With help of DNA, nanotubes may become a bigger force

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In his neatly ordered lab at DuPont, chemist Ming Zheng slides open a glass cabinet and removes a flask of soot that could have been swept from someone's fireplace.

"These are carbon nanotubes," he said, referring to the novel form of carbon discovered in the 1990s to much fanfare. These wonder materials promised new kinds of computer chips, batteries, sensors and other devices.

Nanotubes haven't lived up to the hype, but that may change after Zheng announced this month he and his colleagues had overcome a long-standing hurdle limiting their use.

The problem goes back to the soot.

It's all really a disorganized collection of invisibly small cylinders -- each one a lattice of carbon atoms rolled up in a tube. Mixed up in that flask are hundreds of types with slightly different properties. Some conduct electricity, while others conduct light, for example.

With particles so small, you can't reach into the soot and pull out the type you want to use. Zheng found a way to essentially tag the different types of nanotubes with DNA, enabling them to be selected and used.

It was a problem others had been trying to solve for years, said chemist Mark Hersam, a nanotechnology expert at Northwestern University.

"What they've done is of great fundamental importance for scientific research."

The effort joins biology and nanotechnology -- the science of things on the scale of billionths of a meter. "We are at a historic moment when materials science is meeting biology," said Zheng, the DuPont researcher.

For as long as humans have cared to look, there were just three forms of carbon -- diamond, graphite and amorphous carbon. Then, in the 1980s, scientists created soccer-ball-shaped molecules they called Buckminsterfullerene or "buckyballs." The buckyballs won a Nobel Prize for their inventors.

But attention soon shifted to a fifth carbon form created in the 1990s by Japanese researcher Sumio Iijima of electronics giant NEC. Called carbon nanotubes, or sometimes buckytubes, they were made accidentally in the gunk that collects on the apparatus used to create buckyballs.

Today, nanotubes are used as a type of carbon fiber for lightweight tennis rackets and hockey sticks. But Hersam calls these "low-tech" uses.

Now that they can be sorted, however, the higher-tech uses may finally follow.

Nanotubes aren't invisible when trillions are piled together, but it's impossible to see an individual one even under an ordinary optical microscope, said Zheng. That's because they're smaller than the wavelengths of visible light.

Special high-powered electron microscopes and other instruments have helped scientists work out the nanotube's structure, Zheng explained, pointing to a drawing of a dozen kinds of nanotubes.

In all of them, the carbon atoms form an interlocking chicken-wire structure, curled up into hollow cylinders. But look closely and the chicken wire forms different patterns; each nanotube is rolled with a different degree of twist.

Some conduct electricity, Zheng said, while others act as semiconductors -- the basis of most computer chips -- and still others channel light.

All of this makes them good candidates to find their way into electronic devices, paper-thin screens and super-efficient solar panels. If only they could be sorted out.

That's where DNA comes in. It seemed like a potential tool to work with nanotubes because the double helical molecules are on the same size scale.

That's true of proteins and other important biological molecules, said Hersam. "Life occurs at the nanometer scale."

Zheng first thought about using DNA to sort nanotubes back in 2003. He thought perhaps some strands of DNA would stick to the nanotubes in a way that distinguished the different types.

"For me, it's very natural," he said of mixing biology with materials science.

After studying electronics as an undergraduate and earning a Ph.D. in chemistry, Zheng completed a postdoctoral fellowship at the National Institutes of Health, studying the way antioxidants damaged living cells. That introduced him to the world of biological molecules.

As he started working with DNA, Zheng noticed right away it would attach to nanotubes, enabling them to dissolve in water. Without the DNA, the nanotubes clump, he said, showing a test tube full of nanotubes in water, a muddy grit clinging to the sides like stray coffee grounds.

But add DNA and it turns into a clear liquid, he said, because the DNA molecules are binding to the nanotubes, wrapping around them and keeping them apart. The researchers can't actually see this, since it's all too small, so Zheng relied on the theoretical insights of colleagues Anand Jagota and Suresh Manohar at Lehigh University.

The DNA then helped him sort the nanotubes by slowing down some species more than others as they ran through a column a few inches long -- a marathon for nanotubes.

It turned out, Zheng said, the sorting worked only for DNA encoded with certain sequences of genetic code. That code is spelled out in the order of DNA's four kinds of chemical building blocks, A, T, C and G.

He tested the near-infinite possible sequences starting with the simplest ones -- strings of just one letter -- A-A-A, for example. Then they tried alternating two letters, AT-AT-AT.

Eventually, Zheng and his colleagues tested about 350 types of DNA strands until they found 20 that worked well enough to isolate 12 different species of nanotubes.

Combining the living and inanimate worlds is starting to catch on in a few other labs. At Massachusetts Institute of Technology, a group headed by Angela Belcher is training a type of virus called a phage to manufacture various materials. She does it by manipulating its DNA.

"We're figuring out how to use biology to make catalysts, batteries, solar cells," said Belcher. She realized a few years ago this type of construction was going on in nature when a simple abalone pulls dissolved minerals out of the water and assembles them into beautiful opalescent shells.

Phages don't make shells in nature, but they can be genetically altered to pull ions from a solution and create various useful parts -- wires, semiconductors, or anodes and cathodes. She thinks the technique will lead to new batteries -- she's already made one that she unveiled in the journal *Science* last year.

"Our toolbox is all of chemistry and all of biology," she said.

Physicist A.T. "Charlie" Johnson and his colleagues at the University of Pennsylvania are also using DNA sequences and nanotubes. He wants to create sensors that respond to tiny traces of various gases -- a sort of artificial version of a dog's nose that someday might sniff out chemical weapons or other dangers.

"Combining the nano and the bio is a big trend right now," Johnson said.

"DNA and nanotubes are like the Reese's Peanut Butter Cups of nanotechnology -- two terrific materials alone, but put them together and you get all kinds of new things you didn't expect," Johnson said.
