Double duty: Magnetic nanotechnology holds promise in fighting cancer, advancing computing

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Detecting cancer and reinventing computing are two challenges that seemingly have little, if anything, to do with each other. That is, unless you are a nanotechnologist like Shan Wang, an associate professor of materials science and engineering and of electrical engineering at Stanford. To him, the problems are two sides of the same coin, or more aptly, opposite poles of the same magnet.

"We have known for a long time that magnetism is a fundamental property of all materials and it has found wide applications in electronics and biology, like hard disk drives and magnetic resonance imaging, but there is also great potential to now apply magnetism at the nanoscale," Wang said in an interview in his office at the Geballe Laboratory for Advanced Materials.

There Wang is tuning the characteristics of tiny magnets—on the scale of a billionth of a meter—to help address both cancer and computing. One part of his research group is developing an ultrasensitive detector of DNA and proteins, including proteins associated with cancer. With some of his students, Wang also is making key advances in "spintronics," a new computing technology that could augment or replace silicon microelectronics when progress there is no longer possible because of physical limitations.

Wang's expertise and promising results have made him an important member of two research centers announced this year. On Feb. 27, the National Cancer Institute awarded Stanford $20 million over five years to establish a Center of Cancer Nanotechnology Excellence Wang co-directs with radiology Professor Sanjiv Gambhir. Then on March 9, the university joined with three University of California campuses to announce the Western Institute of Nanoelectronics, a center headquartered at UCLA and dedicated to spintronics research.

Spin for doctors

Wang's specialty in magnetism is particularly important in medical applications because a magnetic field stands out like a flare in the night sky in magnetically neutral biological settings. Magnetism stands out more than fluorescence, the current standard for signaling the detection of a cancer-related protein. That means if a cancer marker could be made to trigger a magnetic change, the result could be production of a more sensitive cancer detector. With better detectors, doctors could diagnose emerging cancers earlier and know sooner whether a particular treatment is working.

The trademarked MagArray biodetection chips Wang is building, each about half a square centimeter, are like little traps for target proteins or DNA strands. The chips are orderly arrays of "ferromagnetic spin valve" sensors, little magnetically sensitive platforms where magnetism and biology converge. Like other microarray chips, they work by exploiting a well-understood phenomenon called "biorecognition." Specific targets, such as proteins or DNA strands, will only link up with specific proteins or complementary DNA strands, respectively. In other words, one can catch a target in a blood or biopsy sample if one provides the right "bait," or probe.

Detection of a particular target with the MagArray chip first involves attaching the probes to sensors on the chip. The sensors, each less than a millionth of a meter wide, are specially designed so that their electrical resistance will change in a predictable way in the presence of a particular magnetic field. The sample is then pumped onto the chip via a system of tiny "microfluidic" pipes. Probes capture the targets. Then magnetically sensitive nanoparticles coated in a chemical that will bond to the target are pumped in. In the presence of an applied magnetic field, the nanoparticles emit their own field—the kind that would predictably change the resistance of the sensor.

When the nanoparticle links to the target, its proximity changes the sensor's resistance. The change is read electrically by a computer as a clear signal of the presence of the target. In a paper in the journal *Sensors and Actuators A* in January 2006, Wang and collaborators published the results of a simplified demonstration of MagArray chips without biological targets and probes. They showed that the change in resistance on a chip is directly proportional to the number of nanoparticles on the chip's sensors. Collaborators on the study, which was funded by the Defense Advanced Research Projects Agency, include electrical engineering Professor Emeritus Robert White, Wang's former doctoral student Guanxiong Li, research associates Robert Wilson and Nader Pourmand, and Brown University Professor Shouheng Sun.

Since doing those experiments, Wang and his current students and collaborators have done further work, as yet unpublished, demonstrating the efficacy of the chip with biodetection. Wang and his team now plan to test for proteins associated with breast and prostate cancers. The researchers aim to produce a handheld device that could rapidly test for a number of diseases. "Our ultimate goal is that if you are sitting in a doctor's office or an emergency room, we'll be providing the doctor with firsthand diagnostics in a time well below one hour," Wang says. "That would be the holy grail."

Spintronic filters and switches

Meanwhile, Wang has made important progress in spintronics as well. While electronic circuits shuffle electrons around based on their charge, spintronic circuits would route electrons based on their magnetic "spin," a quantum mechanical property that can be described as pointing "up" or "down." Spintronics holds great promise as an augmentation or even a replacement for electronics, because circuit operations such as switching (the mechanism that produces the zeroes and ones of binary code) could be performed more quickly using less energy.

To make spintronics work in practice, however, engineers must build working devices, such as filters that can let electrons with one kind of spin through but block the other kind. The most desirable filters would work at room temperature rather than require the extreme cooling typical of many quantum mechanics devices.

Wang's group has indeed done just that, although not yet perfectly. In a paper accepted by the journal Physical Review Letters B, Wang and materials science and engineering doctoral student Michael G. Chapline announce the first room-temperature electron spin filter, which can block electrons of one spin and let through electrons of the other more than 75 percent of the time. Ideally, the filter would sort electrons of opposite spins with virtually 100 percent effectiveness. The research was funded in part by the National Science Foundation.

The whole device is a sandwich of four incredibly thin (just a few nanometers) layers of exotic materials selected for their magnetic properties. On one end is a layer of iron oxide that emits electrons of a particular spin state. Then a layer of magnesium, aluminum and oxygen magnetically insulates this emitting layer from the most important layer—the one that actually does the filtering. That layer is made of cobalt, iron and oxygen. Finally, a gold layer conducts the electrons that have made it through the filter to an atomic force microscope for detection.

In addition to finding materials that will increase the filter's effectiveness, Wang wants to find materials whose magnetic properties can be rapidly switched back and forth to block different spin electrons at different times. Such a switching capability would enable the spintronic equivalent of a transistor.

"In five to 10 years we will really have trouble maintaining Moore's Law," says Wang, referring to the doubling of transistors on a chip roughly every 18 months that has underpinned the information technology industry. "Spintronics is one of the answers to the challenge posed by Moore's Law as we get down to the nanoscale."

Source: Stanford University, by David Orenstein

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