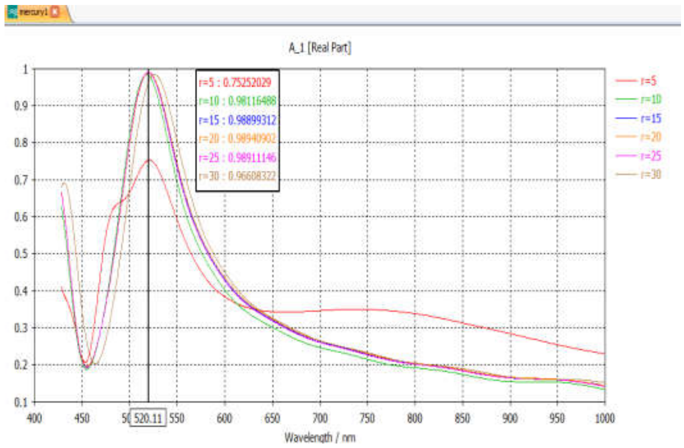
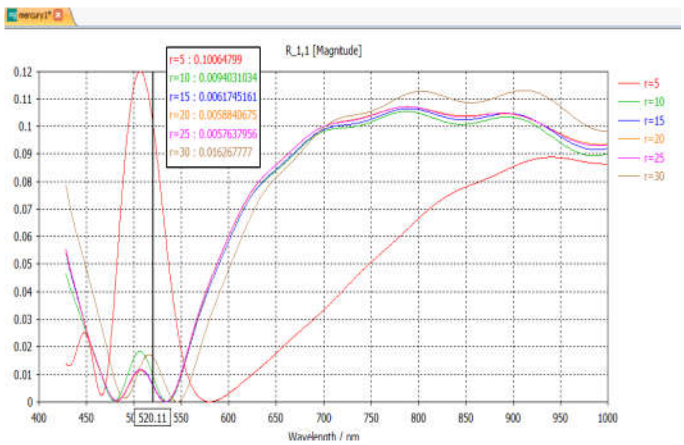


Figure 9. Absorption after changing the radius of the wires



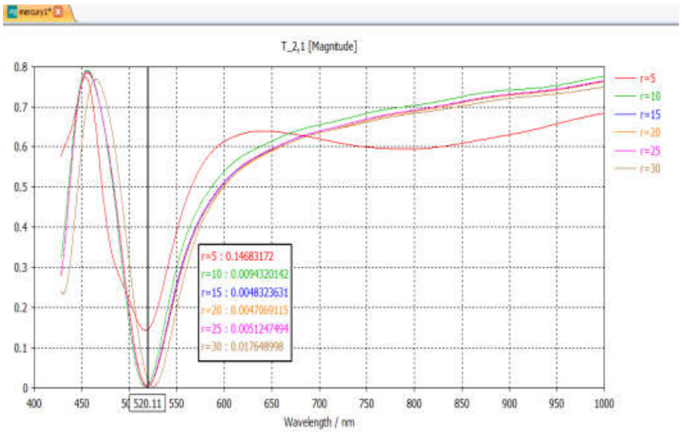


Figure 10. Reflected and transmitted waves at resonant frequency

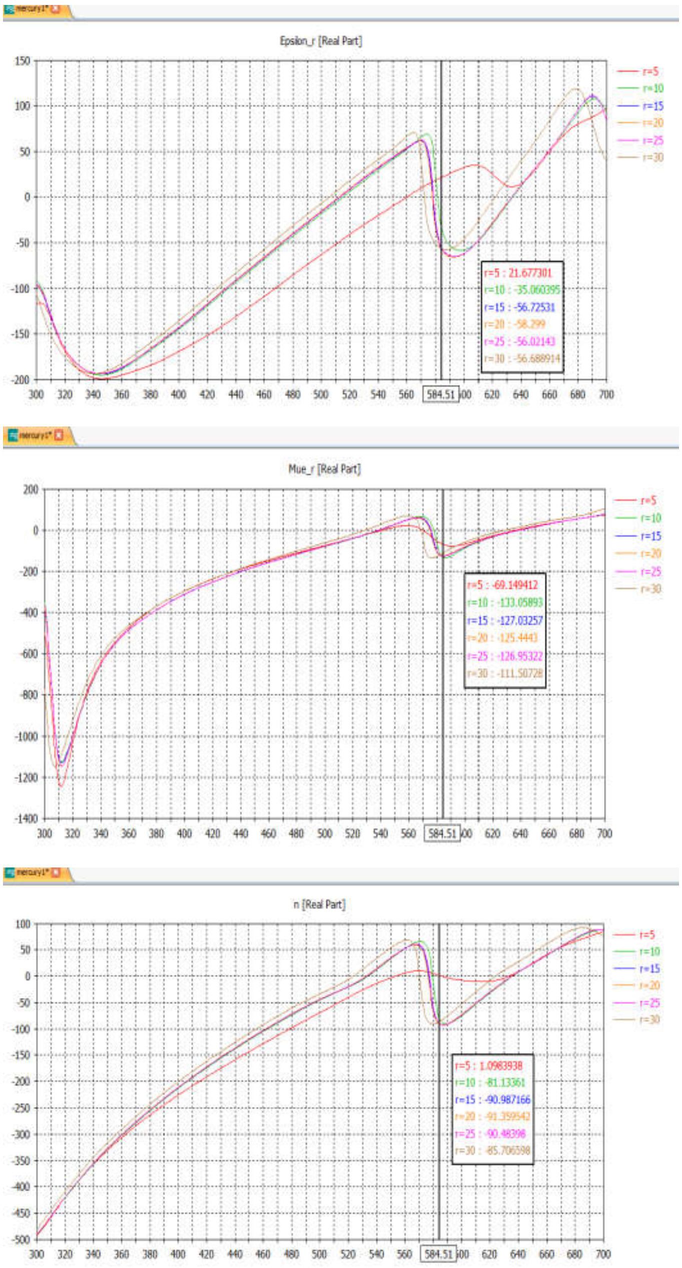


Figure 11: Epsilon_r, Mue_r and n

Next, I plot the Electric and Magnetic Fields and surface current of some frequencies, the electric field and magnetic field were taken in the case of 5nm of the wire radius.

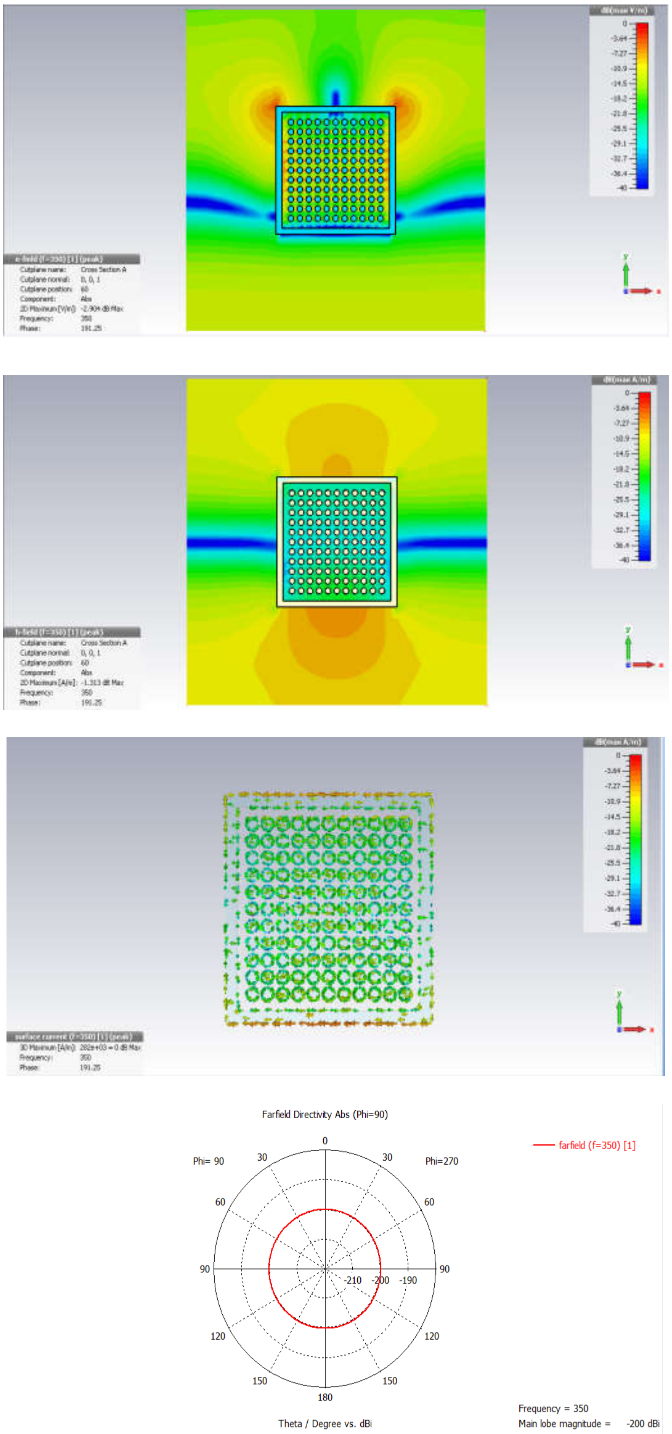
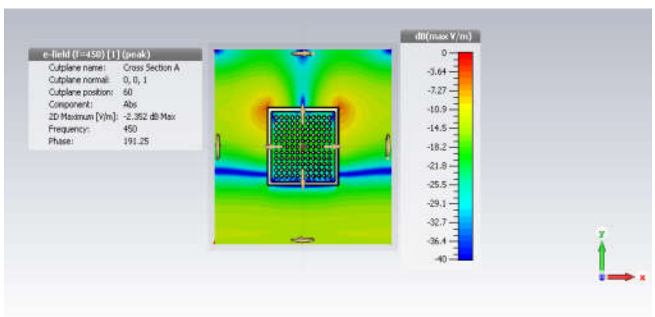


Figure 12. Electric -Field, Magnetic -Field, Surface current and Farfield at 350THz

At 450THz



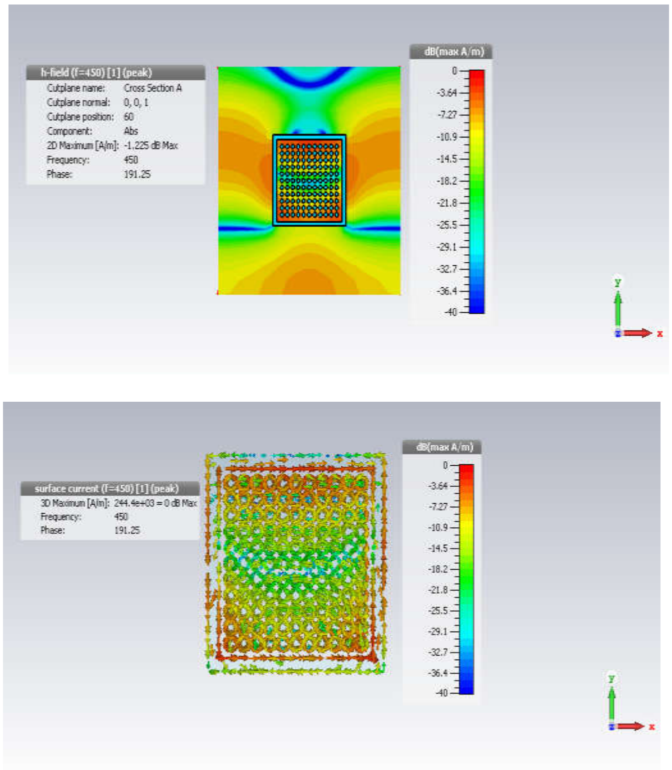
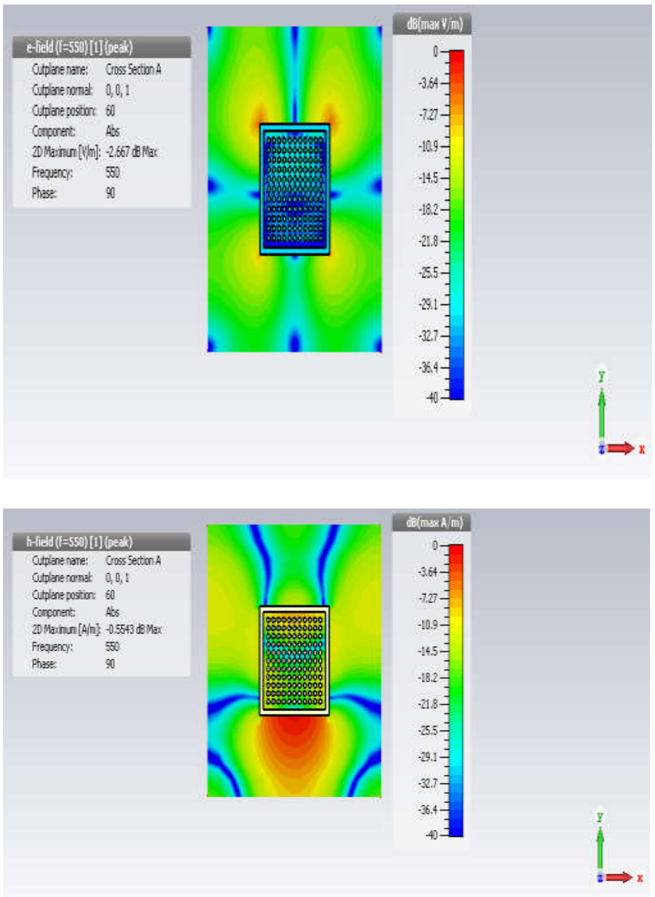


Figure 13. Electric -Field, Magnetic -Field, Surface current at 450THz

Figure 14 below present the Electric field, magnetic field and surface current at 550THz



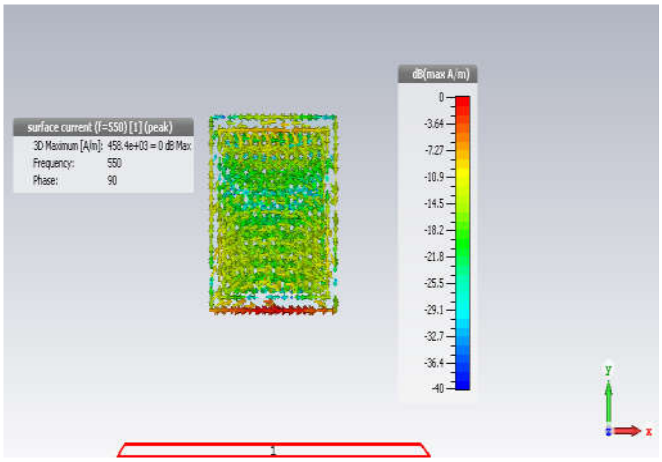
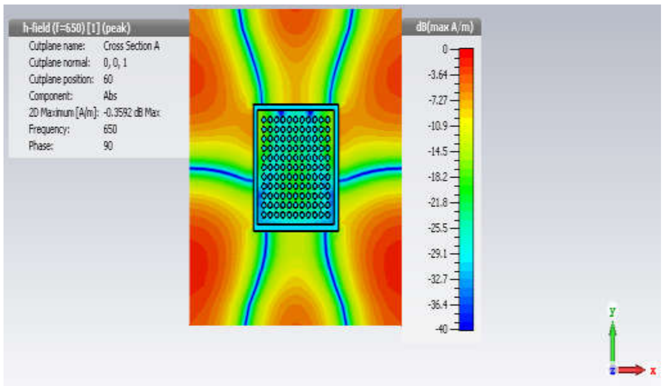


Figure 15. shows the magnetic field at 650THz



Conclusion

Modeling and simulation of the structure was carried out with help of a simulation software. The proposed work was modeled and simulated using CST microwave suit studio, an electromagnetic simulation tool for high frequency ranges. This software is based on finite element modeling method. This paper studied the reflectance, transmission and absorption behavior of mercury metal at frequency range (300-700THz). After that the effective parameters of the material were studied, and it showed that the structure has a double negative material properties which means it has negative values of both electric permittivity and magnetic permeability along a specific frequency range. Changing the radius of the nanowires enhanced the absorption of the structure, where an excellent absorption achieved at the frequency resonant 520.11THz.

REFERENCES

Alici, Kamil Boratay; Özbay, Ekmel 2007. "Radiation properties of a split ring resonator and monopole composite".

Brun, M.; S. Guenneau; and A.B. Movchan (2009-02-09). "Achieving control of in-plane elastic waves". Appl. Phys. Lett. 94(61903): 1-7.

Cotton, Micheal G. (December 2003). "Applied Electromagnetics". 2003 Technical Progress Report (NITA-ITS). Boulder, CO, USA: NITA - Institute for Telecommunication Sciences. Telecommunications Theory (3): 4-5. Retrieved 2009-09-14.

Pendry, J. B., Holden, A. J., Robbins, D. J. *et al.*, 1999. "Magnetism from Conductors and Enhanced Nonlinear

Phenomena", IEEE Tran Microwave Theory Tech, 47(11), 2075~2084.

Pendry, J. B., Holden, A. J., Stewart, W.J. *et al*., 1996. "Extremely Low Frequency Plasmons in Metallic Mesostructures", Phys. Rev. L, 76(25), 4773~4776.

Rainsford, Tamath J.; D. Abbott; Abbot, Derek (9 March 2005). Al-Sarawi, Said F, ed. "T-ray sensing applications: review of global developments". Proc. SPIE. Smart Structures, Devices, and Systems II. Conference location: Sydney, Australia 2004-12-13: The International Society for Optical Engineering. 5649 Smart Structures, Devices, and Systems II (Poster session): 826-838.

Veselago, V. G. 1968. "The Electrodynamics of Substances with Simultaneously Negative Values of Epsilon and Mu", Sov. Phys. Usp, 10(4), 509~514.

Veselago, V. G., Sov. Phys. Usp. 1968. 10, 509. Physical status solidi (b). 244(4): 1192-1196.

Yen, T. J., Padilla, W. J. Fang, N., *et al*., 2004. "Terahertz

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