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Metamaterials: Types, applications, development, and future scope

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ABSTRACT

This paper has presented an introduction about Metamaterials and their scope in the fields of optics, and engineering. In recent years, there has been a growing interest in the fabricated structures and engineered composite materials that have new, physically realizable response functions and properties that do not occur or may not be readily available in nature. In the last decade, a new research area based on the study of Metamaterials has emerged. There is not an absolute definition of Metamaterials but this word is a combination of "meta" and "material", which means something beyond, changed or something advance, and the most commonly used is that they are artificial materials made of a periodic arrangement of unit cells and have negative refractive index and referred to as left-handed materials. Metamaterials are expected to have an impact in the field of optics as well as in the field of engineering. Metamaterials are used as antenna, sensor, and absorber and in Metamaterial and there is no research is possible without the development in the fabrication structure. Metamaterial have a negative refractive index and due to this property metamaterial causes light to bend in unusual ways, and come back out the same way it went in, and invisible cloak may be constructed in future.

Keywords: *Negative refractive index, Permeability, Permittivity, Left-handed materials*

1. INTRODUCTION

Victor Veselago in 1967 firstly proposed a theoretical concept of a different type of material which exhibited reverse physical characteristics and negative refractive index. These materials also include negative permeability and permeability. The first Metamaterial in the year 2000, capable of bending electromagnetic radiation is created by Dr. Smith and his team at the University of California. The Metamaterial is an artificial material or synthetic composite material that are to be manufactured by the combination of multiple elements such as metal and plastics, so these materials derive its properties from its structure rather than its components.

A Metamaterial can be referred to as a material which is composed of periodic, macroscopic structures so as to achieve a desired electromagnetic response. We can design and control the properties of metamaterials so that can be synthesized by embedding artificially fabricated inclusions in a specified medium. This provides the designer with a large collection of independent parameters and this helps in the large advancement in the field of research.

2. THEORY OF METAMATERIAL

2.1 Snell law

The greatest potential of the Metamaterial is to create a structure having the negative refractive index, negative permittivity, and negative permeability that is not found in the non-synthetic materials. Refractive index in the third quadrant is negative in the Snell law. In metamaterials or left-handed materials light is refracted in a contrary way as compared to the normal refractive materials. N. Engheta (2006) described that an incident wave faces negative refraction at the interface Ray bends in inside direction after refracting into the medium which is contrary to positive index medium as shown in figure:

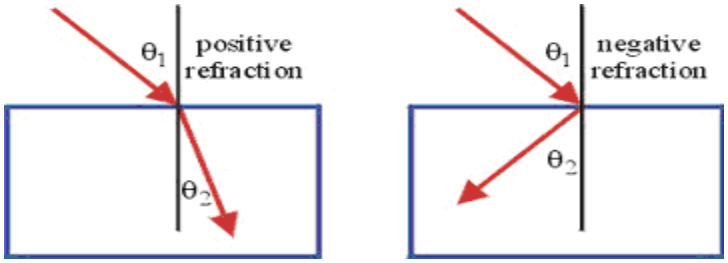

Fig. 1: Snell law in the different medium

2.2 Types of Metamaterials

Three major classes of metamaterial are as follows.

1. Electromagnetic Metamaterials
2. Acoustic Metamaterials
3. Mechanical Metamaterials

2.2.1 Electromagnetic Metamaterials

Electromagnetic metamaterials having the composition of conductive particles and traces in a dielectric matrix, these metamaterials have zero or negative permeability and/or permittivity, and negative refractive index. Kymeta, metamaterial technologies, fractal antenna system, Duke University and imperial university London are the current leader of the Electromagnetic type of metamaterials. These metamaterials are used in the field of microwave and optics such as beam steerers, antenna radomes, modulators, microwave couplers, lenses, and bandpass filters. These types of metamaterials affect the electromagnetic waves by having small wavelength than the wavelength of electromagnetic radiation.

Single Negative Metamaterials

Single negative metamaterials are the type of electromagnetic metamaterials which have either negative permeability or negative permittivity, but not both.

Double Negative Metamaterial

Double negative metamaterials are those metamaterials which have both the negative permittivity and negative permeability with the negative index of refraction so these are also known as backward wave media.

Photonic Metamaterial

It is a type of Electromagnetic metamaterials, these metamaterials are designed to interact with optical frequencies, so these are also known as the optical metamaterials. Photonic metamaterials have zero indexes of refraction and these metamaterials are the active area of research in the field of optics.

2.2.2 Acoustic Metamaterials

Acoustic Metamaterials are made up of two or more Materials with different bulk modulus and mass density, these types of metamaterials having negative effective mass density and/or bulk modulus. The University of Liverpool and Hong Kong University of Science and Technology are the current leader in the research of Acoustic metamaterials and having great interest for their target applications like vibration damping, Anti-sonar, wireless power transfer and seismic protection. These are the artificially fabricated metamaterial which is design to direct, manipulate and control sound waves in liquid, solids, and gases. And any type of sound waves can be controlled by controlling the mass density and bulk modulus.

2.2.3 Mechanical Metamaterials

Mechanical metamaterials are the artificial composite metamaterial consisting of different types of mechanical properties, these type of Metamaterials having Negative Poisson's ratio, Negative Elastic Modulus, Frictional properties and zero Shear Modulus. These are made up of material with a controlled pored structure or inclusion of secondary materials. The Researchers of Harvard University and Northwestern University have a great interest in the new research application of the Mechanical metamaterials in the field of Aerospace and Defense

3. APPLICATIONS OF METAMATERIALS

3.1 Metamaterial as antenna

Metamaterials Antennas are the type of Antennas in which Metamaterials is to be used for increases the performance of the Antenna system, there is the coating of metamaterials is to be used to enhance the radiation and venture up the emanated power. Metamaterials having negative permeability may allow for some properties like high directivity, and better optional frequency, and radiate power enhancement is possible with the use of Metamaterials in an antenna system. Metamaterials consist of an inherent property by which electromagnetic radiation is to be controlled, and increases achieve bandwidth by using superstrate of Metamaterials over conventional patch antenna. Zero refractive index material is mostly used for making high directivity antennas.

3.2 Metamaterial Absorber

Metamaterials can absorb electromagnetic radiation; it gives wider adaptability and high effectiveness over the conventional absorber. These electromagnetic metamaterials are used to create a high electromagnetic absorber and manipulate the loss components of effective parameters.

3.3 Recent Development in Metamaterials

2002: First Resonant antenna was manufactured by Lucent Technology.
2003: Metamaterials employing photonic crystal, and Methods of fabricating electromagnetic metamaterials.
2005: Metamaterials were defined as an arrangement of artificial structural elements, designed to achieve advantageous and unusual electromagnetic properties.
2010: Metamaterials are used as artificial media structure.
2015: Metamaterials are used as manmade media providing electromagnetic properties on-demand.
2017: A software enables Metamaterial-based satellite antenna is now commercially available.

4. FUTURE SCOPE

The Metamaterial is an artificially engineered material having the negative index of refraction, and due to this the Dream of invisibility cloaks is becoming possible and the two steps have already been made in that direction. Duke University is already working on developing Metamaterials Technology and working for hiding obstructive structures or making invisibility cloaks before years 2020. Metamaterial camera may be constructed without a lens or moving parts that uses compressed microwave images.

Metamaterials have better absorption characteristics due to this Metamaterial Solar cells can be constructed which decreases the size of conventional solar cells, and it will increase the absorption of solar energy. This technology could serve as energy efficient satellite communication units for soldiers on the battlefield.

5. CONCLUSION

There is the description of metamaterials and its types with applications. The field of metamaterials is a synthetic field of research and a young field of research with top talent from microwave and optical sciences, materials science, acoustics, nanotechnology and high-performance computing all attracted by the subject. Since the beginning of the century, many research papers have been written on the subject of Metamaterials. So there has a great area of Research and development for the creating new technologies and future development with the development of fabrication structure that offers the exciting possibilities for the new design of the component, devices, and improvement in their silent properties.

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