

MONTREAL, CANADA—More than 6000 physicists braved an early spring freeze here from 22 to 26 March for the American Physical Society's largest-ever March Meeting.

## Carbon Foam Reveals a Fleeting Magnetic Personality

Hold a magnet up to a piece of graphite or a diamond and not much happens. But researchers from Greece and Australia reported here last week that they've created a spongy, ultralightweight form of carbon that for a few brief hours is strongly magnetic. If they can make the magnetism stick around, the material could prove useful in everything from medical imaging and cancer therapy to exotic electronic circuitry based on the

Instead of nanotubes, they got a frothy surprise: a material made up of nanosized carbon clusters connected in a weblike foam. After spotting hints of magnetic behavior, Rode teamed up with magnetic specialists led by John Giapintzakis of the University of Crete in Greece to study the foam in depth.

Giapintzakis's group confirmed that the carbon foam is initially ferromagnetic. Such materials, which are commonly used for

items such as refrigerator magnets, are easily magnetized by even a weak magnetic field and often retain that magnetization after the field is removed. Other common forms of carbon, such as graphite and diamond, by contrast, naturally oppose a magnetic field. The carbon foam's ferromagnetic behavior disappears after a few hours at room temperature but lasts much longer at ultra-low temperatures.

Earlier "discoveries" of magnetic carbon by other groups fizzled after magnetic impurities in the sample were found to be the culprit. But Giapintzakis says extensive tests on the nanofoam show that impurities could account for at most 20% of the magnetism present. "We are sure we do not have an impurity effect," he says. Bolstering the case, Giapintzakis adds, the team has found that other normally nonmagnetic materials such as boron nitride show similar properties when subjected to the same laser treatment.

Giapintzakis and Tomanek say modeling studies suggest that carbon atoms turn magnetic when they cool out of the superhot plasma generated by the laser and condense into tiny four-armed cagelike structures that resemble hollowed-out nanoscale versions of a child's toy jacks. Where the arms meet, several carbon atoms are forced to bind to just three neighbors rather than the usual four, leaving them with free electrons that are magnetically active, Tomanek says. Over time, the structures likely break down, re-

ducing the material's ferromagnetism.

The new carbon nanofoam is also a semiconductor. That means it has the potential to manipulate both an electron's charge and its spin, a property related to its magnetic behavior. That ability could make it and similar materials attractive building blocks for proposed spintronic devices, which compute by manipulating electron spins.

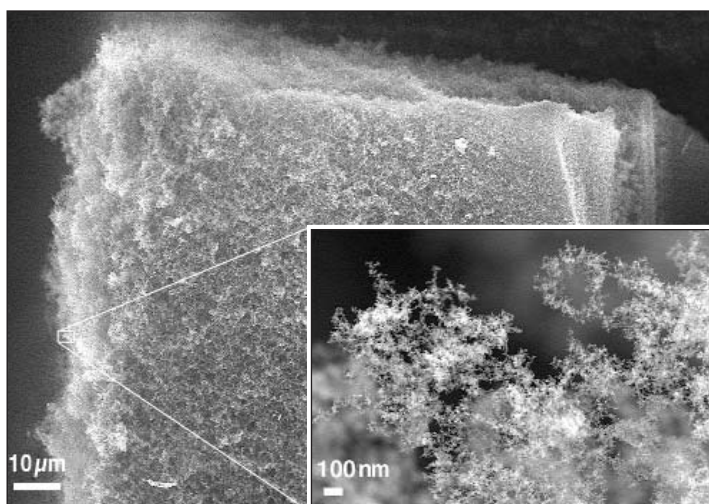
—ROBERT F. SERVICE

## A Positive Spin on Semiconductors

Researchers are working to supplant traditional computer chip technology, which relies on the charge of electrons, with devices that exploit a more ephemeral property of electrons: their spin. Such "spintronic" systems promise to operate at blinding speeds and low power, and they may even work the moment they're turned on. Numerous teams have used lasers to create and manipulate spins. But laser-based systems are impractical for standard computing technology, and groups around the globe have struggled to create and manipulate spins using purely electronic systems. Now, in a pair of reports—one at the APS meeting and another posted on the arXiv preprint server ([www.arxiv.com](http://www.arxiv.com))—a team of California-based researchers announces significant progress in that effort.

At the meeting, Jason Stephens, a graduate student in physicist David Awschalom's group at the University of California, Santa Barbara, reported creating spins by sending an electrical current from a semiconductor toward a thin ferromagnetic layer. Meanwhile, in the online paper, Awschalom's group reports similar effects simply by engineering the atomic lattices of semiconductors to contain strain, a standard industrial technique. Daniel Loss, a spintronics expert at the University of Basel in Switzerland, calls both of the new observations "very interesting." Together they hold the promise of creating all-electronic systems for creating and manipulating spins. "They could open the door, definitely," to new progress in the area, Loss says.

The first success was a lucky accident: Stephens was preparing to test a new way to create spins optically when he found he



**Attractive.** One of the lightest substances ever made, nanoscale froth condensed from superheated carbon atoms is also magnetic at room temperature for a few hours.

magnetic behavior of electrons rather than their charge.

"It's a very intriguing material," says Mil-dred Dresselhaus, a physicist at the Massachusetts Institute of Technology in Cambridge. David Tomanek, a physicist at Michigan State University in East Lansing who collaborated with the Greek and Australian team on the magnetic theory of the nanofoam, adds that the work underscores how nanotechnology can change long-held understandings of which materials can be magnetic. "It shows that we need to revisit the magnetic prejudice of the periodic table," Tomanek says.

The new form of carbon was discovered 5 years ago by a group led by physicist Andrei Rode of the Australian National University in Canberra. Looking for a new way to synthesize straw-shaped carbon molecules called nanotubes, Rode and colleagues fired a high-power, fast-pulsed laser at amorphous carbon in a chamber filled with argon gas.

didn't need the optics at all. He created a standard electronic device called a Schottky diode, consisting of two connected layers of electronic materials: a semiconductor alloy of gallium arsenide topped with a magnetic metal alloy of manganese arsenide. For spintronic devices to work, researchers must coax the spins of electrons to point more or less in the same direction. Flipping spins from pointing up to down, for example, then allows researchers to change a digital 0 to a 1.

However, orienting spins isn't easy. In conventional metals and semiconductors, they point in random directions. One way of lining them up is to use magnetic materials called ferromagnets, such as manganese arsenide. In these materials, electron spins point primarily in one direction—which gives the material its magnetism. Electron spins pointing a different direction can't easily enter the material, making it an excellent filter. So a magnetic Schottky diode is just a way to send aligned—or polarized—spins into a semiconductor. Unfortunately, the method doesn't work very well. Atomic-level disorder at the interface between ferromagnets and semiconductors typically scatters electrons, and as a result, few polarized spins ever make it into the semiconductor.

In preparation for his optical test, Stephens ran his diode in reverse, applying a voltage between the two electrodes that attempted to push electrons first through the semiconductor and then into the metal before exiting the second electrode. In this case, the spins start out unpolarized in the semiconductor. But when Stephens and his colleagues used a laser detection technique to look at the orientation of the spins in their devices, they found that a large number of spins in the semiconductor just below the metal wound up oriented in the same direction. Awschalom believes that the ferromagnetic filter allows electrons with a preferred spin to travel through the ferromagnet, leaving those with the opposite spin to accumulate in the semiconductor. "This is a fundamentally new way to generate spin polarization in a semiconductor," Awschalom says.

And it's not the only new way. Awschalom's group also scored a big hit generating spins without using any magnetic material at all, by simply engineering successive layers of semiconductor materials to harbor a type of bending or "strain" in their atomic lattices. Electric fields in strained semiconductors vary across the material, Awschalom explains, so as electrons move through the lattice, they "feel" the magnetic field changing, which in turn influences their spins.

It remains to be seen whether such

novel techniques will finally give spintronics the push it needs to succeed as a working technology. But Awschalom says that theorists have already begun proposing novel types of spintronic architectures to take advantage of the effects.

—ROBERT F. SERVICE

## Lightning Strikes and Gammas Follow?

The next time an electrical storm lights up a summer night, be aware—the sky's glowing in the dark for longer than you might imagine. Gamma rays shoot out of the sky minutes to hours after lightning strikes. Nuclear reactions fizzing in the atmosphere may be the source, and lightning could be the trigger, researchers reported at the meeting. The late-blooming rays, discovered by Mark Greenfield and colleagues at the International Christian University in Tokyo, Japan, could point to an unsuspected source of nuclear processes in the atmosphere and may give physicists new insights into how lightning forms.



**Shocking discovery.** In the aftermath of a lightning flash, nuclear reactions in the atmosphere create gamma ray showers that last for minutes or hours.

"[Greenfield] seems to be on to something very intriguing," says Joseph Dwyer, a physicist at Florida Institute of Technology in Melbourne. "The implications are big."

Greenfield's group began chasing lightning in 1999, after gamma ray detectors atop the university's physics building recorded radioactive rain—a documented result of radon gas in the atmosphere, but one the physicists had never heard of. Their interest piqued, they started to pay closer attention to the weather. Another surprise came after a lightning storm. Immediately after lightning crackled

through the atmosphere, the detectors would register a burst of gamma rays, followed about 15 minutes later by an extended shower of gamma rays that peaked after about 70 minutes and then tapered off with a distinctive 50-minute half-life.

Lightning packs a 10-million-volt punch, rending the sky with massive electric fields. Physicists know that the fields accelerate electrons, which streak upward and release gamma rays as they decelerate. These gamma rays burst just microseconds after the lightning irradiates the sky. Delayed gamma rays, though, had never been reported before. The timing of the gamma rays—the delay of a few tens of minutes, and the characteristic 50-minute half-life—suggests that they come from nuclear reactions in the atmosphere, Greenfield says. But it would take millions of electron volts of energy to spark such reactions—an amount some physicists think could be supplied only by lightning-triggering cosmic rays, so for now the ultimate source of the reactions is anybody's guess.

Whatever the cause, Greenfield and colleagues suspect that the lightning's electric field sends positive particles, perhaps ionized hydrogen atoms, careening into other atoms in Earth's atmosphere powerfully enough to cause nuclear reactions. The researchers suggest that accelerated protons slam into argon-40, a common isotope in the atmosphere, and transform it into chlorine-39. The chlorine then decays into excited argon-39, immediately giving off a gamma ray as it relaxes. Chlorine-39 has a 56-minute half-life, which fits nicely

with the observed gamma rays. But Greenfield says the gamma rays could also come from many different reactions with an average half-life that just happens to match the observed 50-minute half-life.

To determine which atoms are giving off gamma rays, the group has set up a high-resolution detector to measure the energies of the rays and see whether they match the signature of argon-39. To make such sensitive measurements, the detectors must be within a few hundred meters of the source of the gamma rays. For now, they're sitting on a rooftop, waiting for lightning to strike.

—KIM KRIEGER