Nano machine switches between biological and silicon worlds

April 24 2006

Scientists have created a molecular switch that could play a key role in thousands of nanotech applications. The Mol-Switch project successfully developed a demonstrator to prove the principle, despite deep scepticism from specialist colleagues in biotechnology and biophysics.

"Frankly, some researchers didn't think what we were attempting was possible because standard descriptions in physics, for example the Stokes equation for viscosity indicated that the system might not work. But viscous forces do not apply at the nano-scale," says Dr Keith Firman, Reader in Molecular Biotechnology at Portsmouth University and coordinator of the Mol-Switch project, funded under the European Commission's FET (Future and Emerging Technologies) initiative of the IST programme. "However, we got our molecular switch to work."

The upshot is that the Mol-Switch project was far more successful than expected. The team's switch works with a number of DNA-based motors and can achieve incredible performance.

Specific sensors, which emit electrons, can tell if the biological motor is working, so the switch links the biological world with the silicon world of electronic signals.

The nano-switch explained

Here's how it works. The team uses a microfluidics chip that includes a number of channels measured in nano-metres. The novelty of microfluidics is that it can channel liquids in laminar, or predictable, flow.

The floor of this channel is peppered with Hall-Effect sensors. The Hall Effect describes how a magnetic field influences an electric current. That influence can be measured to a high degree of accuracy. These measurements link the biological motor with the electronic signals of the silicon world.

The biological element of the device starts with a DNA molecule that's fixed to the floor of the microfluidic channel. This strand is held upright, like a string held up by a weather balloon, by anchoring the floating end of the DNA strand to a magnetic bead, itself held up under the influence of magnetism.

A specific type of protein, called a Restriction-Modification enzyme, provides one of the DNA motors. The novelty of this type of DNA motor is that it will only bind to a specific sequence of the DNA bases A, C, G and T. "This binding is very specific, a motor will bind only with its corresponding bases, so you can control exactly where the motor is placed on the vertical DNA strand," says Firman.

The motor is attached to the strand at the specific sequence of bases. Then the team introduces ATP, the phosphate molecule that provides energy within living cells, into the microfluidics channel. This is the fuel for the motor. The motor then pulls the upright DNA strand through it until it reaches the magnetic bead, like a winch lowering a weather balloon.

A Hall-Effect sensor can measure the vertical movement of the magnetic bead which indicates whether the switch is on or off. That, in an over-simplified nutshell, is the essence of the molecular switch, an actuator for the nano-scale world.

The underlying importance

This is particularly important because a nano-scale actuator will be immensely useful. An actuator is a mechanism that supplies and transmits a measured amount of energy for the operation of another mechanism or system. It can be a simple mechanical device, converting various forms of energy to rotating or linear mechanical energy. Or it can convert mechanical action into an electrical signal. It works both ways.

"The light switch, the button that makes a retractable pen, all these are actuators, and by developing a molecular switch we've created a tiny actuator that could be used in an equally vast number of applications," says Firman.

The number of potential applications is staggering. They can be used for flow-control valves, pumps, positioning drives, motors, switches, relays and biosensors.

The system could be used to develop molecular circuits, or even molecular scale mechanical devices. The potential applications are difficult to predict, but are only limited by the imagination of researchers, such is the versatility of an actuator on this scale.

"It could be used as a communicator between the biological and silicon worlds. I could see it providing an interface between muscle and external devices, through its use of ATP, in human implants. Such an application is still 20 or 30 years away," says Firman "It's very exciting and right now we're applying for a patent for the basic concepts."

Potential for DNA sequencing

One hugely important application is DNA sequencing, discovering the order of the four DNA-bases, the absolutely fundamental step for genetic research. This is almost a 'bonus' application, a happy side effect of the actuator's operation.

The team used the Mol-Switch with time-resolved fluorescence for DNA sequencing. The team used Fluorescence Resonance Energy Transfer (FRET) between a fluorescent molecule on the motor and a fluorescent molecule in the DNA sample to be sequenced.

"Knowing the speed of the motor, which is quite reliable and steady at any specific temperature, we could locate the position of the DNA-based fluor [molecule] relative to the binding site of the motor," says Firman. "More work needs to be done. However, the concept is sound and we now have enough evidence to indicate that this could be used to sequence single-nucleotide polymorphisms (SNPs) that cause genetic disorders."

The team investigated a number of DNA motors for the project, notably EcoR124I and FtsK. Both worked and both offered specific advantages, with the EcoR124I providing greater flexibility and the FtsK providing greater speed.

"We're applying for a new project under the [European Union's] New and Emerging Science and Technology (NEST) scheme and, if that's successful, we will be able to develop a commercial product for biosensing," concludes Firman.

Source: IST Results