



MICRO-435 Quantum and Nanocomputing

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MOLECULAR TRANSISTOR - OVERVIEW

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4/11/25

MOLECULAR TRANSISTORS CHARACTERISTICS AND FABRICATION

OBJECTIVES

- A CONCEPTUAL M.T.
- REAL M.T.
- M.T. FAB STEPS
- NANOGAPS FOR M.T.
- (→ MOLECULES FOR M.T.)

WHY MOLECULES?



WHY MOLECULES?

SIZES - VERY SMALL, FEW NM

SMALL DELAY, POWER DISSIPATION

↳ SIMPLE STRUCTURE

(SCATTERING, CAPACITANCES)
? ?

SELF ASSEMBLY

↳ BOTTOM-UP - SMALL COST

LESS "CRITICAL MATERIALS"



WHY MOLECULES?

SMALL → DIFFICULT TO

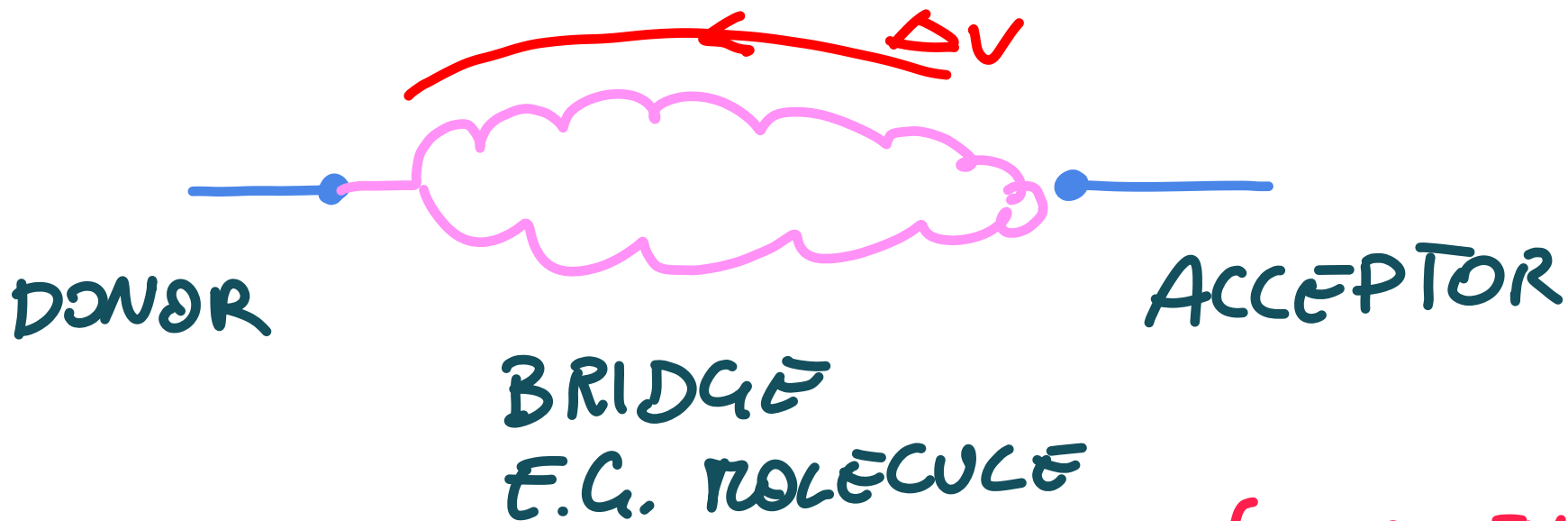
- MANIPULATE
- MEASURE
- EXPLOIT / CONTROL

• •
∩

VARIABILITY
⊗ TECH.
↓
⊗ ELEM. LEVEL

PHENOMENA AT ATOMIC SCALE
↳ QUANTUM EFFECTS
DIFFICULT TO STUDY
MODEL, VERIFY

WHAT DO WE ACTUALLY MEAN?



DEPENDING ON

- ΔV
- BRIDGE CHAR.

↓

CURRENT, CHARGE MOVE

HOPPING? TUNNELING?

- MOL TYPE
- MOL LENGTH
- MOL SIZE
- CONNECTIONS TO D, A

TO BE MORE PRECISE

INFLUENCE CONDUCTION
↓

• TYPE OF COMPOUND

• TORSION (ANGLE)

• LENGTH



MOLECULE

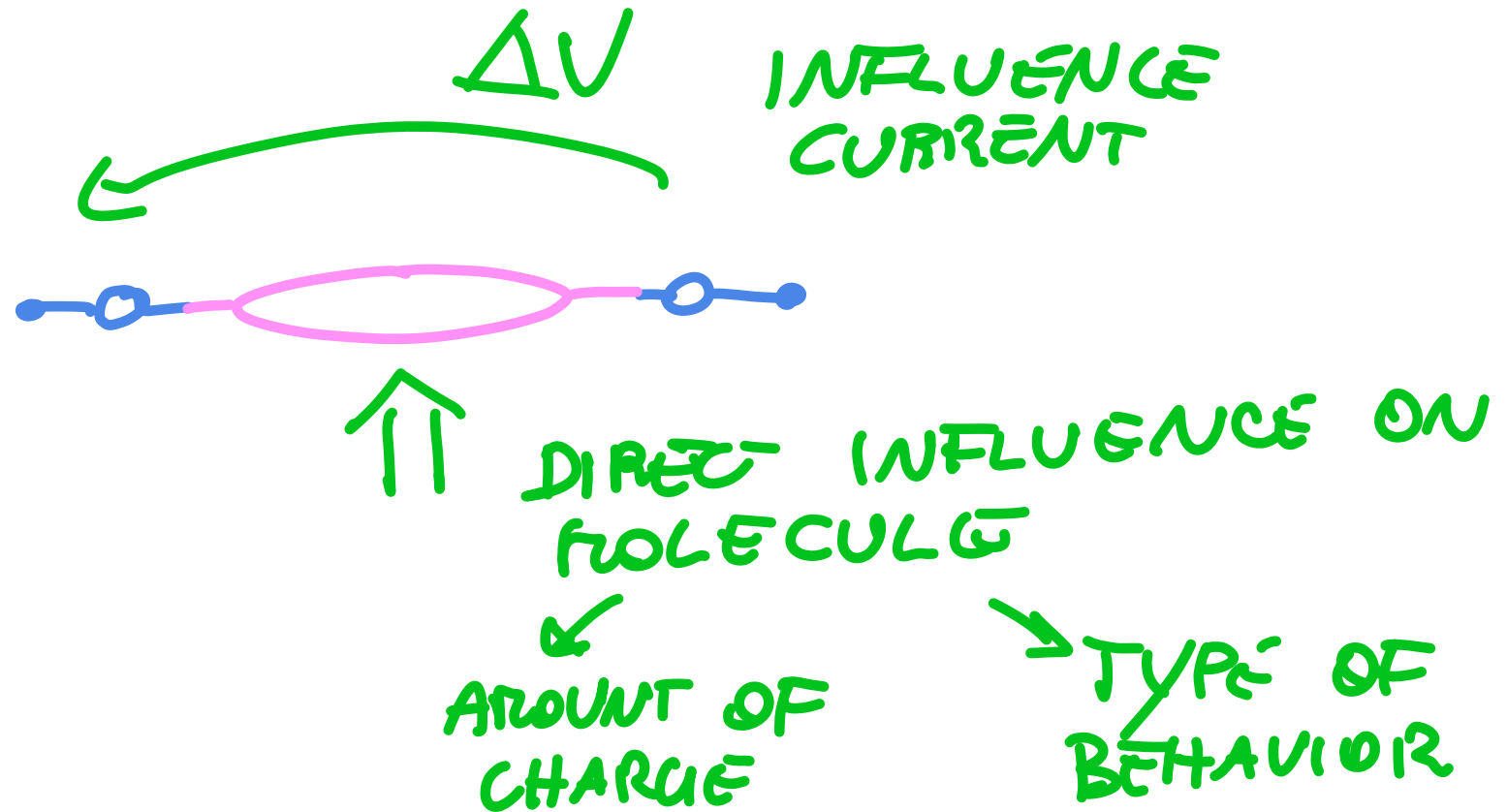
ANCHORING GROUPS

→ FACILITATE CONNECTION

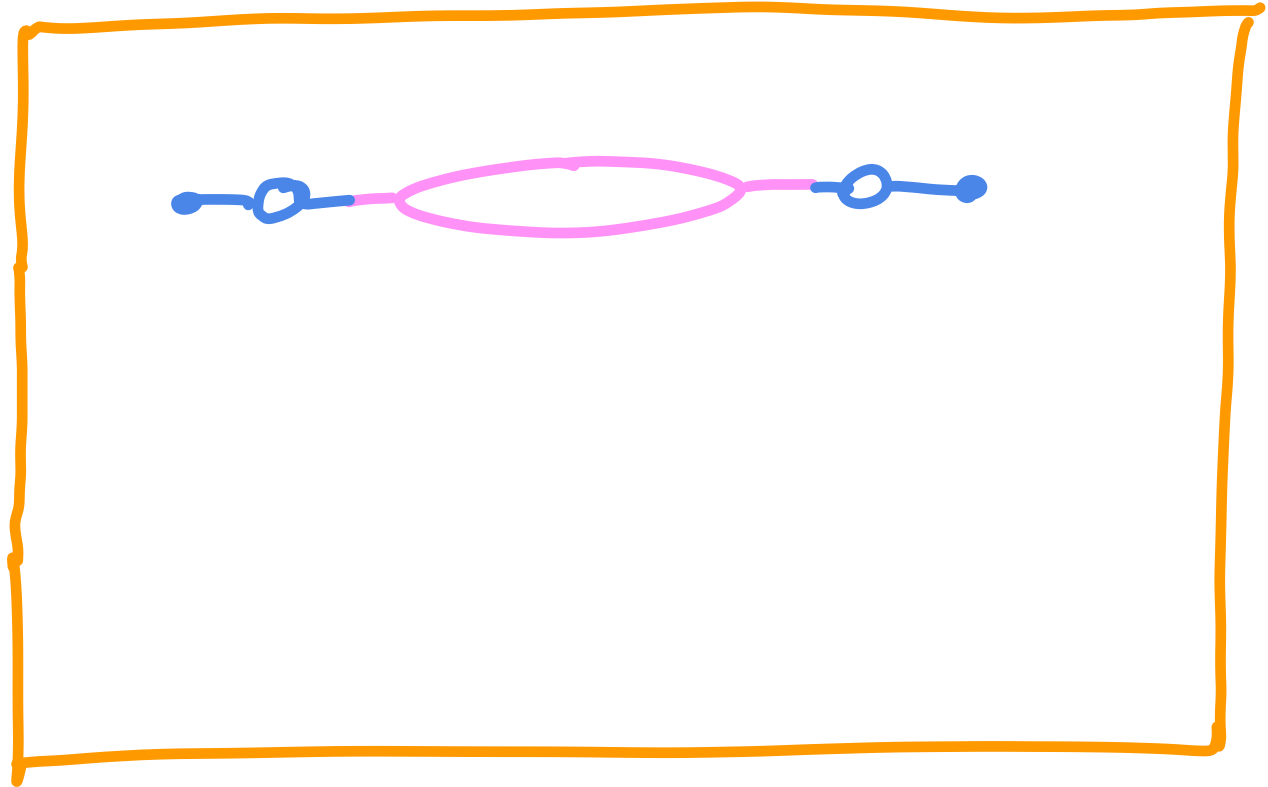
→ INFLUENCE CHARGES INTERACTION

→ CURRENT FLOW

MOLECULE CAN BE INFLUENCED BY EXTERNAL SOURCES



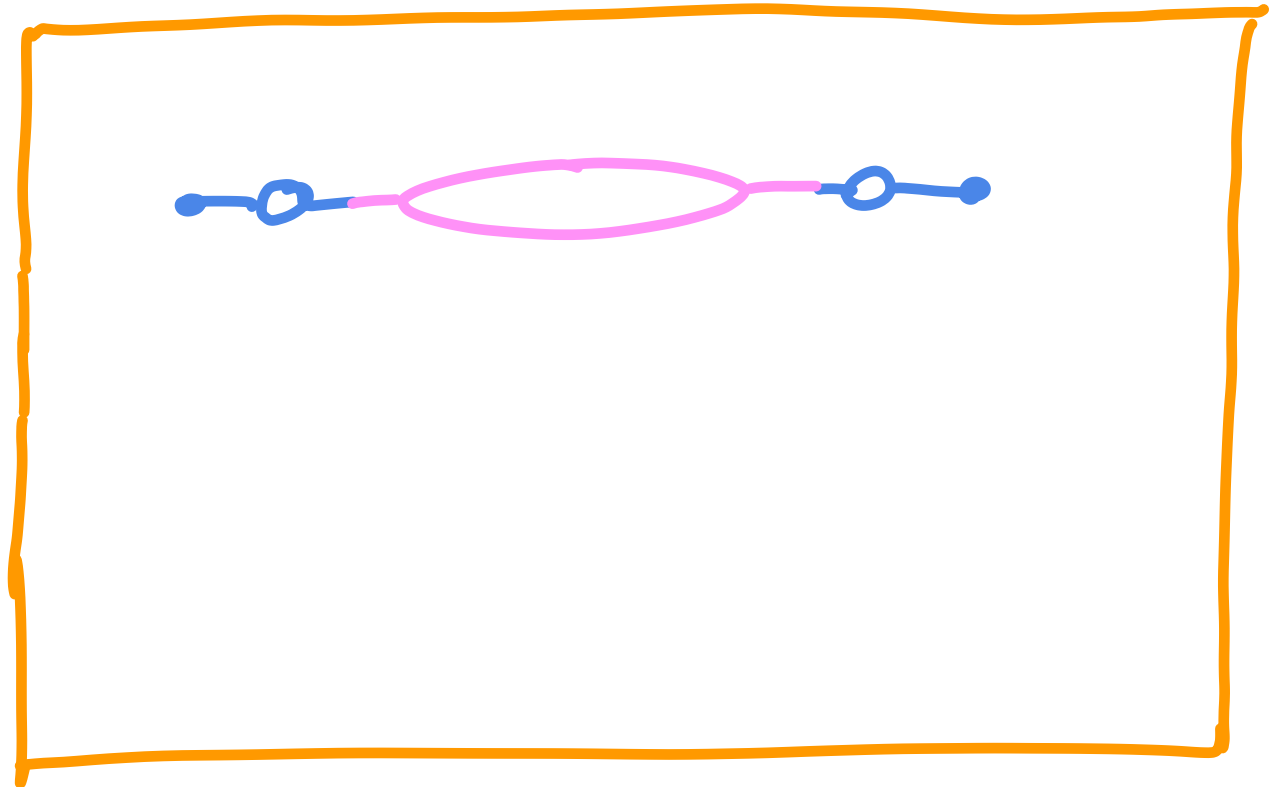
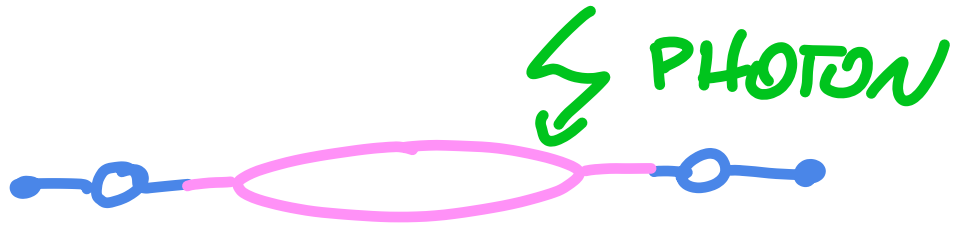
EXTERNAL INFLUENCES



EXTERNAL INFLUENCES

EXTERNAL
COMPOUND

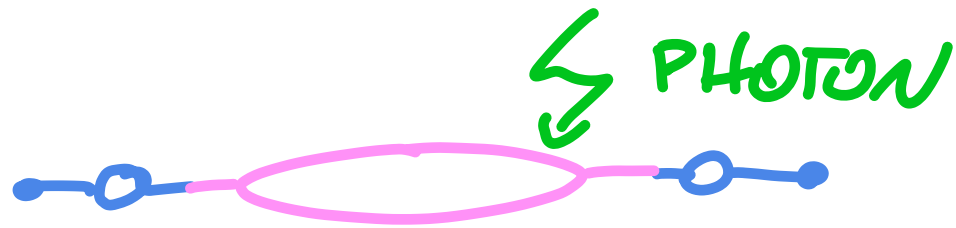
(ex. GAS)



EXTERNAL INFLUENCES

EXTERNAL
COMPOUND

(ex. GAS)



COUPLING
FACTOR

DRAW

SOURCE

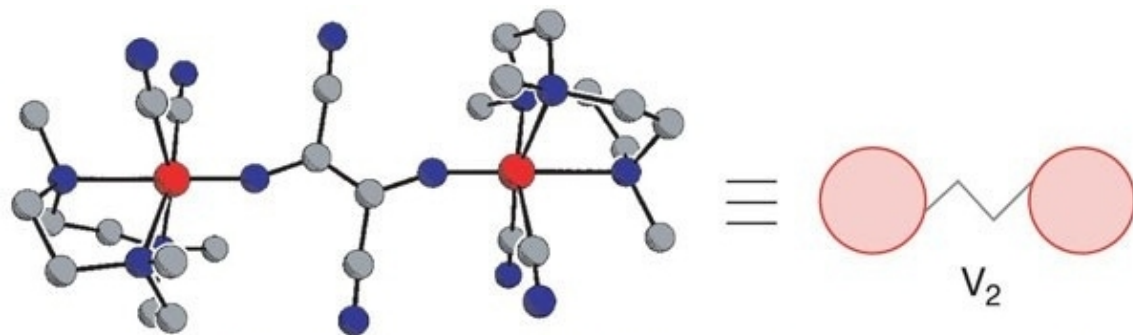


WAVY GREEN LINE

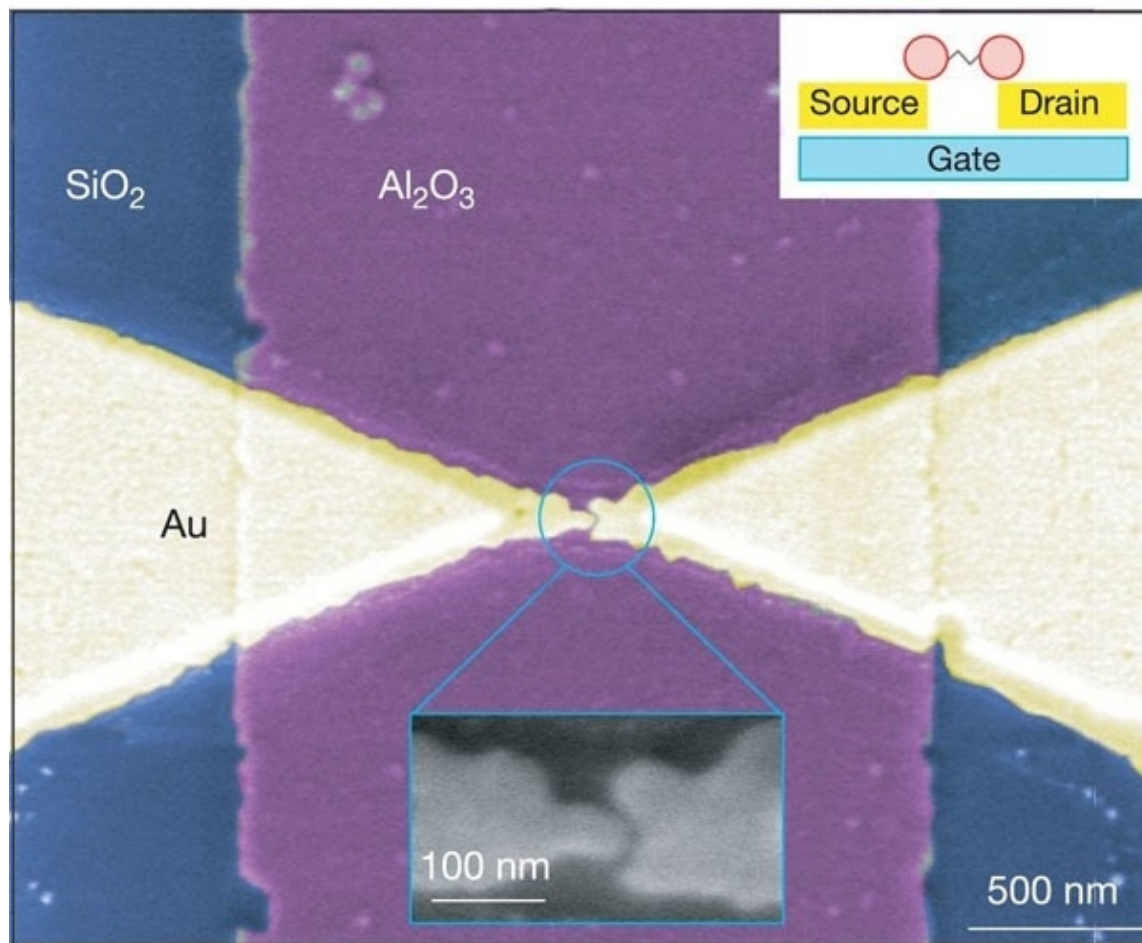


GATE

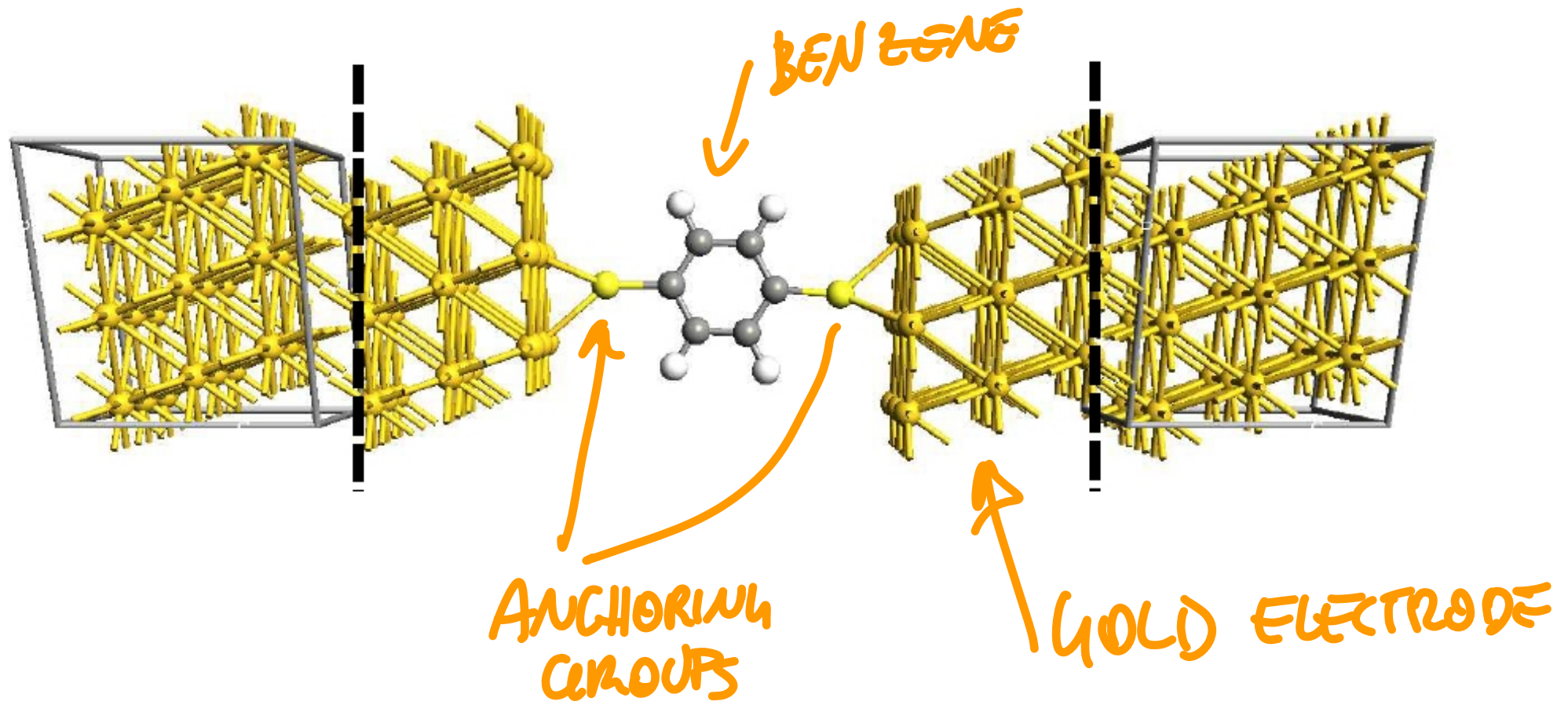
MOLECULAR TRANSISTOR



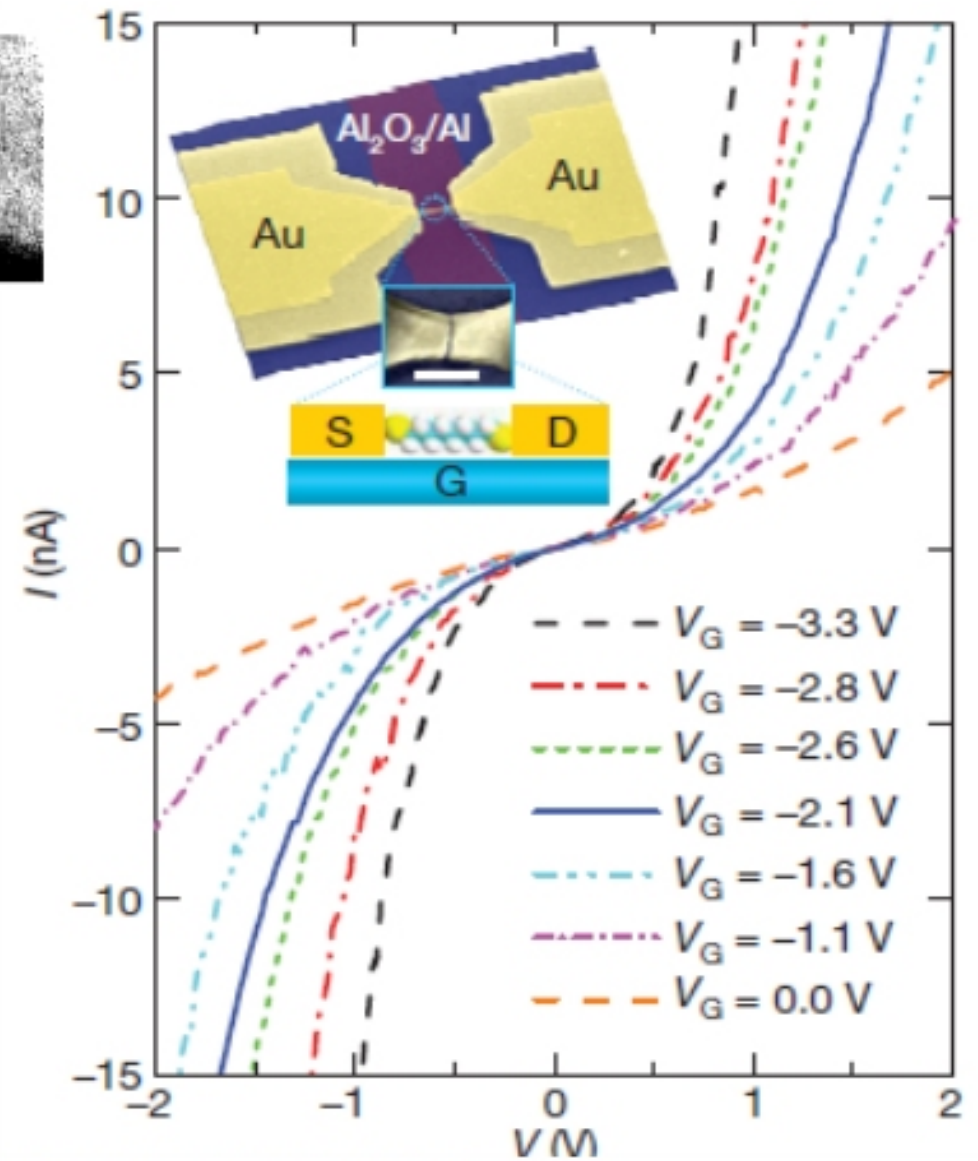
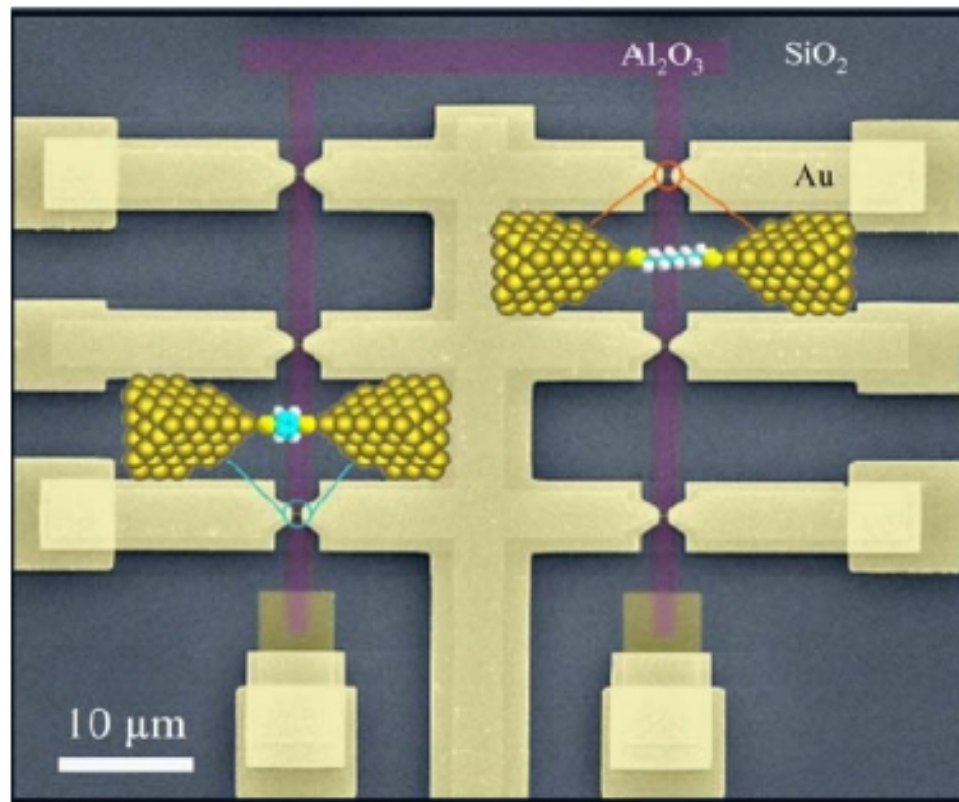
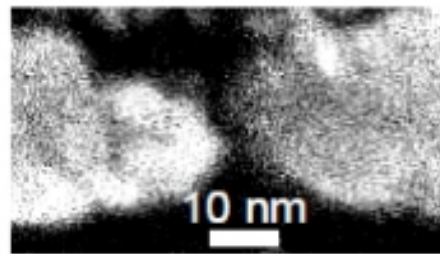
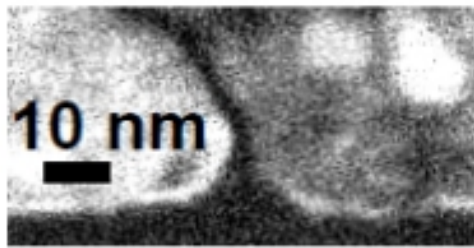
ONE OF THE
FIRST
FABRICATED
MOLECULAR
TRANSISTOR



EXAMPLE: A BENZENE MOLECULAR TRANSISTOR (WIRE)

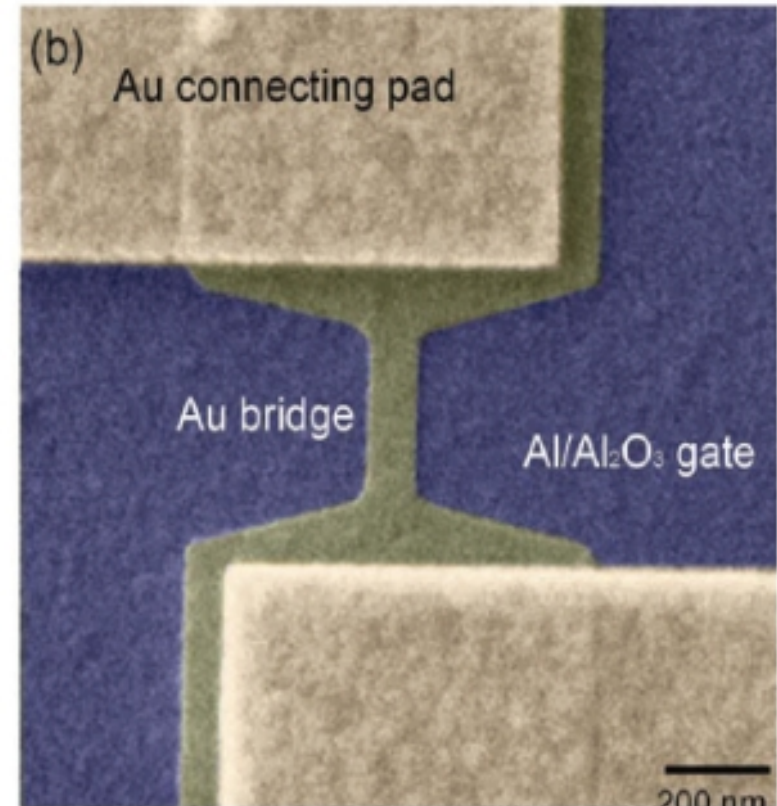
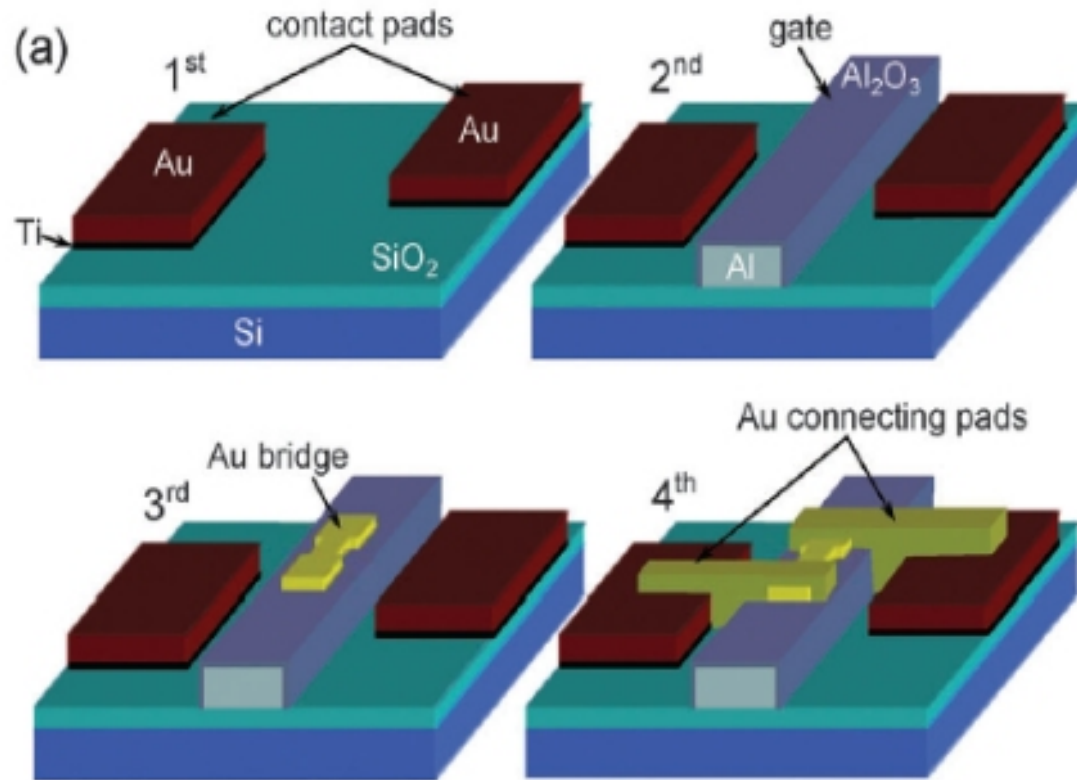


REAL M.T. EXAMPLE (1)



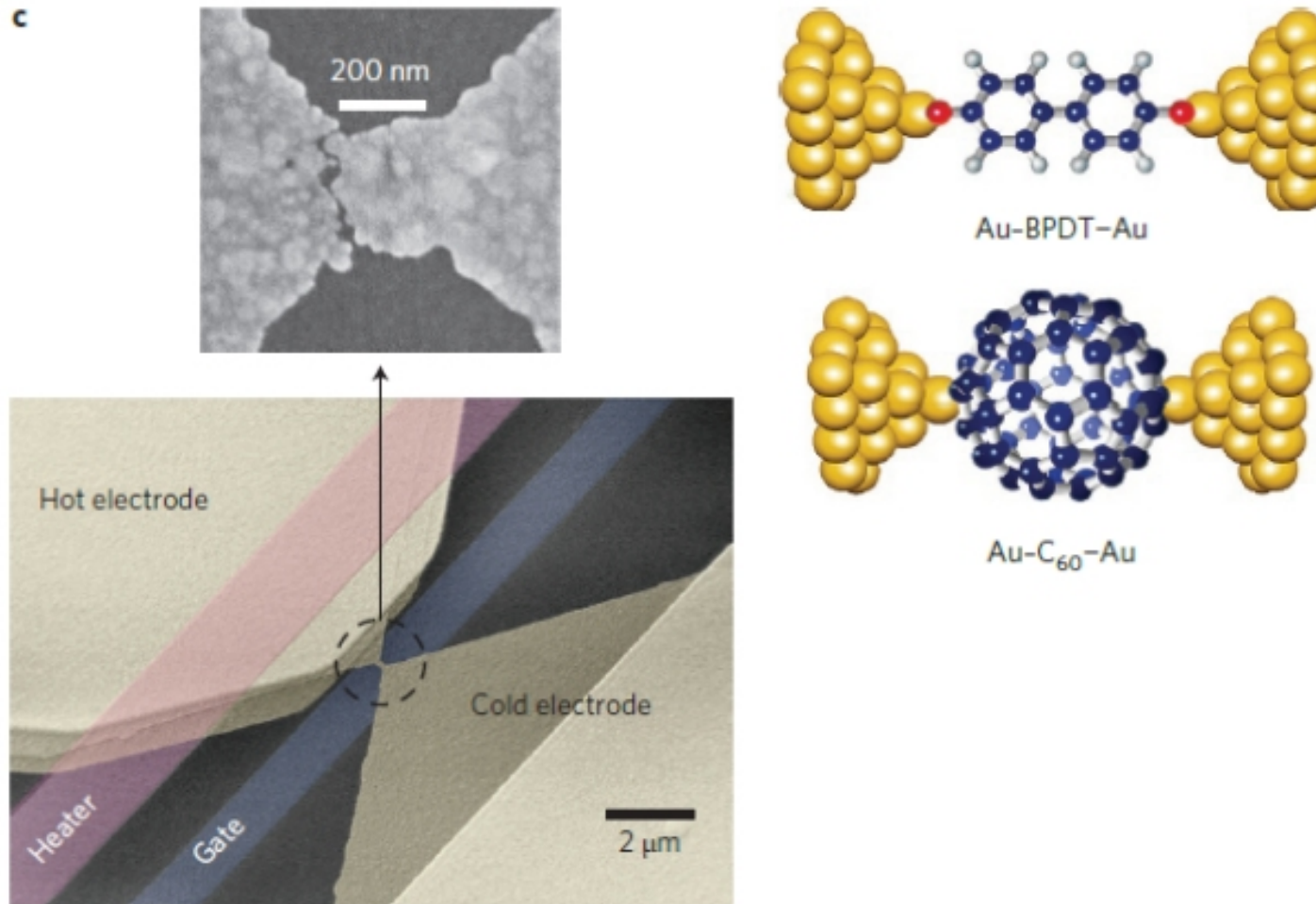
Song, H., Kim, Y., Jang, Y. *et al.* Observation of molecular orbital gating. *Nature* **462**, 1039-1043 (2009).
<https://doi.org/10.1038/nature08639>

REAL N.T. EXAMPLE (2)



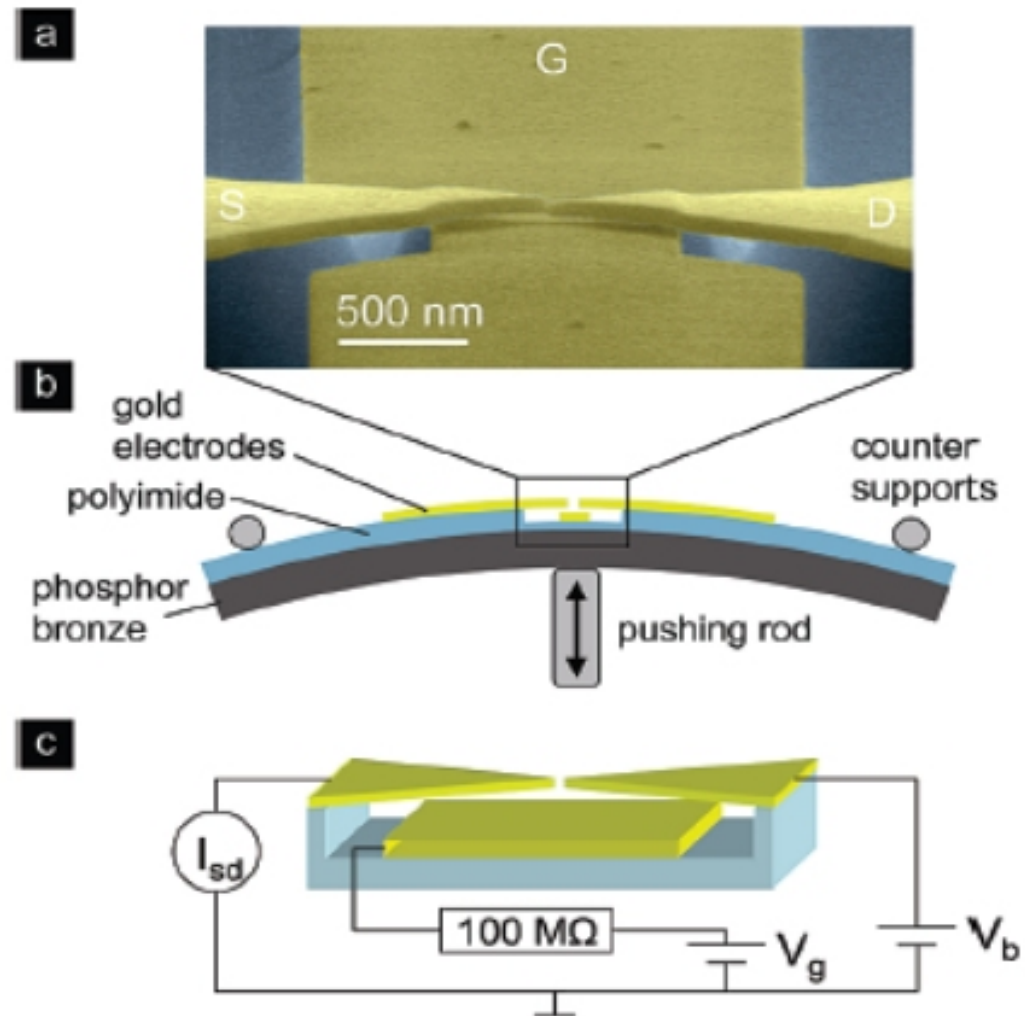
Perrin, Mickael & Burzuri, Enrique & Zant, Herre. (2014). Single-molecule transistors. *Chemical Society reviews*. 44. 10.1039/c4cs00231h

REAL N.T. EXAMPLE (3)



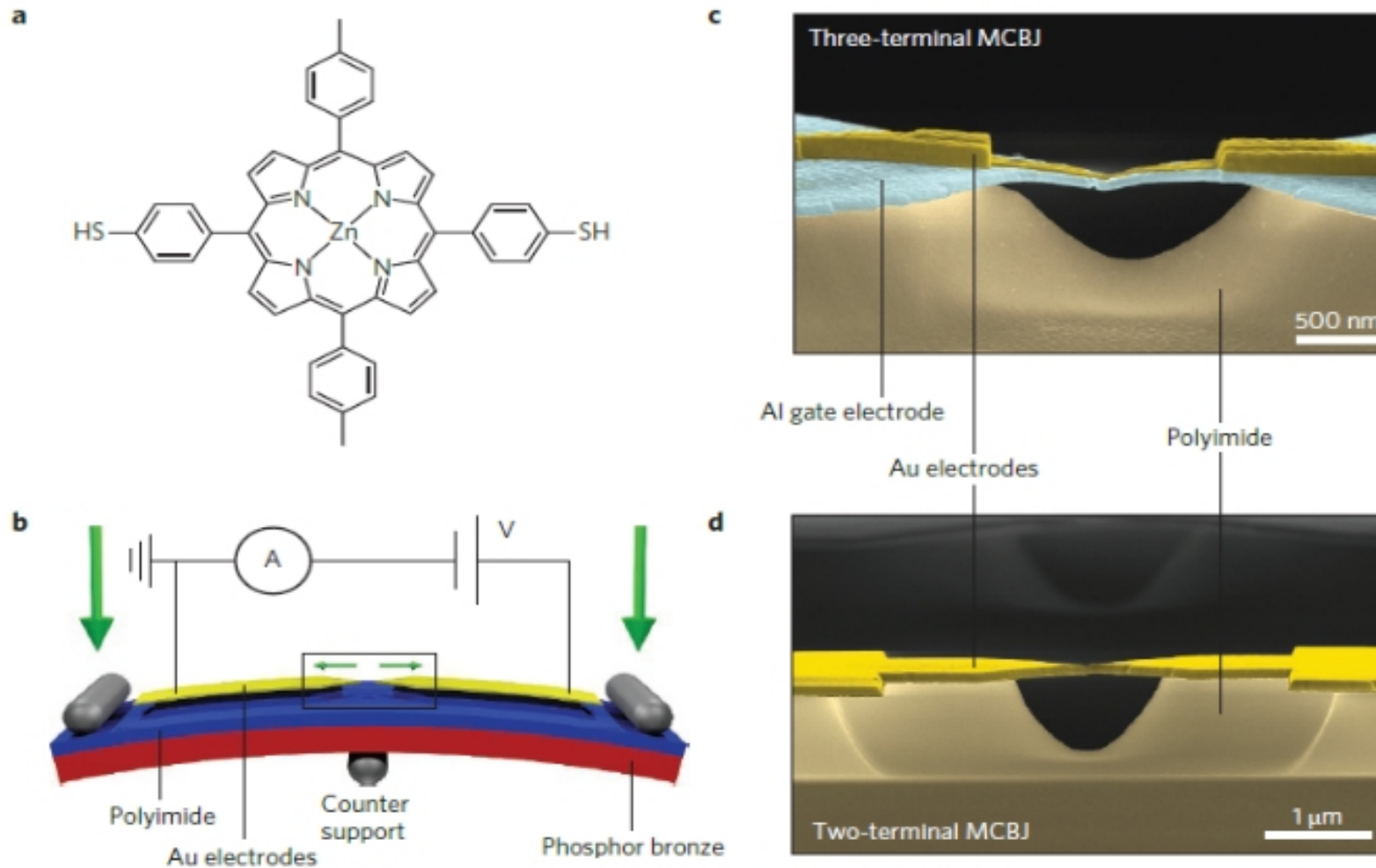
Kim, Y., Jeong, W., Kim, K. *et al.* Electrostatic control of thermoelectricity in molecular junctions. *Nature Nanotech* **9**, 881-885 (2014). <https://doi.org/10.1038/nnano.2014.209>

REAL N.T. EXAMPLE ④



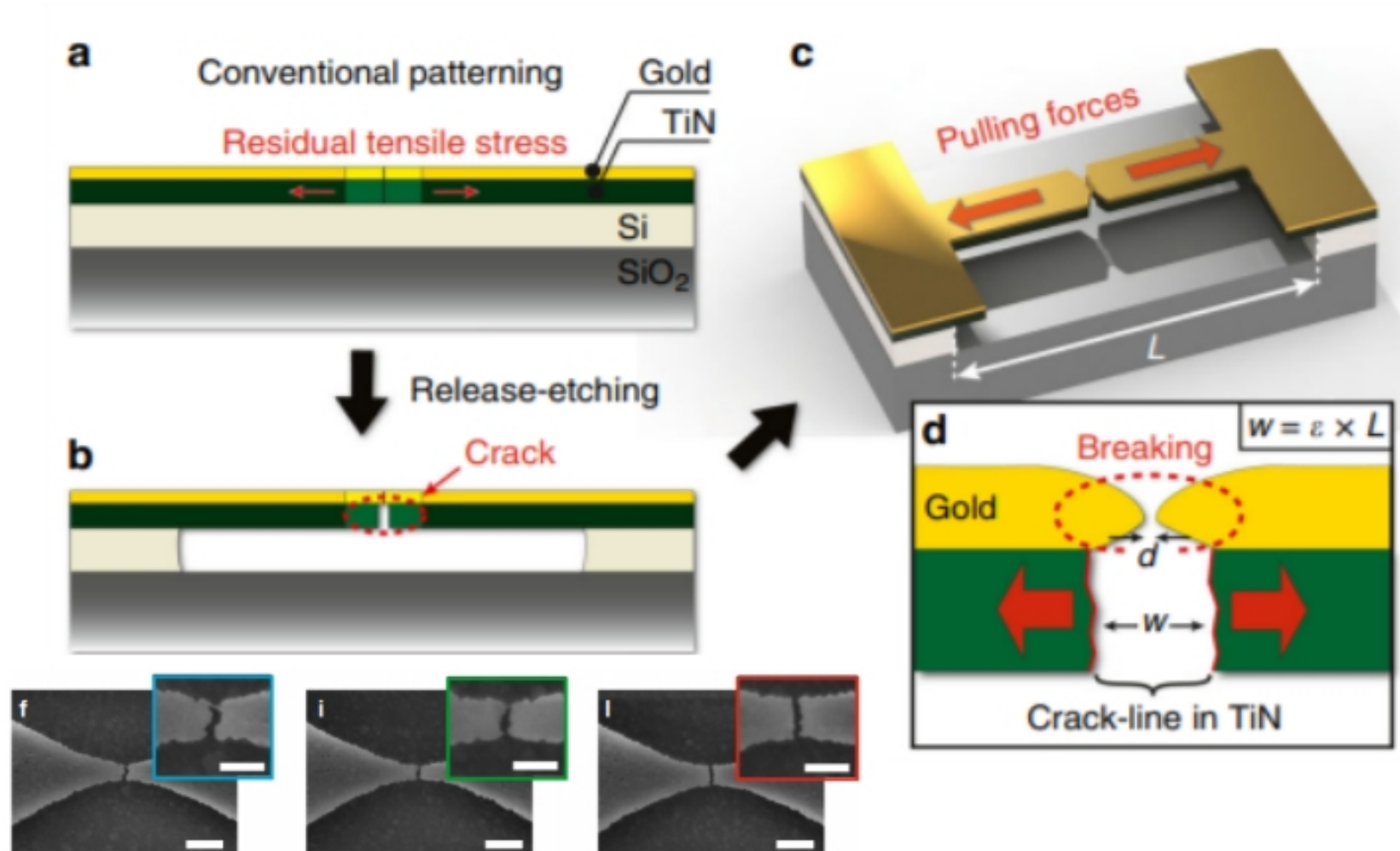
Christian A. Martin, Roel H. M. Smit, Jan M. van Ruitenbeek, *Nano Letters* **2009** 9 (8), 2940-2945
DOI: 10.1021/nl901355y

REAL N.T. EXAMPLE (S)



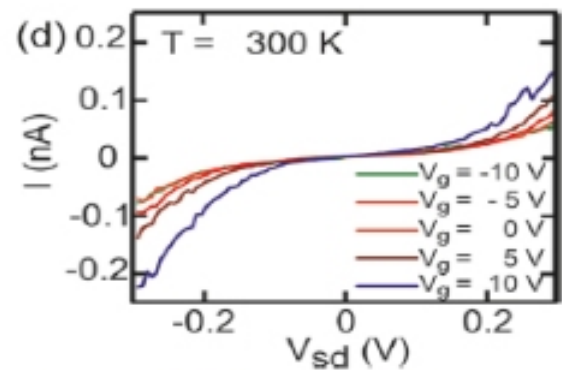
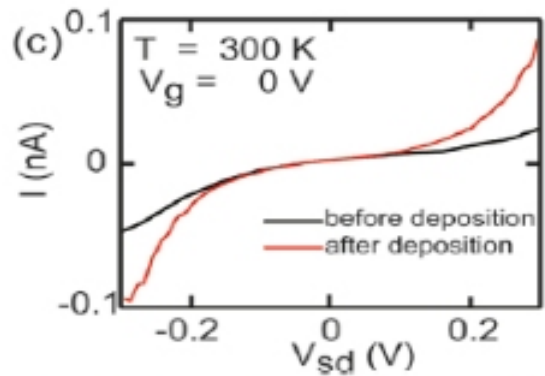
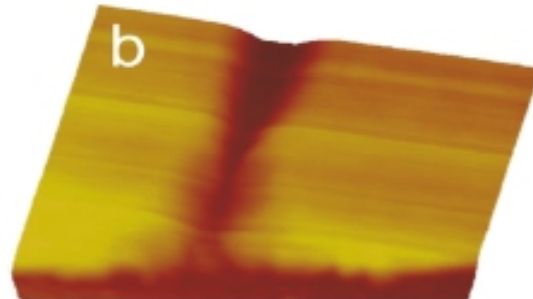
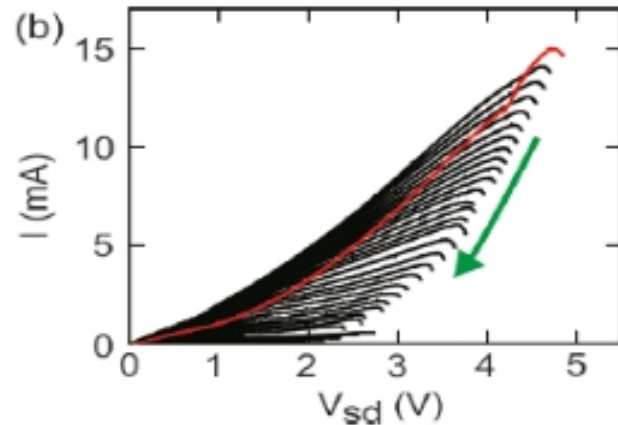
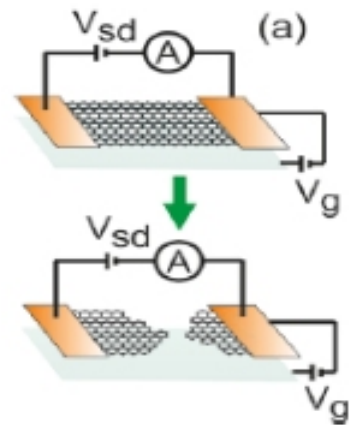
Perrin, M., Verzijl, et al. Large tunable image-charge effects in single-molecule junctions. *Nature Nanotech* **8**, 282–287 (2013). <https://doi.org/10.1038/nnano.2013.26>

REAL N.T. EXAMPLE (6)

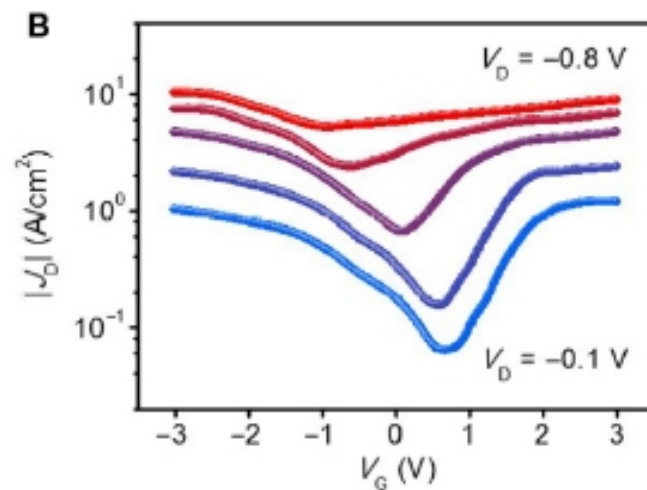
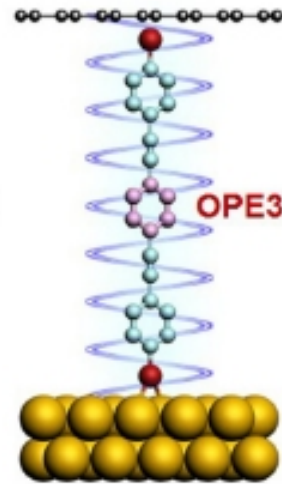
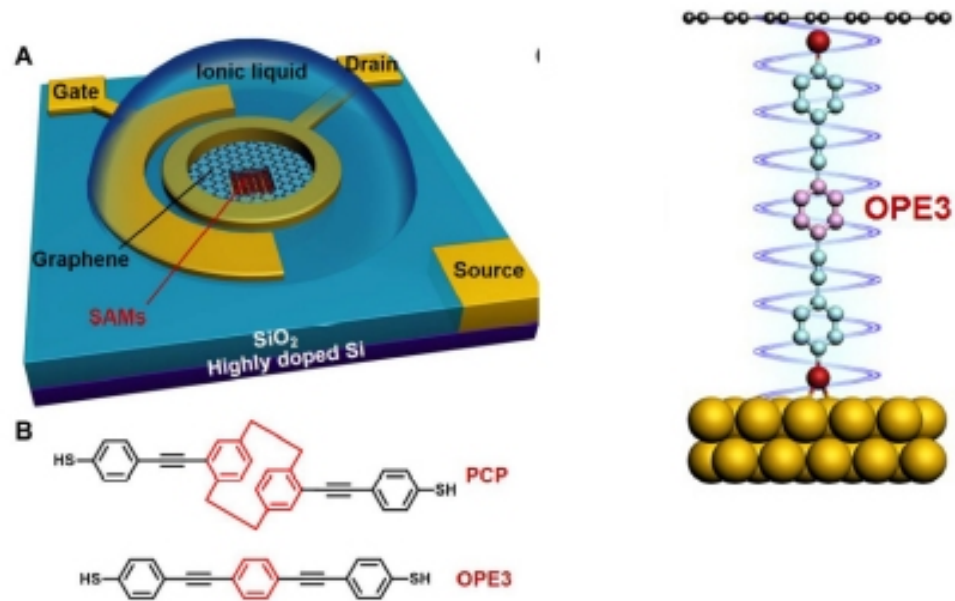


Dubois, V., Raja, S.N., Gehring, P. et al. Massively parallel fabrication of crack-defined gold break junctions featuring sub-3 nm gaps for molecular devices. *Nat Commun* **9**, 3433 (2018).
<https://doi.org/10.1038/s41467-018-05785-2>

REAL M.T. EXAMPLE (7)

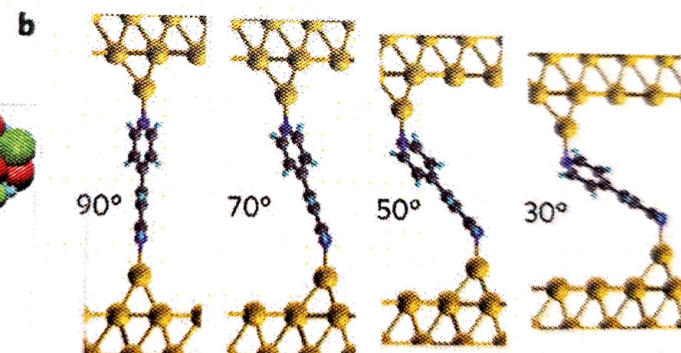
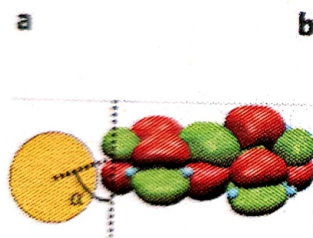
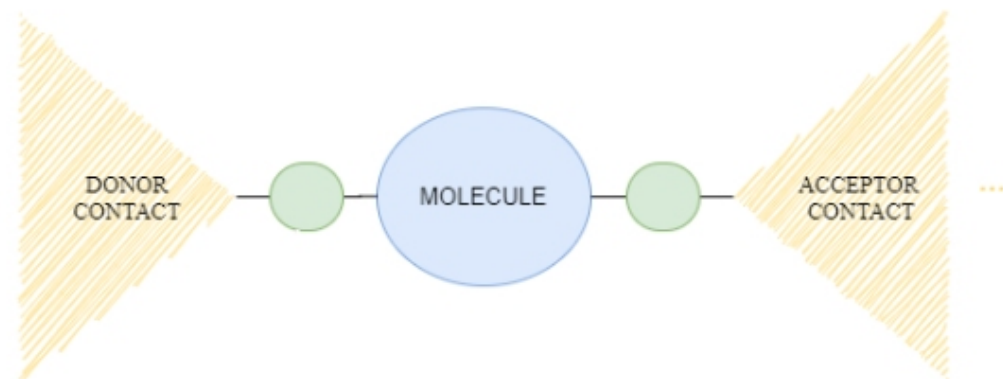
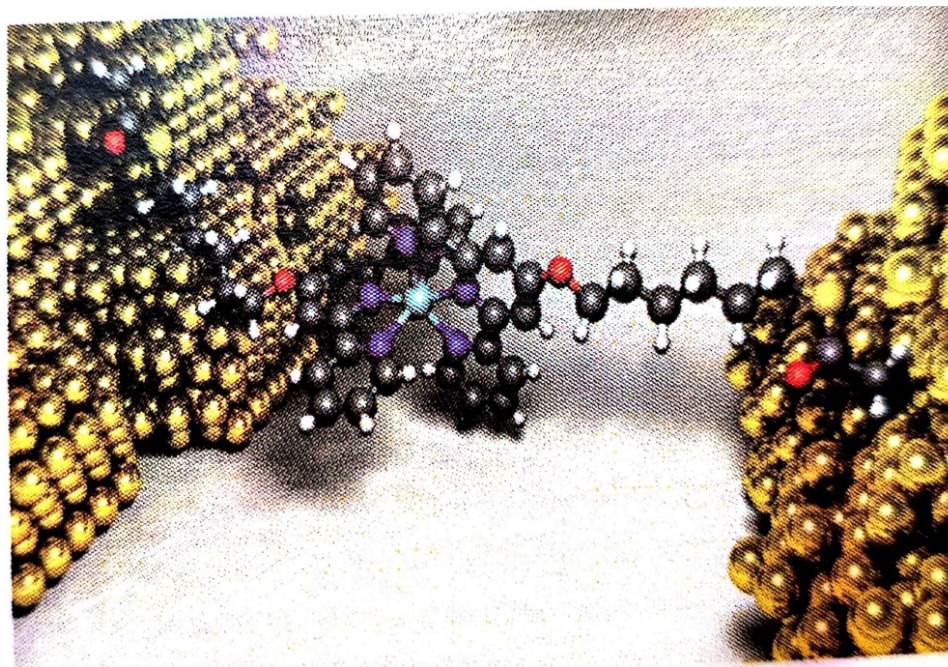


REAL N.T. EXAMPLE \otimes



C. Jia et al, Quantum interference mediated vertical molecular tunneling transistors, 2018.

WHICH ARE THE PARAMETERS INVOLVED IN A REAL N.T.?



PARAMETERS INVOLVED

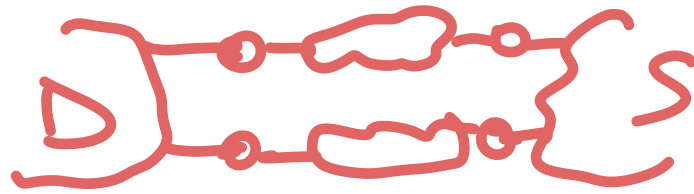
- MOLECULE
 - TYPE OF COMPOUND
 - CHARACTERISTICS → LENGTH
ANGLE
SIZE
- ANCHORING — TYPE → COMPOUND - BOND
- ELECTRODE — MATERIAL, SHARP ⊙ ANCHOR POINT
- ΔV b/w. SOURCE & DRAIN
- EXTERNAL: TYPE → GATE
PHOTON
COMPOUND

VARIABILITY

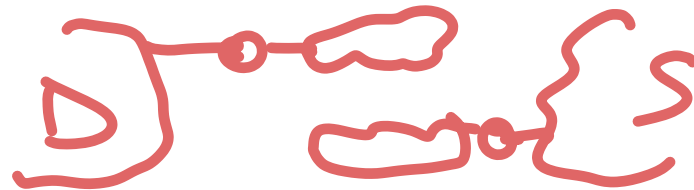
- ROTATION
- NOT PERFECT POL-ANCHOR RING CONNECTION
- NOT PERFECT ANCHOR GROUPS CONNECTION TO ELECTRODES

• WRONG MOLECULE

• SEVERAL MOLECULES



• NO MOLECULE



NEXT OBJECTIVES

- A CONCEPTUAL M.T.
- REAL M.T.
- M.T. FAB STEPS
- NANOGAPS FOR M.T.
- MOLECULES FOR M.T.