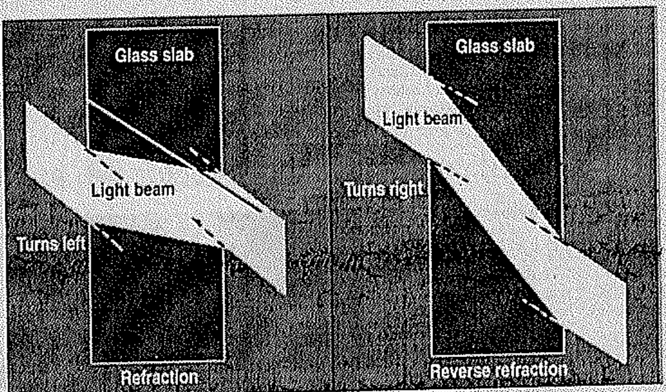
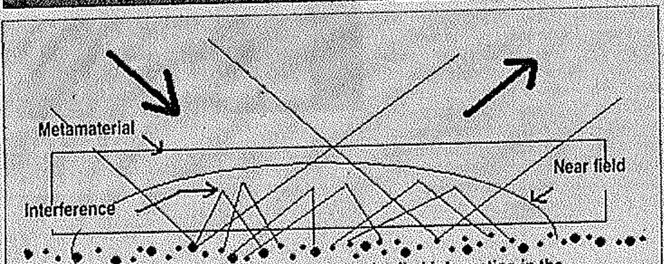
The optical feats of nanocomposites

Man-made materials can reverse and multiply the action of lenses, says

s ananthanarayanan





In reflection, interference destroys detailed information in the 'near field'. A metamaterial, by reverse refraction, disrupts interference and preserves minute surface structure details

Artist's rendering of a light index metamaterial

Credit YUSHIN KIM

LENSES work by bending beams of light when they enter or leave the glass material. Materials have now been developed that bend light beams the *other* way, which helps overcome some limitations of ordinary lenses. And other new materials, as reported in the journal *Nature* by scientists in South Korea, can bend light many times more than usual lenses, a property which has its own uses.

When light crosses from one medium to another, there is essentially a change in its speed, rather like the speed of a car when it moves from firm ground to sandy ground. If the car crosses over at an angle, then one set of wheels enters the sandy part first and slows down. The other set of wheels keeps at the same speed, till it also enters the sand; but till that happens, the car turns inward, towards the side that enters first. This changed direction goes on till the car comes to the end of the sand, and now it is the same set of wheels that entered the sand first that is the first to leave. Leaving the sand, the wheels start going faster, and the car veers back to resume the direction before it entered the sandy area.

In the same way, because of an effect of the new medium like glass, on the electric part of the electric and magnetic oscillations that make up a light wave, light also changes direction when it enters or leaves a medium that is denser than air or vacuum. If the piece of glass is shaped like a lens, different parts of the beam of light strike the glass at different angles and the beam can be made to converge, or diverge, and this is the principle of the camera, the microscope, the telescope or the everyday spectacles that many of us use.

This analogy, of considering light beams to move in straight lines, like a car being driven straight, works well to explain usual optical instruments being used for ordinary levels of magnification of images. But when we enter the zone of *great* magnification or the need to see *great* detail, it becomes necessary to consider that light beams are actually waves, and the convergence of waves cannot be accurately at a point, there is some *spread*, to the extent of the distance between the crests of the waves, or the wavelength. To overcome this limitation, we use either light of a shorter wavelength, like ultra violet light or even X-rays, or we use larger and larger lenses that collect more light waves that limits the spread of the point where they converge. But there is a limit to what light we use and also the size of lenses, and this limitation, caused by the nature of light itself, is a reality that we have lived with.

Reverse refraction

Materials like glass, which has been the standard in optical work, all bend light one way and this is because the arrangement of atoms in the materials only affects the electrical part of the light wave. Using metallic films makes it possible to also affect the magnetic part of the light wave. Russian scientist Victor Veselago in 1967 first proposed that materials could be constructed so that both the electrical and magnetic effects of the material on light waves was the opposite of what it was in usual materials. The idea has taken shape and methods have been found to suspend the metallic formations of sizes that are of the dimensions of the light waves within a material. These formations become magnetic resonators, like tiny coils of wire, and generate magnetic fields that affect the light wave. In 2009, Takuo Tanaka of the metamaterials laboratory in Riken, a major research institute in Japan, developed a technique to use light to deposit metallic particles in a structure that could create conditions for light to be refracted in the opposite direction — what is called the "negative refractive index". In 2006, John Pendry of the University of London and colleagues proposed a method to create an invisible cloak using such negative refracting materials. The principle is that light striking the cloak is made to bend and go completely around the object so that it seems the object was not there at all. It has also been realised since then.

But the more immediate applications of negative refractive index materials are to overcome the limit of optics in viewing detail finer than the wavelength of light. The act of reflection is normally represented as straight-line beams bouncing off the smooth surface of mirrors. But at the detailed level, the picture is one of waves getting scattered by the disordered up-and-down of atoms that form the surface of a material. When the material has been "smoothed", the effect is that while the waves scattered in all directions, by the atoms at the surface, interfere and cancel out, the ones that survive and go forth in strength are the ones that are according to the laws of reflection. But in this process, any details smaller than the wavelength of light get lost and cannot be retrieved by optics.

Here is where negative refracting materials become useful. Although surface information is lost within a few wavelengths from the surface, when we are right at the surface, before the scattered waves have cancelled out, the information is still there. If light in this state enters a negative refracting medium, the information can be captured and moved out for analysis. It is in this field, of very small dimension microscopy, of living tissue, crystal structure, molecules and atoms, that the area of research is proving useful. Although prospects of invisible cloaks are also attractive!

Very high refraction

The other application of techniques to create nanomaterials with custom-made optical properties is in imparting very strong refracting properties. The refracting power is measured by an index that corresponds to the ratio of the speed of light in the vacuum to the speed in the material. Ordinary materials have indices from one, for vacuum, to about 1.6 for glass and high values are 2.5 for diamond or five for silica. In contrast, methods of implanting metallic structures within materials by using focused lasers to convert selectively into metal — the metallic ions that have been placed within the metal — have yielded enormous refractive indices. The group from South Korea, in the paper in *Nature*, reports a refractive index of *more than 30* for light of certain wavelengths in a material created in polyimide sheets, by depositing layers of gold, some 60 micrometres in size, separated by small gaps, where opposite and oscillating charges get formed. "It is possible," the researchers say, "to reach indices of a few hundreds if we work with materials other than polyimide and further shrinking the gaps."

Creating materials with such high refractive indices has important applications. Such materials would immediately enable lenses with very high magnifying power, at reasonable dimensions. This would lead to powerful optical instruments and also very accurate equipment for the vital field of manufacturing computer chips. The technique for creating these materials that contain specially designed structures would also enter the area of optical information storage and increase the capacity of a DVD, for instance, by a factor of up to a million!

Communications is another area of application. Glass fibres used in optical fibre cables are almost loss-free. But there is significant loss at the ends of sections of cable, because of reflection. Metamaterials that eliminate reflection could make sure that connections of optical cables are also loss-free. There is also research into light itself, when it moves at speeds much below its normal speed.

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