CAREERS

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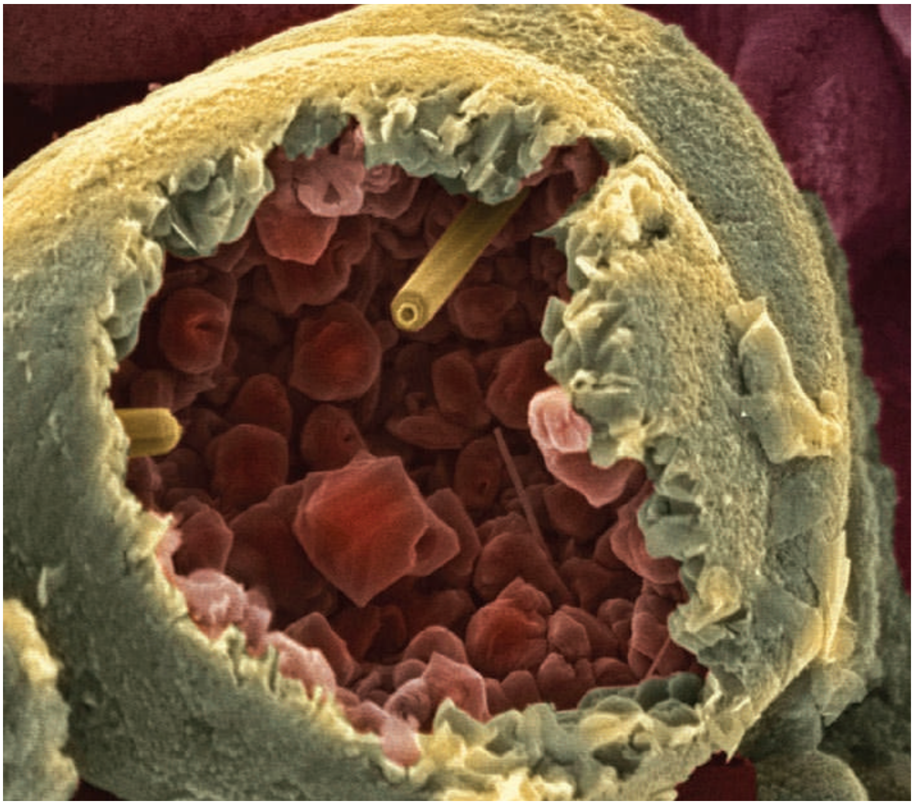

Y. GOGOTSI/SPL

Rod-shaped graphite nanocrystals are strong, stable electrical conductors with many potential uses.

NANOTECHNOLOGY

Small science yields big growth

Nanomaterials have evolved from innovation to application — and the career possibilities have blossomed.

BY CORINNA WU

Carbon-nanomaterial researchers had plenty to celebrate this autumn. In October, Rice University in Houston, Texas, threw a gala to commemorate the twenty-fifth anniversary of the discovery of the football-shaped carbon molecule buckminsterfullerene by Rice researchers. Physicist Andre Geim at the University of Manchester, UK, had planned to attend, but his plans got derailed after he and his colleague Konstantin Novoselov won the Nobel Prize in Physics the week before the gala for their work on graphene, the one-atom-thick sheets of carbon that they produced in 2004 by peeling off layers of graphite with adhesive tape. It was a busy week for nanomaterials innovators.

It has been a busy 25 years. The discovery of buckminsterfullerene in 1985 sparked a revolution in materials science and nanotechnology. That excitement was soon extended to carbon nanotubes, the mechanical and electrical properties of which suggested myriad uses. Now, these nanotubes are fulfilling their promise.

The maturation of the market for nanomaterials opens up job opportunities at all stages of commercialization — in academia, start-up companies, small businesses and large chemical manufacturers. Nanomaterials are finding their way into products such as photovoltaic cells, high-power batteries and advanced drug-delivery systems, and are creating opportunities for applications in industries from electronics and data storage to energy and biomedicine. Scientists with a strong interest and the right skills should find ample career possibilities.

INDUSTRIAL OPPORTUNITIES

Within the past two years, chemical suppliers such as Bayer in Leverkusen and BASF in Ludwigshafen, both in Germany, have begun manufacturing carbon nanotubes in bulk for industry. Most commonly, the tubes are mixed into polymers or metals to create strong, lightweight composites. Companies including Nanocyl in Sambreville, Belgium, and Nanocomp Technologies in Concord, New Hampshire, specialize in commercial nanotube production. The market is now estimated at US$247 million worldwide, and is set to grow to $2.7 billion by 2015, according to nanoposts.com, a nanotechnology consultancy in Stirling, UK. "A lot of nanotechnology applications have been in research space, but we're now seeing a progression into the commercial space," says Michael Strano, associate professor of chemical engineering at the Massachusetts Institute of Technology in Cambridge. This evolution and the projected future revenue and demand tell a promising story for job potential.

Companies all over the world are working on better ways to scale up production and chemically modify nanotubes for specific purposes. The tubes' mechanical strength makes them an obvious ingredient for composites, and the earliest applications involved mixing them into polymers to create strong, lightweight materials used in the automotive and aerospace industries, and in sports equipment. By volume, such uses still command the largest demand for nanotubes, says Daniel Resasco, founder and chief scientist of SouthWest NanoTechnologies in Norman, Oklahoma. Resasco's company has been on a hiring spree over the past year, adding 14 people to its staff, including three PhD chemists, three chemical engineers with bachelor's degrees, one technical chemist and a programme manager with an MBA. ▶

RESEARCH OPPORTUNITIES

Nanotechnology and the environment

Mark Wiesner's nanotechnology talks used to include a slide with the Disney character Tinker Bell on one side and *Star Wars* villain Darth Vader on the other. The point, says Wiesner, a civil and environmental engineer at Duke University in Durham, North Carolina, is that the technology has its bright side and its dark side. Although many researchers are drawn to the field by the bright side (the applications), others are studying the toxic effects of nanomaterials on humans and the environment — phenomena as simple as the tendency for antimicrobial silver nanoparticles to kill useful bacteria.

Research into environmental, health and safety (EHS) effects of nanotechnology has proceeded alongside research into its applications, says Kristen Kulinowski, director of external affairs at the Center for Biological and Environmental Nanotechnology at Rice University in Houston, Texas. "It means not rushing into developing applications and then realizing they're not sustainable," she says. "Let's do risk-relevant research alongside the other stuff."

EHS research draws on disciplines including biology, toxicology, ecology, environmental engineering, chemistry, physics and maths. And materials scientists and chemical engineers seek to create nanoparticles with desirable physical properties but reduced toxicity — for example, by controlling their shapes and sizes or developing coatings to keep them from damaging cells.

Social scientists track policy and regulations involving nanotechnology. Because the field touches on so many scientific and societal issues, "one needs a multidisciplinary platform", says André Nel, director of the Center for Environmental Implications of Nanotechnology (CEIN) at the University of California, Los Angeles. "A single scientific domain is not enough to address the completeness of the problem," he adds.

CEIN is one of two centres created in 2008 by the US National Science Foundation (NSF) and the Environmental Protection Agency (EPA) to study the environmental impact of nanotechnology. A collaboration between the Los Angeles and Santa Barbara campuses at the University of California, it has about 75 researchers, including 30 postdoctoral fellows and graduate students, says Nel.

Duke is headquarters for the second centre, CEINT, which includes five other universities. CEINT employs 36 faculty members and 76 undergraduate and graduate students, says Wiesner, who is the director of the centre. The NSF and the EPA granted the two centres US$38 million over five years; the EPA's $5-million contribution is the biggest it has ever given to the field.

"Looking at nanomaterials was a way of looking at human-induced disturbances to natural ecosystems," says Ben Colman, a postdoc at Duke who has been with CEINT since 2009. "That was attractive to me — asking what happens to these systems when you stress them with novel materials," he says. Colman has had to acquire skills in electron microscopy and X-ray spectroscopy to characterize nanoparticles, because the shape, size and number of particles makes a big difference to how they behave.

The centres are focusing first on the most widely used nanomaterials, including silver, titanium dioxide and carbon nanotubes. Even the most basic questions about what makes a nanoparticle toxic have not been answered, Kulinowski says; the discipline of nanotoxicology is rife with possibilities. **C.W.**

Only a few universities offer interdisciplinary degrees in nanotechnology; they include the University of Washington in Seattle, the National University of Singapore and the University of Copenhagen (a list is available at go.nature.com/ciel5z). The field is still "highly disciplinary", says Strano, with researchers holding degrees in chemistry, physics, materials science and chemical or electrical engineering. But no matter what degree they pursue, all aspiring nanotube researchers would do well to take a course in solid-state physics — "the heart of nanotechnology", says Strano. "These materials are defined by the underlying physics," he adds.

That training will apply to all areas of nanotechnology, not just carbon nanotubes. "Graduates with a strong background in catalysis, interfacial chemistry and nanotechnology will be sought by companies, universities and national labs," says Resasco. The ability to manipulate nanomaterials using electron microscopes and characterize them using spectroscopic techniques is essential for a growing suite of positions. "Working in nanomaterials," says Resasco, "you start developing a way of thinking that's more precise, more atomic-oriented than the typical microscopic research of two decades ago."

Many Rice graduates take postdoctoral positions, but "we have been sending more PhDs directly to industry than ever before", says Wade Adams, director of the Richard E. Smalley Institute for Nanoscale Science and Technology at the university. In the past few years, oil and gas service companies such as Baker Hughes, Halliburton and Schlumberger, all based in Houston, have begun hiring nanotechnology graduates from Rice. The companies are "starting to see how nanotechnology is going to make a difference to them in the future" by developing better catalysts for oil refining, hardening drill bits and improving materials used in natural-gas recovery, says Adams. Graduates also find jobs in small businesses and start-ups that specialize in nanotechnology. In the Houston area alone, more than 20 such start-ups have opened their doors within the past two years, says Adams.

Although good jobs lure many graduates right out of university, postdoctoral research experience can benefit careers in both academia and industry. Many national laboratories do nanotechnology research and collaborate with university groups, says Resasco. "That is great, because they have tremendous infrastructure and facilities," he notes. A postdoc position, Resasco adds, allows a graduate to broaden his or her experience — important in a multidisciplinary field. Resasco has hired PhD graduates with physical chemistry degrees who also had postdoctoral experience in chemical or electrical engineering. "We find this breadth of knowledge particularly useful. Many nanotechnology companies are relatively small, and people with flexibility and a broad set of skills are highly valued," he says.

Even as the commercial promise generates opportunities, basic research continues to interest universities (see 'Nanotechnology and the environment'). Graphene has become the new hot material; it is easily manufactured, flexible, strong and an excellent electrical conductor. It has been on the scene for only six years, and researchers are actively exploring its potential. According to a 2009 analysis by Lux Research in New York City, graphene is set to compete with nanotubes in price and performance in the coming years as a component of composites, coatings and energy-storage devices, and the market for it is projected to grow to $59 million by 2015.

J. RESASCO

"People with flexibility and a broad set of skills are highly valued."
Daniel Resasco

With plenty of scientific and technical challenges ahead, and so much money at stake, there should be lots of opportunities opening up. "The job market is awesome for nanotech researchers because we just don't have enough scientists — even at the master's and undergraduate levels," says Vincent Caprio, executive director of the NanoBusiness Alliance trade organization, based in Skokie, Illinois. "All these companies are hiring people." ■

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