International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-6, Issue-4)

Research Article

April
2017

The Role of Nanotechnology in Making Metamaterials for Object Invisibility

Kurapati Srinivas
Associate Professor in Physics, Gitam School of Technology, Gitam University,
Bengaluru-562163, India

Abstract:

Invisibility is no more a matter of science fiction. To make an object invisible, perfectly invisible device should exhibit the same scattering properties as that of vacuum. Objects in the environment would, absorb, reflect or refract light coming from the environment, making the object clearly visible. The only way to make these kind of materials invisible is to bend the light around an object. In other words, the device together with the object to be camouflaged should reflect no light and cast no shadow. Neither the illusionary see through effect in the computer mediated camouflage nor the reduced radar cross section in stealth technology can offer ultimate apparatus of invisibility. Fortunately, the emerging artificially structured metamaterials have enabled exceptional flexibility in manipulating electromagnetic waves and producing new functionalities and have brought the ancient dream one step closer to reality thatis to make an object invisible.The present paper is a brief review on the principle of these memtamaterials that show Negative Refractive Index material (NIM)behavior with electromagnetic waves. Further, we have discussed the use nanotechnology to create metamaterials that can bend visible light, not just microwaves.

Key words: Object Invisibility, Nanotechnology, metamaterials, Negative Refractive Index(NIM)

I. INTRODUCTION

Invisibility has long been one of the marvels of science fiction and fantasy, from the pages of The Invisible Man, to the magic invisibility cloak of the Harry Potter books, or the ring in The Lord of the Rings. Yet for at least a century, physicists have dismissed the possibility of invisibility cloaks, stating flatly that they are impossible: They violate the laws of optics and do not conform to any of the known properties of matter.

As a viable way to achieve invisibility, this method is clearly beyond our knowledge and ability today. Given the enormous strides made so far in achieving invisibility, it clearly qualifies as a Class I impossibility. Within the next few decades,or at least within this century, a form of invisibility may become commonplace.Controlling and bending light around an object so it appears invisible to the naked eye is the theory behind fictional invisibility cloaks. But so far, cloaking has been mainly limited to the microwave region or to micronscale (millionths of a meter) objects in the visiblelight region.But UCF nanotech experts were able to achieve visiblelight cloaking over a large area by using a multilayer 3DOpenmesh (fishnet) metamaterial to control the material's refractive index and thus control bending of light[1-4].To create the material, they used a nanotransfer printing technique that creates metal/dielectric composite films. These are stacked in a 3D architecture to achieve nanoscale patterns for operation in the visible spectral range. Control of electromagnetic resonances over the 3D space by structural manipulation allows precise control over propagation of light.Metamaterial cloaking for fighter jetsby improving the technique, the team hopes to be able to create larger pieces of the material with engineered optical properties, which would make reallifedevice

But today the impossible may become possible. New advances in metamaterials are forcing a major revision of optics textbooks. Working prototypes of such materials have actually been built in the laboratory, sparking intense interest by the media, industry, and the military in making the visible become invisible.

Though far from becoming a reality, researchers are making strides in optical negative-index metamaterials (NIM) to make objects invisible.

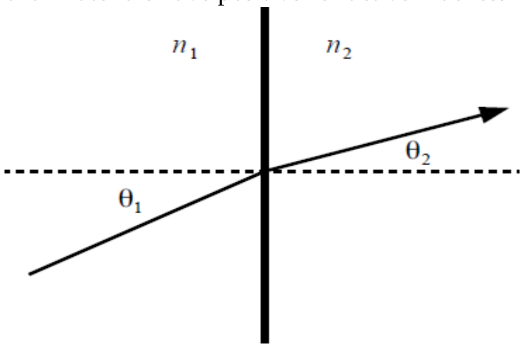
- Metamaterials are typically man-made tohave properties that cannot be found innature.
- Optical NIM have the ability to bend light in ways different from conventional materials.
- Professor Vladimir Shalaev at Purdue University is studying nanostructuredcomposites to create these metamaterials.
- Beyond the invisibility ability, these structures also have applications in microscopes, circuits, and antennae.

So the present work discusses the feasibility of invisibility of an object using Nanotechnology in various sections of this paper.

II. NEGATIVE REFRACTIVE INDEX

Objects in the environment would, absorb, reflect or refract light coming from the environment, making the object clearly visible. Figure 1A: Refraction of light at an interface between materials.

The only way to make these kind of materials invisible is to bend the light around an object. But there's a small problem. No any conventional material can bend light in this way. It turns out that, to bend the light like this the refractive index of the material need to be negative. Figure 1B: Refraction of light at an interface with a NIM. But all the conventional materials have positive refractive indexes.



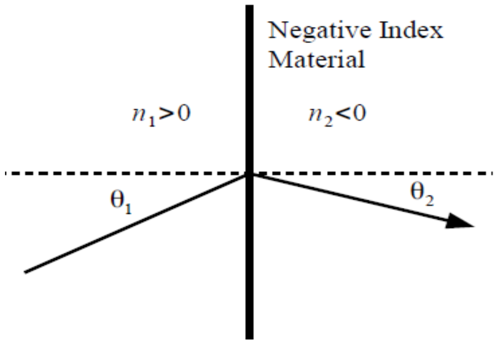


Figure1A:Refraction of light at an interface between materials. Figure1B: Refraction of light at an interface with a NIM.

The refractive indexof air is "1", and all the other conventional materials have refractive indices higher than 1. Then there's only one way to make an object invisible. That is to wrap it with a material which can bend the light, thus giving the name; invisibility cloak.

III. THEORY OF MAXWELLS EQUATIONS

Maxwell's theory of light and the atomic theory give simple explanations for optics and invisibility. In a solid, the atoms are tightly packed, while in a liquid or gas the molecules are spaced much farther apart. Most solids are opaque because light rays cannot pass through the dense matrix of atoms in a solid, which act like a brick wall. Many liquids and gases, by contrast, are transparent because light can pass more readily between the large spaces between their atoms, a space that is larger than the wavelength of visible light. For example, water, alcohol, ammonia, acetone, hydrogen peroxide, gasoline, and so forth are all transparent, as are gases such as oxygen, hydrogen, nitrogen, carbon dioxide, methane, and so on.

There are some important exceptions to this rule. Many crystals are both solid and transparent. But the atoms of a crystal are arranged in a precise lattice structure, stacked in regular rows, with regular spacing between them. Hence there are many pathways that a light beam may take through a crystalline lattice. Therefore, although a crystal is as tightly packed as any solid, light can still work its way through the crystal.

The optical properties of materials are governed by two material constants: the permittivity ε and the permeability μ, describing the coupling of a material to the electric and magnetic field components of light, respectively. A possible (but not the only) approach to achieving a negative refractive index in a passive medium is to design a material where the (isotropic) permittivity, $\varepsilon = \varepsilon' + i\varepsilon''$, and the (isotropic) permeability, $\mu = \mu' + i\mu''$, obey the equation $\varepsilon'|\mu| + \mu'|\varepsilon| < 0$.This leads to a negative real part of the refractive index $n = n' + in''$ [5-6].

The military, unable to create invisible airplanes, has tried to do the next best thing: create stealth technology, which renders airplanes invisible to radar. Stealth technology relies on Maxwell's equations to create a series of tricks. A stealth fighter jet is perfectly visible to the human eye, but its radar image on an enemy radar screen is only the size of a large bird. (Stealth technology is actually a hodgepodge of tricks. By changing the materials within the jet fighter, reducing its

steel content and using plastics and resins instead, changing the angles of its fuselage, rearranging its exhaust pipes, and so on, one can make enemy radar beams hitting the craft disperse in all directions, so they never get back to the enemy radar screen. Even with stealth technology, a jet fighter is not totally invisible; rather, it has deflected and dispersed as much radar as is technically possible.

IV. METAMATERIALS

These special type of materials are known as metamaterials. By their same definition, these are man-made materials that can transcends the optical properties of the conventional materials. Unlike the conventional materials these materials can bend the light in the wrong way and force it to curve around the object that need to be made invisible. These materials would behave in very bizarre ways that if we somehow make a metamaterial in a liquid form, a straw in that liquid would look as shown in the below picture(Fig.2).

However, the making of a metamaterial that can bend electromagnetic radiation in the visible range is a quite challenging task. To do this, one would have to play with electromagnetic waves and light, and their wavefronts and directions of propagation by introducing appropriate geometries. This require quite small yet complex assemblies of micro and nanostructures, that require intricate manufacturing techniques which still remains as a challenge.

Therefore, the first actual metamaterials were experimented in microwave range in electromagnetic spectrum which has wavelengths in centimeter level. This allowed scientists to cope with the complexity of the metamaterial manufacturing. The metamaterial was constructured as a series of unit cells with split ring resonators and conductive wires. The unit cells were in the size range of 10 milimeters which is smaller than the wavelength of the waves tested. Still most of the research is on metamaterial cloaking in microwave or radiowave dimensions.

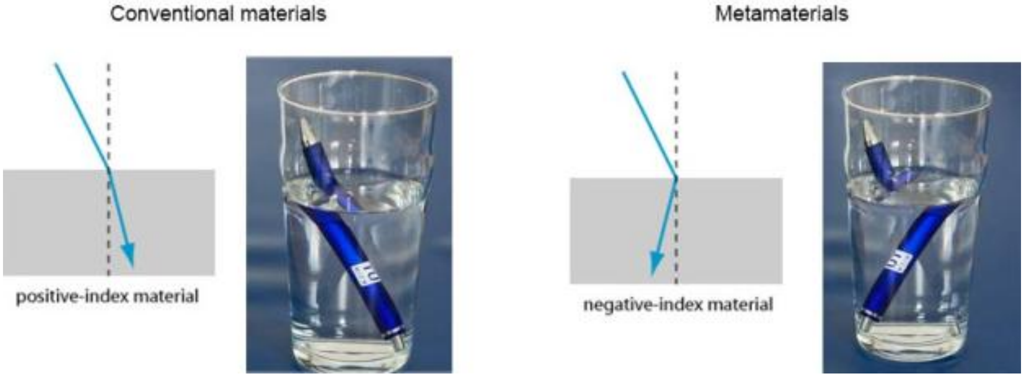


Fig.2 The metamaterial cloak that works for visible light

With the invent of technologies to manipulate matter at the nanoscale, scientists can now build structures with more complicated assemblies. This ability has given the metamaterial research a new boost, as with these techniques, structures that can actually bend electromagnetic wavelength in the visible region is possible.

V. NANOTECHNOLOGY BASED MEMATERIL STRUCTURES

The birth of nanotechnology dates back to a famous 1959 lecture given by Nobel laureate Richard Feynman to the American Physical Society, with the tongue-in-cheek title "There's Plenty of Room at the Bottom." In that lecture he speculated on what the smallest machines might look like, consistent with the known laws of physics. He realized that machines could be built smaller and smaller until they hit atomic distances, and then atoms could be used to create other machines. Moreover, the scanning tunneling microscope made possible the manipulation of individual atoms. In fact, the letters "IBM" were spelled out via individual atoms, creating quite a stir in the scientific world. Scientists were no longer blind when manipulating individual atoms, but could actually see and play with them.

For the gigahertz range, a solution was suggested by Pendry[7] which two concentric split-ring resonators (SRRs) of subwavelength dimensions, facing in opposite directions were predicted to give rise to $\mu' < 0$. .This can be regarded as an electronic circuit consisting of inductive and capacitive elements. The rings form the inductances and the two slits as well as the gap between the two rings can be considered as capacitors. A magnetic field oriented perpendicular to the plane of the rings induces an opposing magnetic field in the loop owing to Lenz's law. This leads to a diamagnetic response and hence to a negative real part of the permeability.

All successful designs for negative refractive index in the optical range have so far used the idea of creating a negative magnetic permeability by means of the excitation of asymmetric currents in pairs of either rods or strips, following the original idea in ref. [8]. The negative permittivity in such structures originates from resonant or o& -resonant oscillations of electrons in metals.

It is typically diffcult to obtain both electric and magnetic resonances in the same frequency range. A possible solution to this generic problem is to use a resonant magnetic structure along with a non-resonant metal structure that provides 'background' negative permittivity in a broad spectral range, including the wavelength where the magnetic resonance occurs. This is easy to achieve as noble metals such as gold and silver have negative permittivity at optical frequencies below the plasma frequency. Hence, merely adding, for example, a metal film above and below the magnetic resonator should provide negative permittivity. An alternative method to achieve the background negative permittivity is to use pairs of continuous metal wires[9], which do not

have an electrical resonance at the wavelength of interest.Then a magnetic resonance is obtained by including appropriately designed pairs of rods, the pairs of the narrower strips act as such o& -resonant wires and, at the wavelength where the magnetic resonance occurs in the broader strips, they simply provide a background negative permittivity[9]

Controlling and bending light around an object so it appears invisible to the naked eye is the theory behind fictional invisibility cloaks. But so far, cloaking has been mainly limited to the microwave region or to micronscale (millionths of a meter) objects in the visiblelight region.

But UCF nanotech[10] experts were able to achieve visiblelight cloaking over a large area by using a multilayer 3D.

To create the material, they used a nanotransfer printing technique that creates metal/dielectric composite films. These are stacked in a 3D architecture to achieve nanoscale patterns for operation in the visible spectral range. Control of electromagnetic resonances over the 3D space by structural manipulation allows precise control over propagation of light.

Researchers from Sandia National Laboratories (a subsidiary of Lockheed Martin) have been working on a dramatically different strategy since 2009.The principle is to fabricate a material with differently-coloured lights attached to motors, which are embedded at the surface. These lights can be rotated and turned on and off dynamically to match the colour of the surroundings.

They are made up of quantum dot nano crystals. Quantum dots are highly fluorescent nanoscale metal semiconductors which can absorb and emit light of different wavelengths (colours). They are commonly used in nanomedicine as imaging and diagnostic tools due to their small size and favourable optical properties.

The closest, most influential work on metamaterial cloaking in visible scale was carried out by group of scientists from University of Central Florida. They have fabricated a fishnet like structure that composed of metal and dielectric composite films. More interestingly, the material is fabricated using a nanotransfer printing method, a readily scalable technique for nanomaterial production. The three dimensional metamaterial fabricated at UCF lab allowed the control of the electromagnetic radiation in the visible region, (Fig.3)a feat that was not achieved before.[10]

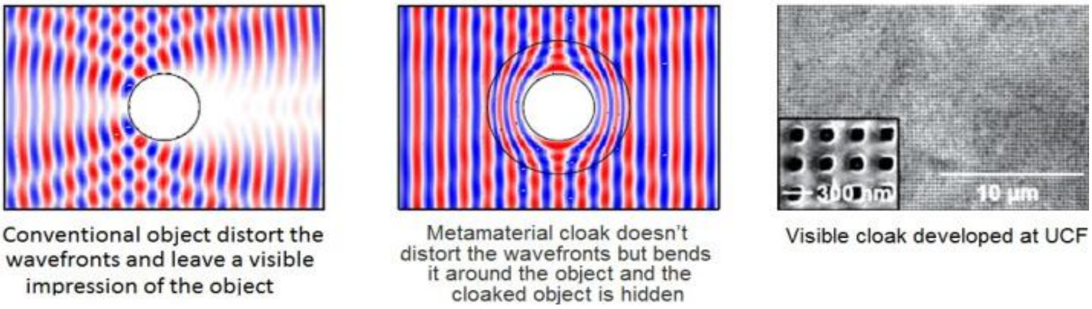


Fig.3(a)conventional object,(b) Metametrial with cloaked object hidden and (c) Visible cloak developed by UCF[10]

Many researchers agree that invisible cloaks are to stay at the lab benches for a long time. They have numerous practical implications that needed to be solved before implementation in any useful applications. So if you were waiting for an invisible cloak soon to see what your employees do when their boss is away. It's probably a good idea to find some other way.

The following example, better known as quantum stealth, demonstrates the application of metamaterials to achieve the invisibility. The quantum stealth is achieved by using metamaterial, which renders the target completely invisible by bending light waves around the target. This metamaterial removes not only visual, infrared (night vision) and thermal signatures but also the target shadow. The University of Illinois, Sandia National Laboratories, and Photonics Inc. were also involved in the studyuse a nanotransfer printing technique to fabricate largearea visible 3D negative indexmetamaterials. Alternating silver and dielectric layers are printed over a large area on a flexible substrate, and deposition conditions are introduced such that nearly ideal geometries with excellent optical properties are obtained.[11-12]

Further efforts are being made to develop a range of new metamaterials to extend this concept and make target invisible in other regions of electromagnetic spectrum including microwaves.

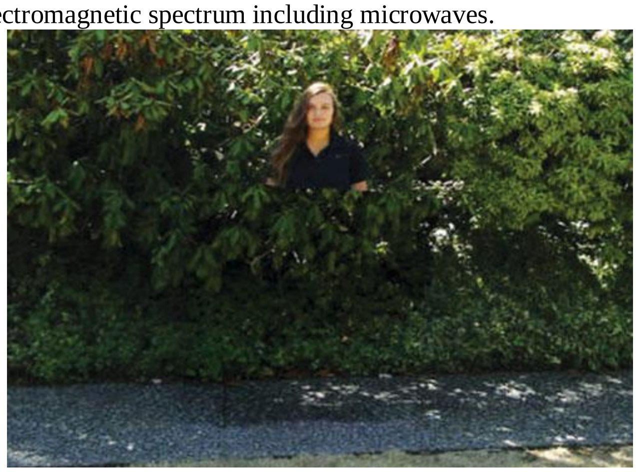


Fig. 4: Quantum Stealth Mock-up[13 [Image: HyperStealth Biotechnology Corp., Canada) Plasmonic Nanostructures for Camouflaging in Infrared region.

There are several new approaches currently under development using metamaterials which can actually bend light around an object. This technology only works for extremely small objects, so what about our Nanosuit.This Nanosuit ability also drains power but makes the wearer invisible. The suit's surface can dynamically scan the surrounding area and modify its skin colour to match in real time. This is the principle behind active camouflage. Now imagine millions of quantum dots that are differently coloured (red, green, blue) all moving around in controlled patterns at the surface of the Nanosuit[13]. By controlling the intensity and position of these quantum dots, and with the proper video input to capture the surrounding environment, you could get very energy-efficient cloaking. While this technology is clearly in the early stages of development, it is an interesting possibility and one to consider for the Nanosuit. Still there is lot of way to go to develop these metamaterials which will exactly come into reality for object invisibility application.

VI. CONCLUSIONS

The military, unable to create invisible airplanes, has tried to do the next best thing: create stealth technology, which renders airplanes invisible to radar. Stealth technology is actually a hodgepodge of tricks. Stealth technology relies on Maxwell's equations to create a series of tricks. A stealth fighter jet is perfectly visible to the human eye, but its radar image on an enemy radar screen is only the size of a large bird. By changing the materials within the jet fighter, reducing itssteel content and using plastics and resins instead, changing the angles of its fuselage, rearranging its exhaust pipes, and so on, one can make enemy radar beams hitting the craft disperse in all directions, so they never get back to the enemy radar screen. Even with stealth technology, a jet fighter is not totally invisible; rather, it has deflected and dispersed as much radar as is technically possible.

ACKNOWLEDGEMENTS

I would like to acknowledge Prof. Vijaya Bhaskara Raju, Director of GITAM Institute of Technology, GITAM University Bengaluru Campus, India and Prof. R. Venkatanadh, Research Coordinator, GITAM University, Bengaluru for their constant encouragement to finish this work.

REFERENCES

[1] Fountain, H. “Strides in Materials, but No Invisibility Cloak,” New York Times, Nov. 8, 2010.
[2] Cai, W. S., et al. "Optical Cloaking with Metamaterials." Nature Photonics 1.4 (2007): 224-27.
[3] Shalaev, V. M. "Optical Negative-Index Metamaterials." Nature Photonics 1.1 (2007): 41-48.
[4] Xiao, S. M., et al. "Loss-Free and Active Optical Negative-Index Metamaterials." Nature 466.7307 (2010): 735-U6.
[5] Depine, R. A. & Lakhtakia, A. A new condition to identify isotropic dielectric-magnetic materialsdisplaying negative phase velocity. *Microwave Opt. Technol. Lett.* **41,** 315–316 (2004).
[6] McCall, M. W., Lakhtakia, A. & Weiglhofer, W. S. The negative index of refraction demystifi ed. *Eur. J.Phys.* **23,** 353–359 (2002).
[7] Pendry, J. B. *et al*. Magnetism from conductors and enhanced nonlinear phenomena. *IEEE Trans.Microwave Theory Tech.* **47,** 2075–2084 (1999).
[8] Podolskiy, V. A., Sarychev, A. K. & Shalaev, V. M. Plasmon modes in metal nanowires and left-handedmaterials. *J. Nonlin. Opt. Phys. Mater.* **11,** 65–74 (2002).
[9] Zhou, J. et al. Negative index materials using simple short wire pairs. Phys. Rev. B 73, 041101(R) (2006).
[10] Li Gao et al., Negative Index Materials: Materials Selections and Growth Conditions for LargeArea, Multilayered, VisibleNegative Index Metamaterials Formed by Nanotransfer Printing, *Advanced Optical Materials*, 2014, DOI: 10.1002/adom.201470019
[11] G. V. Naik, J. L. Schroeder, X. Ni, et al., Optical Materials Express, 2 (2012) 478
[12] F. Marquier, K. Joulain, M.P. Mulet, et al., Optics Communications, 237 (2004) 379.
[13] Hyperstealth Biotechnology Corp., discusses the implications of militaries which can now become invisible with his light bending technology called "Quantum Stealth". *October 19, 2012, Vancouver, B.C.*http://www.hyperstealth.com/Quantum-Stealth/index.html