Metamaterials Characterization

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Revised on:1/9/2014 & Accepted on: 29/1/2015

ABSTRACT

Meta-materials are usually metal-dielectric composites having unique electromagnetic properties. These unique electromagnetic properties of meta-materials have attracted much interest. Therefore, meta-material fabrication is developing, The fabrication method is based on the design of polymer material with holes. Where these holes are filled with metal in a micro-structure form which produce the meta-materials. The method for design this structure includes arrays of wires, which allow the permittivity to be tuned through the details of the wire diameter and spacing. Metamaterials are characterized by many parameters, one of them is its ability to control electromagnetic waves in the subwavelength, depending on the resonant unit cells. This work is done by using a simulation program to draw a metamaterials in the form of 2D array of wires as a fiber. Then simulate the effective mode index inside them. our results show that the effective mode index is increased by increasing the plasma frequency.

توصيف مواد - ميتا

الخلاصة:

المواد الميتا هي المركبة عادة من ماده معدنية عازلة تمتلك خصائص كهرومغناطيسية فريدة من نوعها. وقد اجتذبت هذه الخصائص الكهرومغناطيسية الفريده لمواد الميتا الكثير من الاهتمام . لذلك تصنيع مواد الميتا بتطور مستمر، وتستند طريقة التصميم على اساس تصميم مادة البوليمر مع الثقوب. حيث تمتلئ هذه الثقوب مع المعادن في شكل هيكل الصغيرة التي بالتالي تنتج مواد الميتا. طريقة لتصميم هذا الهيكل يتضمن مصفوفة من الأسلاك ، والتي تسمح للسماحية ليتم ضبطها من خلال تفاصيل قطر السلك والتباعد. وتتميز مواد الميتا بالعديد من المعلمات ، واحد منهم هو قدرتها على السيطرة على الموجات الكهرومغناطيسية في اجزاء من الطول الموجي اعتمادا على وحده الرنين للخلايا. ويتم هذا العمل باستخدام برنامج محاكاة لرسم مواد الميتا في شكل مجموعة من الأسلاك ثنائية الابعاد باعتبارها من الألياف. ثم محاكاة مؤشر فعال وضع داخلها. نتائجنا تظهر أن مؤشر الوضع الفعلي يزداد بزيادة تردد البلازما.

INTRODUCTION

Related to the metamaterials (MMS) design the structure of it has properties not available in nature.They consist of a periodic structure (e.g. , square) unit cells with crystalline nature, with side length of a. The electromagnetic wave with λ wavelength interacts with this material which consist of small metallic resonator instead of physical atoms or molecules arranged in a unit cell. The electromagnetic properties of the medium here be made to enter highly unusual regimes, such as one where the electric permittivity ε and the magnetic permeability μ become simultaneously (in the same frequency region) negative, depends on the way in which the incident light wave interacts with these metallic "meta-atoms" of a metamaterial [1].

Using Maxwell equations, In 1967, Veselago considered materials with both ε< 0 and μ< 0 supports backward electromagnetic waves with opposite phase and group (energy) velocities. The refractive index, should be n= $-(\varepsilon.\mu)^{1/2}$ as Veselago found., when light is incident on the interface between such a medium and air the negative refraction occurs [2]. Metamaterial elements can be any shape: for example, spheres, rings, crosses and chevrons; scatter incoming radiation in very precise ways. By software The electromagnetic properties can often be changed [3].

Physicist David Smith and his colleagues, demonstrate the first laboratory of a metamaterial in 2000 at the university of California, Sandiego. Following up on theoretical work done by Jon Pendry of imperial college London in 1990 's, these researchers showed that an array of tiny copper wires and rings had a negative refractive index of microwaves, meaning that the deflection in a direction opposite to that normally observed is happening to the microwave radiation when incident to the material [3]. The ability to bend radiation in such a way had potential for creating invisibility cloaks[4]. Metamaterial applications extend from split ring resonators[5], perfect lens [6] to nanowires [7,8].

Using a medium made of a matrix (e.g. 20 x 20)identical resonant of metallic wires metamaterials can exhibit very deep subwavelength spatial scales. [9].

An image of the source is reconstituted on the other side of array if a source excites the resonance in the near field on one end of wire array ,however at terahertz frequencies and for sub wavelength wire spacing. Using the fiber drawing method to produce and fabricate of wire array with unusual characterization [10].

Here we present the mode distribution of drawn metamaterials as a fiber, comprised of microstructured indium-filled polymethyl-methacrylate (PMMA), exhibiting a plasmonic response in the THz. The properties of these analyzed metamaterials are mentioned in Ref. [11].

Theoretical Work:

The two-dimentional metallic wire array of diameter d and separation a in a dielectric with permittivity ε_d and refractive index n_d, irradiated by an electromagnetic field with electric component parallel to the wires, can be seen as a metamaterial with lowered effective plasma frequency fp such that [12]:

$$f_p^2 = \frac{\frac{(C_0)^2}{n_d}}{2\pi A_{cell}[\ln a^2/d(2a-d)]} \quad \ldots(1)$$

Where, C_0 : the speed of light in : avacuum, and A_{cell} : is the average area per wire of the metamaterial. The dielectric constant or the complex permittivity (ω) represents one of the most important optical properties of the metal , which presents the metal reaction to an electric field as a function of frequency, where the dielectric constant according to the Drude model for metals [11].

$$\varepsilon(w) = 1 - \frac{w_p^2}{w^2 + i\gamma w} \quad \dots(2)$$

Where

ωp is the plasma frequency, and is the damping constant which $\gamma = 1/\tau$, and τ is the relaxation time.

The refraction phenomenon depends on frequency, which is happening, When the light passes from a low density material to another with high density . The refractive index of materials is complex, a form in which the real part describes the index of the material and the imaginary part describing the damping (attenuation) of the material [11]:

$$N = n(w) + ik(w) \quad \dots(3)$$

Where

n is the index of refraction and k is the damping constant, and for most materials when $\mu = 1$, the index of refraction is [11]:

$$n = \sqrt{\varepsilon} \quad \dots(4)$$

That yields

$$|n(w) + ik(w)|^2 = \varepsilon_1(w) \quad \dots(5)$$

And thus

$$\varepsilon_1 = n^2 - k^2 \quad \dots(6)$$

$$\varepsilon_2 = 2nk \quad \dots(7)$$

$$n^2 = \frac{\varepsilon_1}{2} + \frac{1}{2}\sqrt{\varepsilon_1^2 + \varepsilon_2^2} \quad \dots(8)$$

$$k = \frac{\varepsilon_2}{2n} \quad \dots(9)$$

The fabrication was performed using COMSOL multi -physics simulation program to build indium wires in PMMA background. Minimum dimension spacing is achieved after drawing the wires and fibers in several steps.

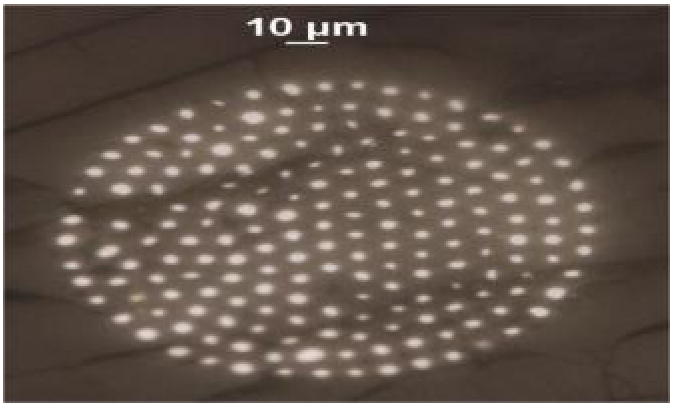
The large diameter of indium wires to lattice spacing ratio (d/a) allows higher frequencies to be reached with larger structures. This approach predicts that wires with approximately 1 µm diameter and 6 µm spacing would produce a plasma frequency in the mid-IR, at 12.7 THz. Such a wire array was simulated using COMSOL.

The properties of the metamaterial fibers that used in this fiber are summarized in the table below [11]:

Table (1): Metamaterial parameters[11].

Case	Wire Diameter (µm)	Wire Array Spacing (µm)	Plasma Frequency (THz)
1	1	5	16.5
2	1	6	12.7
3	1	7	10.3
4	1	8	8.66
5	2	5	24.9
6	2	6	18.1
7	2	7	14.1
8	2	8	11.4

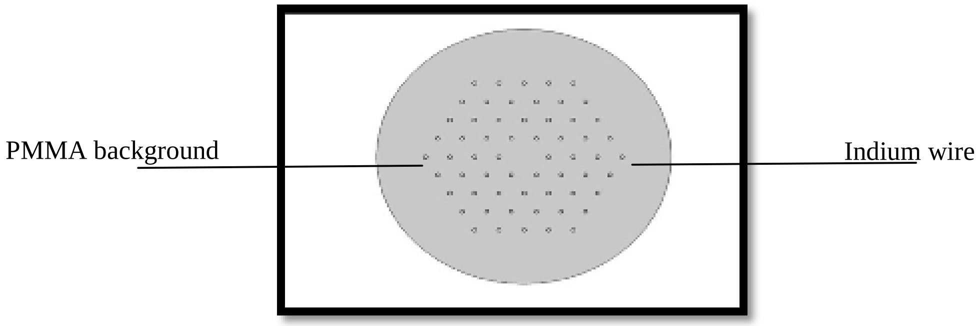
One of these fabricated metamaterials explained below[11]:



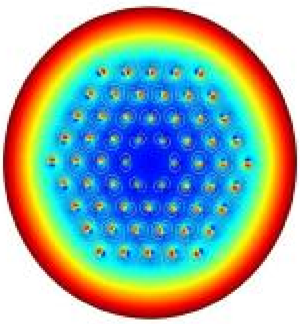
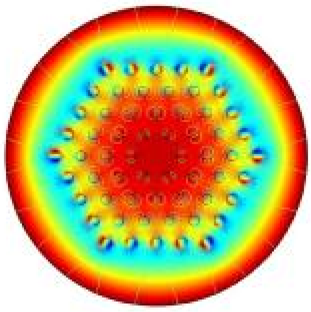
Figure(1): drawn meta-material with 3-8µm array features at 40X magnification[11].

Results And Discussion:

Comsol multi physics software was used to fabricate metamaterials fibers and show the mode analysis inside the array of the fibers. Matlab software also was used to complete the results, as shown in the figures below:



Figure(2): Metamaterial pre design using Comsol multiphysics program .

 **16.5 THz**	 **24.9 THz**

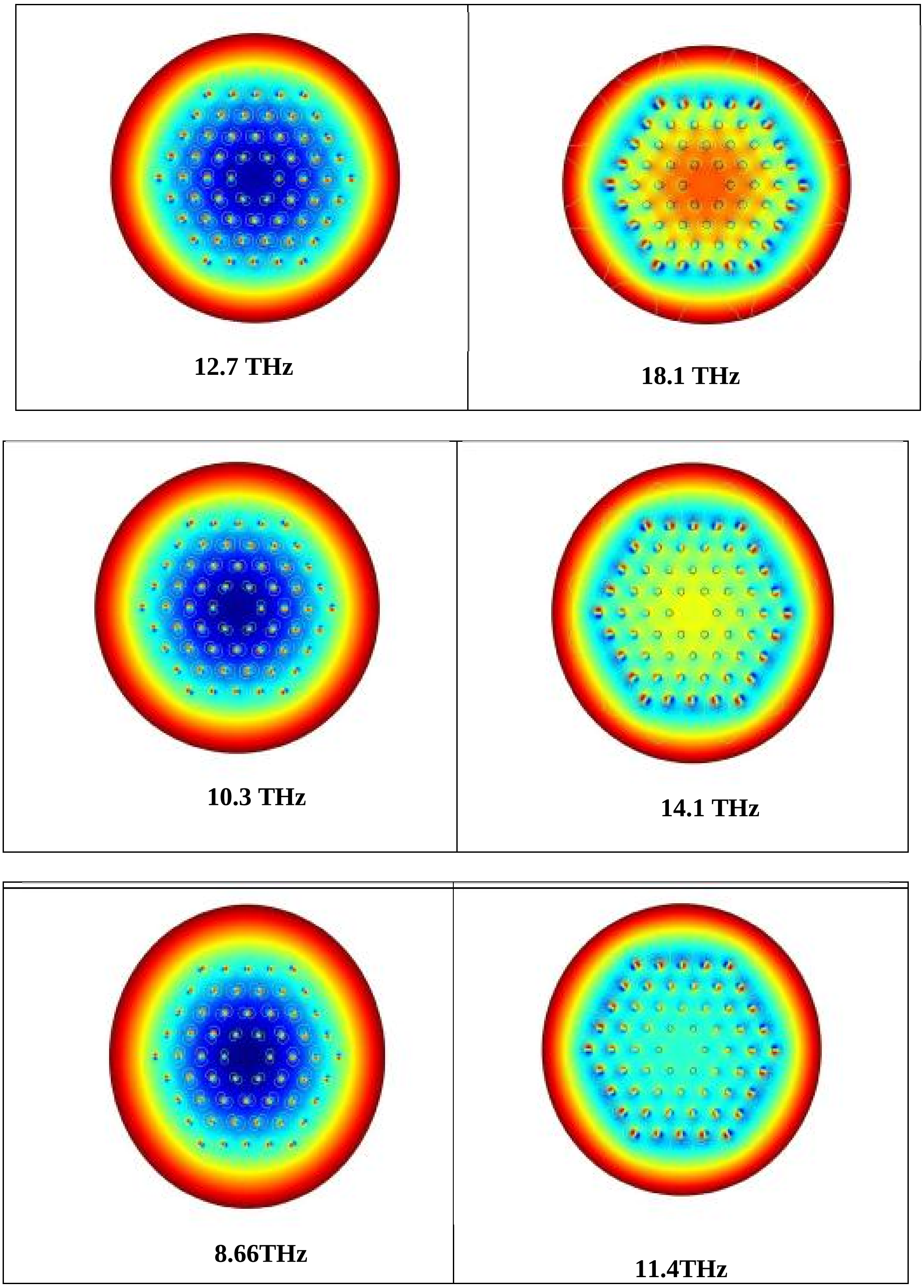


Figure.(3): Mode analysis for different metamaterials with different frequencies.

As shown in the fig. (3) the frequencies interact with indium array in different ways in each case, this interaction depends on the lattice parameters (a and d).
The mode index of each case was different as shown in the table and figures below:

Table(2): Effective mode index for metamaterials.

Case	Plasma Frequency (THz)	Effective mode index
1	16.5	1.425063
2	12.7	1.423505
3	10.3	1.422046
4	8.66	1.420764
5	24.9	1.429336
6	18.1	1.42744
7	14.1	1.426646
8	11.4	1.425931

The results of this table are plotted in the figures below:

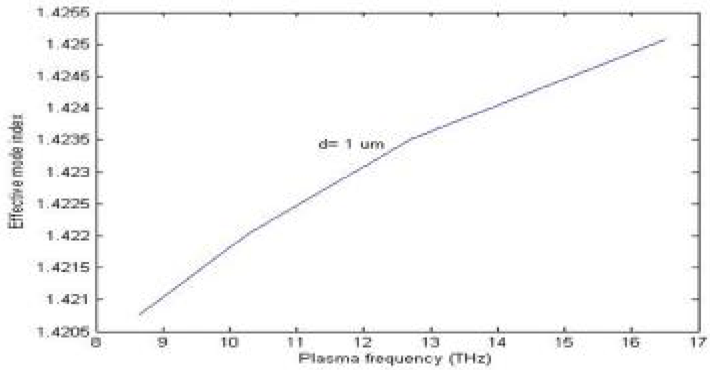


Figure.(4): The effective mode index for each frequency using wire of diameter d =1µm.

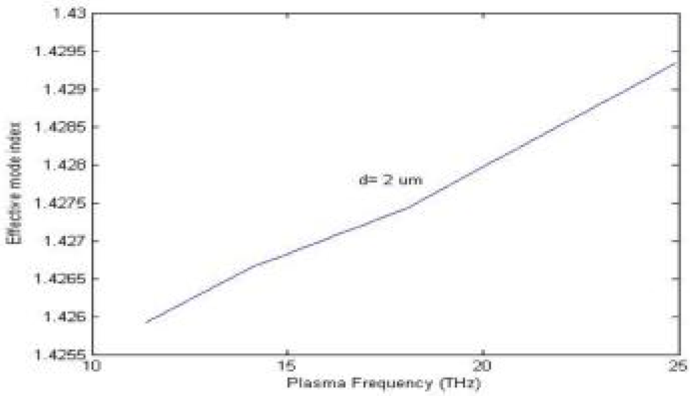


Figure.(5): The effective mode index for each frequency using wire of diameter d =2 µm.

The effective mode index depends on the wire diameter ,for example, in case one ,Table (2) the effective mode index equal to 1.425063 which corresponds to 1 µ m wire diameter and 5 µ m wire spacing . In case 5 in the same table the effective mode index equal to1.429336 with 2 µ m wire diameter and 5 µ m wire spacing, it is clear that the value of effective mode index increases with increasing the indium wire diameter with the same wire spacing (5 µ m).By comparing the other cases , the same behavior is seen. So the expected distribution profile for results in fig. (3) changes due to variation of the mode interaction for each design.

As shown in these figures (4,5) the effective mode index increased with increasing in the plasma frequency for different wire spacing and the same wire diameter.

Conclusion:

In this work the simulation program is built using Comsol program to fabricate and simulate the meta-material when drawing as a wire array in the form of fiber. The results show that the effective mode index increased with the plasma frequency, where it equal to 1.425063 at 16.5 THz in the case of d=1μm and it reaches to 1.429336 for 24.9 THz when d=2μm. Also the change of the wire diameter with wire spacing may yield different types of meta- materials with different mode index and as a result with different frequencies that used for different applications.

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