

Beyond CMOS

Miniaturization ends with CMOS

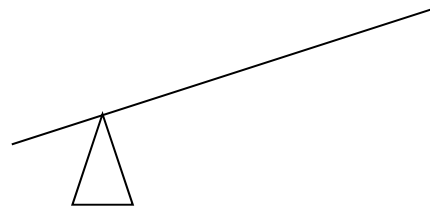
There are no technologies (single electron transistors, molecular electronics, superconducting electronics, spintronics, NEMs...) that can provide performance similar to CMOS at a **much** smaller size scale.

There are presently no transistors cheaper than silicon transistors

Candidates for orders of magnitude improvements of performance are quantum computing and molecular electronics.

Gain requires leverage

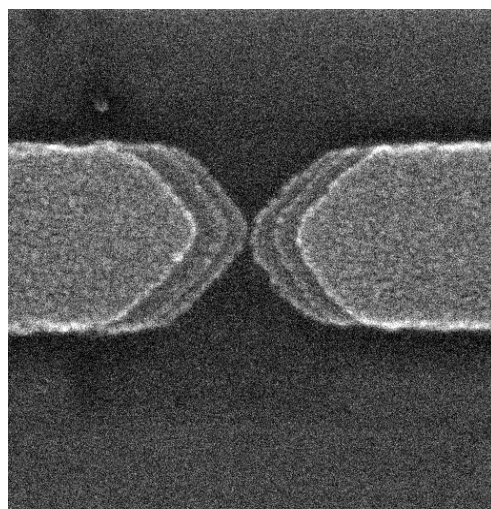
There are two lengths in an amplifier.



In CMOS the gate insulator is much thinner than the gate length.

If the short length is 1 nm, the long length is 10 nm.

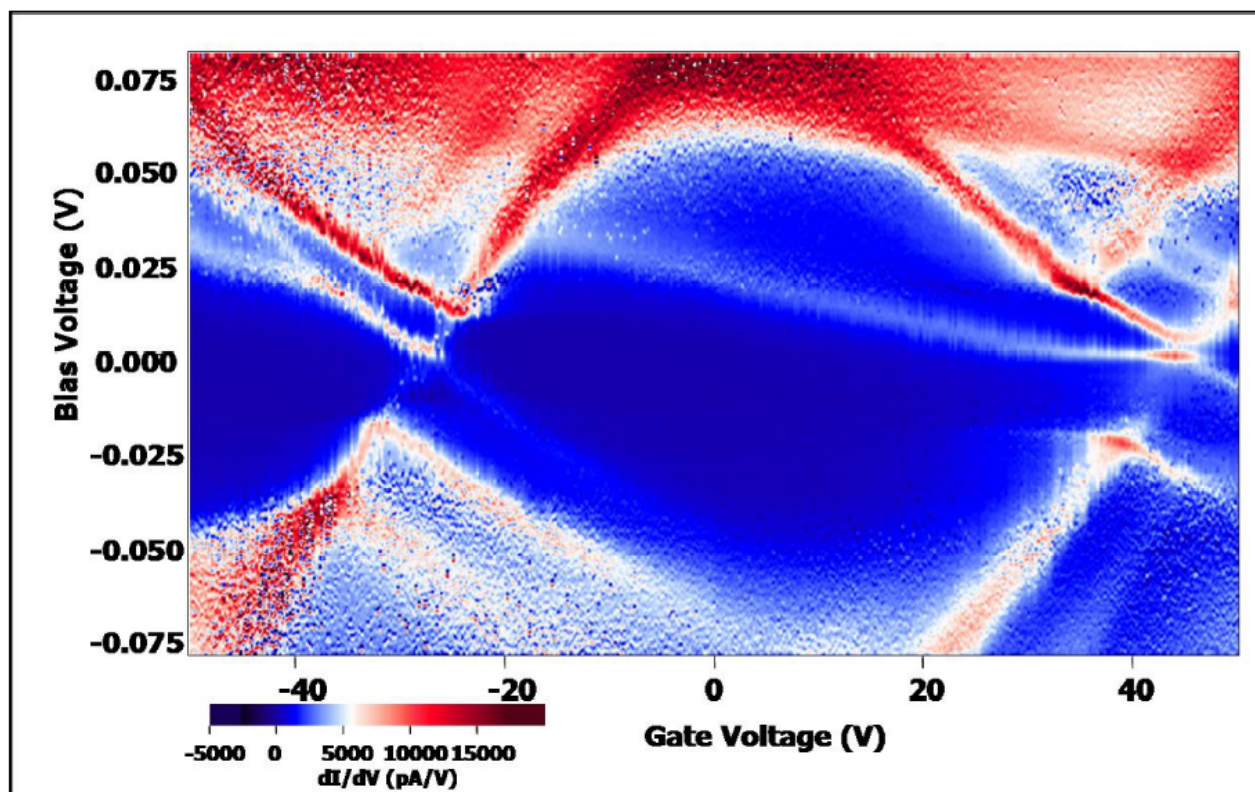
Measuring molecules



electrode 25-6

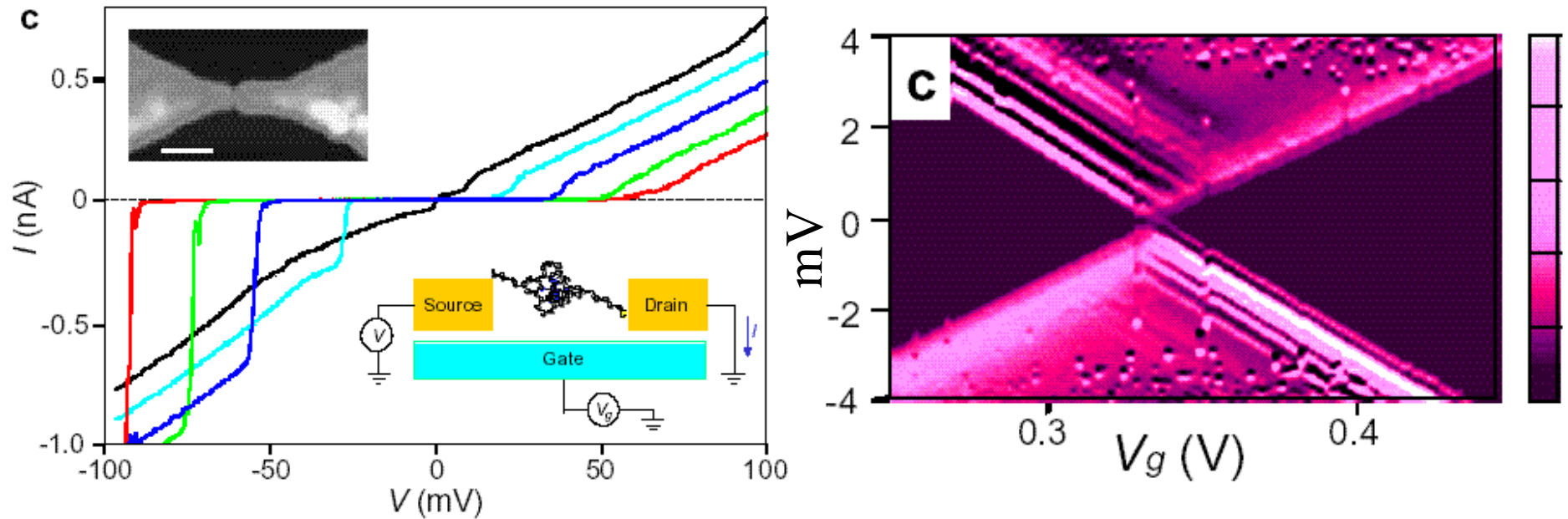
8.3μm

1,4-benzenedithiol

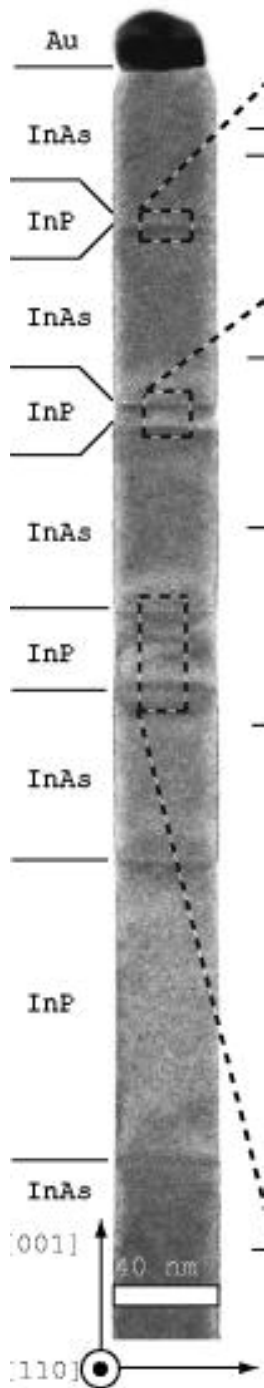


Results are unreproducible

Molecular electronics



Jiwoong Park, Abhay N. Pasupathy, Jonas I. Goldsmith, Connie Chang, Yuval Yaish, Jason R. Petta, Marie Rinkoski, James P. Sethna, Héctor D. Abruña, Paul L. McEuen, and Daniel C. Ralph, *Nature* 417 p. 722 (2002).

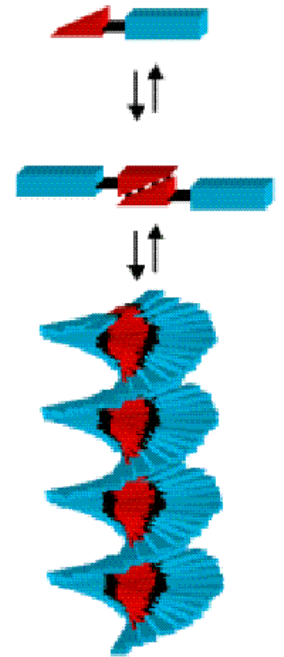
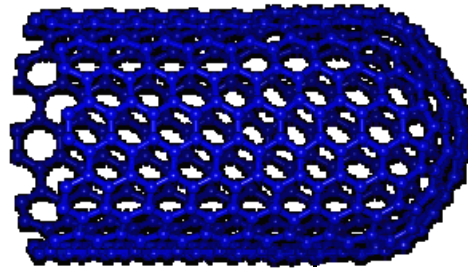


Use big 'molecules' as electronic components

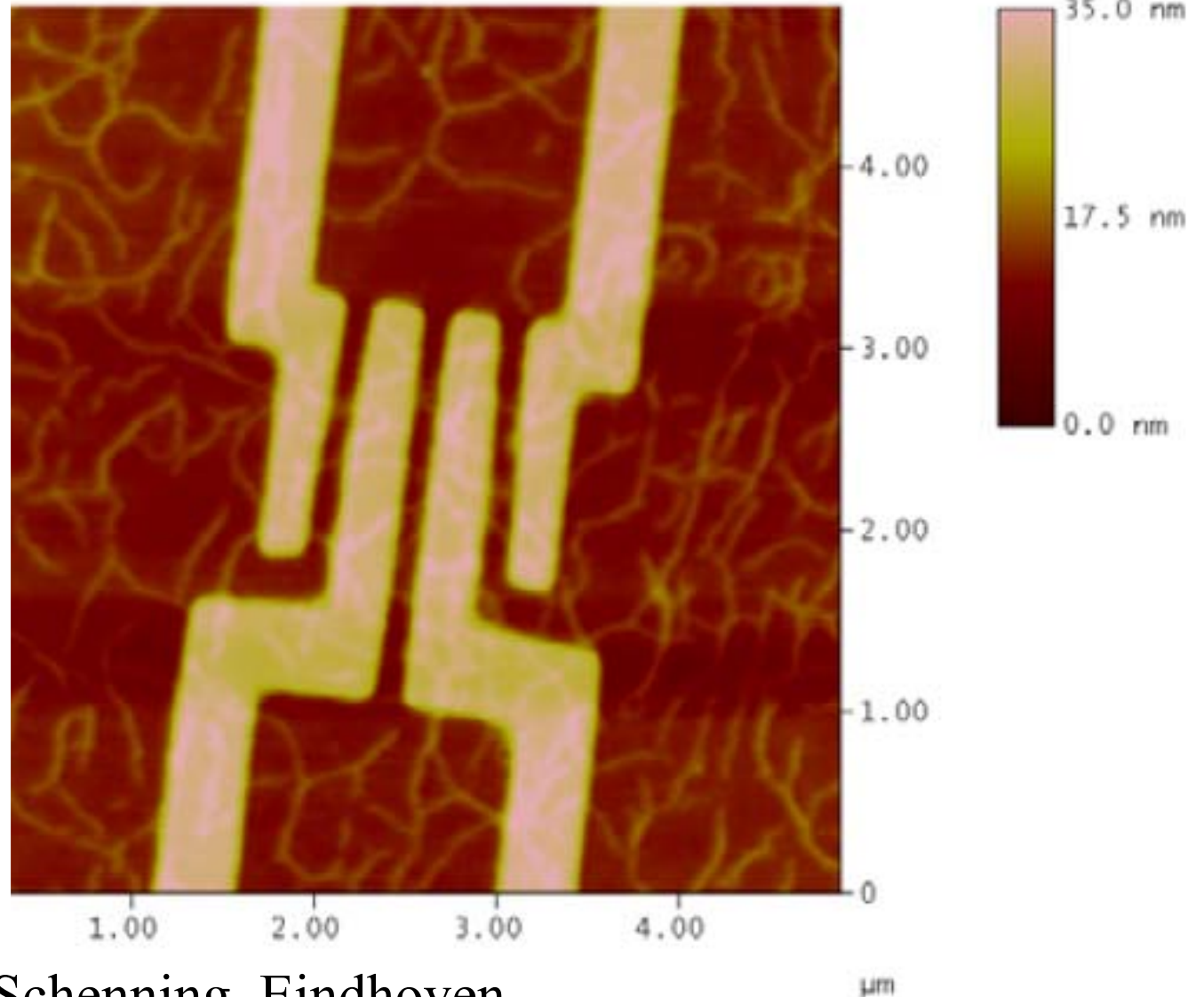
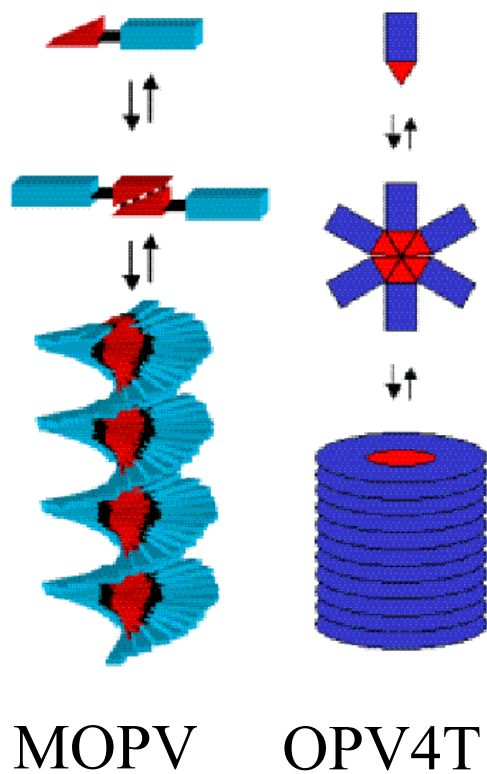
Easier to make reproducible contacts.

Imaging of individual molecular assemblies possible

Nanowires or nanocrystals of conventional semiconductors

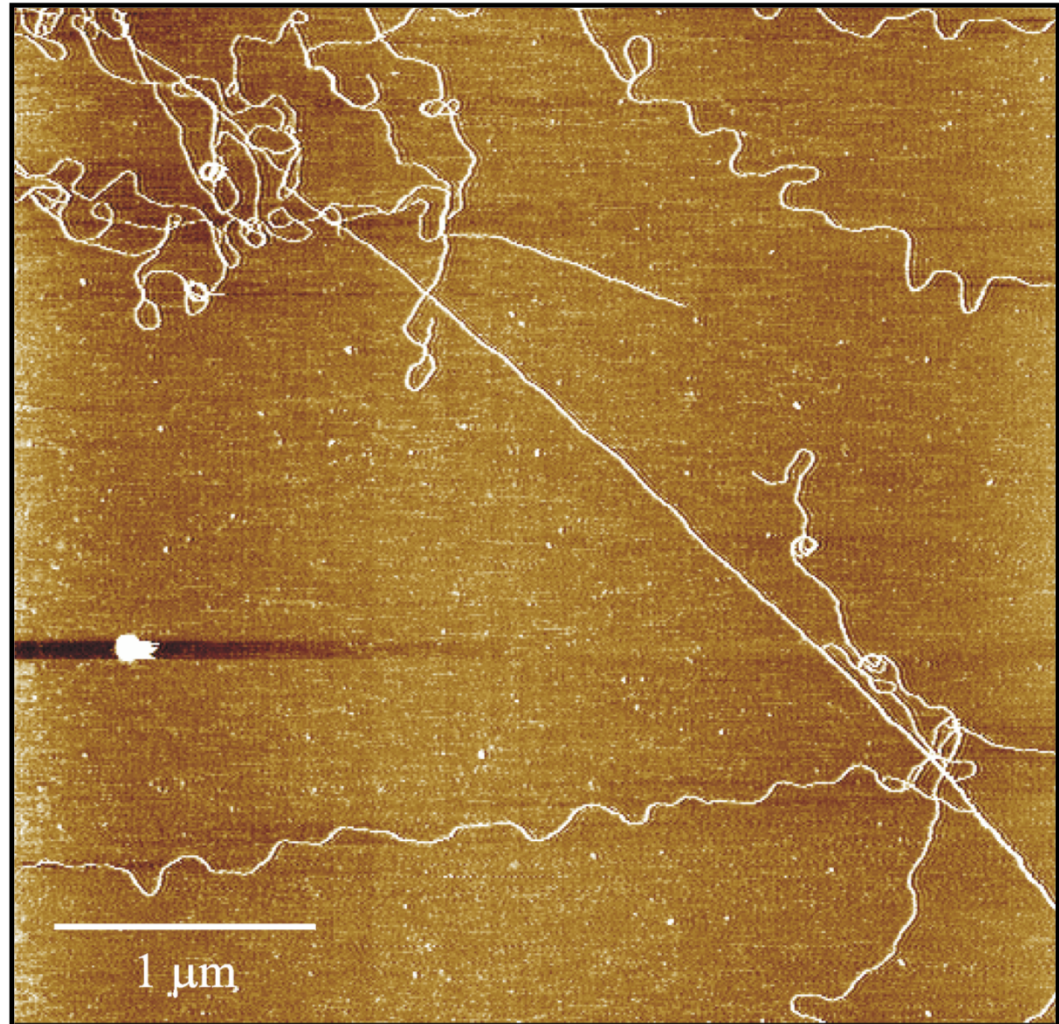
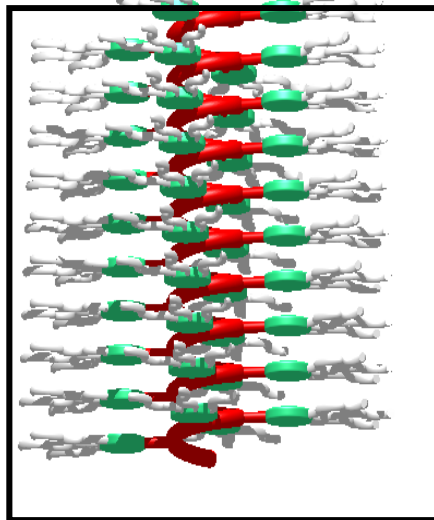
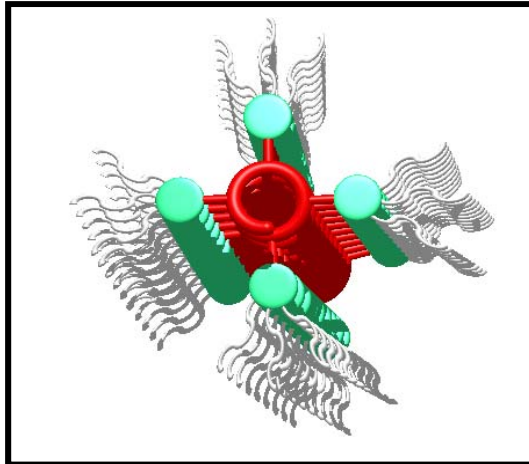


AFM image of MOPV4 fibers



Albert Schenning, Eindhoven

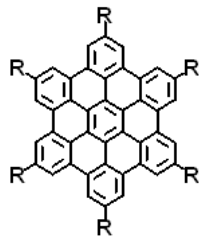
Using templates for self-assembly



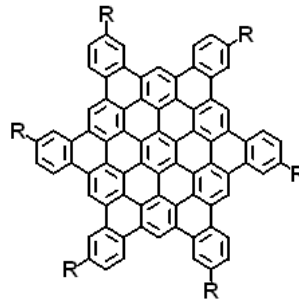
Alan Rowan, Nijmegen

Phthalocyanine Polyisocyanides

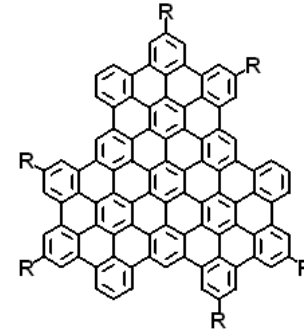
hexabenzocoronenes



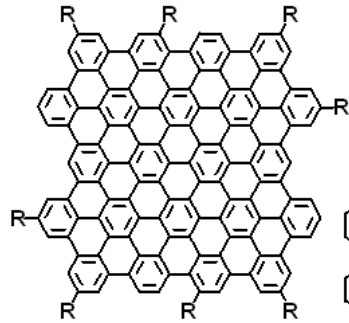
C42 (HBC)



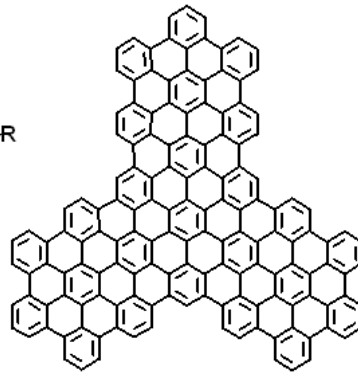
C78



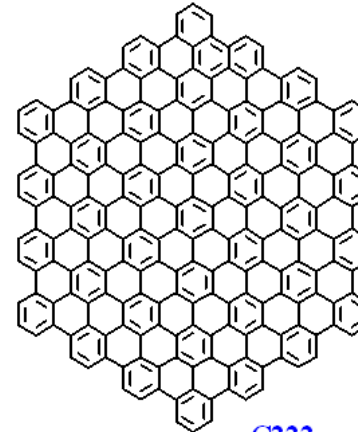
C96



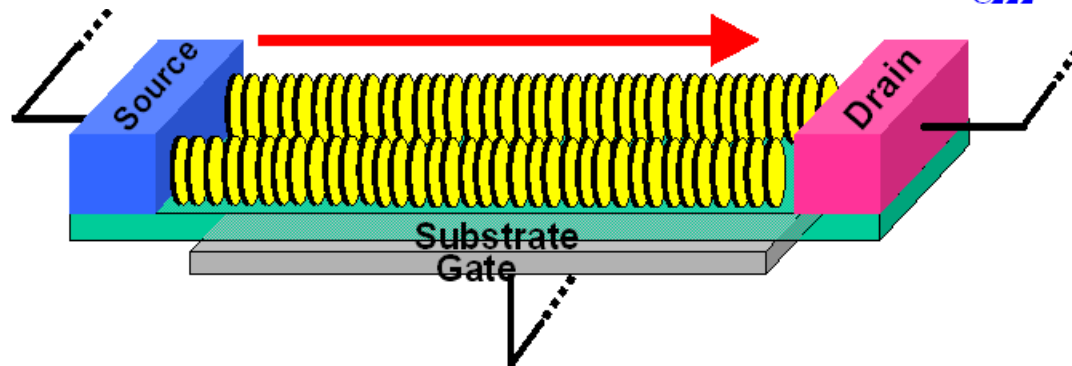
C132



C150

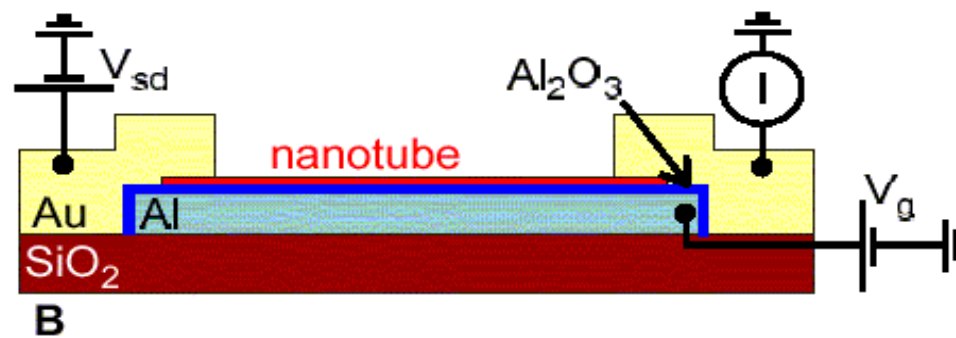
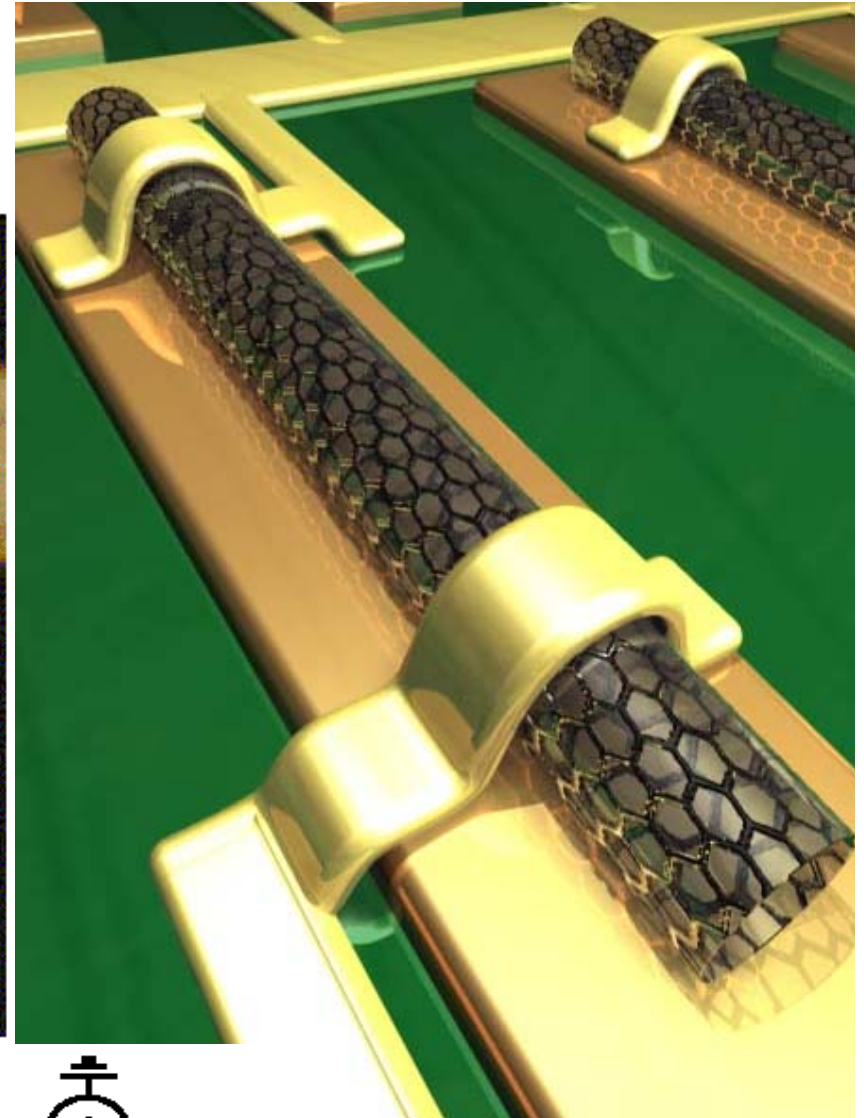
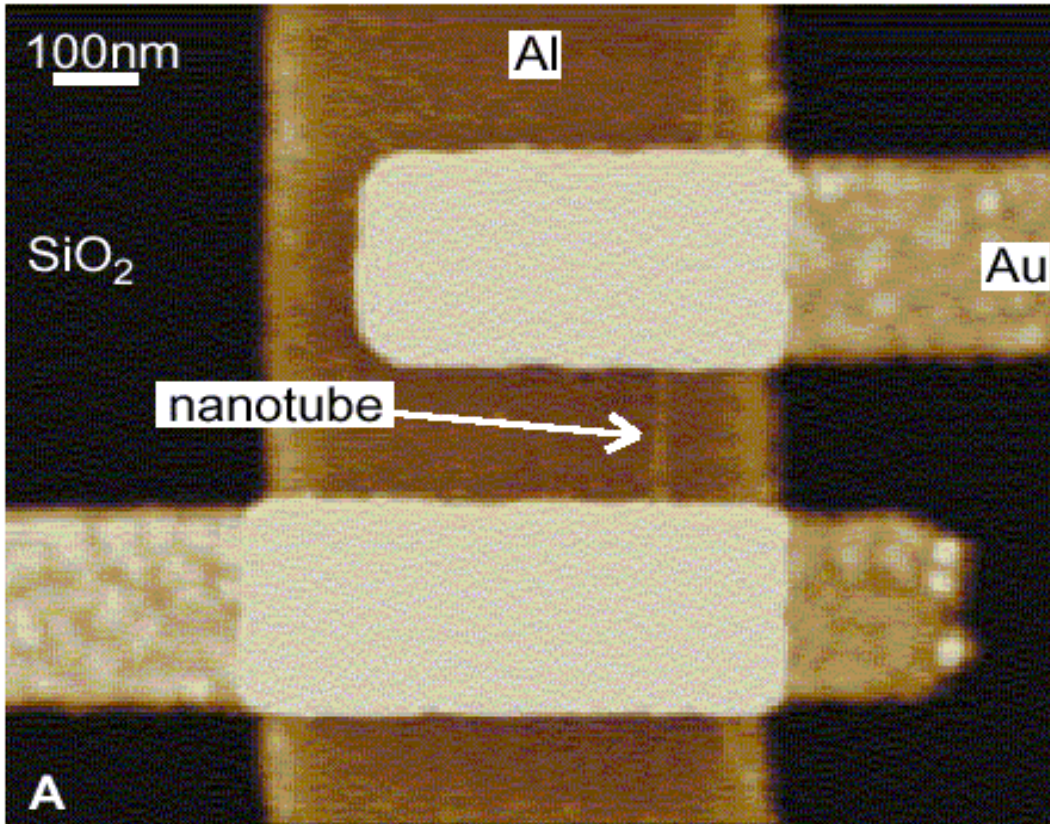


C222



Müllen, Mainz

Carbon nanotube transistors



After Miniaturization

Increasing the level of self-assembly in a fabrication process will replace miniaturization as a guiding principle for making cheaper circuits.

Molecular transistors must be large molecules. Transistors will have dimensions of ~ 10 nm

Low current drive of molecular devices will mean they will have to be put in parallel.

Lighting panels and solar cells will be the first self-assembled devices.

Organic microprocessor



A modern computer has the processing power of a mosquito brain.