LIGHT-BENDING TO THE EXTREME

Credit: Yushin Kim, Korea Advanced Institute of Science and Technology

How does a lens work? Well, as the light arrives at the lens it gets bent towards the focal point of the lens. The denser the lens material is in comparison to the surrounding air, the more it is deflected. The materials property that quantifies this effect is the refractive index.

For lenses, the general rule is that a larger refractive index is better. That’s because the maximum resolution of a lens gets better as the refractive index increases. This is of crucial importance for applications where resolution matters, for example in the fabrication of semiconductor transistors, says Xiang Zhang, a physicist from the University of California in Berkeley.

“A large index is very useful for high-resolution imaging and lithography. That’s what the billion dollar semiconductor industry critically needs and have investigated in heavily.”Typically, the refractive index varies anywhere between 1 (air) and 3. That of window glass is about 1.5.

Bumki Min from the Korea Advanced Institute of Science and Technology (KAIST) along with colleagues from other institutions now have demonstrated an artificial material whose refractive index is a staggering 38.6. Their paper is published in this week’s issue of *Nature*.

Such a huge refractive index can’t be achieved with an ordinary material. What the researchers have fabricated instead is called a metamaterial – with the greek *meta*meaning beyond. Typically, metamaterials are made from metal wires and loops. Incoming light excites electrons in the metal, and if designed in the right way these motions can lead to strong optical effects.

Min’s metamaterial consists of metallic “I”-shaped structures that are placed close together (see the figure).This structure makes a clever use of the electric as well as a magnetic components of light waves. For example, the narrow gap between two neighbouring I’s strongly enhances the electric component of the light wave, whereas the narrowness of the metal stripes is important to enhance the magnetic properties. Combined, these two effects cause the high refractive index of this structure.

However, there is also a drawback. The structure prefers certain directions – the ones along the metal bars – and this means that the high refractive index is strongly dependent on the polarization direction of the light. On the other hand, says Min, "this can be overcome by designing honeycomb-like metallic ring structures" – which are symmetric in all directions.

Yet, it doesn't really make sense to talk about refractive index in a structure made up of a few metallic crossbars. "As the optical refractive index is essentially a volumetric measure of the bending power, it is important to check out its bulk property," says Zhang. Min and colleagues also address this issue by stacking several layers on top of each others. The layered structure still has a high refractive index that ranges between 8 and 33.2, depending on the wavelength of the light used.

At the same time, even though this suggests high-resolution lenses, there have been metamaterials designs that could image objects with arbitrary resolution, the so-called superlenses. These are also made of metamaterials, albeit ones whose refractive index is negative. In theory, superlenses are even more powerful than the lenses that could be made with Min's metamaterials. In praxis, however, superlenses only work for narrow wavelength ranges, and then with large losses.

The present materials should be more robust and work over a broader range of wavelengths.

So far, the most prolific applications of metamaterials are the so-called cloaking devices, which can render objects to some degree invisible. But despite all the hype, as I outlined before, at this stage cloaking devices are far from being of any practical use. Instead, it seems to me that it is structures such as these high refractive index devices that could be key to finally achieve significant practical uses of metamaterials. Furthermore, given that metamaterials now enable full range of refractive indices, from negative values to the high positive values of the present design, entirely new possibilities arise from complex metamaterial designs that combine areas with different refractive indices in a single device for entirely new effects.

Source: http://allthatmatters.heber.org/2011/02/16/light-bending-to-the-extreme/