RETURN TO NANO / BIO INTERFACE CENTER

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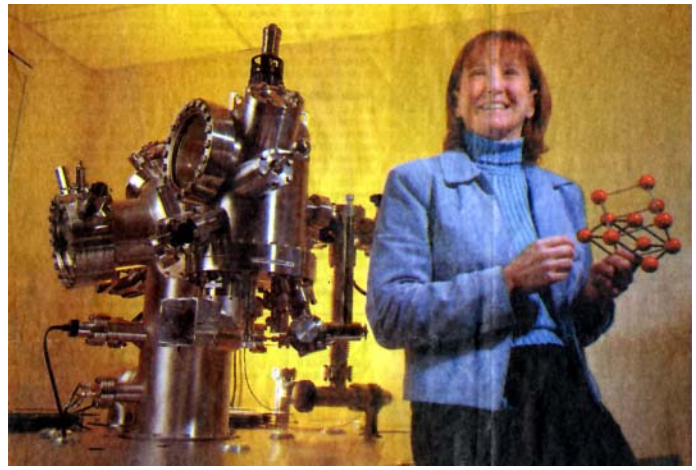

# Tiny, on a grand scale

**Nanotechnology's next big challenge: Making and manufacturing minuscule machines. Penn's Dawn Bonnell is leading the way.**

**By Peter Mucha**
**Inquirer Staff Writer**

It was one of those *eureka!* moments that researchers live for.

Dawn Bonnell was riding Amtrak from Philly to Boston when it hit her - a way to build the gadgets of the future. If it worked, engineers could pick and choose from the smallest parts imaginable - atoms, molecules and other minuscule structures - and use them to make tiny new devices.

Figuring out how to do that has been one of the major hurdles in her field, nanotechnology, and the implications are huge.

In the high-stakes world of electronics, smaller means faster and more efficient, cheaper and more profitable, even unpredictably new and powerful. Computer chips faster than could ever be built with today's silicon-based materials. Medical test strips packed with hundreds of sensors. Thinner, lighter TVs. Eventually, perhaps, even nanobots, machines tailored to such tasks as unclogging arteries or exploring other planets.

Even four years after that fateful train ride, sitting in her office at the University of Pennsylvania where she directs a new Nano/Bio Interface Center, Bonnell still remembers the flash of insight.

"I was pretty excited," she says, "I was sitting on the train, saying, 'Yes! Yes! Yes!' "

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Nanotechnology is the scientific search to find uses for all sorts of super-small things.

Things so minuscule, they're measured in billionths of a meter - nanometers - a dimension as dwarfed by a human hair as a baseball is by Everest.

Among the mini-materials: colorful atom clusters called quantum dots. Super-strong cylinders called nanotubes. Spheres called buckyballs. And the vast array of nature's own remarkable molecules, including DNA.

Already, nanotechnology's discoveries have led to more efficient traffic lights, better paints, residue-repelling windows, drift-resistant golf balls, and much-roomier computer hard drives. On the way, if research reports pan out, could be batteries that recharge in six minutes, filters that quickly turn foul water pure, and injectable materials that can detect, even destroy cancer.

Almost all of the successes so far, however, exploit one or two nano ingredients at a time - from tiny oxide particles that make sunblock clear to ultra-thin coatings that help tennis balls last.

Creating things that are more complex is the next frontier. It means moving nano materials from being mere ingredients to being parts of a nanogizmo.

Bonnell's quandary: How do you make something out of parts too tiny to hold? She knew how to draw intricate patterns of electrical charges. That could be done on the surface of special materials called ferroelectrics, whose molecules have flippable electric poles. If only there was a way to get atoms to stick to just those patterns.

On the train, as she read a paper by Carnegie-Mellon University's Greg Rohrer, she realized the solution was as simple as light.

Under illumination, he'd discovered, silver atoms stick to positively charged areas that naturally occur on some materials.

Here was her answer. By using ferroelectrics and applying precise patterns of charges, she realized, atoms could be anchored where they were wanted, so that nanoparts could be attached.

It was a step-by-step process - one that could possibly be used not just to make single devices, but manufacture batches of them.

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If this process lives up to Bonnell's hopes - it works in lab tests, but factories would be the true test - it would be a quantum leap forward for nanotechnology.

"Even if just a small percentage of all the materials we are exploring right now happen to be useful, it will mean major changes in ways we live," said Yury Gogotsi, director of Drexel's Nanotechnology Institute. He himself is investigating using the world's strongest material - carbon nanotubes - to store hydrogen for use as a cheap, clean fuel for cars.

Within a decade, nanotechnology's global economic impact - now about $13 billion - could grow to $2.6 trillion, as it upgrades everyday products, transforms electronics, and makes inroads into medicine, according to industry analyst Lux Research. Small wonder, then, that many major corporations are investing, and more than 1,000 start-ups, including one to develop Penn's process, are competing in the field, said Matthew Nordan, Lux's vice president of research.

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Penn's process, called ferroelectric nanolithography, isn't the only way to arrange nanostructures.

The field's current bag of tricks range from "self-assembly," in which molecules join and even align in predictable ways, to "dip-pen lithography," which uses the tip of a super-sensitive atomic force microscope like a ballpoint, depositing atoms like ink. Templates, lasers, DNA, and magnetic fields can also be used to move and arrange molecules.

But, as Bonnell wrote in last month's issue of the Journal of Materials Research, her method accommodates all sorts of nanoparts - nanodots, proteins - while others operate on only one substance at a time.

"Ferroelectrics are clear winners," said Oak Ridge National Laboratory's Sergei Kalinin, who did key research on Penn's process while a post-doctoral student there. They can store bits of information "orders of magnitude smaller" than the magnetic media used in videotapes and computer disks, he explained in an e-mail.

Flipping through PowerPoint printouts, Bonnell explains the science. The molecules of ferroelectrics can flip their electric poles because of a movable metal atom inside them.

The first step is to flip all the poles on a piece of ferroelectric material the same way. Then selected spots are reversed, using a scanning probe microscope, an electron beam, or electrode stamping.

The patterns can be simple - Bonnell shows a picture of nanowires a few atoms thick - or as complex as a portrait of Penn president Amy Gutmann. Metals will stick only to those charged spots, and only in the presence of light.

Individual molecules can then be attached to those metal anchors. Theoretically, the steps can be repeated to create ever more complex structures.

To see how far this idea can fly, Bonnell's group is trying to build a light-sensitive switch with only a handful of metal dots and a few molecules. But instead of wires, current would be conducted by a protein that shrouds a molecule of a chemical called a porphyrin, a cousin to chlorophyll. When light hits the device, current flows through it.

While setup sounds simple enough, the work requires the brainpower of a team of scientists working in several departments - physics, chemistry and biochemistry.

Penn's Nano/Bio Center, established in November with an $11.4 million grant from the National Science Foundation, is also studying how to better measure nanoscale phenomena, the mysteries of how molecules make muscles move, and possible environmental hazards of nanotechnology.

It is a competitive field, and Bonnell's team is very much in the game.

"Frankly, I think Professor Bonnell might be ahead of everybody on this," said UCLA's Eli Yablonovitch, codirector of its Center for Scalable and Integrated Nanomanufacturing.

On the other hand, Northeastern University's Ahmad Busneina said other methods, including his use of templates, will prove to be more capable. He heads the Center for High-Rate Nanomanufacturing, another NSF seed project.

"It's hard to say what is really going to be put into general practice," said Paul Weiss, director of Penn State's Center for Molecular Nanofabrication and Devices. His group recently discovered loosely linked protopolymers that might help position other nanoparts. "The race hasn't really started."

There's a lot to learn, said physicist A.T. "Charlie" Johnson, part of Penn's nano team. But the payoffs, though perhaps five or 10 years away, could be remarkable. "What you could do with these molecules is just enormous... . We can do completely new things."