Electronics based on Single Molecules

A talk by Dr. Emanuel Lörtscher
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As device dimensions continue to shrink into the sub-10 nm length-scale regime,[1] conventional semiconductor technology[2] based on complementary-metal-oxide semiconductor (CMOS) architectures will be approaching fundamental physical limitations. New strategies, including 1D-device concepts, innovative device architectures, smart integration schemes and the use of novel materials, need to be explored and their potential for application in nanoelectronics devices to be assessed. Molecular electronics is one possible candidate for future nanoelectronics as it is aimed at the use of small ensembles or even single molecules as functional building blocks in electronic circuits.[3]

In the first part of the presentation, various experimental approaches to contact and electrically address single molecules will be presented. In particular, the mechanically controllable break-junction technique (as used under ultra-high vacuum conditions and at variable temperatures down to 4 K at IBM Research – Zurich) will be introduced.

In the second part, various aspects of transport at the molecular scale will be discussed, ranging from the electronic coupling of the molecule to metal electrodes[4,5] to the conductance of the molecular backbone e.g. in conjugated B-systems of different lengths.[6] These fundamental and systematic investigations of the transport properties at the single-molecule level provide the know-how required to chemically synthesize and tailor molecular building blocks that exhibit intrinsic molecular functionality.

The third part therefore focuses on the original vision of molecular electronics to exploit intrinsic molecular functionalities for electronic operations. Besides current-switching and charge-storing, current rectification is one of the most basic functionalities required for any electronic application. Diblock dipyrimidinyl-diphenyl molecules consisting of a donor and acceptor moiety, resembling the visionary concept of Aviram and Ratner,[3] will be investigated using a statistical measurement procedure.[7,8] The current-voltage characteristics exhibit a temperature-independent rectification of up to a factor of 10 in the temperature range between 300 K and 50 K. Distinct molecular energy levels in resonance will be discussed using a semiempirical model assuming a variable coupling of the molecular energy levels as well as a nonsymmetric voltage drop across the molecular junction.

Finally, concepts to achieve conductance switching in molecular systems by an external stimulus will be presented by two examples of switching by conformational change or redox activity. Furthermore, the voltage-induced switching is used to demonstrate its application as non-volatile memory element. The performance parameters of the device with bit separations ranging from 7 to 70, bit retention times of several minutes and its operation at low voltage (1.1 V) demonstrate the high potential of molecules as bottom-up building blocks for future nanoelectronics.

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