

# Metamaterials Veer Toward the Visible

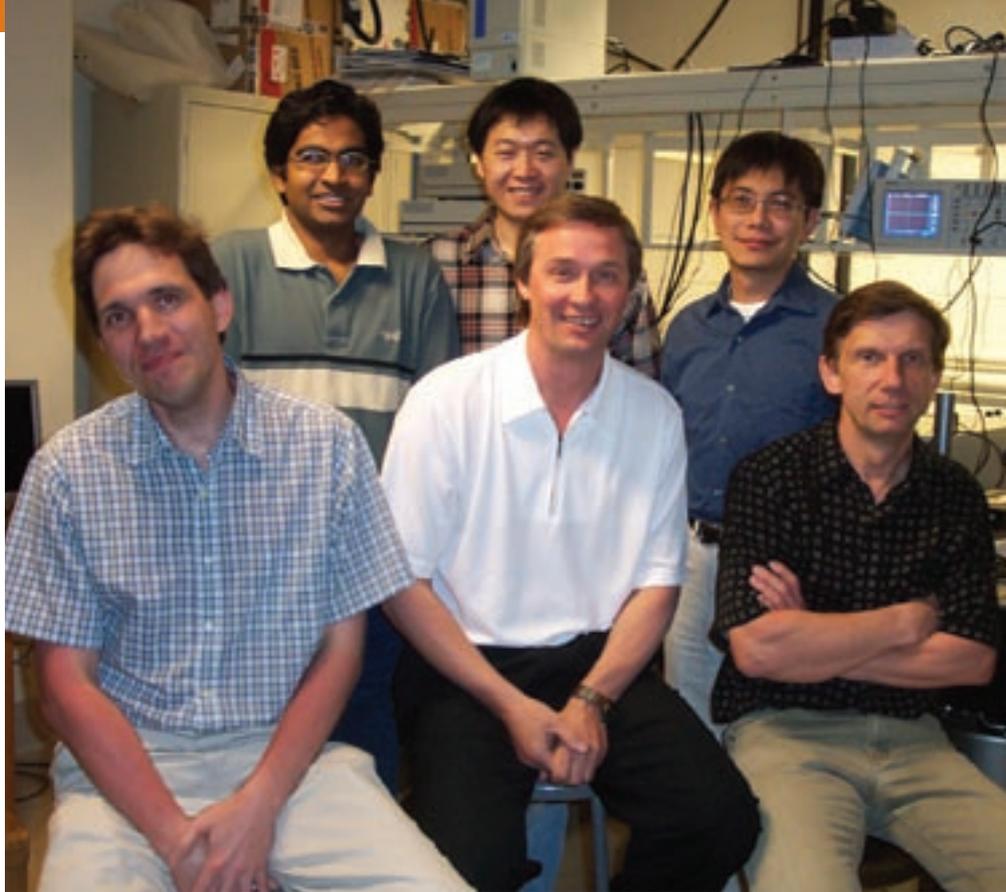
Science may be incremental, but in the case of metamaterials that appear “invisible” to certain wavelengths of light, the increments are coming in rapid succession. A field of investigation that began at the start of the decade and progressed through the microwave region of the spectrum is now tickling the edge of the visible band.

At Purdue University in Indiana, a research team has created a metamaterial that has negative values for both effective permeability and effective permittivity—a so-called “dual-band” or “double-negative” refractive index—for light with a wavelength of 813 nm. Furthermore, the group’s metamaterial showed a single-negative refractive index at 772 nm, which is clearly in the visible range (*Opt. Lett.*, doc. ID 78578, posted April 17).

The researchers included Purdue scientists Vladimir M. Shalaev, Alexander Kildashev and Vladimir Drachev and students Shijun Xiao, Uday K. Chettiar, Wenshan Cai and Hsiao-Kuan Yuan.

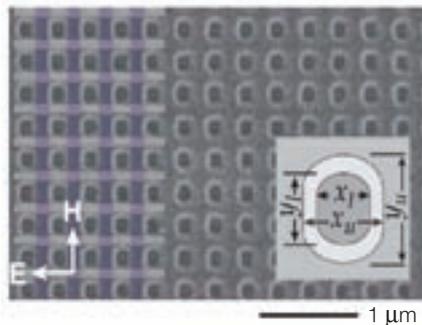
The material is a sub-wavelength-sized cross-grating built from two perforated 33-nm-thick silver layers separated by a 38-nm-thick layer of alumina (a dielectric). To demonstrate the double-negative refractive index, the team illuminated the grid such that the incident magnetic field was polarized along the set of wider parallel strips.

It’s harder to make double-negative metamaterials than the single-negative variety, Shalaev said. Thus, experiments with single-negative metamaterials tend to involve shorter wavelengths of radiation than double-negative substances. The 813-nm light is the shortest wavelength at which the dual-band negative index has been achieved, and the 772-nm result slightly edges out the 780-nm single-



Vladimir Shalaev

Front row, from left: Purdue scientists Alexander Kildashev, Vladimir M. Shalaev and Vladimir Drachev. Back row, from left: students Uday Chettiar, Wenshan Cai and Hsiao-Kuan Yuan.



Fishnet metamaterial developed by Vladimir Shalaev and colleagues at Purdue University. The holes are 120 nm across and separated by about 300 nm.

negative result reported by a team at the University of Karlsruhe in Germany (*Opt. Lett.* **32**, 53).

The Purdue group is one of several engaged in a fast-moving race—both theoretical and experimental—to fabricate materials that will deflect light in exotic ways. At press time, three California Institute of Technology researchers reported negative-index

refraction in the blue-green region of the spectrum (*Science* **316**, 430), but their results applied only to surface plasmon polaritons in two-dimensional waveguides, Shalaev said.

Will scientists ever be able to create metamaterials that will be undetectable to visible wavelengths of light—which is the everyday meaning of “invisible,” after all? According to Shalaev, current metamaterials have been tested for single wavelengths, whereas a true “invisibility cloak” would have to perform flawlessly over a spectrum hundreds of nanometers wide.

Given that the refractive index of materials is wavelength-dependent, construction of such a cloak could be a real challenge. However, Shalaev and three of his *Optics Letters* co-authors recently proposed a way to create a cylindrical cloak that would work at optical frequencies (*Nature Photon.* **1**, 224) in a manner similar to that demonstrated recently at microwave frequencies by John Pendry of Imperial College and David Schurig and David R. Smith at Duke University (*Science* **314**, 977).

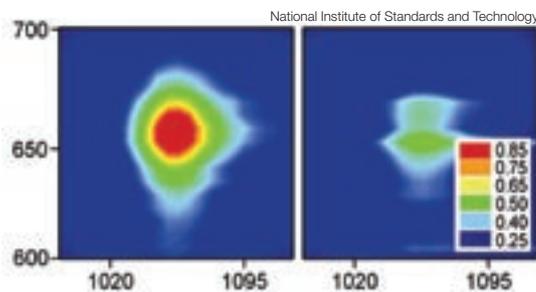
— Patricia Daukantas

# Optical Measurements of Carbon Nanotubes

A team based at the National Institute of Standards and Technology (NIST) has measured key optical properties of a semiconducting nanotube that could play a role in cancer treatment or sensor systems.

These single-walled carbon nanotubes, which are about 300 nm long and 1 nm wide, have a unique optical signature that allow them to be tracked in biomedical applications, according to Erik K. Hobbie, the NIST polymer scientist who led the effort (*Phys. Rev. Lett.* **98**, 147402).

The group, which also included researchers from the Rochester Institute of Technology (RIT), coated the nanotubes with single-strand oligomeric DNA, which acts as a dispersant to overcome the tendency of the nanotubes to bunch



When light is polarized along a single-walled carbon nanotube (left), fluorescent emission is strong. For perpendicular polarization (right), however, the emission disappears.

together. They dispersed the tiny objects in a polyacrylic acid solution, let them solidify into films and then stretched the films to align the tubes. The plastic films make the “perfect platform for studying these tubes optically” because they fix the alignment of the highly anisotropic particles, Hobbie said.

Next the researchers subjected the films to small-angle neutron scattering and small-angle X-ray scattering to make

sure that the nanotubes were dispersed properly. Near-infrared fluorescence spectroscopy and optical absorption spectroscopy brought out the optical signature of the oriented nanotubes.

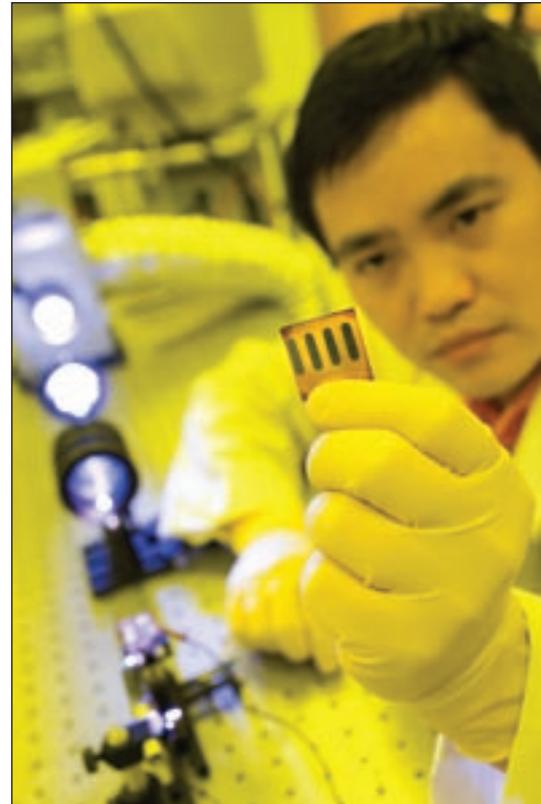
The team was actually looking at the optical properties of excitons, or electron-hole pairs, within the nanotubes. Excitons play an important role in determining the optical properties of nanotubes. The dielectric response consists of real and imaginary parts. While other researchers had studied the imaginary part that governs the absorption and re-emission of light, the NIST group was one of the first to measure both that parameter and the real part that governs scattering.

The binding energy of these excitons is fairly large compared to other semiconductors, and that leads, in effect, to a lower dielectric constant, Hobbie said. Theory had predicted this effect, but the NIST/RIT collaboration confirmed it.

The carbon nanotubes are one-dimensional direct-band-gap semiconductors, and they exhibit an intrinsic fluorescence in the near infrared,

Hobbie said. That property has generated much interest. If the carbon nanotubes were placed in some type of biological material and then injected into a human body, physicians could track that material as it passes through the body, thanks to its fluorescence.

Another potential application might exploit the particles’ near-infrared absorption to treat cancer. In such a scenario, the tubes could be embedded in a substance that would seek out cancer cells within a patient’s body. Physicians would then shine near-infrared light on that part of the body to produce enough localized heating to kill the cancer cells.



## Did You Know?

Wake Forest University researchers have boosted the efficiency for organic plastic solar cells to a new record for the type of device. The lightweight plastic devices could someday be less bulky and expensive than traditional silicon solar panels. However, they have lagged far behind silicon photovoltaics in efficiency. The research group led by David Carroll and Jiwen Liu has doubled the efficiency of these plastic cells—from 3 to 6 percent—within the past two years, largely by creating tiny “nano-filaments” within the plastic to capture sunlight. The solar cells will need to be able to convert 8 to 10 percent of sunlight into electricity in order to attract commercial interest.

Above: Jiwen Liu, a researcher in the Wake Forest University Center for Nanotechnology and Molecular Materials, tests a new solar cell in the center’s laboratory in Winston-Salem, N.C.

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