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LIMITATIONS OF METAMATERIALS FOR INVISIBILITY CLOAKING

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Abstract

Electromagnetic invisibility cloak (hide) has begun a new period in the scientific community. With the advent of metamaterials and its recent developments, researchers have now turned their faces to invisibility cloak. Metamaterials are man-made materials that have surprising electromagnetic property and it may show the characteristics of negative refractive index in materials that are normally not found in nature in any material. These exotic properties of metamaterial have opened up new possibilities for invisibility and other electromechanical fields. However, although metamaterials have created the field for invisibility cloaking but it has some limitations as well. Specially, constructing a perfect invisibility cloak in the visible range using metamaterials is still a big issue. In this paper, we have focused the limitations of metamaterial for invisibility cloaking beside basic principle of metamaterials and contributions in cloaking.

Keywords: Cloaking; invisibility; metamaterials

Abstrak

Jubah halimunan elektromegnetik telah memulakan tempoh baru dalam komuniti saintifik. Dengan kedatangan metamaterial dan perkembangan terbaru, para penyelidik telah kini beralih kearah jubah halimunan. Metamaterial adalah bahan buatan yang mempunyai sifat-sifat kejutan elektromagnet dan ia boleh menghasilkan ciri-ciri indeks biasan negatif pada bahan yang biasanya secara semulajadi tidak dijumpai di dalam mana-mana bahan. Ciri-ciri eksotik metamaterial ini telah membuka kemungkinan baru untuk bidang-bidang halimunan dan elektromekanik lain. Namun, walaupun bahan metamaterial telah mencipta bidang jubah halimunan tetapi ia mempunyai beberapa batasan. Terutamanya, dalam membina jubah halimunan yang sempurna dalam lingkungan boleh dilihat menggunakan metamaterial masih menjadi isu besar. Dalam kertas ini, kami telah memberi tumpuan terhadap batasan metamaterial untuk jubah halimunan disamping prinsip asas metamaterial dan sumbangan dalam penjubahan.

Kata kunci: Penjubahan; halimunan; metamaterials

1.0 INTRODUCTION

Metamaterial cloaking means a metamaterial is being used in invisibility cloaking. According to some research papers a cloak of invisibility can be in principle possible. Researchers have found that to do such cloaking the materials of some exotic properties are needed because the normal natural materials do not fulfill the requirements of cloaking. So, it requires a artificial material that fulfill the requirements i.e metamaterials. Victor Veselago proposed a materials that had some different charecteristics like as negative (-ve) permittivity (ε<0) and permeability (μ<0) than the ordinary materials in 1968 [1]. Afterwards this matter was neglected due to the absence of natural materials. In 1999 J.B. Pendry and his colleagues counted further information into the metamaterial theory. To obtain -ve permittivity (ε), metallic wires array can be used that is proved by them but the challenge remains for -ve permeability (μ) [2]. Later on, Smith et al. in the year of 2000 acheived to produce a composite material that has simultaneous –ve, μ & ε practically and they [3] manufactured a compositional split ring resonator (SRR) structure that was referred as Left Handed Materials. A Negative refraction index which is dependent on μ and ε. These materials have strongest property that gives the ability to focus light. To design metamaterials at very low frequency using superconducting components, it makes easy to to develope and manupulate unequal diamagnetism which maintains the magnetic property of cloak [2], [4]. Now-a-days, because of these striking behaviour of composite material, it can be adopted as solution in the various sectors, like in the field of telecommunications, micro-electromechanical system, medical instrumentations etc. [5,6,7,8] which were previously unavailable. In this paper we will discuss the straightforward principle of metamaterials, their contribution in cloaking, limitations and future research opportunity in this field.

2.0 METAMATERIALS

Metamaterial is a scientifically made material with surprising properties made of traditional materials with traditional properties [9]. In 2001 Shelby et al showed that –ve refraction was performed in their first experiment using a metamaterial. It made up of a two dimensional array of replicate unit cells of copper strips SRR [10]. Material which has –ve permittivity & permeability is called a Double Negative (DNG) material. It is required for negative refraction. Some metamaterials may have single-negative value . Now-a-days it has become easier to understand these exceptional characteristics of a material using micro-structuring based on a scale that much less than the wavelength of certain electromagnetic radiation according to specific application [11]. For example, if the order of a wavelength is being centimeters in the microwave frequency range, the size of a unit cell will be millimeters. Recently it has been also revealed that by changing some design parameter like height, width, opening gap of rings, nature of substrate of each unit cell the resonant frequencies can be adjusted [8,9]. Nevertheless, beside the SRR several design works have been evolved from different structures, in specific the Ω (omega)-structure, the U-structure, the V- structure, the H-structure and so on[12, 13, 14, 15,16,17]. It allows for realization of man made media with quite extraordinary and supreme properties, namely required for attainment of cloaking devices.

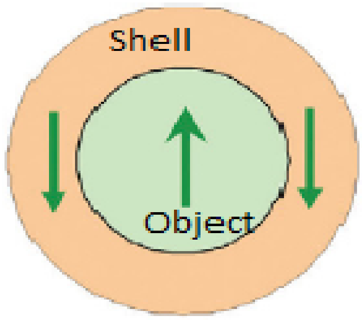
3.0 CLOAKING BY METAMATERIALS

Cloaking by metamaterials means the cloaking is done by using metamaterials. This is performed by controlling the paths crossed through by the light through an original optical material. Metamaterials dominance the transmission of particularized parts of the light spectrum. It then demonstrates an object seemingly invisible. The term 'electromagnetic cloak' mentions to a device that hides an object at a certain frequency for electromagnetic radiation. An object can be invisible in three conditions -if the source can not get reflect waves, if waves are scattered in other directions and if any shadow is not created by it(the last refers that the wave is not scattering in the forward direction). So, it can be said that the outside existing fields should not be disturbed by the object to be invisible. Up to date only few techniques have been adopted to cloak where metamaterial played a very important role.

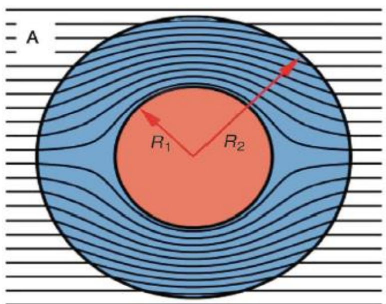
The first technique according to Alú and Engheta, metamaterial coating that was used to reduce the scattering from mini objects dramatically [18]. The coating have to be adapted according to the object to be hidden. This type of scattering detection can be obtained by a technique like covering the main scattering object using different types of layers of dielectric materials such as single or multiple. For instance, a spherical dielectric object which has larger permittivity compare to the neighboring medium can be crossed a dielectric shell that has smaller permittivity compare to the neighboring medium. The diameter of shell can be selected in such a way that the scattering between shell and core cancel out in them due to their opposite dipole moments as seen in the Figure-1a.

The second technique engages the unusual charecteristics of negative-index media, which is possible by the advent of metamaterials as this type of materials show -ve refractive index. Like they can be used in super lens where the field broken up by the polarizable object is weakened more and to a greater extent by the super lens materials [19,20] until it goes invisible.

The third technique is grounded on the thought that a transformation of space can be imitate by an appropriate transformation of ε and μ, at least as far as brightness is concerned [3]. Here using metamaterial a transformation which requires a point in space and enlarges it to constitute a sphere can then be utilized to cover any object inside this field [20] as seen in Figure-1b.The advantage of the coordinate transformation approach is that it is essentially independent of the shape of cloaked object and/or fundamental material.



(a)



(b)

Figure 1(a) Scattering cancellation technique (b) co-ordinate transformation technique [20]

4.0 LIMITATIONS OF CLOAKING DUE TO METAMATERIALS

According to the Table 1, although few successful research works were regarded cloaking with metamaterials but still there are some limitations. Here we are going to discuss them briefly-

- If the wavelength that is being manipulated is very small, it becomes very difficult to manufacture units in reality for metamaterials. In addition, that could be small enough to be considered uniform.
- Researchers have developed many successful metamaterials that can redirect microwave as seen in Figure 2a and Figure 2b, and infrared radiation for cloaking that have a relatively large wavelength, but only largest wavelength (red light) has successfully be cloaked against in the laboratory.

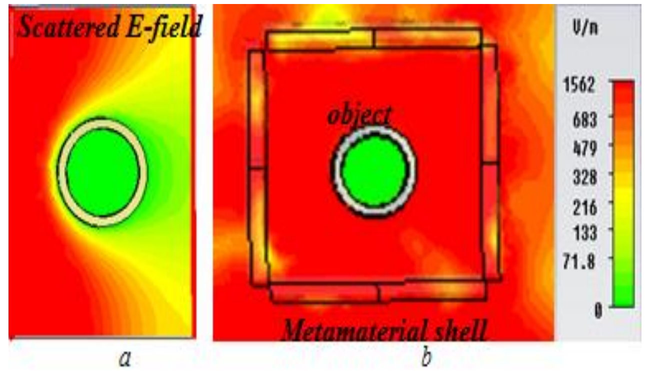


Figure 2 (a) Simulated E-field distribution of uncloaked and (b) metamaterial-cloaked cylindrical object in microwave frequency where EM wave gets back to the original path for the cloaked object [31]

- Each metamaterial is designed and tuned to operate with a specific wavelength. Therefore, it works only on that specific wavelength. So, obviously this creates a difficulty in cloaking the entire visible light spectrum so, an object that is being cloaked in a red light will still be visible in violet light. Although researchers have developed 'Frequency Selective Surface (FSS)' that is called tunable metamaterials but it does not handle more than one wavelength at a time.
- According to the given demonstration, it is evident that most of the cloaks tailored by metamaterial works only in the narrow range of frequency. Therefore, broadband cloak that can operate in the whole electromagnetic spectrum, including the visible spectrum practically is still unavailable at this moment.
- In the ideal case of operation the electromagnetic wave energy should encircle the cloaked object which is faster than light speed, but in practical the limitations arises in case of impenetrable objects in free space.
- People those who will be in a cloaked area (built by metamaterials) they will not be able to see the out because all visible light will be bending around where they are positioned. Therefore, they will be invisible, but they will be blind too.

5.0 FUTURE RESEARCH OPPORTUNITY

As a new type of artificial materials, metamaterials can be applied to many disciplines for further development, such as filter, waveguide, resonator, solar cell , antenna and lots of fields. However, cloaking is the most desired operations in the field of military science using metamaterials. In case of invisibility to do perfect invisibility cloaking, there is a big problem in wavelength range that remains unsolved. So, there is an opportunity to design such a metamaterial that will cover the whole visible wavelength. In doing so, more emphasize can be given to tunable metamaterials that can be operated (tuned) simultaneously. For blind problem in a cloak, a new super glass spectacle can be designed for human eyes that can be used for viewing even staying inside the cloak.

Table 1 some significant contribution of metamaterials in the colaking

Contributors	Year of Contribution	Contribution
Dollin *et al.*	1961	They mentioned about an structure of anisotropic and inhomogeneous magneto-dielectric, that when a plane wave falls on a body from an infinite distance, it passes through it [20].
Victor Veselago *et al.*	1968	Theoretically showed that a material having negative effective properties (i.e. negative permeability and negative permittivity) show some exotic properties compare to the natural materials [1].
Kerker *et al.*	1975	They mentioned about an 'Invisible bodies' or structure and formed an idea of scattering cancellation [21].
D.R. Smith *et al.*	2000	They constructed and shows experimentally such a material with simultaneous negative ε & μ [22].
D. Schurig *et al.*	2006	They successfully demonstrated the idea of cloaking at microwave frequencies using metamaterial [23] but it had some complexity. It was operating at a certain frequency of X-band.
H. Chen *et al.*	2007	They proposed an acoustic metamaterial based 3D cloak that is free from the limitation of bandwidth like the electromagnetic cloak. [24].
Hu Tao *et al.*	2008	They showed a cloak operating at 0.5 THz using a flexible terahertz metamaterial [25].
F. Bilotti *et al.*	2010	They proposed a plasmonic metamaterial based optical cloak at optical frequecy range, but they did not show any experimental proof [26].
L. Pei-Ning *et al.*	2011	They claimed a negative index metamaterial (NIM) based single layer cloak that operates at X-and Ku-band [27].
Dongheok Shin *et al.*	2012	They demonstrated an elastic metamaterial based broad band (10–12 GHz) electromagnetic cloak. Besides transforming the field around the object (for hiding) it also gains the automatic property form the deformation of the elastic [28].
Nathan *et al.*	2013	They claimed a metamaterial based 2D-unidirectional cloak that was capable to reduce the scattering of an object ten times of the wavelength [29].
Matekovits *et al.*	2014	They showed a width modulated metasurface-based cloak operating for K-band only[30].
S. S. Islam *et al.*	2015	They demonstrated a single layer metamaterial based cloak for C-band operation. Their cloak operating in the near zero refractive index region of the metamaterial. They designed square, triangular and eye-shape design using the same metamaterial. They also showed the metamaterial characteristics in the two axes [31,32].

6.0 CONCLUSION

After the discovery of metamaterials, invisibility cloaking has become facts instead of fiction. Many researchers have now turned into metamaterials in the application sector apart from cloaking and military applications. In this paper we tried to emphasize on cloaking especially using metamaterials. We have also pointed out some significant limitations and research opportunities in this field in order to overcome these limitations. Therefore, we hope that this work will help new researchers in this field.

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