

be too long for practical use, and those based on birefringence, while small, are too lossy to be practical. To address this, the researchers decided to pursue a hybrid device, which combines a central birefringent section with mode-matching tapered-waveguide input/output couplers to reduce optical loss. The researchers fabricated samples of the devices in an InGaAsP heterostructure consisting of an InP top cladding layer, an InGaAsP waveguide layer, and an InP buffer layer. A silica layer was deposited to form a hard mask. The waveguide was formed by writing the waveguide pattern into a 200-nm thick layer of polymethylmethacrylate (PMMA) using electron-beam lithography, transferring the pattern into a hard-mask layer of silica with reactive ion etching using CHF_3 chemistry, and finally deep etching into the InP layers using chemically assisted ion beam etching. The final devices were all less than 50 μm long.

The group then tested the devices by launching polarized light at a wavelength of 1.55 μm into them and measuring the rotation of the plane of polarization as a function of the width of the central birefringent section. The rotation angle increased with decreasing width, and ranged from nearly zero for a 1500-nm-wide central section to over 250 degrees for a 500-nm-wide central section. The overall insertion losses were only about 1 dB, dominated by propagation loss rather than back reflections, which can degrade photonic circuit performance. The devices were also found to operate over a 100 nm wavelength range, demonstrating that they could be used in a broadband photonic circuit configuration. Given these results, hybrid polarization-control devices of this nature may form a key component of future integrated microphotonic systems.

COLIN MCCORMICK

SnO₂ Nanowires Used to Fabricate Fully Transparent Thin-Film Transistor Devices

The extraordinary properties of semiconductor nanowires have led many researchers to pursue novel device applications. For example, conventional transparent thin-film transistors (TFTs) that use single-crystal channel materials typically require growth and annealing at high temperature and expensive single-crystalline substrates. In contrast, high-performance, nanowire-based TFTs have been fabricated on glass and plastic substrates. A key advantage to this approach is its capacity to separate the nanowire growth step from the device fabrication, which makes moot the compatibility between the device substrate with nano-

wire growth. High temperatures can therefore be used to obtain nanowires composed of single crystals, which are then transferred to the device substrate, configured into thin-film form, and processed into TFTs using conventional techniques. Heretofore, opaque semiconducting nanowires, (e.g., silicon), were used with electrodes made from normal metals such as Au or Ni but new frontiers such as "invisible electronics" require optical transparency. Recently, W. Lu and co-researchers from the University of Michigan fabricated fully transparent nanowire-based TFT devices that exhibit excellent transistor performance.

As reported in the August issue of *Nano Letters* (p. 2463, DOI: 10.1021/nl0712217), Lu and co-researchers grew single-crystalline, Ta-doped SnO₂ nanowires using a simple, inexpensive method and used them as channel material in field-effect transistor (FET) and TFT devices. The researchers chose SnO₂ nanowires because they have high optical transmittance and easily form Ohmic contacts with conducting oxide films. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) showed that the nanowires have a mean, uniform diameter of 55 nm with lengths measured in the tens of micrometers. High-resolution TEM showed that each nanowire is a perfect single crystal. FET devices with a channel consisting of a single nanowire, fabricated on Si substrates to investigate the intrinsic electrical properties of Ta-doped SnO₂ nanowires, displayed field-effect mobilities over 100 $\text{cm}^2/\text{V}\cdot\text{s}$. In contrast, undoped SnO₂-nanowire devices displayed pronounced Schottky barrier behavior. The researchers then fabricated fully transparent TFTs on glass substrates using arrays of parallel, doped nanowires as the transistor channel and indium tin oxide source and drain electrodes. Techniques, such as sputter deposition, that can be used in large-scale production were employed. Furthermore, the high-temperature limit in the fabrication process was 250°C, making it compatible with many plastic substrates. Even at low nanowire coverage, the TFTs exhibit high mobilities similar to the single-nanowire devices as well as excellent optical transparency and transistor performance, such as transconductance, bias, voltage range, and on/off ratio. The researchers said that "[our] study circumvents the position-registry problem hindering single-nanowire based approaches and may lead to large-scale applications of high performance, transparent, nanowire-based thin-film devices on diverse substrates."

STEVEN TROHALAKI

Carbon Nanotubes Endure Heavy Wear and Tear

The ability of carbon nanotubes to withstand repeated stress yet retain their structural and mechanical integrity is similar to the behavior of soft tissue, according to researchers J. Suhr of the University of Nevada in Reno, V. Pushparaj of Rensselaer Polytechnic Institute, and their colleagues.

When paired with the strong electrical conductivity of carbon nanotubes, this ability to endure wear and tear, or fatigue, suggests the materials could be used to create structures that mimic artificial muscles or electromechanical systems, the researchers said.

"The idea was to show how fatigue affects nanotube structures over the lifetime of a device that incorporates carbon nanotubes," said Pushparaj, a senior research specialist in Rensselaer's department of materials science and engineering. "Even when exposed to high levels of stress, the nanotubes held up extremely well. The behavior is reminiscent of the mechanics of soft tissues, such as a shoulder muscle or stomach wall, which expand and contract millions of times over a human lifetime."

As reported in the July issue of *Nature Nanotechnology* (p. 417; DOI: 10.1038/nnano.2007.186), the research team created a free-standing, macroscopic, 2-mm square block of carbon nanotubes, made up of individual, vertically aligned, multi-walled nanotubes. The researchers then compressed the block between two steel plates in a vice-like machine.

The team repeated this process more than 500,000 times, recording precisely how much force was required to compress the nanotube block down to about 25% percent of its original height. Even after 500,000 compressions, the nanotube block retained its original shape and mechanical properties, the researchers said. Similarly, the nanotube block also retained its original electrical conductance.

In the initial stages of the experiment, the force needed to compress the nanotube block decreased slightly, but soon stabilized to a constant value, said Suhr, an assistant professor of mechanical engineering at the University of Nevada.

As the researchers continued to compress the block, the individual nanotube arrays collectively and gradually adjusted to getting squeezed, showing very little fatigue. This "shape memory," or viscoelastic-like behavior—although the individual nanotubes are not themselves viscoelastic—is often observed in soft-tissue materials.

While more promising than polymers and other engineered materials that exhib-

it shape memory, carbon nanotubes by themselves do not perform well enough to be used as a synthetic biomaterial, said the research team. However, the researchers are combining carbon nanotubes with different polymers to create a material they anticipate will perform as well as soft tissue. The team is also using results from this study to develop mechanically compliant electrical probes and interconnects.

Zinc Compounds Tuned to Model Other Materials

P. Canfield, S. Bud'ko, S. Jia, and G. Samolyuk of Ames Laboratory and Iowa State University have discovered a family of zinc compounds that can be tuned, or manipulated, to exert some of the physical properties and behavior of other materials, ranging from copper to elements like palladium, to more complex electronic and magnetic compounds. Their versatility makes the zinc compounds ideal for basic research efforts to observe and learn more about the origins of phenomena such as

magnetism. The compounds, based upon the RT_2Zn_{20} family (where R represents a rare-earth atom and T represents a transition metal atom), are mostly zinc and are "tuned" by substituting the R and T atoms.

Canfield said, "We can make compounds for up to 10 transition metals, and for each of those we can include between seven and 14 rare earths. So that's between 70 and 140 compounds."

As reported in the May issue of *Nature Physics* (p. 334; DOI:10.1038/nphys568), one of the compounds the researchers made, YFe_2Zn_{20} , turned out to be even closer to being ferromagnetic than palladium, a nearly ferromagnetic material that scientists have traditionally studied to better understand magnetism.

Canfield describes palladium as a "runner-up" in terms of band magnetism—the magnetism of the common metals like iron, cobalt, or nickel. These metals become ferromagnetic at such high temperatures that it is difficult to study them in detail, so palladium is the next-best option.

"The problem is that as an element, palladium is a little hard to tune," said Canfield. "There is one palladium site, and it's not that versatile. For basic research as well as possible applied materials, you want compounds that allow for the manipulation of their properties. We can tune the rare earth-iron(2)-zinc(20) so we're able to push these compounds even closer to ferromagnetism and try to understand the consequences of this," he said.

The tunability of the new family of zinc(20) compounds is allowing the researchers to approach the ferromagnetic transition point from where they hope to achieve another ambition—pushing the material to become ferromagnetic at very low temperatures by tweaking and tuning.

"If we could do that," said Canfield, "then we could actually witness the birth of this type of small moment ferromagnetism—instead of just before and after pictures, we could watch the whole film."

News of MRS Members/Materials Researchers



Pierre-Gilles de Gennes

Pierre-Gilles de Gennes, 1991 Nobel laureate who made seminal contributions to solid-state, soft-matter, and polymer physics, died in Orsay at age 74 on May 18, 2007. A home-schooled graduate of Ecole Normale Supérieure, de Gennes pursued a doctorate in neutron scattering and magnetism at the Saclay CEA Center. In 1961 following a post-doctoral year at Berkeley and a two-year stint in the navy, de Gennes assumed an assistant professorship at the University of Paris, Orsay. His first book, *Superconductivity of Metals and Alloys* (translated by his long-time colleague, P. Pincus), was derived from lecture notes designed to give both experimentalists and theoreticians access to the topic. The stimulating interplay between theory and experiment was one signature of de Gennes' creative oeuvre and in the late 1960s he infused concepts from Landau theory into liquid crystal phase transitions. This catalyzed an international pursuit of the physics underlying this delicate state of matter at the core of the ubiquitous LCD. In France his highly-collaborative discoveries were so prodigious that the resulting multi-authored papers were published under the inclusive by-line, "The Orsay Liquid Crystal Group." Their findings are summarized in de Gennes's 1974 text, *The Physics of Liquid Crystals*.

In 1971 at age 39, de Gennes was awarded a prestigious chair at the Collège de France and turned his attention to condensed phases of soft matter. His provocative view of macromolecular statics and dynamics (see his *Scaling Concepts in Polymer Physics*, 1979) inspired new experiments using carefully tailored macromolecules and launched a corresponding escalation of theory. Unique rationalizations of phenomena in entangled polymer melts, for example, "reptation"—the snake-like oscillatory motion of a chain confined to a "tube" circumscribed by neighboring chains—started a renaissance in polymer physics and chemistry. Moreover, influenced by the attention that de Gennes

incited by working in these technologically important fields, the traditional "hard science" disciplines in U.S. academe acquiesced and admitted soft matter physicists and polymer chemists to their ranks, a decision that ultimately engendered a refreshing receptivity in those disciplines toward the exciting advances taking place in the life and soft-material sciences.

Following the award of the Nobel Prize in physics, de Gennes endeavored to introduce young students to the excitement of science, visiting some 200 high schools within three years (see his *Les Objets Fragiles*, 1994). An inspirational pedagogical style permeated both his scientific and public lectures: "A lot of people were surprised that a Nobel laureate, who lives and thrives in the convoluted language of intense scientific discourse, could have people laughing within five minutes into his lecture and keep them chuckling the whole way through," recalls my son about hearing, at the age of 14, de Gennes's 1999 lecture "Bubbles, Foams and Other Fragile Objects."

Between 1975 and 2002 de Gennes was director of the École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris (ESPCI) where he expanded the traditional engineering disciplines in physics and chemistry to include biology. A recipient of numerous awards (Holweck Prize, Ampère Prize, CNRS Gold Medal, Matteuci Medal, Harvey Prize, Wolf Prize, Lorntz Medal, and ACS and APC awards), and member of the French, Dutch, American, and National Academies, and the Royal Society, he concluded his career at Institut Curie working on an array of diverse topics—dynamics of wetting, granular materials, cellular adhesion and brain function. In a commemorative ceremony on June 5 in Paris, the newly-elected Président de la République Nicolas Sarkozy presided over the dedication of "Espace Pierre-Gilles de Gennes," at the ESPCI Museum.

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