METAMATERIALS

Chirality-assisted negative index

The creation of a negative refractive index — responsible for a host of interesting phenomena, including negative refraction, the inverse Doppler effect and reverse Čerenkov radiation — usually requires a material with simultaneous negative permittivity and negative magnetic permeability. The problem is that this is hard to achieve in practice, especially at optical wavelengths.

It now seems that manmade chiral metamaterials may provide an answer. Two separate research collaborations in the United States and Europe have now independently provided experimental proof that such chiral materials can be fabricated to provide a negative index in the terahertz and microwave regions.

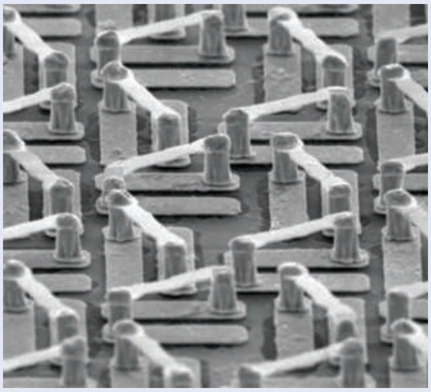
Shuang Zhang and colleagues at the University of California, Berkeley, and Oklahoma State University report a negative index at terahertz frequencies with the assistance of a man-made chiral metamaterial (*Phys. Rev. Lett.* **102,** 023901; 2008), while Eric Plum at the University of Southampton and an international team of collaborators report a negative index due to chirality at gigahertz frequencies (*Phys. Rev. B* **79,** 035407; 2008).

Both results make use of chirality — a structural design that does not show mirror symmetry. Some naturally occurring materials, such as milk or sugar solutions, have extremely weak chirality. Now chirality in man-made metamaterials that is orders of magnitude stronger than in those natural materials has been demonstrated.

Chirality plays a part in all fields of physics. In optics, it is known for its effect on the spin of photons: that is, its influence on left-handed and right-handed circularly polarized light. In conventional materials, these two circular polarizations propagate with the same phase velocity.

According to Zhang, once chirality is introduced, this behaviour is changed, with one polarization propagating with a faster phase velocity and the other with a slower phase velocity. "If the chirality is really strong, one circular polarization will experience very slow phase velocity and even finally becomes negative. As a result, the refractive index can be negative even though the permittivity and permeability are not simultaneously negative, as required by the conventional negative index materials consisting of small metallic coils and rods", he told *Nature Photonics.*

The Zhang group used this effect to observe a negative index between 1.06 and 1.27 THz in a sample measuring 1.5 cm × 1.5 cm composed of an array of micrometre-scale gold resonators (image above) with bridges roughly 20 μm long elevated by pillars 4.5 μm tall.


UNIVERSITY OF CALIFORNIA, BERKELEY

The results are likely to inspire further work into the potential for chiral metamaterials, such as isotropic and active designs. The US team is now working towards a new type of chiral metamaterial that can flip the handedness of the chiral structures upon illumination by a control light beam.

DAVID PILE

IMAGING

Seeing diamond defects

The high-resolution imaging of individual colour centres in diamond using stimulated emission depletion microscopy is set to offer new insights into the physics underlying solid-state light emitters.

Vahid Sandoghdar

Although optical techniques have played an important part in the development of natural sciences and engineering, diffraction has been a serious limitation for a long time — arguably too long. In the context of optical microscopy, this limitation is often formulated as the Abbe limit, which restricts the resolution of imaging to $(\lambda/2)$NA, with NA being the numerical aperture of the imaging system and λ the wavelength of illumination. Put simply, the long-held wisdom has been that the wave nature of light does not let us resolve two light emitters that are spaced at nanometre separations.

The dogma of this diffraction limit being a fundamental barrier in optical studies was seriously brought into question when scanning near-field optical microscopy (SNOM) was introduced in the 1980s[1,2]. Research showed that if one images a sample using non-propagating near fields, there is no theoretical limit on how high the resolution can be. Unfortunately, SNOM has proved to be very difficult to implement at a resolution below 50 nm because of challenges associated with reproducible probe fabrication and very small signals. Furthermore, it is by nature only applicable to surface studies. Nevertheless, SNOM fueled single-molecule microscopy[3], which in turn provided a viable approach for achieving very high spatial resolutions. The idea is that if one can turn on each molecule selectively, one can determine the centre of the point spread function of each molecule very accurately, thus resolving them even if they are very close to each other. Indeed, single dye molecules spaced by about 10 nm have been resolved in three dimensions at liquid helium temperature, where the exquisite spectral selectivity allows one to address each molecule separately[4].