ZnO nanowires may lead to better chemical sensors, high-speed electronics

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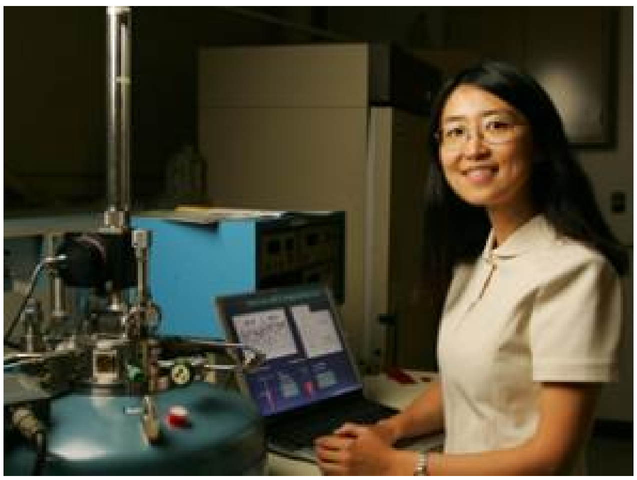

In physicist Grace Lu's explorations on the frontiers of the nanoworld, she uses this instrument to analyze the magnetic properties of wires about 50 nanometers wide — so small that you could fit 20,000 of them side to side within the eye of a full-sized needle. Photo credit: Phil Channing

Devices for detecting dangerous substances can literally be life savers, in situations ranging from soldiers on the battlefield to luggage screeners at airports. Yet chemical sensors now available for such tasks have their drawbacks. They aren't always sensitive enough to detect tiny amounts of a hazardous chemical, for instance. Once exposed it can takes hours until they are ready to sense again.

But research from the nanoworld, where individual molecules become scientific tools for inventing miraculous micro-gadgets, is revealing new and better ways to recognize malicious chemicals.

At the heart of novel detection devices now on the drawing board are threads of metal oxide small enough to fit through they eye of a needle too small to see. These “nanowires” are measured in billionths of a meter, or nanometers. A typical nanowire is about 50 nanometers wide — you could fit 20,000 of them side to side within the eye of a full-sized needle.

Making such nanowires and embedding them in delicate electronic circuitry occupies the creative energy of Jia Grace Lu, one of three new scientists (two of whom are women) to join the USC College physics and astronomy department this year.

Her interest in physics was ignited in childhood; she grew up in China in a family populated by physicists, including her grandfather, father and several uncles.

“Usually they don’t encourage girls to do hard science, but I was fascinated by physics,” said Lu, associate professor of physics and astronomy. She knew she wanted to be a scientist even before entering middle school. She came to the U.S. at age 14 for high school, and received undergraduate degrees in physics and electrical engineering from Washington University in St. Louis. She earned her physics doctorate at Harvard, and most recently has pursued her nanoworld explorations at University of California, Irvine.

Lu’s work on nanowires has focused on zinc oxide, which offers particularly attractive properties for nanosensing and other devices. Zinc oxide nanowires can be used in a type of transistor that responds to the presence of various gases with exquisite precision, thus acting as a powerful chemical sensor.

Transistors are important components of electronic circuits, controlling the flow of information by regulating the transmission of electric current. In transistors made with a zinc oxide nanowire, the presence of foreign substances alters the wire's ability to conduct the current. Nitrogen dioxide gas, for instance, will reduce how much current the wire conducts, whereas carbon monoxide will increase it. Different substances increase or decrease the current by different degrees, so specific chemicals can be identified by how much they affect the flow of current.

Zinc oxide can also be used as a sensing material when in the form of a thin film. But the nanowire structure studied by Lu has several advantages over film sensors, mostly due to its larger surface-to-volume ratio. A small dose of nitrogen dioxide gas on a thin film might diminish the current by only 2 percent, much harder to measure than the 50 percent decrease observed in a zinc oxide nanowire.

Nanowires also can be more quickly reset to begin sensing again. For films, elaborate methods are needed to cleanse the surface, requiring from half an hour to many hours. With nanowires, a voltage signal to the transistor drives away the chemical, restoring the original sensing condition in a matter of minutes. (The precise amount of time needed to refresh the sensor can also be used to help determine the identity of the chemical being detected.)

So far, Lu and her group have focused on ways of making the zinc oxide nanowires and demonstrating their sensing effectiveness in principle. In the next few years she hopes to see laboratory versions of working devices, each containing several sensing units to create a sort of "electronic nose" for sniffing out a wide range of nasty chemicals, including nerve gas and various explosives. Several sensing units can then be embedded in electronic circuitry with computing power to analyze the patterns in the transistor signals corresponding to various gases.

“We’re working on how we can distinguish gases in a complex environment, not just a mixture of two gases,” said Lu. “Ultimately we want to develop an ultra-sensitive and highly selective chemical sensing system that mimics the mammalian olfactory system.”

Battlefield soldiers could carry this kind of “electronic nose” in a cell phone-sized device to detect toxic chemicals rapidly and, because it could be quickly refreshed for reuse, repeatedly.

Of course, the sensors and computing elements in such devices require electrical power, and once again nanowires can help. In transistors, the wires just lay flat, but Lu is investigating other configurations in which the zinc oxide wires stand vertically in an array that can serve as a tiny battery, rechargeable by solar power. The battery would be small enough to integrate on a single chip with the sensing unit and computing circuitry.

Besides sensing dangerous substances, zinc oxide nanodevices could have many other uses — in logic gates for computer circuits, for instance, or as solar-electric cells, or as photodetectors.

Lu’s plans include making even smaller nanowires — only a few nanometers across — from metals and semiconducting materials. Smaller wires would operate in the realm where the rules of quantum physics take control. Experiments with such wires will build the know-how essential for future applications in ultra-fast electronics and quantum computers. Eventually, Lu’s work may even lead to a better understanding of the nanoworld itself, paving the way for even more useful nanoinventions in the decades to come.

Source: By Tom Siegfried, USC College