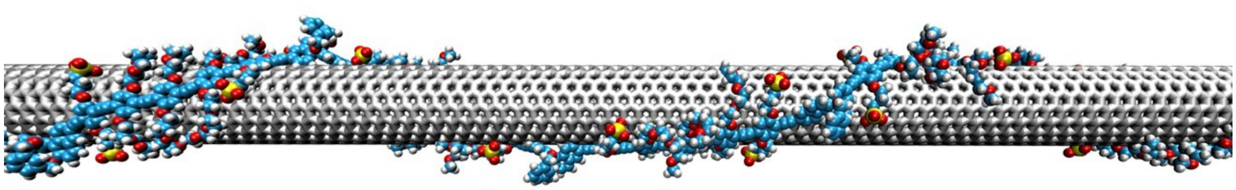
Researchers devise new ways to engineer carbon-based semiconductors for electronics of the future

March 11 2024, by RA Smith



By wrapping a carbon nanotube with a ribbon-like polymer, Duke researchers were able to create nanotubes that conduct electricity when struck with low-energy light that our eyes cannot see. In the future, the approach could make it possible to optimize semiconductors for applications ranging from night vision to new forms of computing. Credit: Francesco Mastrocinque

It might look like a roll of chicken wire, but this tiny cylinder of carbon atoms—too small to see with the naked eye—could one day be used for making electronic devices ranging from night vision goggles and motion detectors to more efficient solar cells, thanks to techniques developed by researchers at Duke University.

Their work is published in the journal *Proceedings of the National Academy of Sciences*.

First discovered in the early 1990s, carbon nanotubes are made from single sheets of carbon atoms rolled up like a straw.

Carbon isn't exactly a newfangled material. All life on Earth is based on carbon. It's the same stuff found in diamonds, charcoal, and pencil lead. What makes carbon nanotubes special are their remarkable properties. These tiny cylinders are stronger than steel, and yet so thin that 50,000 of them would equal the thickness of a human hair.

They're also amazingly good at conducting electricity and heat, which is why, in the push for faster, smaller, more efficient electronics, carbon nanotubes have long been touted as potential replacements for silicon.

But producing nanotubes with specific properties is a challenge.

Depending on how they're rolled up, some nanotubes are considered metallic—meaning electrons can flow through them at any energy. The problem is they can't be switched off. This limits their use in digital electronics, which use electrical signals that are either on or off to store binary states; just like silicon semiconductor transistors switch between 0 and 1 bits to carry out computations.

Duke chemistry professor Michael Therien and his team say they've found a way around this. The approach takes a metallic nanotube, which always lets current through, and transforms it into a semiconducting form that can be switched on and off.

The secret lies in special polymers—substances whose molecules are hooked together in long chains—that wind around the nanotube in an orderly spiral, "like wrapping a ribbon around a pencil," said first author Francesco Mastrocinque, who earned his chemistry Ph.D. in Therien's lab at Duke.

The effect is reversible, they found. Wrapping the nanotube in a polymer changes its electronic properties from a conductor to a semiconductor. But if the nanotube is unwrapped, it goes back to its original metallic state.

The researchers also showed that by changing the type of polymer that encircles a nanotube, they could engineer new types of semiconducting nanotubes. They can conduct electricity, but only when the right amount of external energy is applied.

"This method provides a subtle new tool," Therien said. "It allows you to make a semiconductor by design."

Practical applications of the method are likely far off. "We're a long way from making devices," Therien added.

Mastrocinque and his co-authors say the work is important because it's a way to design semiconductors that can conduct electricity when struck by light of certain low-energy wavelengths that are common but invisible to human eyes.

In the future, for instance, the Duke team's work might help others engineer nanotubes that detect heat released as infrared radiation, to reveal people or vehicles hidden in the shadows. When infrared light—such as that emitted by warm-blooded animals—strikes one of these nanotube-polymer hybrids, it would generate an electric signal.

Or take solar cells: This technique could be used to make nanotube semiconductors that convert a broader range of wavelengths into electricity, to harness more of the sun's energy.

Because of the spiral wrapper on the nanotube surface, these structures could also be ideal materials for new forms of computing and data storage that use the spins of electrons, in addition to their charge, to process and carry information.

More information: Francesco Mastrocinque et al, Band gap opening of metallic single-walled carbon nanotubes via noncovalent symmetry breaking, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2317078121

Provided by Duke University