Electron transport through single gold atoms and hydrogen molecules switching on the atomic scale

Trouwborst, Marius Leendert

Preface

At the time of writing this thesis, Intel Corporation announced the production of 32 nm ”node” processors in 2009. Hence, in the very near future, computers will be build from transistors with line widths of less than 300 atoms. Even more fascinating is the number of dopants in such processors: less than 30 atoms are used for the doping of a single transistor.

Meanwhile the race for miniaturization continues, clearly requiring an understanding of the physical processes on the atomic scale. These processes can be investigated by atomic or molecular junctions, where only a few atoms or molecules provide the connection between two electrodes. Since the electrical conductance of the whole system is dominated by this small number of atoms or molecules, one can learn about the physical phenomena on the (sub-)nanometer scale. Quantum tunneling, (local) phonon heating, electron-phonon coupling and electromigration (related to the force of electrons on the metal ions), form just a few intriguing examples.

For this thesis, electronic conductance measurements are performed on atomically sharp electrodes, fabricated by so called mechanically controllable break junctions. Such electrodes are created by pulling a metallic wire. For ductile materials, like gold, stretching such wires creates a neck of atoms at the weakest point of the wire. With further stretching, the wire breaks, resulting in two atomically sharp electrodes.

Such electrodes can be used to measure the mechanical and electrical properties of single atoms and/or molecules. For example, with our experimental setup we can control the electrode separation with an accuracy of 5 pm. This gives us the opportunity to investigate the mechanical properties of metallic wires, at electrode separations smaller than the size a single atom. As will be shown in this thesis, a detailed description can now be given of the adhesive forces between the apex atoms of the two electrodes.

Furthermore, measurements are presented on hydrogen molecules. The hydrogen molecule, as on of the most simple molecules in nature, can very well be used for understanding the role of molecular vibrations on the electrical properties of molecular junctions. As will be shown, by vibrationally exciting hydrogen molecules, a strong heating effect can be observed. Interestingly, this heating mechanism has some remarkable consequences. For example, a new type of memory is presented, based on molecular hydrogen. The operating voltage of the switch is simply given by the vibration frequency of the molecule. Hence, this thesis gives new physical insights in the mechanical properties and conductance properties of single atomic and molecular junctions.

Marius Trouwborst
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