State-of-the-art of Metamaterials: History, Introduction and Application

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***Abstract*—To satisfy the demanding of different fields, Metamaterials appears in twenty-first century. The innovative design of Metamaterials creates many new materials which break the limitation of nature and lead material design into a brand new world. After a short exploration in this field, many new materials have been designed. Metamaterials including electromagnetic Metamaterials, elastic Metamaterials, acoustic Metameterials and structural Metametirials etc have significantly changed the world.**

INTRODUCTION

A Metamaterial (from the Greek word μετά *meta*, meaning "beyond") is a material engineered to have a property that is not found in nature. [1] Metamarerials are made of a composite artificial material or structure which is designed in crucial physical size thus acquire a supernormal property that is different from the normal materials. These artificial materials are made of carefully designed building blocks, or "meta-atoms," which are typically much larger than conventional atoms but much smaller than the wavelength of incident light, allowing the material to act as an effective medium with the desired optical properties. [2]

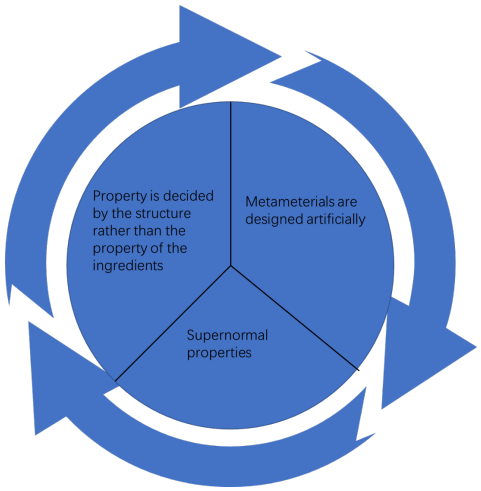

Figure 1. Metamaterial

HISTORY

The history of Metamaterials traces back to the second world war when artificial dielectrics in microwave engineering is developed. Yet, there are seminal explorations of artificial materials for manipulating electromagnetic waves at the end of the 19th century. [3] In 1967, a Russian physicist named Victor Veselago published his seminal work entitled "The Electrodynamics of Substances with Simultaneously Negative Values of ε and μ". [4] In 1968, it was translated in English. Nowadays, it is considered the beginning of Metamaterials. However, at that time, the experimentation was not conducted until 33 years later due to lack of experimental materials and sufficient computing power. In 2000, a team of UCSD researchers produced and demonstrated metamaterials, which exhibited unusual physical properties that were never produced in nature before. [5]These materials obey the physic laws, but behave differently from the materials in nature. That was the time when Metamaterials were shown in front of human race.

DIFFERENT TYPES OF METAMETERIALS

Electromagnetic metamaterials

The Electromagnetic metamaterials are based on the theory of Veselago which states that the materials whose dielectric constant and permeability are both negative have different properties with normal materials. In other word, when a beam of light was shot into this medium,the incident light and refract light occupy the same side of the normal line which is different of the properties of normal materials. Different from normal materials, Electromagnetic metamaterials are divided into different classes, which are negative index, single negative, bandgap, double positive medium, Bi-isotropic and bianisotropic, chiral, and FSS based.

Elastic

The elastic metamaterials use different parameters to achieve a negative refract index that are not electromagnetic. "a new design for elastic metamaterials that can behave either as liquids or solids over a limited frequency range may enable new applications based on the control of acoustic, elastic and seismic waves." [6]

Acoustic

When sound enters into a kind of medium, like light, refraction and reflection both exist.When it comes to Acoustic metamaterials, by control different forms of sound, as with like electromagnetic waves, sonic waves can exhibit negative refraction. [7]

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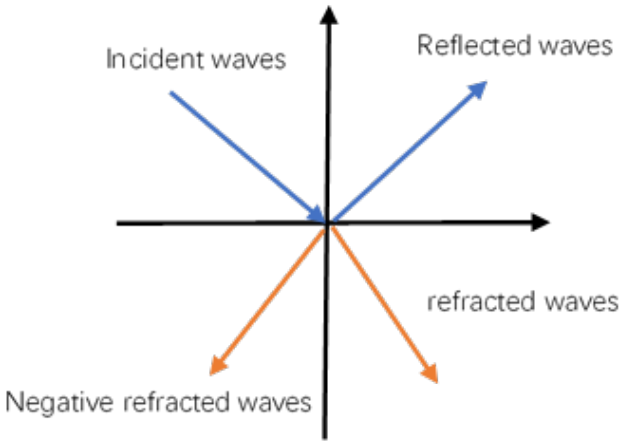

Figure 2. wave reflected and refracted

Structural

The structural metamaterials have properties of light weight and crushability. Such materials can withstand a load of at least 160,000 times their own weight by over-constraining the materials. [8]

Nonlinear

The properties of this metamaterial change with the power of incident waves. The nonlinear metamaterials have much stronger ability in including the local electromagnetic fields. This metamaterial is important to non-linear optics.

APPLICATION OF METAMATERIALS

cloaking devices

The realization of traditional Electromagnetic stealth is to apply material that can absorb electromagnetic waves to object, in that way the object is hard to be detected. However, the limitation of this method is that it only decreases the risk of being detected by radar which has specific frequency.

In 2006, Pendry and his team put forward a method that using transformation of coordinates to design metamaterials, using the different distribution of dielectric constant and permeability to control the travel path of electromagnetic and produce no scattering to realize cloaking. [9] The shape that Pendry stipulates is sphere which has lots of limitations. However, later than that,Cummer and his team designed a cylindrical cloaking device [10] Ma design an arbitrary cloaking device in 2009. [11]

However, the cloaking devices are still on experimental stages, it will be far that the devices come into people's life.

Self-healing plastics

Self-healing plastics uses small molecule connection or makes a "bridge" on the plastic chemical object to make a form of a long chain. When the plastic break, these connection would break and change the shape. The position broken would appear red points. When the outside environment(PH, temprarure) changes, the "bridge" inside would reframe and fix the broken position itself. When the process finishes, the red point disappear.

Generally, ceramics are superior in strength to metals at high temperatures, however, they are brittle and sensitive to flaws, and this brings into question their integrity and reliability as structural materials. [12] Mn+1AXn phase ceramics, also known as MAX Phases, can autonomously heal crack damage by an intrinsic healing mechanism.

Stanene

The conductivity of a conductor is hard to reach 100%. However, stanene—— a material made of a single atomic layer. The single atomic layer is made up with atom Sn rather than atom C. This endows the new material the unique property —— conductivity of 100%.

In 2013, Zhang in Stanford theorize the Stanene for the first time [13] According to their model, the stanene is insulation inside and conductor outside. In that way Stanene can realize the conductor with 100% conductivity in indoor temprature.

Aerogel

Aerogel can be made of plenty of object, including SiO2, metallic oxide and carbon. Because the fact that the air take most of its ingredient, Aerogel is also a good insulator. Furthermore, the structure of it endows it strong tenacity. Nowadays, the scientist in NASA has been doing an experiment of Aerogel to make it as the insulating material of aircraft when going through the atmosphere.

SUMMURY

Since twenty-first century, metamaterials have been a priority of scientific research. More and more kinds of metamaterials have come into appearance which bring the scientific field much convenience. The application of metamaterials is blending into people's normal life. In the lately a few years, metamaterials must still be the focus of scientific research.

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