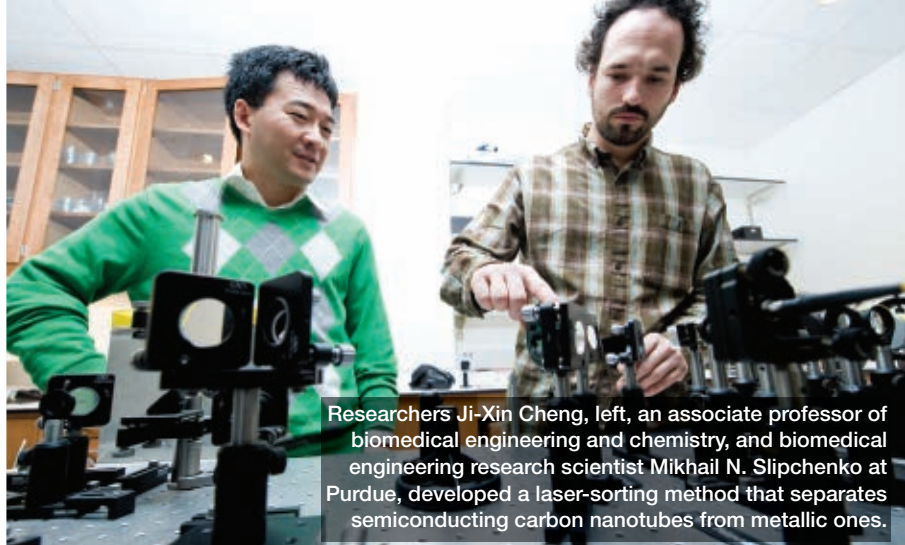


## Lasers Sort Carbon Nanotubes

Laser pump-probe experiments may be just what nanoelectronics needs, providing a way to sort single-walled carbon nanotubes by how they conduct charge. Semiconducting single-walled carbon nanotubes (which are basically rolled bundles of graphene) offer a lot of promise as components in future electronics. They have the potential to provide smaller, faster and more efficient systems than the silicon circuitry used today. One obstacle for the technology, however, is that making semiconductor nanotubes also creates metallic nanotubes. The difficulty of separating the (semiconductor) wheat from the (metallic) chaff has limited both their electronic and photonic applications thus far.

Now, researchers at Purdue University report that transient-absorption spectroscopy can quickly distinguish between the two types of nanotubes (*Phys. Rev. Lett.* **105**, 217401, 2010). Not only is the method capable of quickly distinguishing the electronic characteristics of the nanotubes, but it also provided a way to



Researchers Ji-Xin Cheng, left, an associate professor of biomedical engineering and chemistry, and biomedical engineering research scientist Mikhail N. Slipchenko at Purdue, developed a laser-sorting method that separates semiconducting carbon nanotubes from metallic ones.

Purdue

image the individual nanotubes optically. Given that their diameters range from 0.7 to 4 nm, they are far too small to be seen using normal microscopy. Atomic force microscopy (which provides surface shape information) was used to locate the nanotubes and confirm the results of the pump-probe images.

Transient-absorption spectroscopy is widely used to study the electronic energy structure and energy relaxation process in materials. In this case, the pulse from a pumping laser (at 707 nm) perturbs the electronic state of the nanotube, and the probe pulse (at 885 nm) senses the changed electronic state in the form of either enhanced emission (for semiconducting nanotubes) or enhanced absorption (for metallic ones).

Because the bandgap energy of nanotubes depends on the tube diameter,

different pump and probe wavelengths are needed for various sized nanotubes. Scanning through wavelengths could separate the metallic from semiconductor nanotubes at a variety of sizes. The method could be extended to provide information on chirality and carrier dynamics within other nanostructures, too.

For electronics manufacturing purposes, the method could be used in conjunction with laser ablation (to remove unwanted nanotubes). Although the researchers performed the technique with nanotubes on glass, future work will focus on imaging when nanotubes are on a silicon surface.

“We have begun this work on a silicon substrate, and preliminary results are very good,” said Ji-Xin Cheng at Purdue University.

—Yvonne Carts-Powell

## Lighting up the Inside of a Single Molecule

By combining scanning tunneling microscopy methods that use electrical and optical imaging, researchers could see optical transitions within a molecule with submolecular resolution. Researchers in Wilson Ho’s group at the University of California, Irvine, used STM-induced luminescence spectroscopy and microscopy combined with STM imaging and tunneling spectroscopy to distinguish between vibronic couplings in orbitals in the same molecule (*Phys. Rev. Lett.* **105**, 217402, 2010).

The technique provides information on where light is coming from within the molecule. This could be useful for many

optical and opto-electronic applications. In solar cells based on dye molecules, for example, excited electrons can relax either by generating the desired current or be wasted as emitted light. “Chemistry is different for an electron in an excited state,” Ho says. With this technique, researchers can see information that was unavailable before. “It is possible to design molecules that modify the locations where light emission occurs, thus improving the efficiency of solar cells and chemical reactivity,” according to Ho.

Lead author Chi Chen and colleagues used the electrons that tunnel between the tip and the specimen in a

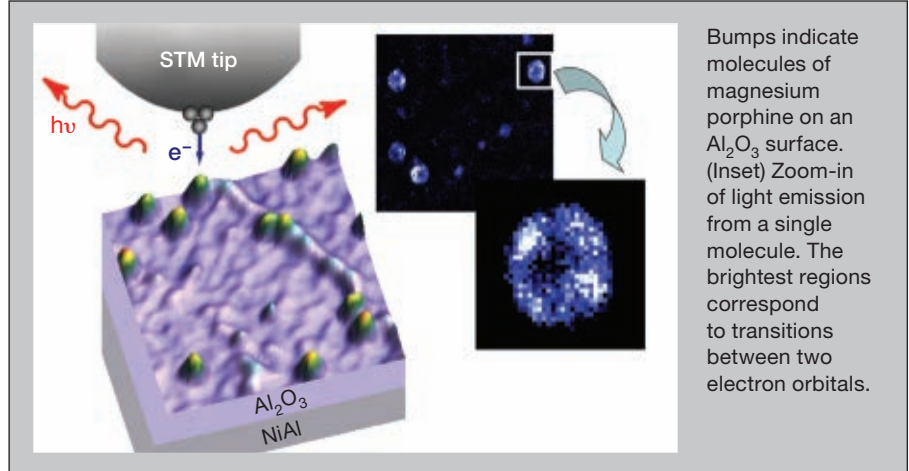
scanning tunneling microscope (STM) to excite molecules of magnesium porphyrin into emitting light. A molecule of MgP consists of a magnesium ion surrounded by the four pyrrole rings. One of the benefits of using STM is that the location of the tip is known to a tenth of a nanometer, and the effect of the tip is so localized.

When tunneling electrons excite molecules into emitting light, the location is well known and well controlled, and thus it is possible to spatially locate the position of emissions with high precision. The researchers also recorded spectra from specific areas of a single molecule.

They obtained a fluorescent image of a single MgP molecule in a ringlike pattern with four bright maxima and a relatively dark center. "These images provide a visualization of the basic concepts of chromophores and fluorophores that have been discussed in chemistry textbooks for many years," the researchers wrote. The fluorescence spectrum of porphyrin depended on the part of the molecule that was excited. They suggest that the observed luminescence originates from the transition between the lowest unoccupied and the highest occupied molecular orbital. By looking at the spectra produced in response to the tunneling electrons, the researchers distinguished two orthogonal vibronic transitions.

The paper described using electrons to generate photons. However, since the report was published, the team has been shining molecules with femtosecond

Wilson Ho, University of California, Irvine



Bumps indicate molecules of magnesium porphine on an Al<sub>2</sub>O<sub>3</sub> surface. (Inset) Zoom-in of light emission from a single molecule. The brightest regions correspond to transitions between two electron orbitals.

lasers to study photon-induced electron transfer to the single magnesium porphine molecules. Now that they have a tool for submolecular analysis, they are using it: "We want to measure the lifetime of the photon-induced electron transferred to

the single magnesium porphine molecule and measure the spatial dependence of this lifetime at different positions in the interior of the single molecule."

—Yvonne Carls-Powell

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