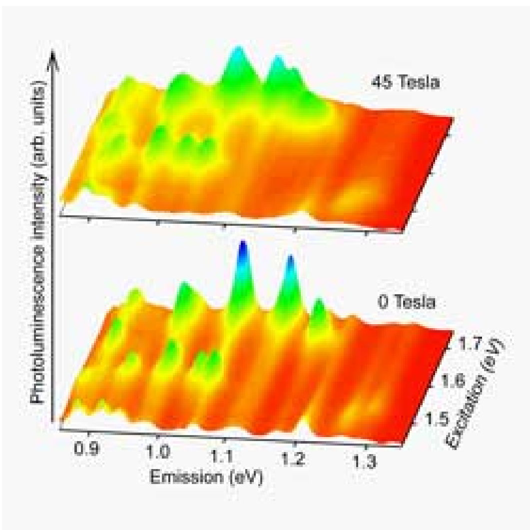
Magnetic Forces May Turn Some Nanontubes Into Metals

May 25 2004



Research Documents First Instance of Band-gap Shrinkage in a Semiconductor

A new study, published in today's issue of the journal Science, finds that the basic electrical properties of semiconducting carbon nanotubes change when they are placed inside a magnetic field. The phenomenon is unique among known materials, and it could cause semiconducting nanotubes to transform into metals in even stronger magnetic fields.

Scientists found that the "band gap" of semiconducting nanotubes shrank steadily in the presence of a strong magnetic force, said lead researcher Junichiro Kono, an assistant professor of electrical and computer engineering at Rice University. The research, which involved a multidisciplinary team of electrical engineers, chemists and physicists, helps confirm quantum mechanical theories offered more than four decades ago, and it sheds new light on the unique electrical properties of carbon nanotubes, tiny cylinders of carbon that measure just one-billionth of a meter in diameter.

"We know carbon nanotubes are exceptionally strong, very light and imbued with wonderful electrical properties that make them candidates for things like ‘smart’ spacecraft components, ‘smart’ power grids, biological sensors, improved body armor and countless other applications," said paper co-author Richard Smalley, director of Rice’s Carbon Nanotechnology Laboratory. "These findings remind us that there are still unique and wonderful properties that we have yet to uncover about nanotubes."

By their very nature, semiconductors can either conduct electricity, in the same way metals do, or they can be non-conducting, like plastics and other insulators. This simple transformation allows the transistors inside a computer to be either "on" or "off," two states that correspond to the binary bits — the 1’s and 0’s — of electronic computation.

Semiconducting materials like silicon and gallium arsenide are the mainstays of the computer industry, in part because they have a narrow "band gap," a low energy threshold that corresponds to how much electricity it takes to flip a transistor from "off" to "on."

"Among nanotubes with band gaps comparable to silicon and gallium arsenide, we found that the band gap shrank as we applied high magnetic fields," said physicist Sasa Zaric, whose doctoral dissertation was based upon the work. "In even stronger fields, we think the gap would disappear altogether."

Nanotubes, hollow cylinders of pure carbon that are just one atom thick, come in dozens of different varieties, each with a subtle difference in diameter or physical structure. Of these varieties roughly one third are metals and the rest are semiconductors.

In the experiments, which were performed at the National High Magnetic Field Laboratory (NHMFL) in Tallahassee, FL, Kono's group placed solutions of nanotubes inside a chamber containing very strong magnetic fields. Lasers were shined at the samples, and conclusions were drawn based upon an analysis of the light that was emitted and absorbed by the samples.

"The behavior we observed is unique among known materials, but it is consistent with theoretical predictions, and we believe we understand what's causing it," said Kono. "Our data show, for the first time, that the so-called Aharonov-Bohm phase can directly affect the band structure of a solid. The Aharonov-Bohm effect has been observed in other physical systems, but this is the first case where the effect interferes with another fundamental solid-state theorem, that is, the Bloch theorem. This arises from the fact that nanotubes are crystals with well defined lattice periodicity. I wouldn't be surprised to see a corresponding effect in other tubular crystals like boron nitride nanotubes."

Kono said the discovery could lead to novel new experiments on one-dimensional magneto-excitons, quantum pairings that are interesting to researchers studying quantum computing, nonlinear optics and quantum optics. Kono said it's too early to predict what types of applied science might flow from the discovery.

The NHMFL experiments were conducted in fields up to 45 Tesla in strength — the strongest continuous magnetic field in any lab in the world. Kono said he is arranging for additional tests in stronger magnetic fields. He has already met with research groups in France, Tokyo and at New Mexico's Los Alamos National Laboratory, each of which has facilities that use brief pulses of power to create short-lived magnetic fields that are exceptionally strong.

The research was supported by the Welch Foundation, the Texas Advanced Technology Program, the National Science Foundation, the NHMFL and the State of Florida. Other co-authors included NHMFL's Xing Wei, and Rice's Robert Hauge, Gordana Ostojic, Jonah Shaver, Valerie Moore and Michael Strano. Rice's team represented the Carbon Nanotechnology Laboratory, the Center for Nanoscale Science and Technology, the Center for Biological and Environmental Nanotechnology and the Rice Quantum Institute.

The original news release can be found on [Rice University web-site](#).