Experimental aspects of molecular electronics

(XXXII. GradDays Heidelberg 7.-11.4. 2014)

presented by

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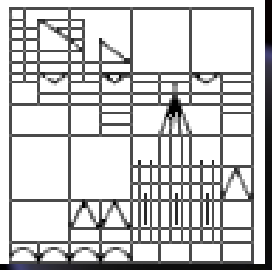
Based on a lecture worked out by A. Erbe, J. C. Cuevas, F. Pauly & E. Scheer, 2006 to 2014

Universität Konstanz



Outline of this opening lecture

1) What is molecular electronics?

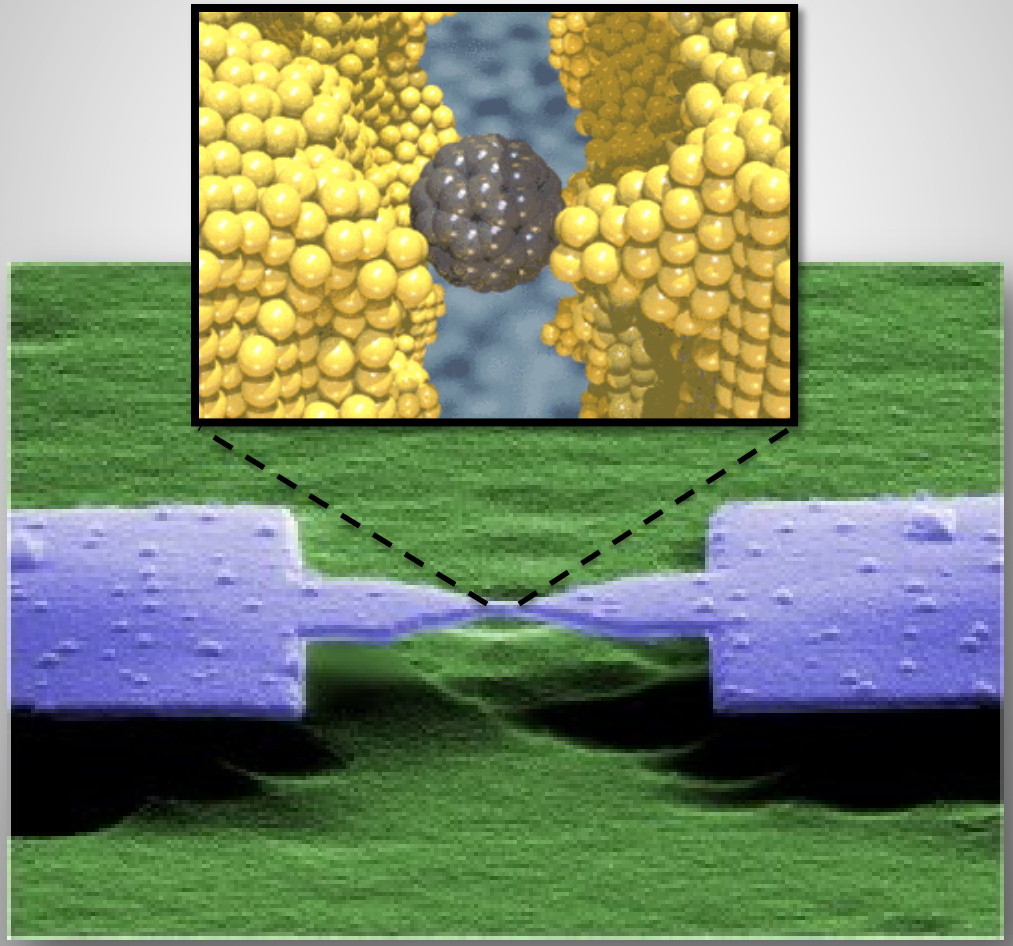
2) What are you going to learn in this course?

3) Questions, comments and suggestions.

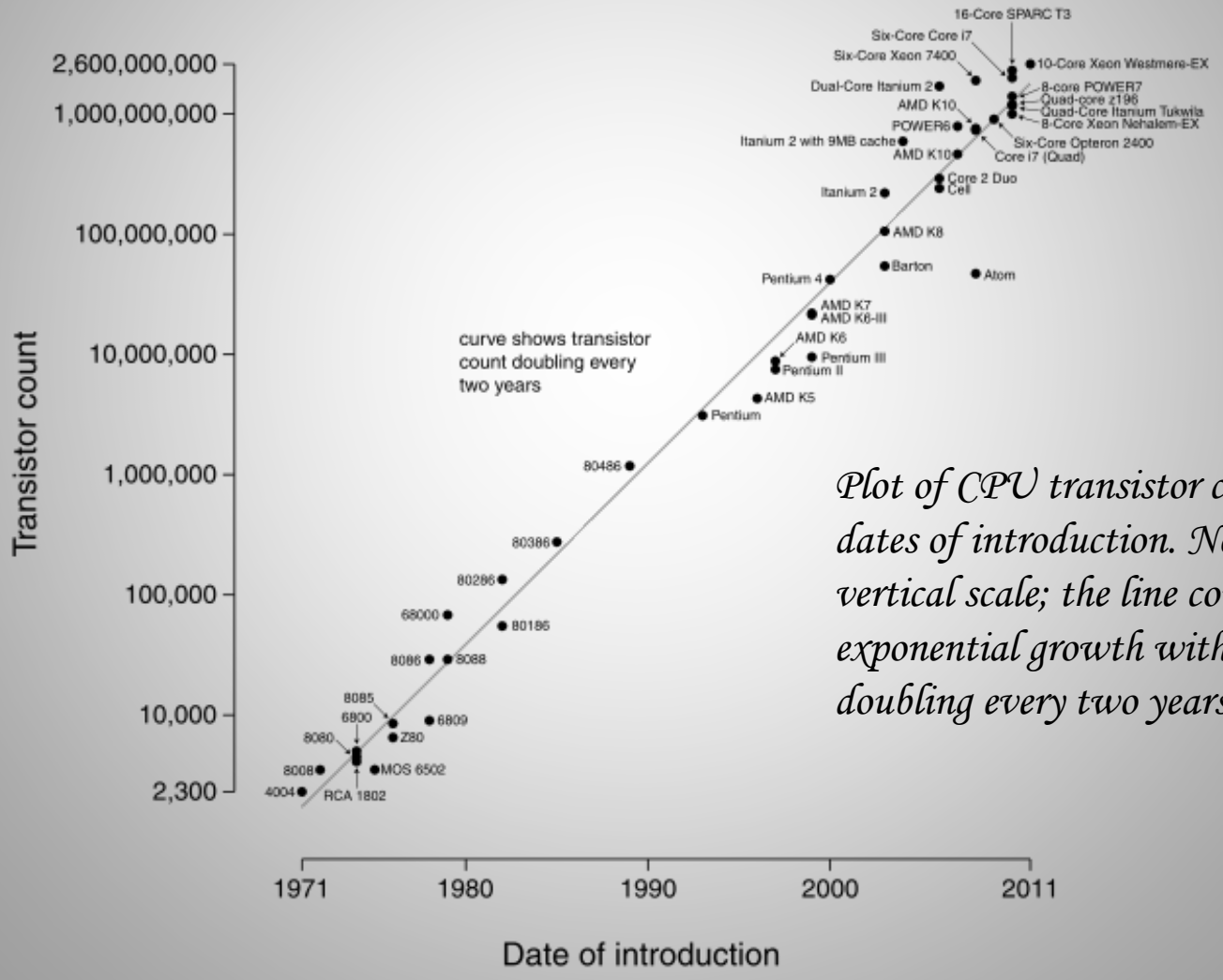
1. What is molecular electronics?

What is Molecular Electronics?

Molecular Electronics is an interdisciplinary field of science which aims at using molecules as active elements in nanoscale electronic circuits. The hope is that molecular electronics can become in the near future a viable technology that supplements today's silicon-based electronics.

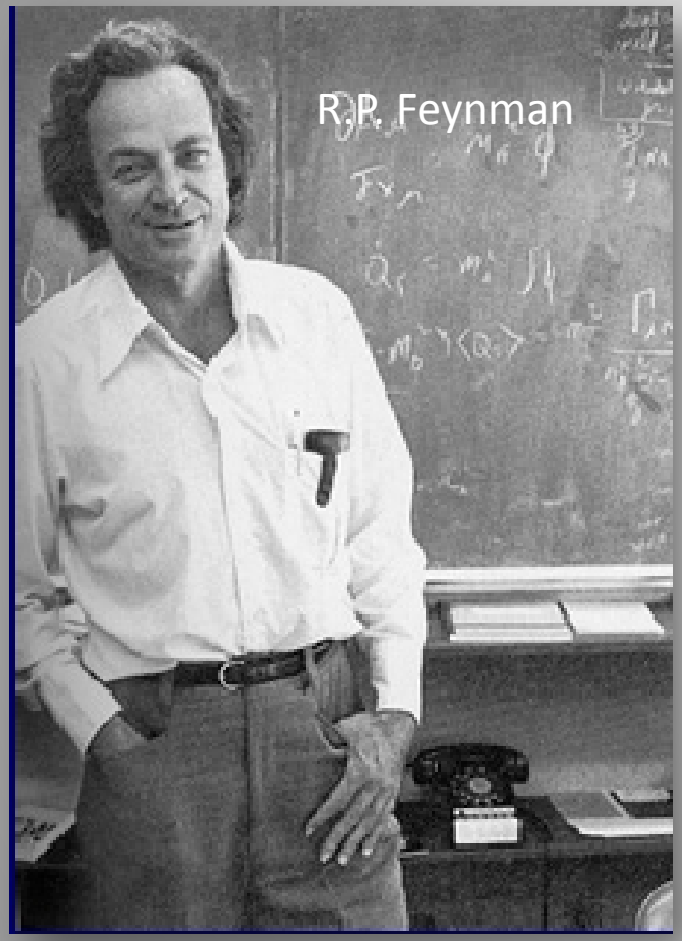


Motivation for Molecular Electronics: Need of new technologies



Plot of CPU transistor counts against dates of introduction. Note the logarithmic vertical scale; the line corresponds to exponential growth with transistor count doubling every two years.

Motivations for Molecular Electronics: basic science



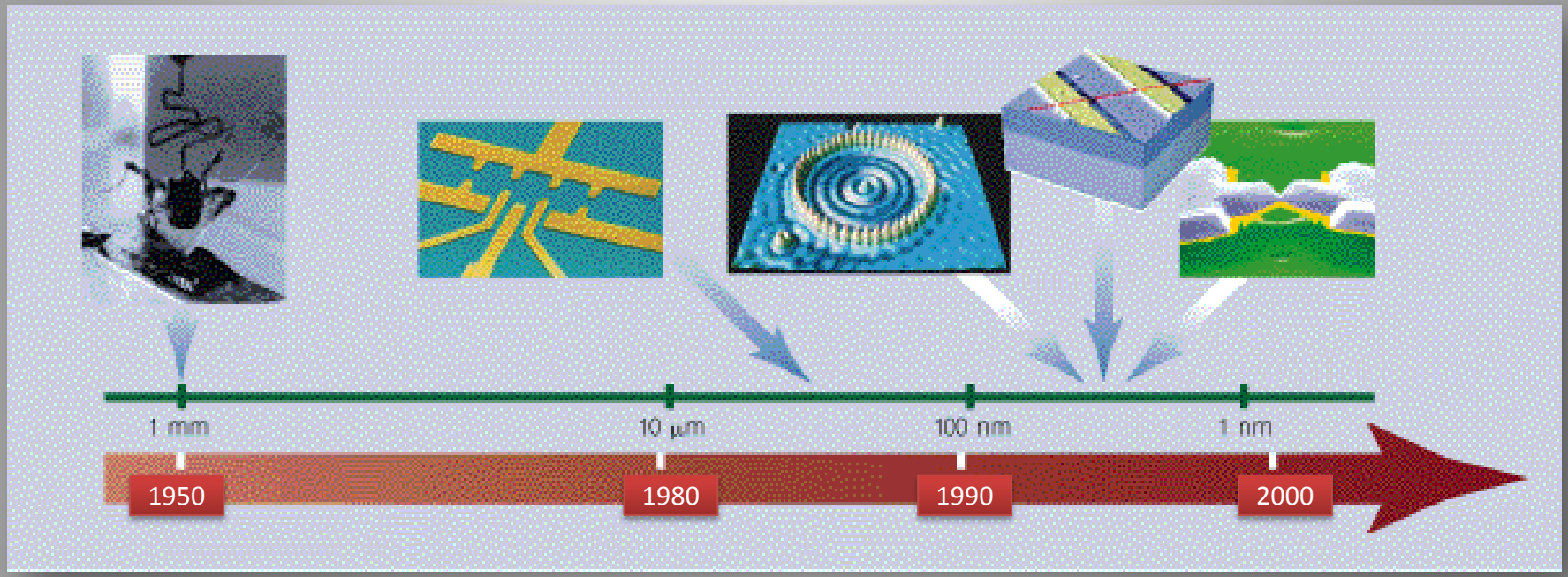
"There is plenty of room at the bottom"

… when we have some control of the arrangements of things on a small scale we will get an enormously greater range of possible properties that substances can have, and of different things we can do … we can manufacture in different ways.

Feynman, Caltech 1959.

Towards nanoscale electronics

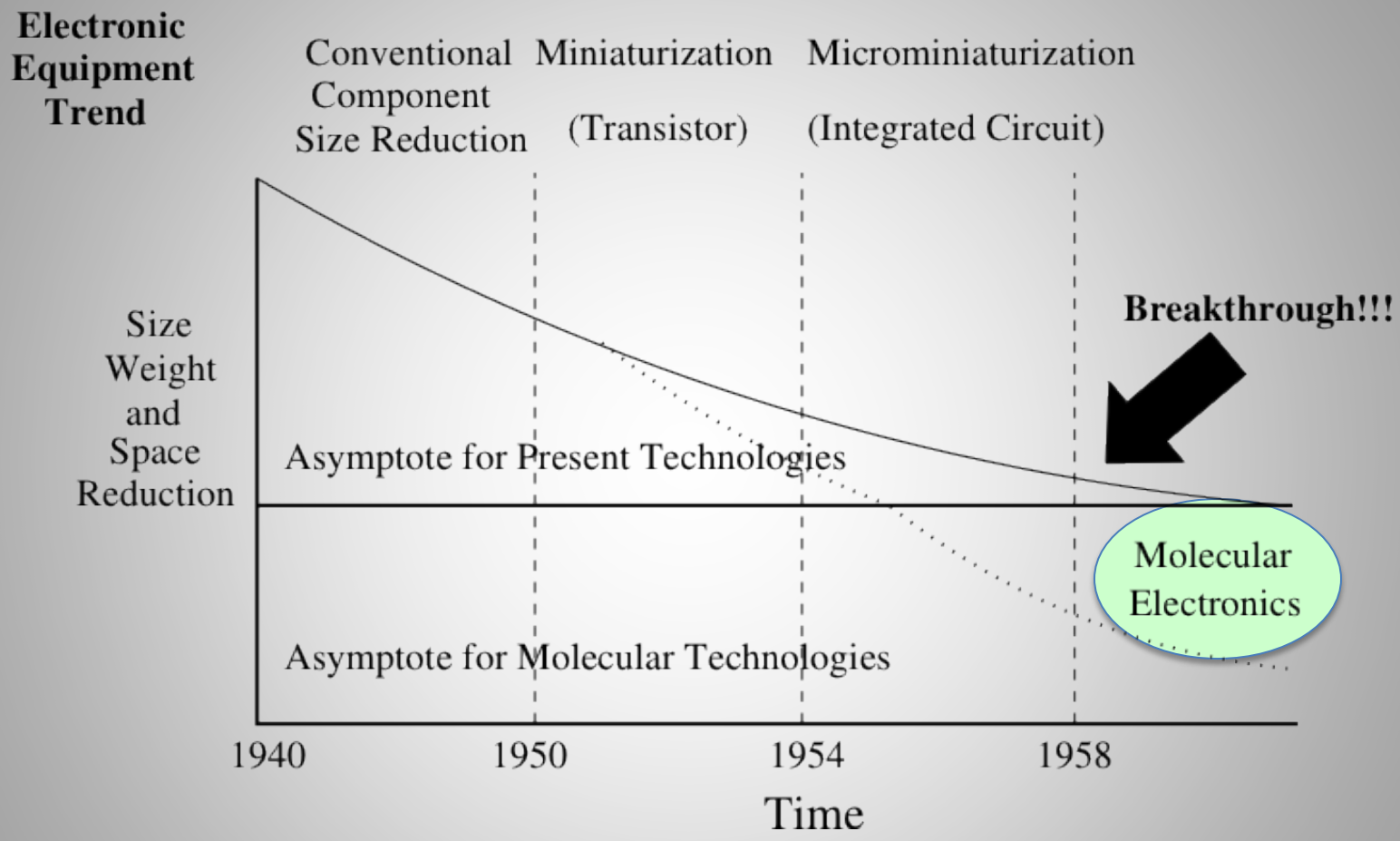
The advances in nanofabrication techniques have made possible to study the electronic transport through single atoms and molecules, which has given rise to the field of Molecular Electronics.



Fundamental issues:

- **New physical phenomena**
- **Potential applications**

Molecular Electronics: Origin



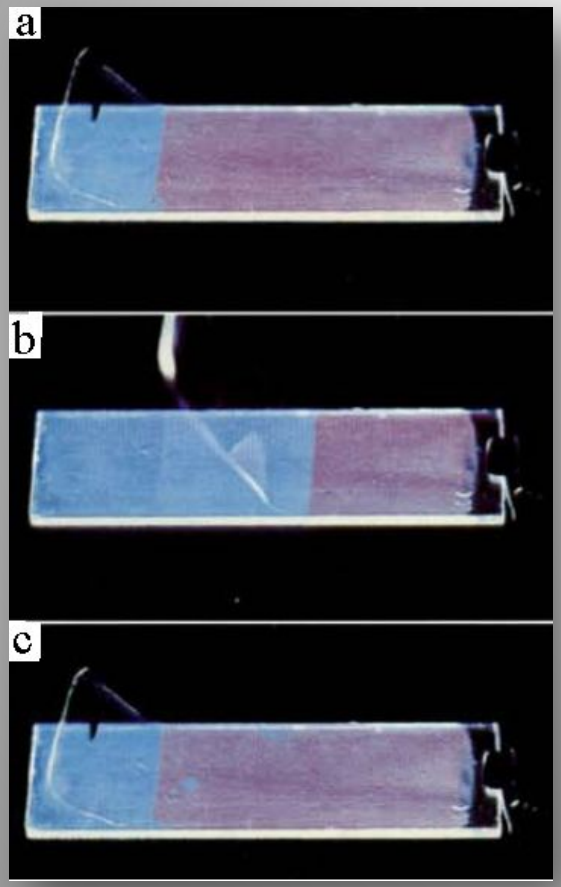
[Graph presented by colonel Lewis of the US Air Force in the first conference on molecular electronics held in November 1958. Here, one can see the trend in the miniaturization of the electronic components during the 1940's and 1950's. According to Lewis, molecular electronics should have constituted the next breakthrough in electronics by the end of the 1950's.]

Molecular Electronics: Origin

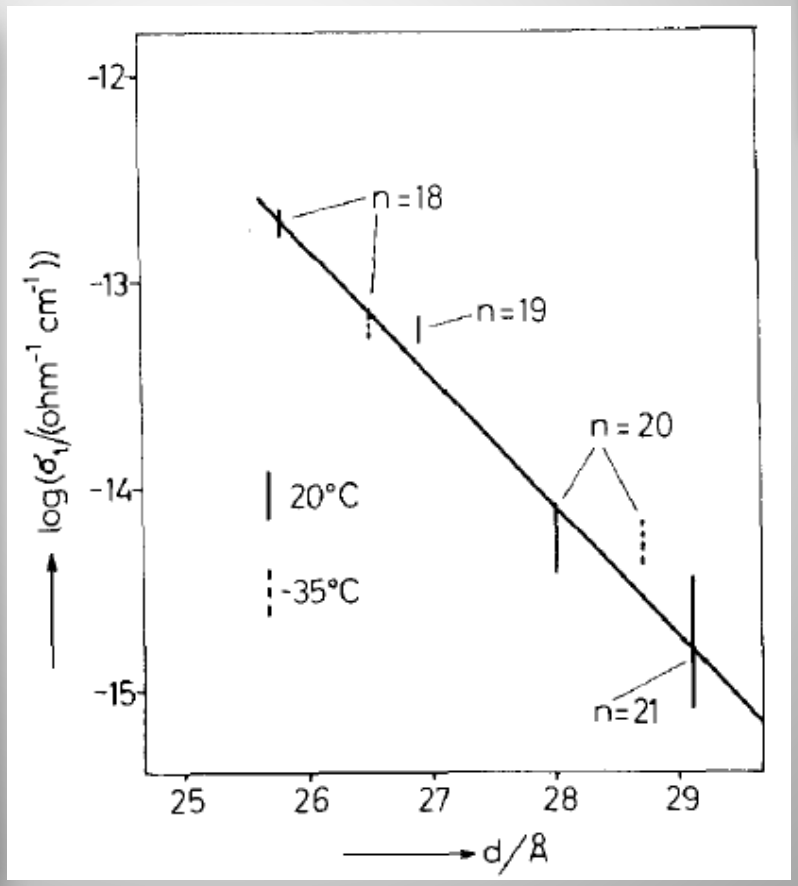
Hans Kuhn (Swiss chemist) and coworkers (1960's and 1970's):

Transport through molecular mono-layers

Hans Kuhn



Langmuir-Blodgett film



Tunneling through fatty acid salt mono-layers

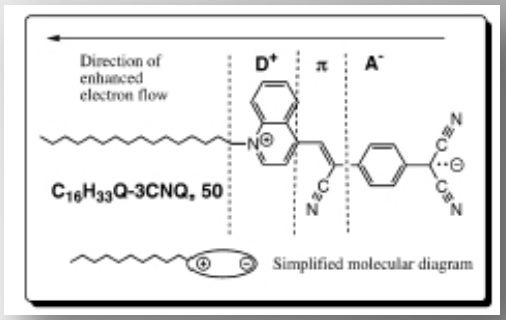
Molecular Electronics: Origin

"Molecular rectifiers"

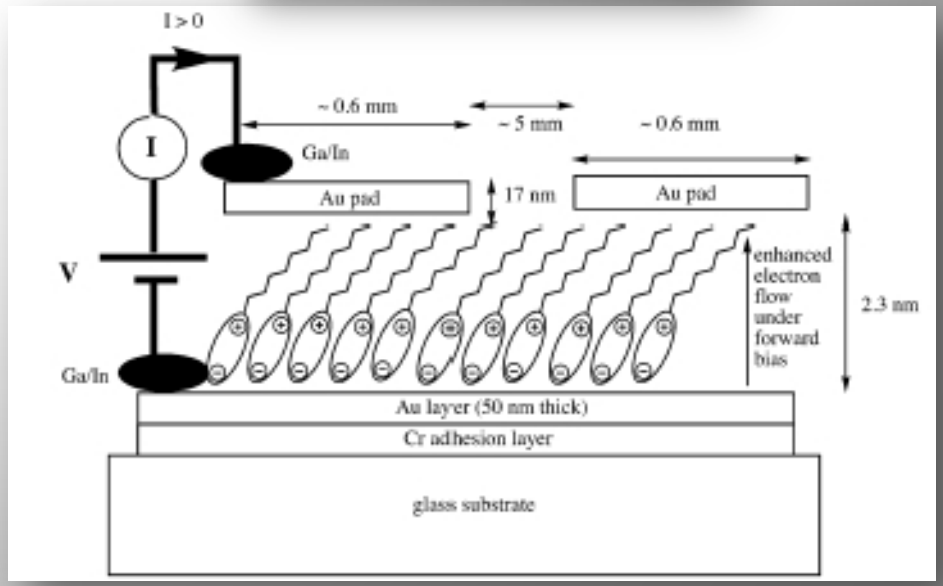
Arieh Aviram and Mark A. Ratner

(Chem. Phys. Lett., 1974)

"The construction of a very simple electronic device, a rectifier, based on the use of a single organic molecule is discussed. The molecular rectifier consists of a donor pi system and a acceptor pi system, separated by a sigma-bonded (methylene) tunneling bridge. The response of such a molecule to an applied field is calculated, and rectifier properties indeed appear."



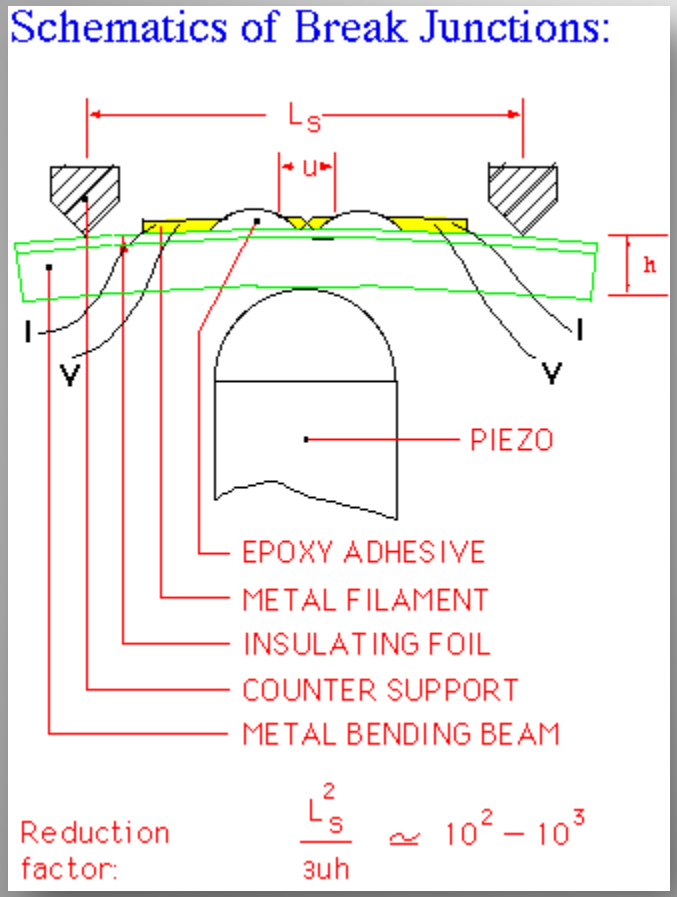
(… 23 years later)



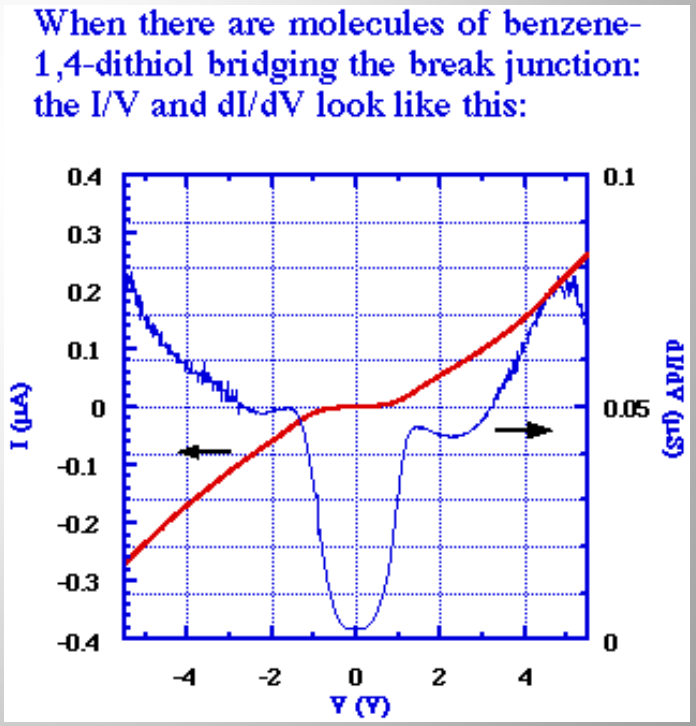
R. Metzger et al., JACS 1997

Molecular Electronics: Origin

Challenge in the 1990's: To contact single molecules.

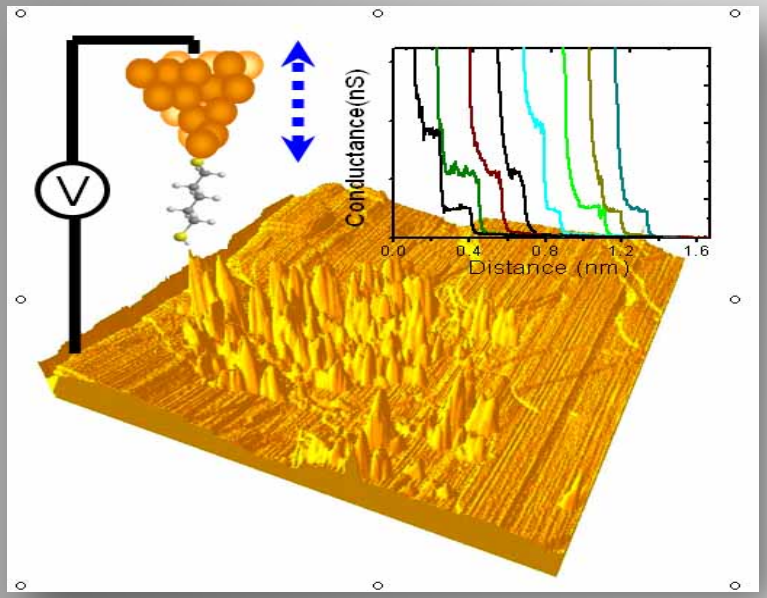


M. Reed et al., Science 1997

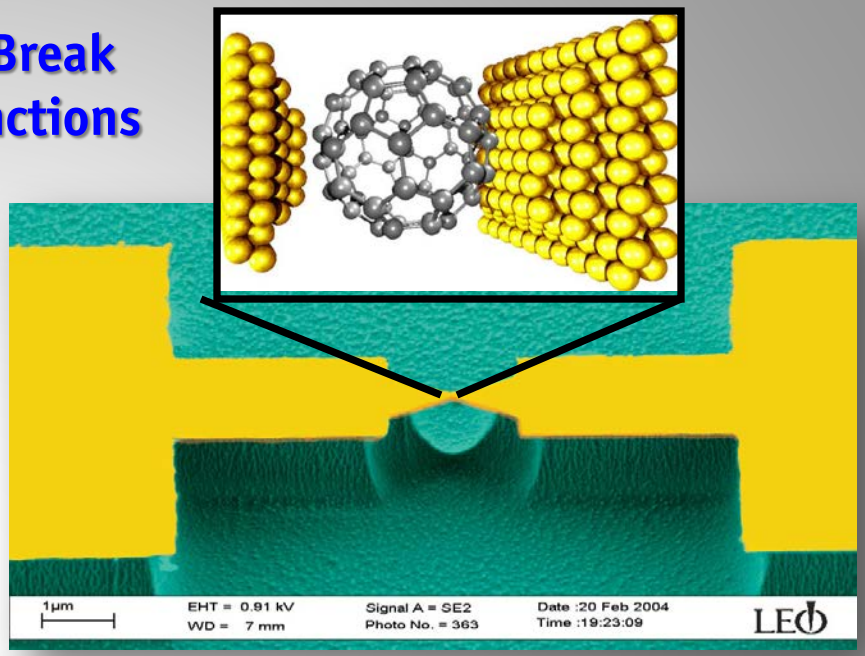


Molecular Electronics: Experimental techniques

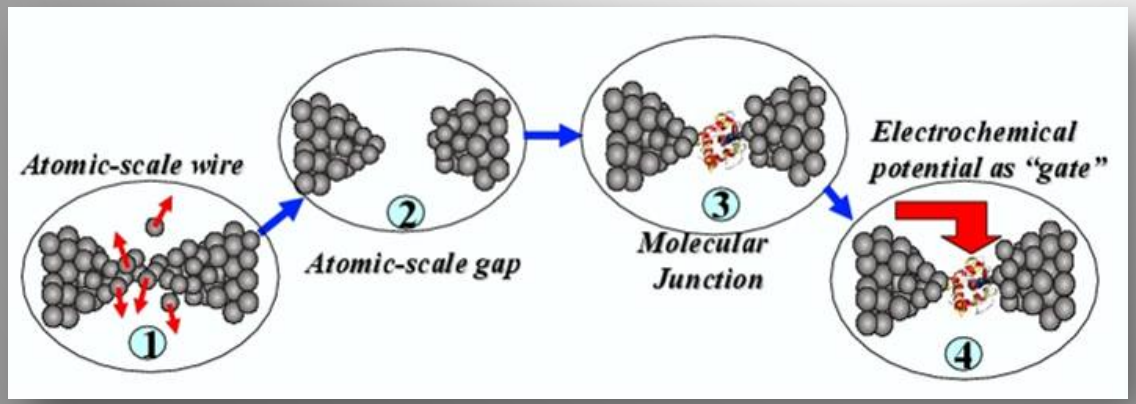
1. Scanning tunneling microscope



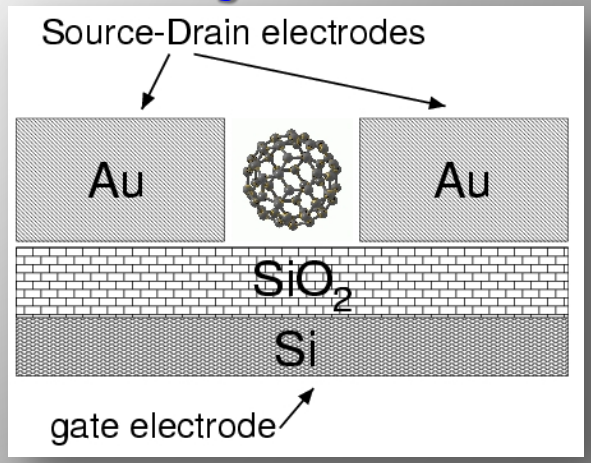
2. Break junctions



3. Electrochemical methods

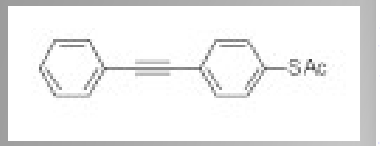


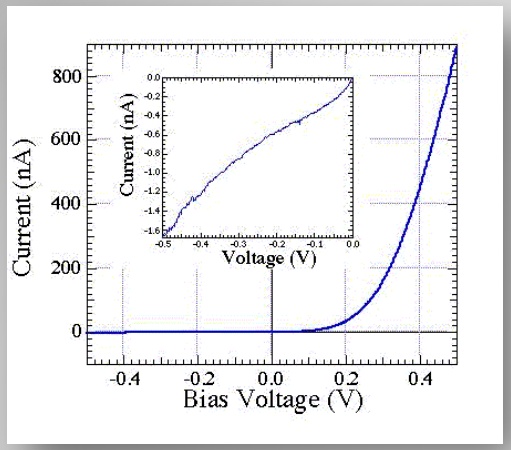
4. Electromigration



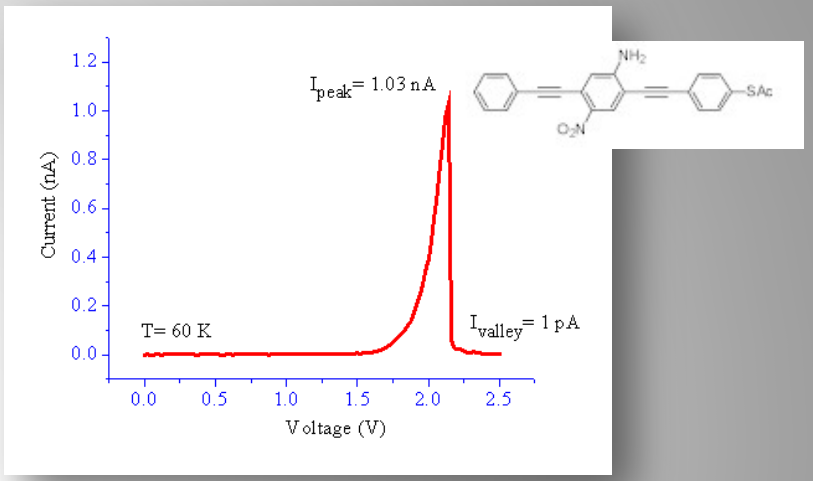
Molecular Electronics: Functional structures

1. Diode: Au-SAM-Ti-Au (Nanopore)
4-thioacetatebiphenyl, M. Reed, APL (1997)

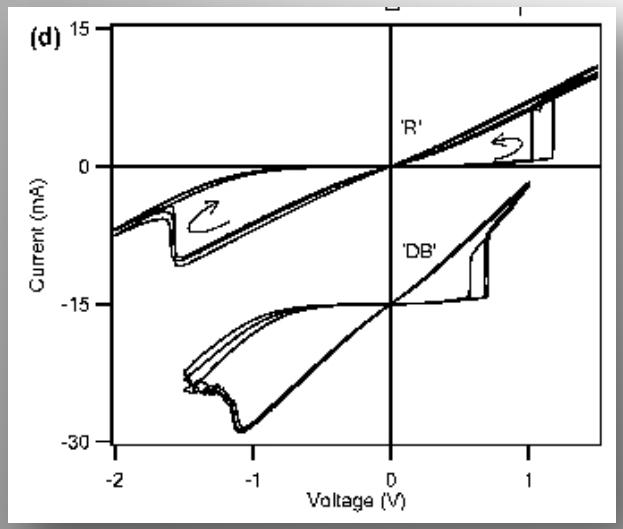




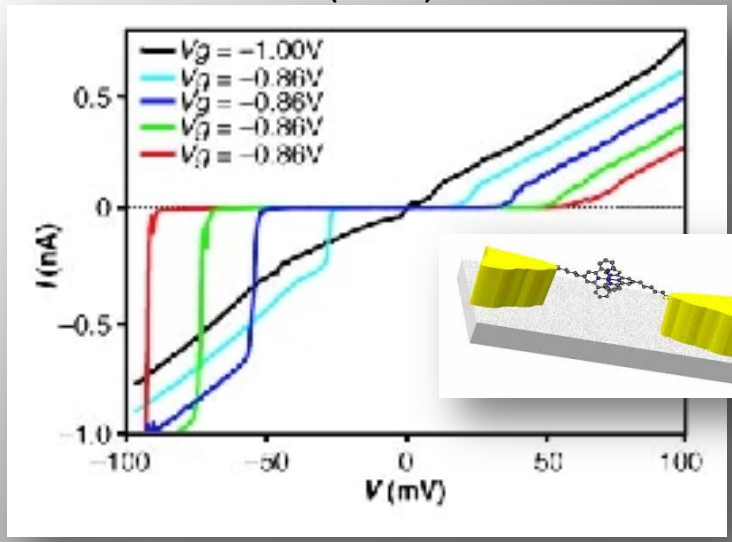
2. Switch: Nanopore (60 K)
M. Reed et al., Science (1999)



3. Reconfigurable Switch: Catanane
J.R. Heath et al., Science (2000)



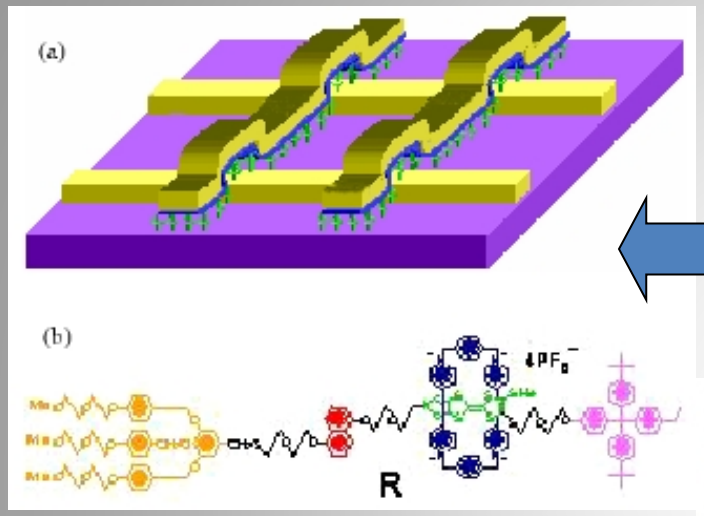
4. Single-electron transistor:
Park et al., Nature (2002)



Molecular Electronics: Scaling and integration

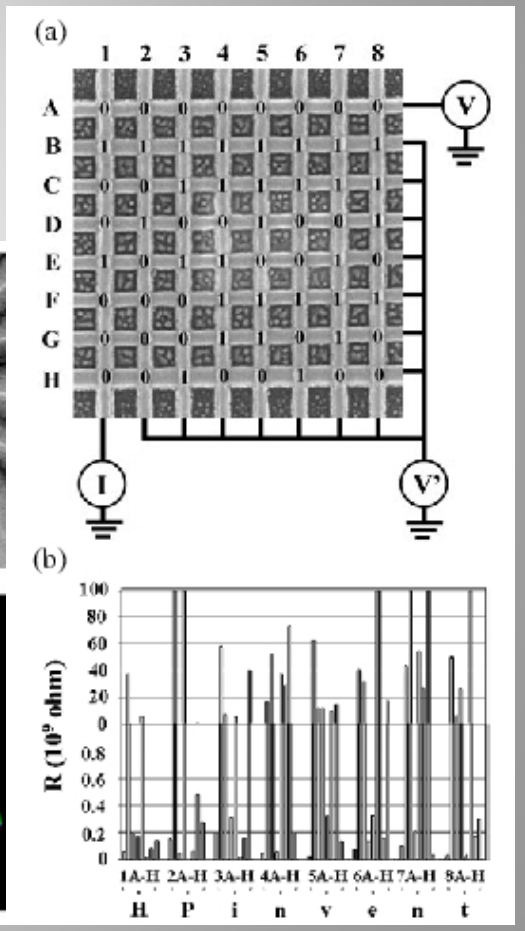
HP invent: nanoscale molecular-switch crossbar circuits (2003)

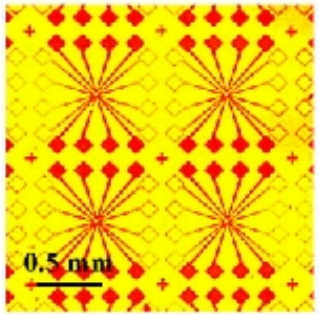
Nonvolatile memory with 6.4 Gbits/cm²

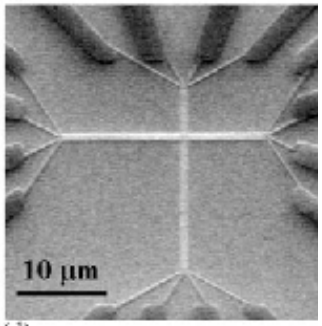


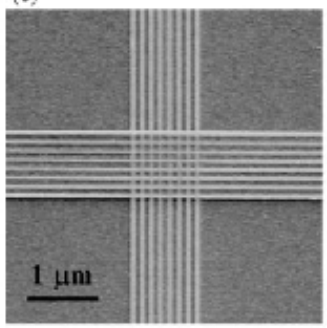
[2]rotaxenes

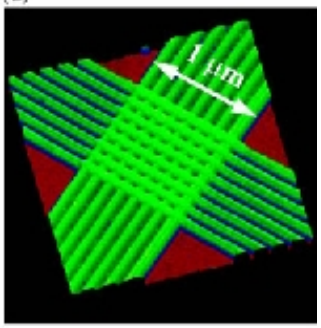
SAM between metallic nanowires









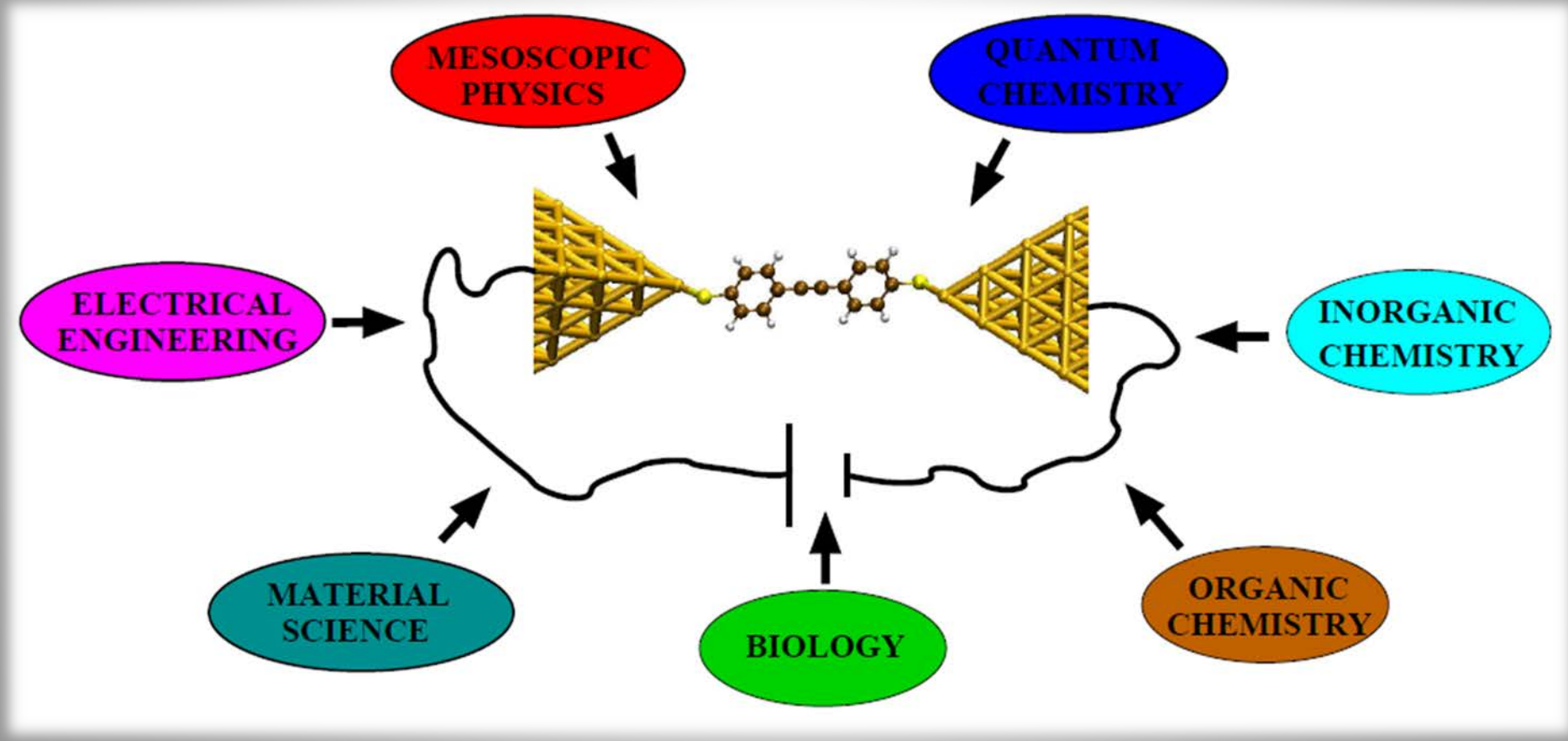


Crossbar (Pt/Ti)

Imprinting lithography

Molecular Electronics: general goals

- Understanding of the transport mechanisms at the molecular scale.
- Development of novel molecular-based nanodevices.



2. What are you going to learn in this course?

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Part I: Theoretical Fundamentals

1. Introduction
2. Reminder of solid state physics
3. Scattering Approach: Landauer Theory

Part II: Experimental Fundamentals

4. Realization of reduced dimensions
5. Molecules for molecular electronics
6. Single-atom and single-molecule contacts

Part III: Applications to Selected Topics in Molecular Electronics

7. Crash Course Green's Functions &
   Coherent transport through atomic and molecular junctions
8. Single-molecule transistor: Coulomb blockade and Kondo physics
9. Vibrationally-induced inelastic current
10. Beyond electrical conductance: shot noise, thermopower

If time allows: Part IV: Selected Recent Research Results

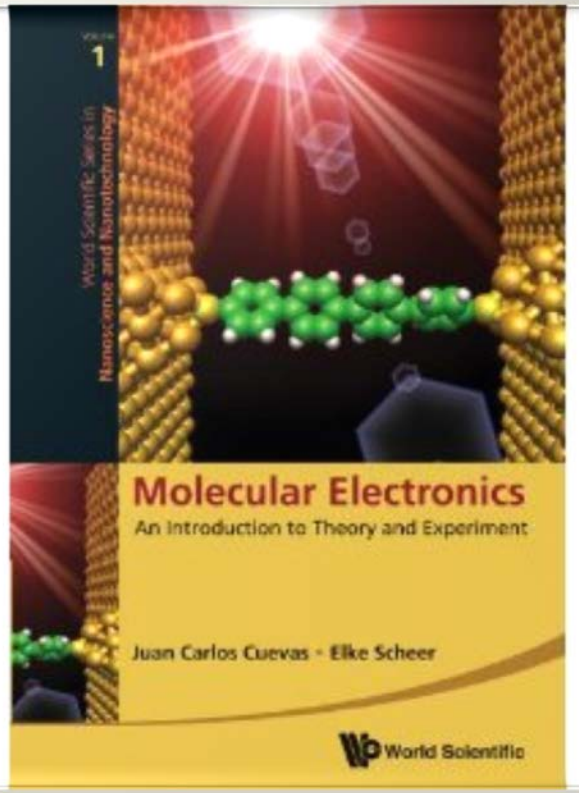
11. Electronic Transport Measurements
12. Atomic switches
13. Single-molecule contacts: Characterization and functionalities
14. Suggestions?

Literature/References

- *Electronic Transport in Mesoscopic Systems*, S. Datta, Cambridge Univ. Press (1997)
- *Quantum Transport: Atom to Transistor*, S. Datta, Cambridge Univ. Press (2005)
- *Introducing Molecular Electronics,* Lectures Notes in Physics, Vol. **80**, Eds. G. Cuniberti et al., Springer Verlag (2005)
- *Electrical Transport in Nanoscale Systems,* M. di Ventra, Cambridge Univ. Press (2008)
- *Nanoelectronics and Information Technology,* R. Waser, Wiley-VCH, 3rd ed. (2012)

Main reference of the course

Molecular Electronics:
An Introduction to Theory and Experiment
J.C. Cuevas and E. Scheer,
(World Scientific, Singapore, 2010).



Web page of the lecture

- **Link:** http://gsfp.physi.uni-heidelberg.de/graddays/

- **Material to be found on the web page (not yet….):**
  - Program of the lecture.
  - Scripts and handouts (will be updated in the course of the lecture).

- **Password needed for copyright-protected material**

3. Questions, comments and suggestions