The metamaterials are coming

but you may not be able to see them

By Mark Martinez

> "What differentiates our modern material science, with the metallurgy or alchemy of the past, is that the innovations of today's materials are all drawn from hard science."

credit: http://en.wikipedia.org/wiki/File:Light_shining2.JPG

Alchemy—the mystical creation of materials with magical properties—has long been abandoned as pseudoscience. But something resembling this very old art has recently emerged as a true science in modern times: material science.

What differentiates our modern material science with the alchemy of the past, is that the innovations of today's materials are all drawn from empirical evidence. One ubiquitous example is the cell phone. The super small materials in cell phones, which use electron spins to hold information, are actually byproducts of research in modern physics (1). Another type of materials that came from physics research seems almost fantastical: metamaterials.

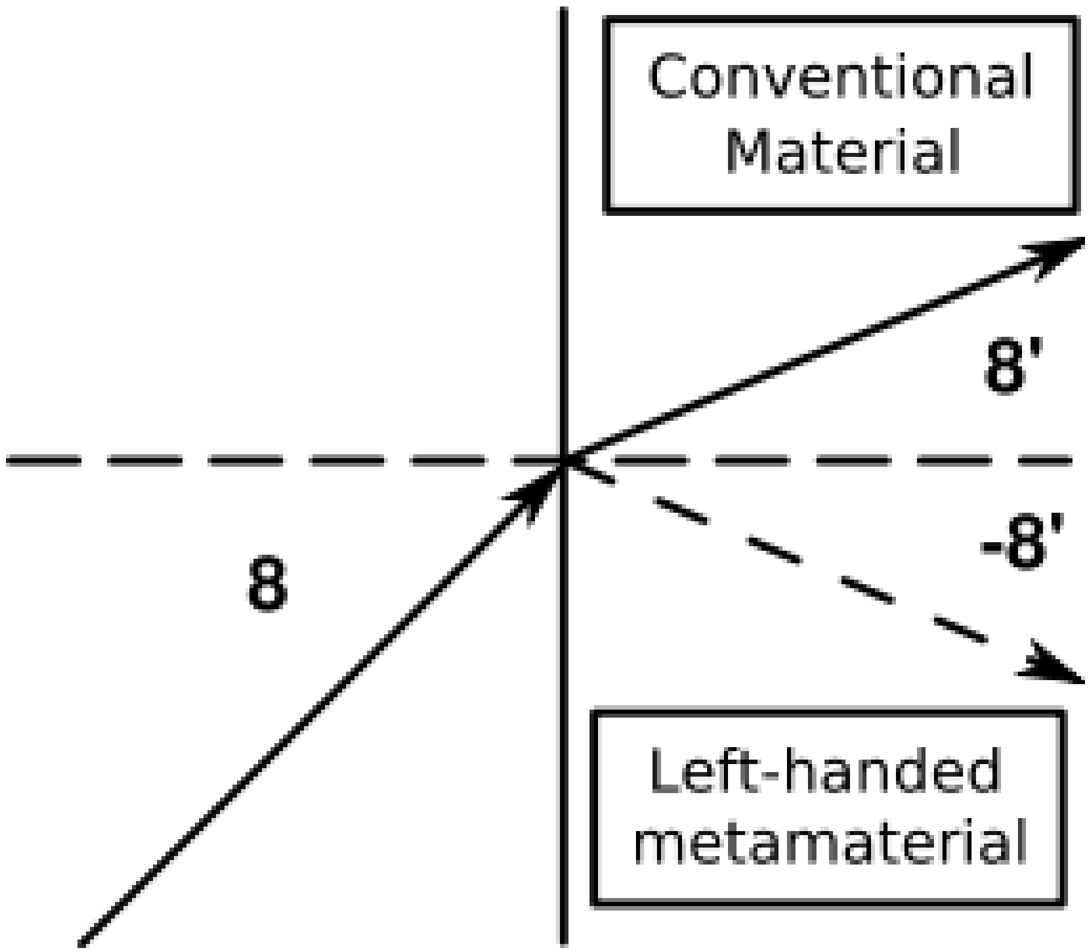
What are metamaterials?

Metamaterials are substances that have a negative refractive index (2). This means that with metamaterials it is possible for light to completely move around an object as if it were not there. Snell's law is a mathematical description of how light moves through an object (3). According to Snell's law, every object that light passes through has both a permittivity and permeability value, which are measures of how light interacts with it. In order to have a negative refraction index, a material must have negative permittivity and permeability. Yet until now, there were no materials in existence that had a negative refraction index. Normally for a material to refract light negatively it must be composed of structures smaller than the wavelengths of the light it refracts (4).

Metamaterials were first hypothesized by physicist Victor Veselago in 1967(5), but it was only in the last decade that invisibility was actually achieved. In 2002, a group at The Pratt School of Engineering of Duke

University was able to make a material that rearranged microwave radiation almost completely (6).

Invisibility has been popularized in science-fiction for years. But there are several major differences between the invisibility cloak from the Harry Potter series and what is currently being researched. First of all, the size of most metamaterials is drastically smaller than anything in the macroscopic world (7). It was only in 2008 (in a study performed at UCLA) that the first 3-dimenstional metamaterials were created with "fishnet"-like structures (8). The second difference is possibly just as disadvantageous: metamaterials are exceedingly fragile objects (4). Unlike Harry Potter's cloak, they do not have the elasticity of clothes.



▲ **Figure 1.** A display of negative refraction.

Advancing into the macroscopic

In one of the most recent tests for metamaterials, a joint collaboration of scientists from the University of Birmingham, Imperial College London, and Technical University of Denmark, created a material with a negative refractive index that was macroscopic (7). This experiment is the first to create an actual "invisibility cloak" that is three orders of magnitude (1000 times) greater than the light reflected, meaning that macroscopic objects up to centimeters long can be concealed.

"Normally, for a material to refract light negatively it must be composed of structures smaller than the wavelengths of the light it refracts."

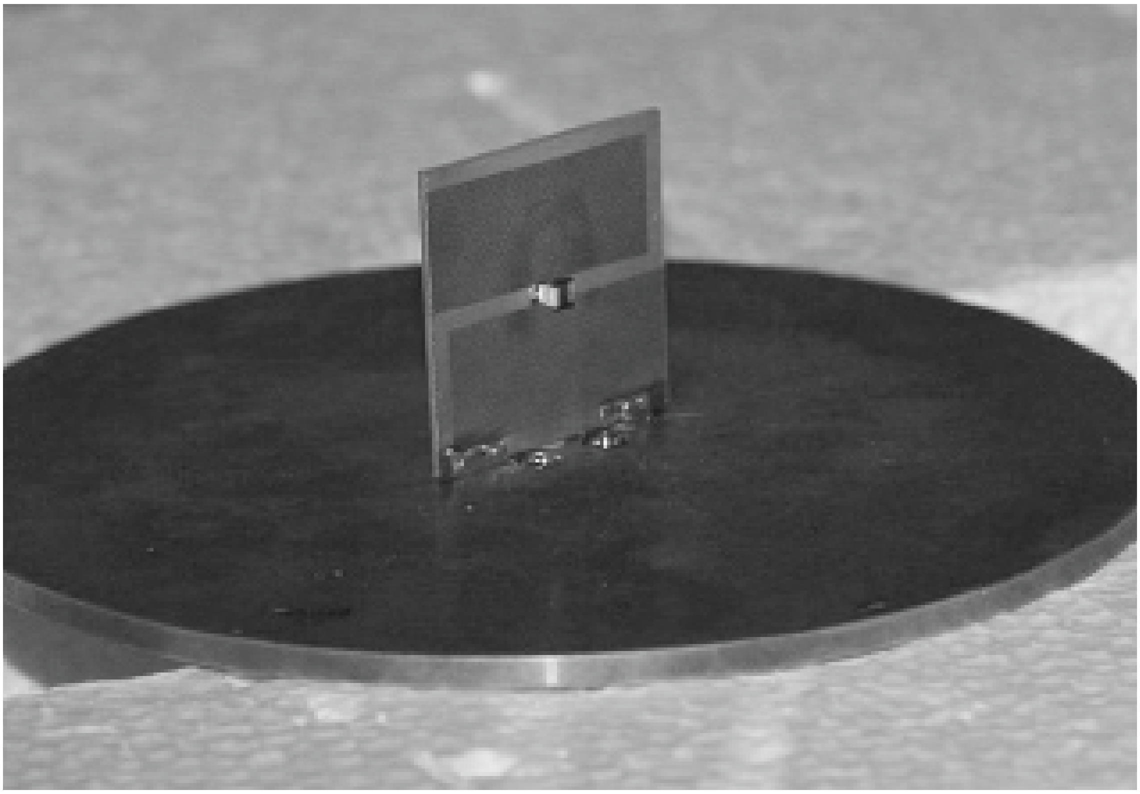
The materials used in the experiment were natural birefringent crystals. The researchers managed to completely cover an object with these crystals (7). Using carpet cloaking, bulging objects (such as the abnormally shaped mirror used in the experiment) can seem like a flat conducting sheet that does not reflect light (7).

The use of birefringent crystals also means that it is possible to create cloaks without the aid of complex nano-fibers, drastically cutting the time of production and allowing larger objects to be concealed. The type of crystal used and its shape must match perfectly for there to be a true cloaking of light. However, the researchers also noted that if only a certain type of light needs to be refracted, then the regulations for the type of materials used could become more lax (7).

The group performed the experiment by creating a birefringent crystal composed of calcite prisms. Calcite is a naturally anisotropic (directionally dependent) material that is available in macroscopic quantities, ideal for the experiment. The prism covered an abnormally shaped mirror and tested how light was refracted when shone on the mirror. Because the mirror was abnormally shaped, light shone on it would refract in an angle different from the incident (incoming) angle (7).

The group tested the carpet cloak by covering the abnormally shaped mirror with the calcite prism and shooting a beam of green light of 532 nanometers at an incidence angle of 45° and 75°.

The group discovered that when the



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▲ **Figure 2.** A metamaterial antenna.

mirror was covered by the calcite prism, the angle of reflection was exactly the same as the incidence angle. Like expected, when the calcite prism was removed from the mirror the reflected light left the mirror at varying angles (7).

One of the more successful trials of carpet cloaking was the reflection of white light. White light is composed of the entire visible spectrum. As the calcite prism could successfully mask the shape of the abnormally shaped mirror, the carpet cloaking method can effectively mask all visible light (7).

> *"...a normal antenna needs to be half the size of the wavelength to function properly, while a metamaterial antenna need only be one fiftieth of the size of the wavelength."*

Uses

There are currently several uses for metamaterials. There is the obvious hope that someday a true invisibility cloak can be created, but there are actual applications viable today. Metamaterial antennas have revolutionized the strength and size of antennas (9). Normal antennas have several detrimental qualities, such as large size, and a large dispersion of waves. However, metamaterial antennas are fractions of the size of normal antennas and operate just as well. For example, a normal antenna needs to be half the size of the wavelength to function properly, while a metamaterial antenna need only be one fiftieth of the size of the wavelength. The metamaterial antennas are able to act so powerfully because of its refractive properties. The refractive index of metamaterial antennas are near 0, so the waves emitted are focused perpendicularly to the source (9).

Metamaterials continue to be developed and perfected. David Smith of Duke University stated that the difference between the metamaterials made in 2006 and the ones made in 2009 was like the difference between day and night (10). With innovative research and public interest for the materials remaining high, the perfection of metamaterials is only a matter of time. Although the creation of a true cloaking device will not occur for several more years, more and more different uses for metamaterials are constantly being found. The end is nowhere in sight, and if things go according to plan, it never will be. H

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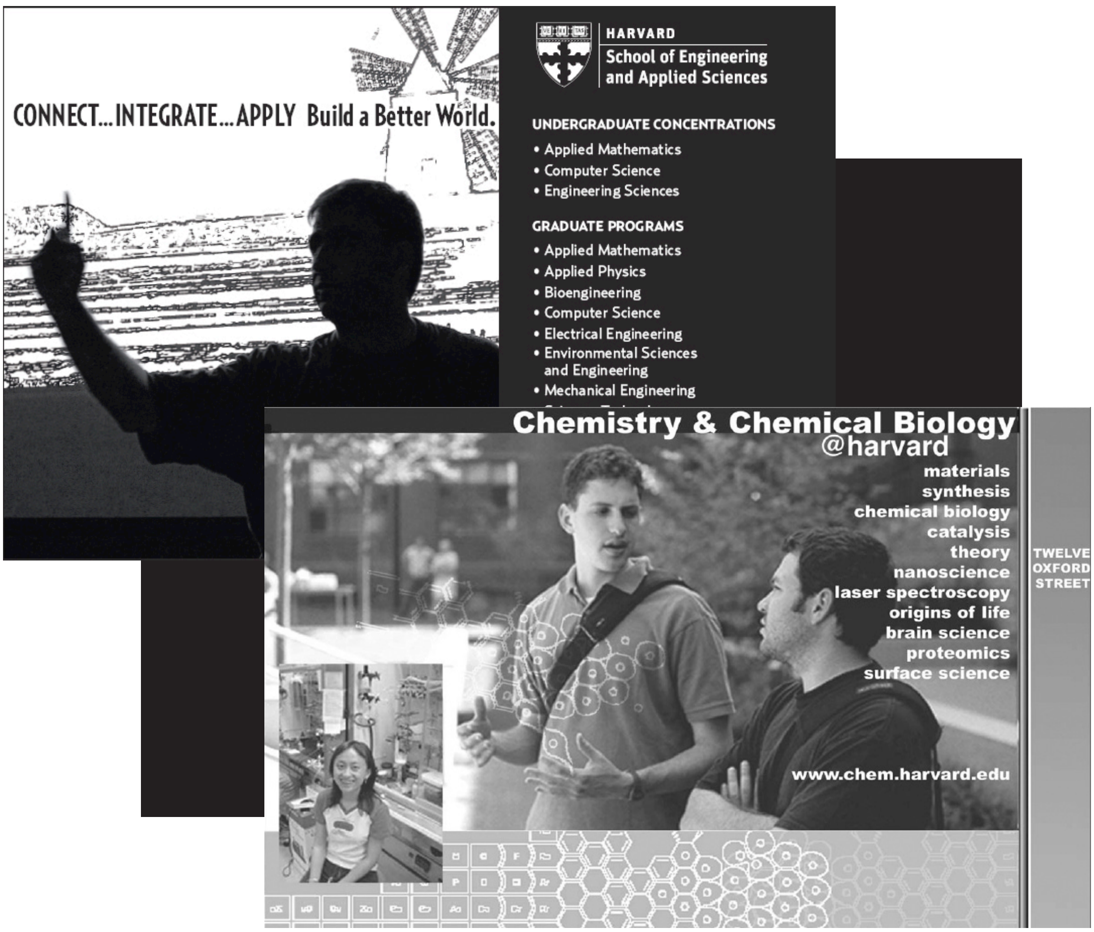

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