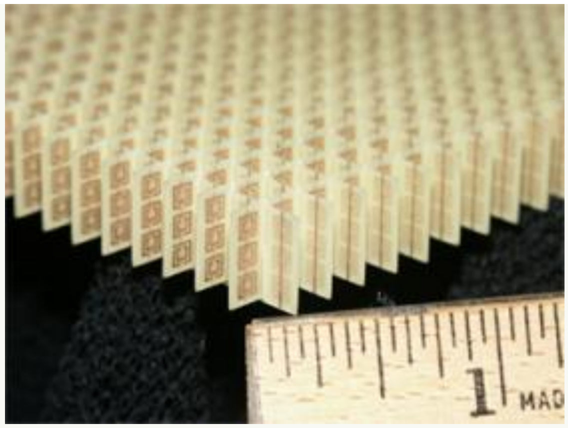
WHAT ARE THE REALISTIC PROMISES OF METAMATERIALS AND CLOAKING?

Metamaterials are very exciting structures, one of the most exciting areas in photonics, I think. That’s because they allow an almost arbitrary modification of light (or acoustic) waves propagating through the material. Sadly, however, the highly promising potential of metamaterials gets often completely overblown by news reporting on fantastic effects. Cloaking devices are the prime example. Here I try to come up with a few points that might help to sort science from fiction.

Metamaterials are small metallic structures, typically rings or wires, that locally change the materials properties. These structures are much smaller than the wavelength of light. To a light wave, it is as if the structure is not made of tiny rings and wires, but looks like a homogeneous material. Hence their name ‘metamaterials’.*Meta* is Greek and means beyond. The first metamaterials all used the same small units of wires and rings, repeated over and over. With this, you can achieve a negative index of refraction, which enables superlenses – lenses with perfect resolution.



The original metamaterial designs consisted of electromagnetic resonators made of rings and wires. These devices are for THz and GHz radiofrequencies. Credit: NASA, via wikimedia

The next key advance was that metamaterials needn't only consist of uniform assemblies of rings and wires. If you change the properties of each unit of a metamaterial, you can create a material that to light looks as if it changes its properties. This way it is possible to modify the propagation of light as it goes through the metamaterial. You can make it go round corners, turn it around. In theory, the possibilities are nearly endless, that much is clear.

The prime example to demonstrate the possibilities of metamaterials is the optical cloak. The term is borrowed from the science fiction series Star Trek. And naturally, it is these kind of visions that let our fantasy go wild when thinking about metamaterials cloaking. Images of Star Trek, or 'Harry Potter cloaks' and the 'invisible man' are often conjured when journalists, university press offices and even scientists try to explain metamaterials to the public. Sadly, in relation to what metamaterials can do, this is nonsense.

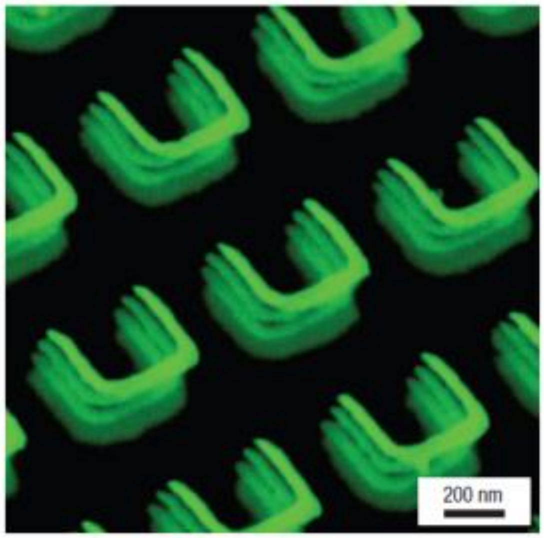
So here are a few things that metamaterials can and cannot do.

The bad news:

* *It only works for a limited range of wavelengths.* The way metamaterials function is through electromagnetic properties of a material (its permittivity and permeability). These need to take specific value at each position in the metamaterials grid for the device to work. However, the desirable values for permittivity and permeability can only achieved in a narrow range of wavelength. Many devices operate only at a single wavelength. Even if some metamaterials design allow for a broader range of wavelengths, really broad operation across the entire visible range or beyond doesn’t seem possible. Imagine a cloaking device that only screens out red colours, not very useful for those science fiction applications, isn’t it?

* *Metamaterials are lossy.* The way the little metallic elements of metamaterials work is that they create local electromagnetic fields that influence a light beam. These fields are created by electrons that move around in the metal. No metal is a perfect conductor, and there will always be losses. In particular, metamaterials devices have no electrical plugs, which means that the movement of electrons is

not done actively by outside electric fields. Instead, metamaterials work passively and are powered by the same light wave whose properties they modify. This inevitably leads to losses. So your fantasy invisibility cloak would make you seem a little faded, not much more.



Metamaterials for visible light are made from tiny nanostructures. Image reprinted by permission from Macmillan Publishers Ltd: Nature Materials 7, 31-37 (2008).

* *Metamaterials are tiny structures fabricated with high precision*. Unless you want to compromise on quality and losses (see above), metamaterials are made on the nanoscale with high precision. As I said, they need to be smaller than the wavelength of light. This means for visible light we are talking about individual elements not much larger than the tiny transistor on your computer chip. Making them on a large scale (people, cars, space ships) would be really difficult. Nevertheless, people have recently made metamaterials structures on plastic substrates, which is encouraging.

* *For a given functionality, you cannot change the shape of a metamaterial during operation*. The design of a metamaterial strongly connects electromagnetic properties to a fixed relative position in space. If you stretch and bend a metamaterial, it wouldn't work in the same way anymore. It might change wavelength of operation, become more lossy, or may completely lose its function.
* *The term 'metamaterial' is not equivalent to cloaking*. I have seen news report where the presence of merely an electromagnetic resonance in a metamaterial structure was hailed as cloaking. Seriously…

The good news:

* *If you want to think big in cloaking, think small*. The fact that cloaks best work narrowband screams for a number of applications you wouldn't call cloaks. How about narrowband electromagnetic filters? For example, one could shield the radiation from a mobile phone by a metamaterials device that directs it away from the head.
* *There are so many other applications metamaterials are good for*. I mentioned superlenses. Other types of lenses are possible. For example Luneburg lenses, which have a 180 degree field of view and image this hemisphere onto a 2D photo plane. Or they are used to simply modify light: twist its direction of polarisation, act as filter ….

Indeed, I am a big believer in the potential of metamaterials, and promoted them early on. But it saddens me to see their potential hyped beyond the realistic. Sure, it is nice to fantasy about science fiction-like properties. But these are best left to writers of fiction.

In my view, there are many applications of metamaterials. Most will not be very glamorous. Perhaps they will have a very specific use or won't operate for visible light, in the infrared instead, or at radiofrequencies. Nevertheless, metamaterials have a lot to contribute to science and technology. And if we are better aware of their advantages as well as disadvantages, we may get a more realistic idea in what areas metamaterials could deliver best.

Source: http://allthatmatters.heber.org/2010/11/16/what-are-the-realistic-promises-of-metamaterials-and-cloaking/