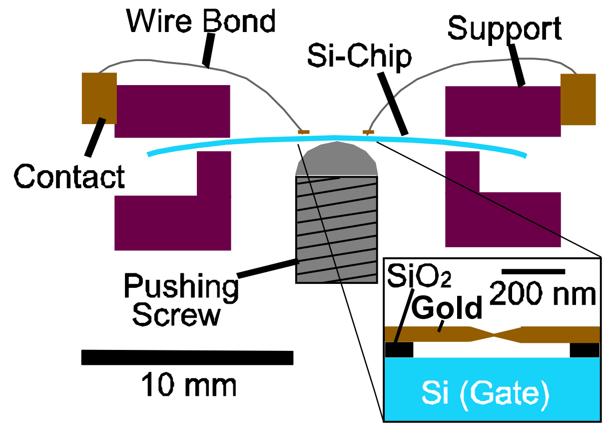
New Tools for Molecular Electronics

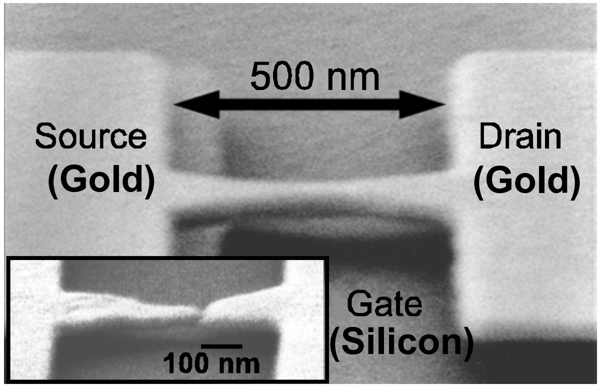
Dan Ralph, Cornell University, DMR-0244713

We are investigating the electrical properties of single molecules, to understand the ultimate physical limits of small-scale electronics. The key to this work is to develop new ways of contacting single molecules and systematically measuring their properties.

We have developed a tool that enables electrical measurements on a molecule while simultaneously pulling on the molecule to change its geometry and also applying an electrical field to control its energy levels. This combined control enables detailed understanding of how changes in molecular structure affect electrical conduction.



An electrically-gated and mechanically-adjustable single-molecule transistor. A molecule is connected to two closely-spaced gold electrodes 40 nm above a silicon gate. The distance between electrodes is controlled by bending the silicon chip.



Nanoscale gold bridge that is broken (inset) to make the two electrodes in the mechanically-adjustable molecular transistor.

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The ultimate limit possible for shrinking the size of electronic components would be to make them from single molecules. Only recently have the first techniques been developed for making electrical measurements on individual molecules, so that the field of molecular electronics has begun to develop. However, so far the tools available for making electrical measurements on single molecules are quite crude. In many experimental schemes, it is difficult to tell even whether or not a molecule is present, because non-linear electron tunneling between closely-spaced bare electrodes or conduction through unintentional metallic shorts can easily be mistaken for molecular signals. This has led to errors in the interpretation of some experimental results.

What is needed are new tools with more experimental "knobs" -- ways to controllably modify the electrical behavior of a single molecule under test, so that its properties can be compared in more meaningful and systematic ways to predictions. We have completed the development of a tool for measuring single molecules that allows simultaneously both tuning of the spacing between electrodes using fine-scale mechanical motion and also tuning of the energy levels on the molecule with an electrical silicon gate. These combined capabilities enable greatly improved understanding of electron motion in molecules, by allowing simultaneous control over both the geometry of the molecule and the energies of the states in which electrons can travel. We have demonstrated the performance of the devices using single C_{60} ("Buckyball") molecules.

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Education:

One undergraduate (Sara Slater) and one graduate student (Ferdinand Kuemmeth) are supported by this grant and another (Alex Champagne) receives partial support.

Dan Ralph serves as Director of Undergraduate Studies in Physics at Cornell, and in addition to teaching at Cornell he frequently serves as a lecturer at international physics schools for grad students:

(2003) “Frontiers in Magnetism”, Boulder School of Condensed Matter Physics
(2004) “Nanoscopic Quantum Physics”, Les Houches School of Theoretical Physics, France
(2005) “Mesoscopic Physics”, Boulder School of Condensed Matter Physics

Societal Impact:

This work on developing ways to connect molecules into electrical circuits and on understanding their electrical properties will help to determine how single-molecule electronics can be applied in useful technologies.

The students working on this project are receiving the training in nanofabrication, physics, and presentation skills to be future leaders in nanotechnology.