Abstractions

FIRST AUTHOR

Despite great demand for nanoscale sensors by the security, environmental and healthcare industries, the performance of current devices is disappointing owing to technical limitations. The trickiest job is connecting nanometre-sized structures to the much larger silicon wafers required to produce functioning devices. Integrating different materials, such as carbon- and silicon-based structures, has also proved problematic. And device performance is often sacrificed when bulk silicon is etched down to the nanometre scale. When Yale University graduate student Eric Stern joined a project — funded by the US Defense Advanced Research Projects Agency — to build such a nanosensor, he assessed the limitations of existing nanomaterials. His modification of a conventional silicon-based approach led to a new nanowire design for an immunodetection device (see page 519).

What was the project's original goal?

At the outset, the government had grave concerns about stockpiled chemical and biological weapons in Iraq. The goal was to develop a general sensor that could detect these agents and be worn by every soldier. Although such a device is still very much a work in progress, we've hopefully moved it a step closer to reality.

Did you stumble on any unexpected applications for the nanosensors?

The most exciting application is in detecting stimulus-induced cellular responses. Sensors with this capability could be used in diagnostics to differentiate between various potentially pathogenic cell types. They would require samples of only a few cells and no artificial labels.

What was the main hurdle to overcome?

After much study of thousands of nanotube and nanowire devices, we decided to use a more conventional approach and etch the nanowires from bulk silicon. The real trick was finding the best way to do this in order to get pristine nanostructures with smooth side walls. From a sensing-device point of view, it's never been done before.

What's been the biggest victory for you?

I was frustrated with the inability of groups to reproduce high-quality semiconducting nanowires required for sensing studies. This limitation has prevented nanosensing from taking off. Our approach lays some of the groundwork necessary to overcome this.

Your team represents five different departments at Yale. Was that by design?

Yes. A strong collaboration between specialists from multiple disciplines must be created to perform a study like this. ■

MAKING THE PAPER

David Leigh

Chemists open the gate for a new type of molecular machine.

Many cellular processes are driven by biological motors, and a range of synthetic mimics have been developed that function as nanomachines. However, there has tended to be a notable difference between naturally occurring and artificial machines. Biological motors — for example those responsible for flexing muscles — drive chemical systems away from equilibrium, whereas machines synthesized by chemists move them towards it.

David Leigh had been constructing molecular machines for a decade when research in his lab at the University of Edinburgh, UK, took a new course. At a group meeting in 2003, Leigh asked PhD student Euan Kay to present the mechanisms that theoretical physicists had proposed for biomolecular motors. "He did a great job of explaining the different mechanisms in a language that organic chemists could understand," recalls Leigh. "By the end of the presentation, it was as if the scales had fallen away from our eyes." It was then that the team first came up with a plan for a synthetic molecular machine that could transport particles away from their natural distribution (see page 523).

Its design was inspired by a thought experiment proposed 140 years ago by physicist James Clerk Maxwell. Maxwell imagined a tiny demon able to open a trap-door between two containers filled with gas. This demon would open the door only to allow particularly fast molecules to move from the container on the right to that on the left. Eventually, this would increase the temperature of the container on the left (which would contain all of the faster-moving molecules) and decrease the temperature of the other. Such spontaneous heating and cooling in the absence of energy input conflicts with the second law of thermodynamics, which (among other things) forbids an increase in the order of a system without any energy being added from outside.

Leigh's team designed a molecule that, like Maxwell's demon, moves and sorts particles according to their relative positions. This molecule, known as a rotaxane, consists of a ring threaded onto a linear unit and held in place by two bulky chemical groups (stoppers). A 'gate' located in the thread, closer to the left stopper than the right, blocks the movement of the ring along the thread.

When the ring was to the left of the gate and light was shone on it, the ring transferred the light's energy to the gate, changing its shape. The ring could then pass to the other side before the gate closed. But when the ring was on the right side, it was positioned too far away from the gate to transfer light energy to open it. As a result, the particles accumulated on the right. Because light energy was put into the system, it did not violate the second law of thermodynamics.

It took two lab members, PhD candidate Viviana Serreli and postdoc Chin-Fa Lee, more than three years to construct a rotaxane able to carry out this task. During this time the team synthesized and tested many smaller components, each time refining the design, before putting together the complete molecule. "The first time we shone the light and saw the distribution of the rings change, being driven away from equilibrium, was a very humbling moment," says Leigh.

Now he plans to make a molecular motor that functions like a biological pump in a membrane. "We want to make things that are far beyond the current state of the art," he explains. ■

KEY COMPETITION

When Dominique Bergmann learned that she and a lab she'd previously collaborated with were working on the same genetic pathway, her heart sank. "There was a moment of sheer, utter panic," says Bergmann, a biologist at Stanford University in California. The pathway includes three genes involved in the development of stomata — pores in plants that take in carbon dioxide for photosynthesis and prevent excessive water loss.

Bergmann's group had collaborated with Keiko Torii, a biologist at the University of Washington in Seattle, and colleagues on a separate project, but didn't realize their research would steer them towards similar molecules. But in the end, says Bergmann, the two sets of results complemented each other.

Her team found two of the genes, *SPEECHLESS* (see page 537) and *FAMA* (reported in a previous paper), and Torii's group found the other, *MUTE* (see page 501). These are the first genes required for the development of stomatal cell lineages to be identified.

Similar molecules in animals, including humans, have a role in the differentiation of neural and muscle cells. Bergmann considers stomata to be among the "most influential cell types on the planet". The next challenge, she says, will be deciphering how the three genes interact. ■