How to drive light round the wrong bend

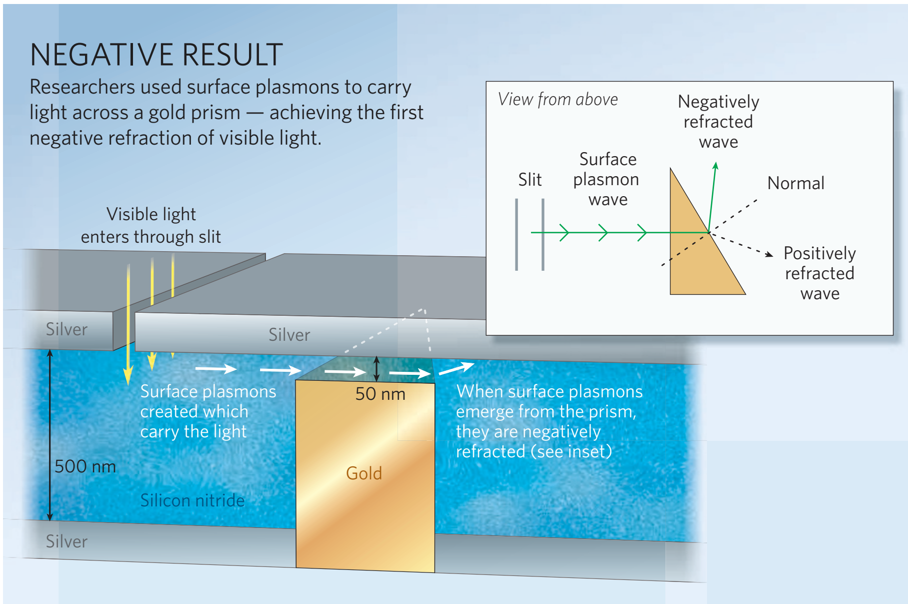
Can visible light ever be manipulated so that it bends the wrong way? If it could, a range of futuristic devices would be tantalizingly close to reality, such as a lens for imaging features smaller than the wavelength of light, or a shield to render objects invisible.

Several scientists have written off such 'negative refraction' in the visible range as practically impossible but a group is now claiming to have achieved it, spurring a debate about what constitutes true refraction.

Light bends in a specific way when it passes from one medium to another — an effect called refraction. Negative refraction describes a situation in which light bends the opposite way. It happens only if the direction in which the peaks and troughs travel along a light wave can be reversed relative to the direction in which the wave itself is travelling.

A material with a negative refractive index would focus light perfectly instead of dispersing it. This led John Pendry of Imperial College London to predict that a 'perfect' lens could be made, which would image features smaller than the wavelength of light. Some asserted that refraction could only ever have a positive value. But the debate was settled in 2003 when negative refraction was demonstrated for microwaves[1,2] and later for infrared waves.

Researchers achieved the effect with 'metamaterials' that had components of roughly the same size as the light's wavelength. More recently, Pendry used a metamaterial to bend light around an object to create an 'invisibility shield', also for microwaves[3].



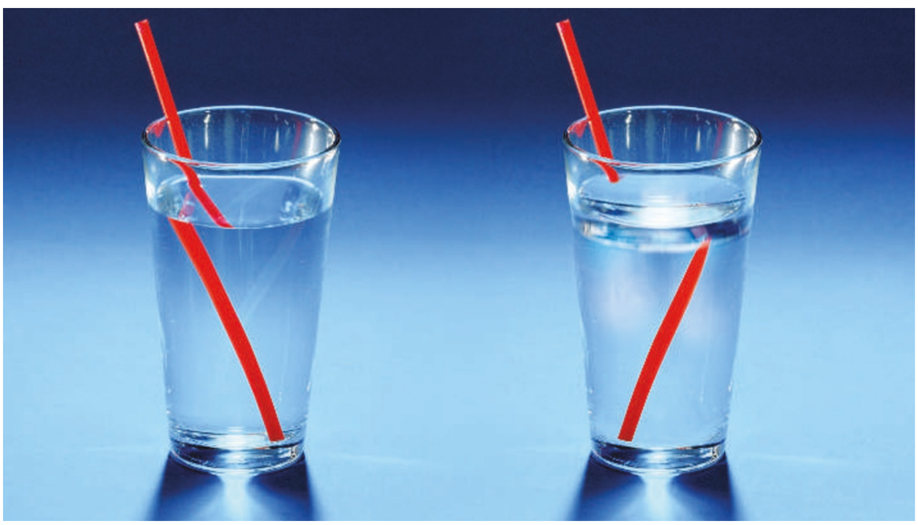
But achieving similar effects for visible light has seemed well out of reach. Radiation in the microwave and infrared ranges has wavelengths in the order of micrometres or centimetres, so the components of the material used to negatively refract them are also on this scale. But building something equivalent for visible light, with a wavelength of some 500 nanometres, is a huge challenge.

Now Jennifer Dionne and Henri Lezec, working in Harry Atwater's group at the California Institute of Technology in Pasadena, have unveiled a material that they say has a negative refractive index for visible light. Dionne presented the results on 11 January at Nanometa 2007, a conference on nanophotonics and metamaterials held in Seefeld, Austria, and the group has submitted them for publication.

Rather than try to create a material with components as small as the wavelength of visible light, theoreticians recently suggested taking advantage of electromagnetic waves called surface plasmons, created when light hits free electrons oscillating on the surface of a metal, to guide the light in the desired direction. This is what Dionne and Lezec have now done. Their device, called a waveguide, consists of the insulator silicon nitride sandwiched between two sheets of silver.

Light enters the device through a slit in the upper silver sheet. Once inside, the light wave couples with oscillating electrons in the silver to create a surface plasmon wave that travels along the metal's surface. But embedded in the silicon nitride is a gold-coated prism, with a gap between it and the upper silver sheet that is just 50 nanometres wide (see graphic). As the surface plasmon wave crosses this gap, it is refracted. Dionne says that she has detected light with wavelengths of 480–530 nm (blue-green) emerging from the device having undergone negative refraction. The refractive index reached as low as −5 (compared with +1.33, for light travelling from air into water).

Passing the surface plasmons through the thin gap above the prism confines their move-



E. SCHREMPP/SPL

A straw in a glass of water seems disjointed because of refraction (left). But in this rough mock-up of what would happen if water had a negative refractive index (right), the effect is startling. The underside of the water's surface can be seen but not the bottom of the glass. For more accurate models, see ref. 4.

ment, so only one mode of surface plasmon wave can get through. At certain wavelengths of light, the frequency of the surface plasmon wave is close to the frequency of the oscillating electrons within the bulk of the metal. In this case the surface plasmon wave and the oscillating electrons interact in such a way that the direction of travel of the wave's peaks and troughs is reversed, giving negative refraction.

For Dionne, the goal of "peeking round the corner" has been achieved. "It's like alchemy," she says. "But it works."

Others in the field are more cautious. Mark Stockman, a theoretician at Georgia State University in Atlanta, is concerned about the system's inefficiency, pointing out that only about 1% of the light gets through. Dionne emphasizes that enough light gets through to be detected directly and says she thinks improvements can be made.

And some are unconvinced that it offers true negative refraction. Allan Boardman, a theoretician from the University of Salford, UK, and Vladimir Shalaev from Purdue University in West Lafayette, Indiana, who are also trying to negatively refract visible light, argue that the experiment simply shows negative refraction of plasmons, rather than of light itself. "It's not negative refraction per se," says Boardman. "They've got to qualify it a lot more."

But others such as Nikolay Zheludev of the University of Southampton, UK, say this doesn't really matter, because the end result is the same. "If everything is correct, this is a grand claim," says Zheludev. "Yes, they had negative refraction," agrees metamaterials and plasmonics expert Eli Yablonovitch from the University of California, Los Angeles. "I don't see much controversy there."

Pendry is also convinced, although he says he didn't expect to see the effect demonstrated so soon. "It is very impressive," he says. "They've done it in a most spectacular way."

Whether the approach counts as true negative refraction or not, to do anything useful with it will require turning the two-dimensional system into a three-dimensional device. Atwater envisages stacking a dense array of waveguides on end: "We have not done this yet, but at least this work illustrates the inherent possibility of doing so." ■

Katharine Sanderson

1. Parazzoli, C. G., Greegor, R. B., Li, K., Koltenbah, B. E. C. & Tanielian, M. *Phys. Rev. Lett.* **90,** 107401 (2003).
2. Houck, A. A., Brock, J. B. & Chuang, I. L. *Phys. Rev. Lett.* **90,** 137401 (2003).
3. Schurig, D. *et al. Science* **314,** 977–980 (2006).
4. Dolling, G., Wegener, M., Linden, S. & Hormann, C. *Optics Express* **14,** 1842–1849 (2006).

D. MOWBRAY, CIMMYT

WHEAT FUNGUS SPREADS OUT OF AFRICA
Stem rust threatens key crops in Asia.
www.nature.com/news

PR's 'pit bull' takes on open access

The author of *Nail 'Em! Confronting High-Profile Attacks on Celebrities and Businesses* is not the kind of figure normally associated with the relatively sedate world of scientific publishing. Besides writing the odd novel, Eric Dezenhall has made a name for himself helping companies and celebrities protect their reputations, working for example with Jeffrey Skilling, the former Enron chief now serving a 24-year jail term for fraud.

Although Dezenhall declines to comment on Skilling and his other clients, his firm, Dezenhall Resources, was also reported by *Business Week* to have used money from oil giant ExxonMobil to criticize the environmental group Greenpeace. "He's the pit bull of public relations," says Kevin McCauley, an editor at the magazine *O'Dwyer's PR Report*.

Now, *Nature* has learned, a group of big scientific publishers has hired the pit bull to take on the free-information movement, which campaigns for scientific results to be made freely available. Some traditional journals, which depend on subscription charges, say that open-access journals and public databases of scientific papers such as the National Institutes of Health's (NIH's) PubMed Central, threaten their livelihoods.

From e-mails passed to *Nature*, it seems Dezenhall spoke to employees from Elsevier, Wiley and the American Chemical Society at a meeting arranged last July by the Association of American Publishers (AAP). A follow-up message in which Dezenhall suggests a strategy for the publishers provides some insight into the approach they are considering taking.

The consultant advised them to focus on simple messages, such as "Public access equals government censorship". He hinted that the publishers should attempt to equate traditional publishing models with peer review, and "paint a picture of what the world would look like without peer-reviewed articles".

Dezenhall also recommended joining forces with groups that may be ideologically opposed to government-mandated projects such as PubMed Central, including organizations that have angered scientists. One suggestion was the Competitive Enterprise Institute, a conservative think-tank based in Washington DC, which has used oil-industry money to promote sceptical views on climate change. Dezenhall estimated his fee for the campaign at $300,000–500,000.

> "Media massaging is not the same as intellectual debate."

In an enthusiastic e-mail sent to colleagues after the meeting, Susan Spilka, Wiley's director of corporate communications, said Dezenhall explained that publishers had acted too defensively on the free-information issue and worried too much about making precise statements. Dezenhall noted that if the other side is on the defensive, it doesn't matter if they can discredit your statements, she added: "Media massaging is not the same as intellectual debate."

Officials at the AAP would not comment to *Nature* on the details of their work with Dezenhall, or the money involved, but acknowledged that they had met him and subsequently contracted his firm to work on the issue.

"We're like any firm under siege," says Barbara Meredith, a vice-president at the organization. "It's common to hire a PR firm when you're under siege." She says the AAP needs to counter messages from groups such as the Public Library of Science (PLoS), an open-access publisher and prominent advocate of free access to information. PLoS's publicity budget stretches to television advertisements produced by North Woods Advertising of Minneapolis, a firm best known for its role in the unexpected election of former professional wrestler Jesse Ventura to the governorship of Minnesota.

The publishers' link with Dezenhall reflects how seriously they are taking recent developments on access to information. Minutes of a 2006 AAP meeting sent to *Nature* show that particular attention is being paid to PubMed Central. Since 2005, the NIH has asked all researchers that it funds to send copies of accepted papers to the archive, but only a small percentage actually do. Congress is expected to consider a bill later this year that would make submission compulsory.

Brian Crawford, a senior vice-president at the American Chemical Society and a member of the AAP executive chair, says that Dezenhall's suggestions have been refined and that the publishers have not to his knowledge sought to work with the Competitive Enterprise Institute. On the censorship message, he adds: "When any government or funding agency houses and disseminates for public consumption only the work it itself funds, that constitutes a form of selection and self-promotion of that entity's interests." ■

Jim Giles