Successful test of single molecule switch opens the door to biomolecular electronics

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A team of scientists led by biophysicist Stuart Lindsay from the Biodesign Institute at Arizona State University have created the first reproducible single molecule negative differential resistor and in the process have developed a groundbreaking experimental technique that provides a "roadmap" for designing single molecule devices based on biochemistry.

The findings will be discussed in a presentation by Lindsay on February 18 at the American Association for the Advancement of Science annual meeting in Washington, D.C. in an 8:30 a.m. session entitled "Frontiers in Bioinspired Materials and Nanosystems." The findings will also be reported in a forthcoming edition of the American Chemical Society's journal Nano Letters.

Lindsay's team reports achieving an experimental result that physicists have been trying to detect for a long time - negative differential resistance in a single molecule attached to electrodes.

The specifically designed molecule, a hepta-aniline oglimer, belongs to a group of molecules that biochemists have long believed to be capable of being molecular switches, but that have failed to exhibit those properties in conductance experiments. The team solved the problem by developing a technique where the molecule could be tested in an electrolyte solution, a condition that past experiments have never attempted because of the problem of interaction between the solution and the electrodes.

"Almost everything we know about charge transfer in molecules is based on measurements made with the molecules suspended in solution," Lindsay said. "Chemists have understood for a while that the solvent itself plays a major part in charge transfer processes - the ions in the solution are necessary to make the process happen.

"Yet almost every 'molecular electronic' measurement made to date has been made in a vacuum or other conditions that suppress solvent-mediated events. It's no wonder that we could not get reliable results," he said.

Though numerous molecules have been identified as targets for future use as nano-scale electronic components such as switches, photoelectric devices and hydrogen generators, some major technical problems have stymied further research. The first of these has been the difficulty in making reliable connections with single molecules in order to test their electronic behavior. Recently, this problem this problem may have been solved by using the scanning probe microscope to make and measure single molecule contacts with molecules designed to bond at their ends with a surface and the probe tip.

The second problem, however, has been that these connected molecules have failed to exhibit the predicted electrical properties when tested without a conducting solution. Physicists attempting these measurements avoided using electrolyte solutions because the applied current would leak into the surrounding solution. Lindsay and his team solved this problem by applying an insulating coating to the entire probe, except its very tip, so there was minimal electrical contact with the solution.

According to Lindsay, the solution is required to make the process work because, without it, the initial insulating property of the molecule prevents the first electron from ever jumping on to the molecule, a kind of catch-22. Ions in the solution "jiggle" the molecule enough to bring about an unusual configuration of the molecule that does allow the electrons from the electrodes to jump on to the molecule, a process first pointed out by Rudy Marcus of Cal Tech (for which he was awarded the 1992 Nobel prize in chemistry).

The oligoaniline molecule the team tested has three electrical states, a neutral state where it is an insulator, a second state where electrons are removed to oxidize the molecule and make it a conductor, and a third state where more electrons are removed and turn it back into an insulator. Measuring the connected molecule in a sulfuric acid solution, the team was able to make reproducible measurements showing all three states by measuring the current through it as electrons were removed by another electrode, turning it from an insulator to a strong conductor and then back into an insulator again.

Given the measured electrical properties of the oligoaniline, Lindsay notes that if the molecule is maintained at its highly conductive state (at low voltage) and then the voltage applied to the molecule is increased, the connections to the molecule will, themselves, rip electrons out of the molecule, pushing it back into its insulating state. This decrease of current with increasing voltage is called "negative differential resistance" (NDR) and it allows a useful device to be made with just two electrodes, not the three originally used.

"NDR is the basis for memories, switches and logic elements," said Lindsay. "It has been observed in molecules before but never in controlled conditions, never at low voltages, and not in a predictable way."

Lindsay stress that the main value of the finding is not so in having found a molecule that could be developed into a working electrical switch, as it is in discovering some critical design parameters that should make possible future successful research in designing molecular devices.

"We have a working rational roadmap now for how to do this and we're already hard at work applying it to a wide variety of potentially exciting applications," he said.

Authors on the Nano Letters paper are Lindsay, who is also the Nadine and Edward Carson Professor of Physics and Chemistry and Biochemistry at ASU; ASU physicists Fan Chen, and Jin He; and Columbia University chemists Colin Nuckolls, Tucker Roberts and Jennifer E. Klare.

Source: Arizona State University

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