SUSTAINABILITY

Building Single-Molecule Circuits

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As electronic devices become ever smaller, and the demand for ever tinier components grows, understanding how current flows through these materials at the nanometer (billionth of a meter) scale is becoming increasingly important. Latha Venkataraman conducts research on the molecular level, where she focuses on probing, manipulation, and control of single molecules as active elements in electrical circuits. "I am working to understand the interplay of physics, chemistry, and engineering at the nanometer scale," she said.

By probing and understanding electronic structure and properties at this scale, her research findings will not only influence the design of molecules as active electronic components; they will also enhance the understanding of charge transport across metal-organic interfaces, with impact on the fields of organic electronics, photovoltaics, catalysis, and biological processes, including respiration and photosynthesis. "These experiments provide a deeper understanding of the fundamental physics of electron transport, while laying the groundwork for technological advances at the nanometer scale," she said.

To fabricate circuits with a single molecule, a physical connection has to be made between the single molecule at the nanoscale and the metal electrodes, in microscale. Building such circuits with atomic precision is beyond the capabilities of top-down approaches; indeed, one of the main challenges has been to figure out how to measure the resistance of electronic components that consist of a single molecule. Although there are a number of techniques that have been used, the large variations in the experimental results produced by these techniques had made it difficult to predict how individual molecules will behave as electronic devices.

Venkataraman's pioneering research has made possible these measurements by using a bottom-up approach to form single-molecule circuits where a molecule self-assembles into a gap between two metal electrodes. The ability to create devices with known structure is then controlled by the chemistry at the metal-molecule interface, which can be tuned.

In her lab, these device fabrications and their characterizations are carried out using state-of-the-art scanned-probe microscopes, which are built inhouse to have sensitivity to small currents and forces, as well as to have the required mechanical stability. In her group, these instruments are then used, for example, to measure electronic conduction or single bond breaking forces. They show that these properties relate not only to the molecular structure, but also to the metal contacts and linking bonds.

"A single-molecule circuit is the ultimate limit one can achieve," says Venkataraman. "Understanding how to control and transfer charges on this scale allows us to push the frontier."

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