Toward realization of molecular-based devices and circuits

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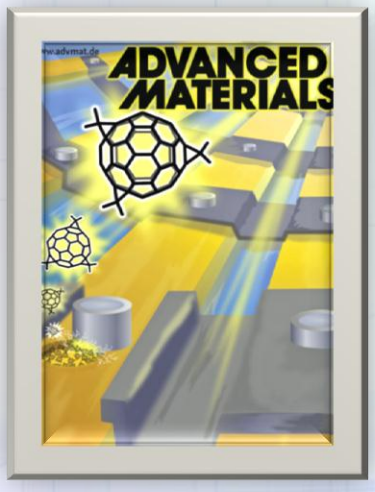
Shachar Richter, Tel Aviv University, Israel



Small **2008**, *4*, 55-58; *Nano Lett.* **2009**, *9*, 1296-1300; *Adv. Mater.* **2010**, *22*, 2182-2186;
J. Phys. Chem. Lett. **2010**, *1*, 1574-1579; *Jpn. J. Appl. Phys., Part 1* **2010**, *49*, -;
J. Nanosci. Nanotechnol. **2010**, *10*, 8260-8264; *Appl. Phys. Lett.* **2011**, *99*, 033108 ;
J. Phys. Chem. Lett. **2011**, *2*, 1125-1128; *Small* **2005**, *1*, 848-851; *JACS* **2012**

Realization of molecular logic/memory devices

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Engineering and Architecture

Fabrication

Parallel technique (photolithography)

CMOS compatible

Locate the molecules (mass quantities)

Self Assembly

External Forces

System

Wiring Density

Realization of logic/memory devices

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Molecular requirements

Switch / amplify

Charging

conformation

Magnetic

optical

Doping

Control

Assembly

interface

Design

Desired property

Anchor

Protection Moiety

Vertical approach

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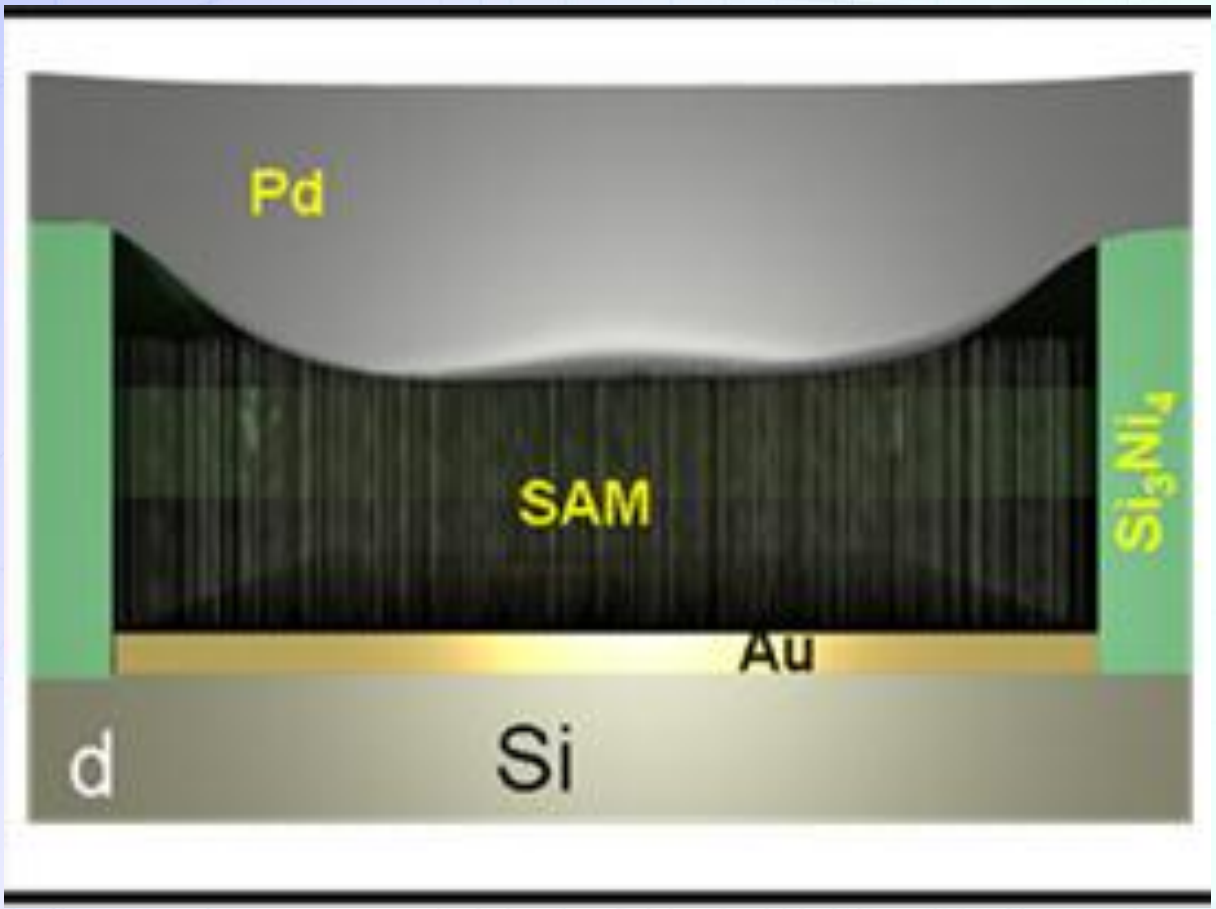

- The junction width determined by the molecular length
- Encapsulated
- Mass production
- Allows the fabrication of transistors and circuits

A prototype of molecular device

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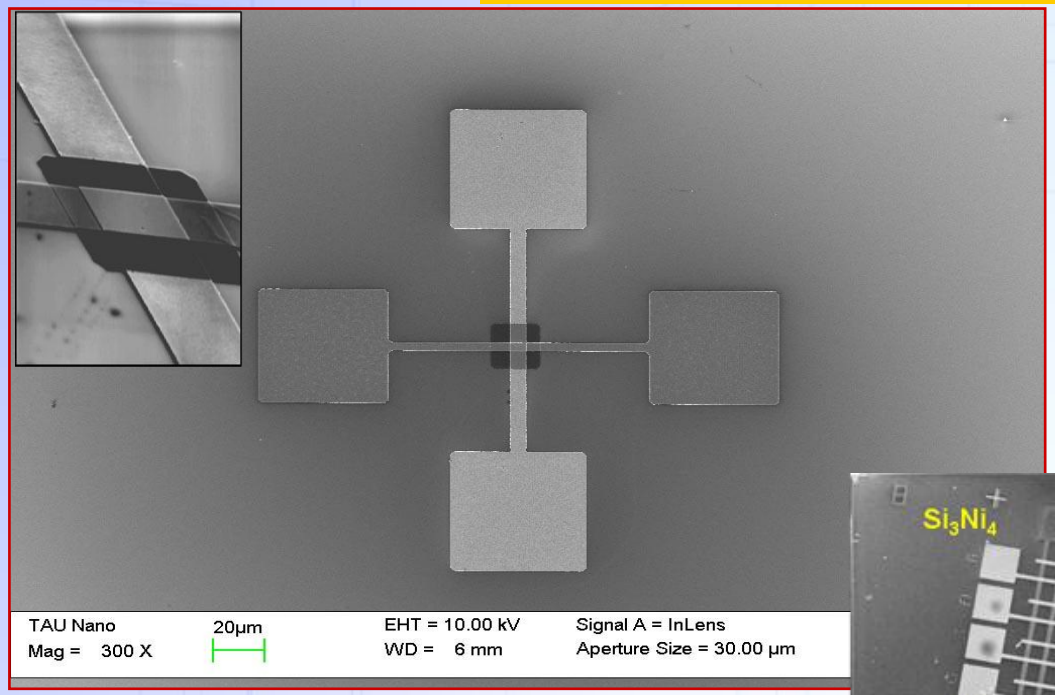
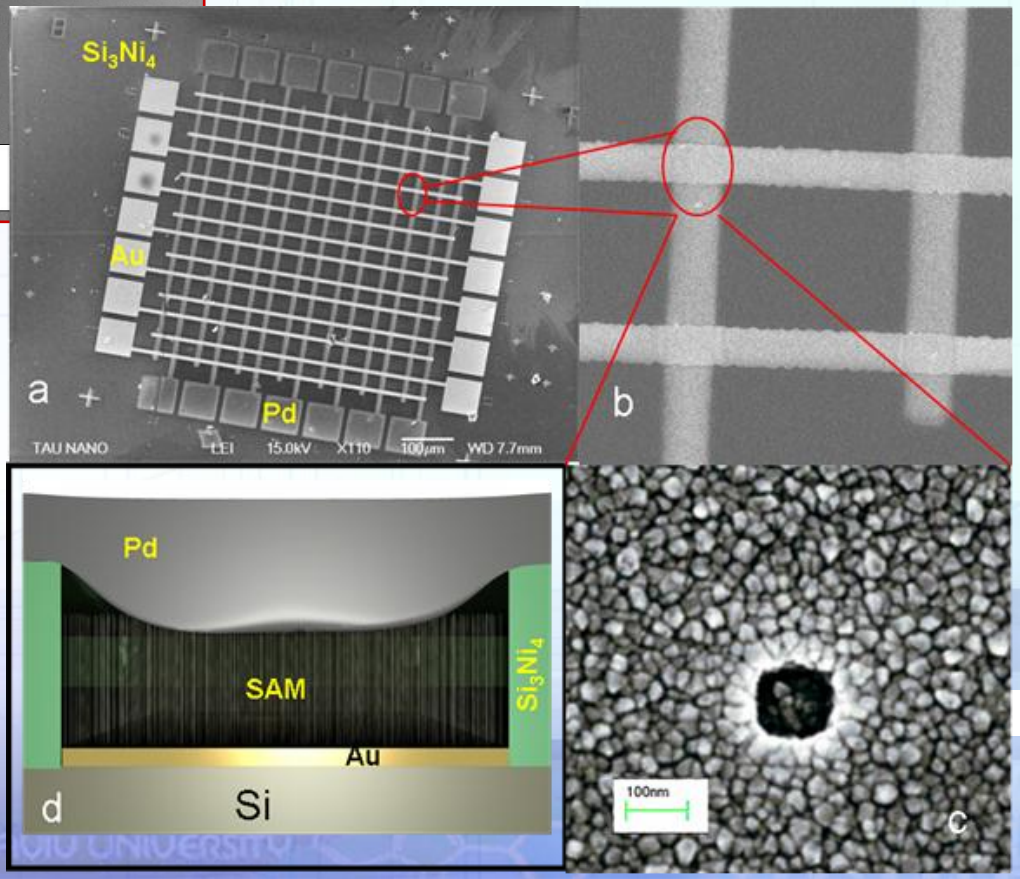
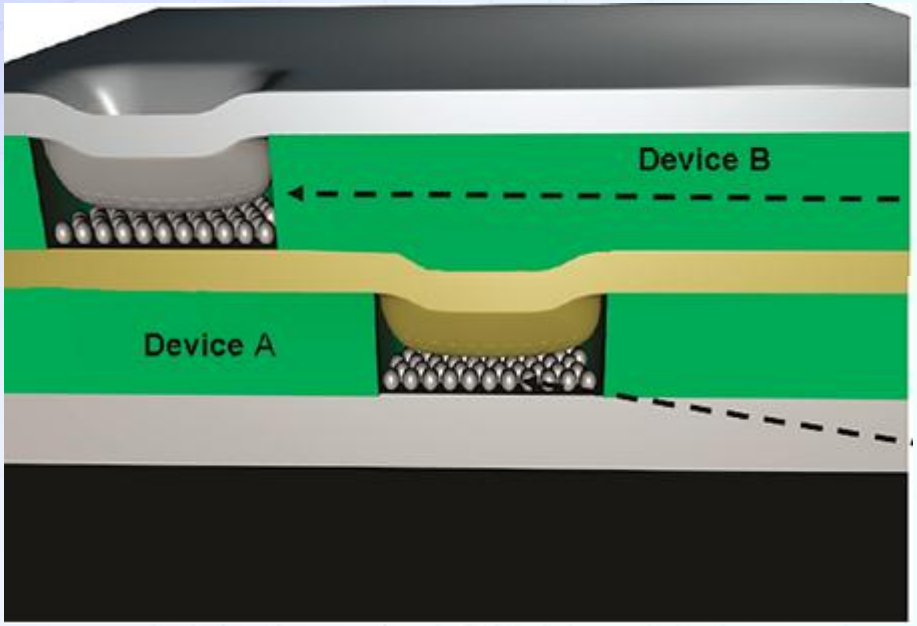




3D Molecular Circuit

Device B

Device A



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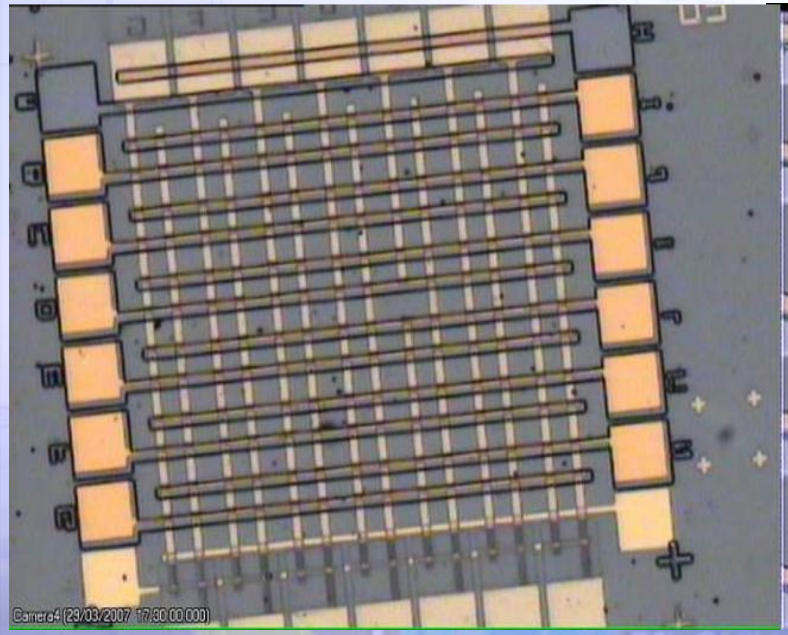
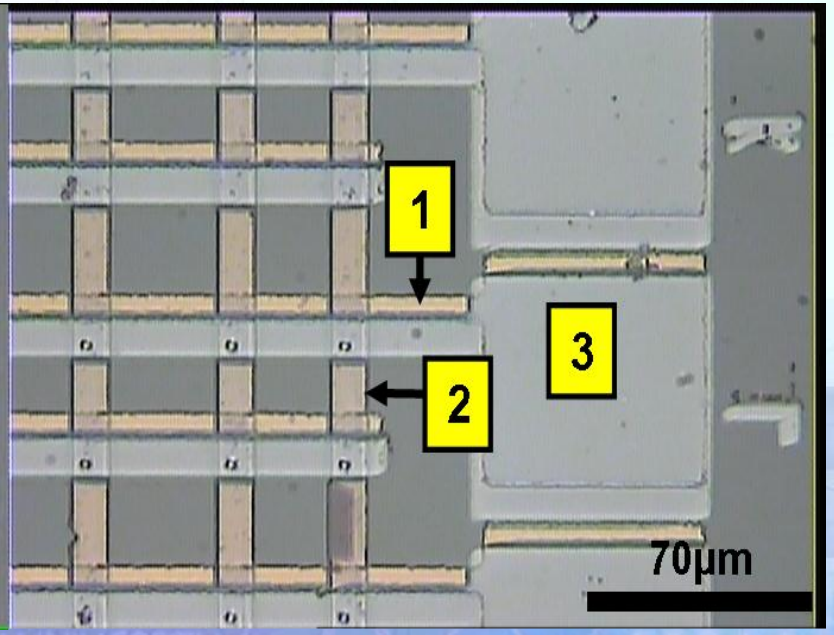
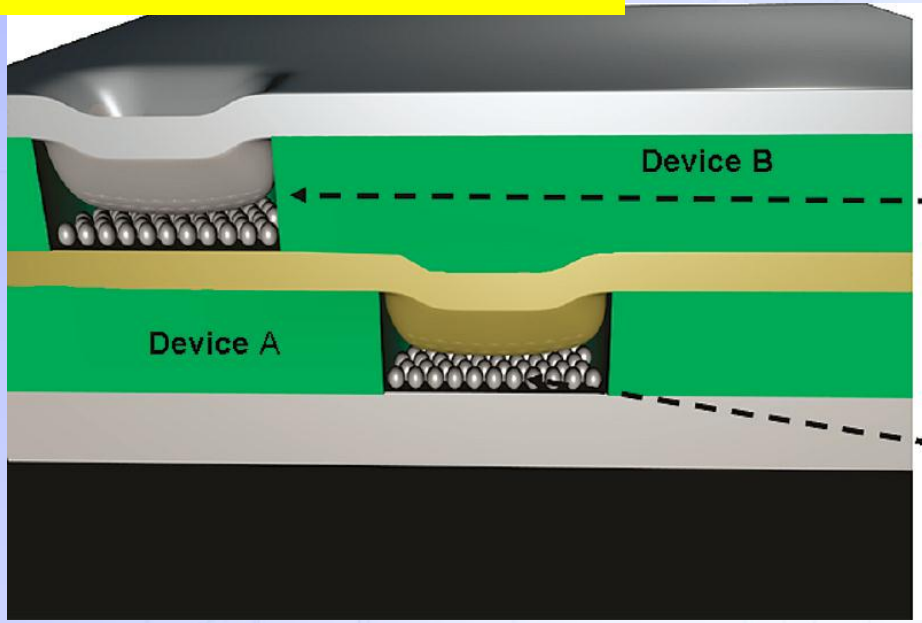
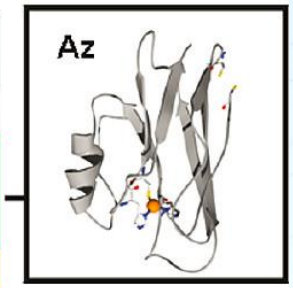
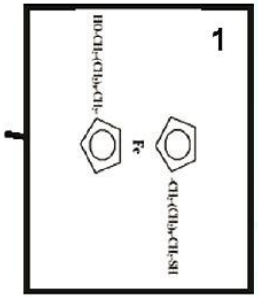




3D Molecular Circuit







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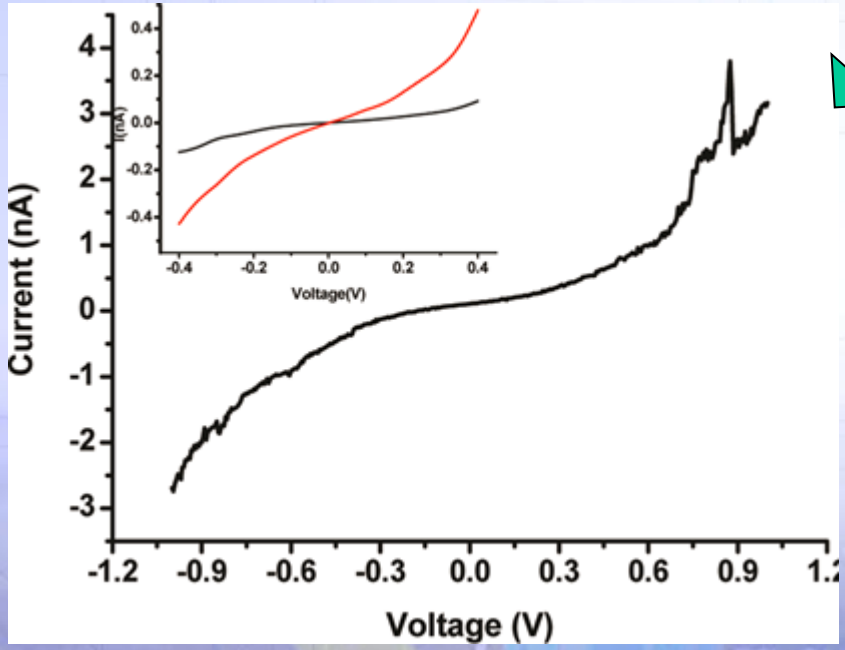
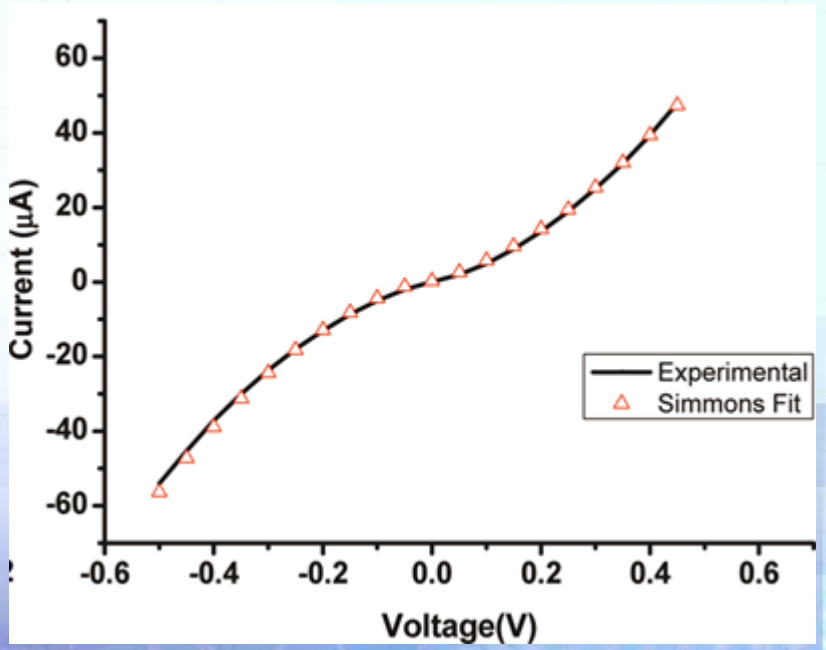
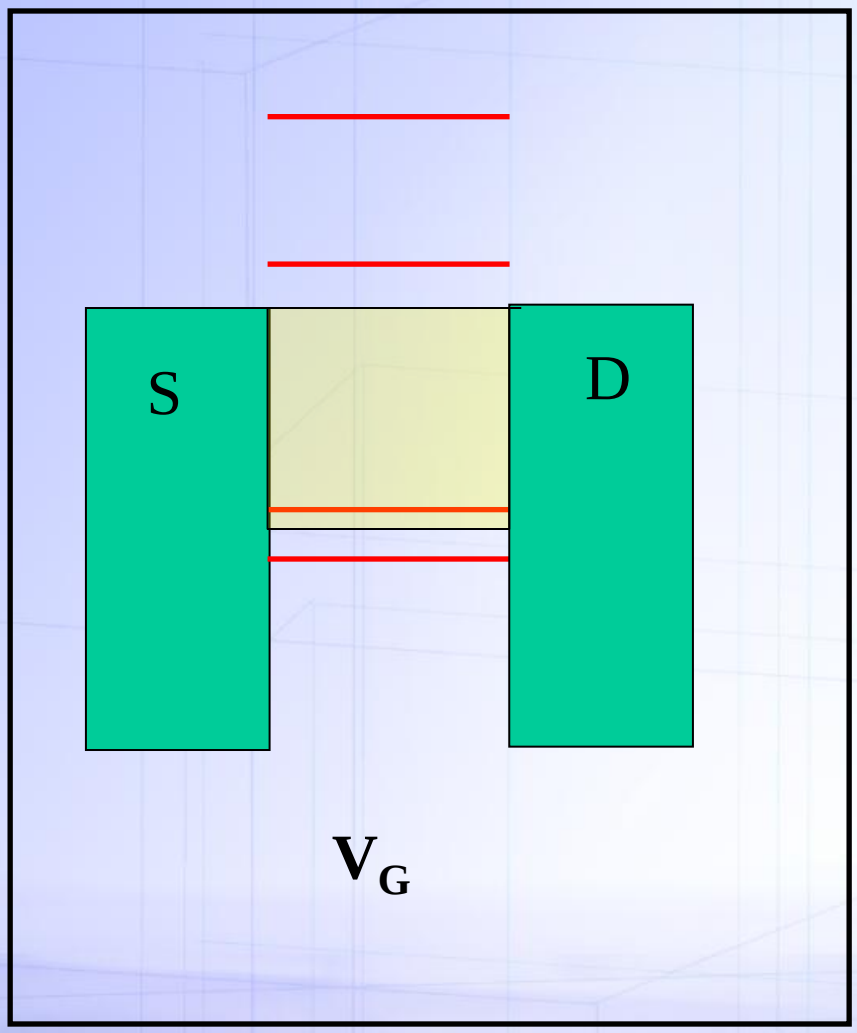




Transistors: our motivation



Gating Molecular Junctions (a simplified picture)

Gating on the molecular scale

- Tuning the molecular energy Levels within the Fermi window
- Control over the potential in the bridge- compensate for interface problem
- New types of devices
- Limits for miniaturization

J. Phys. Chem. Lett. 2011, 2, 1125

Transistor architecture

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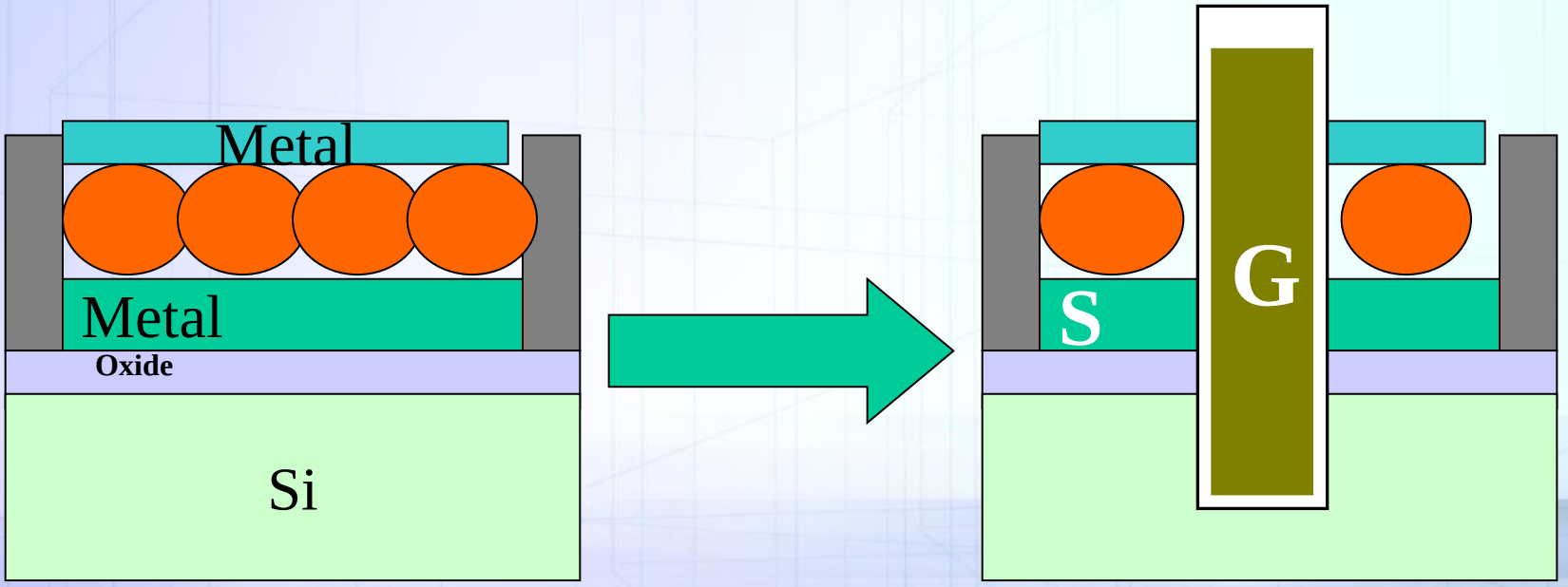
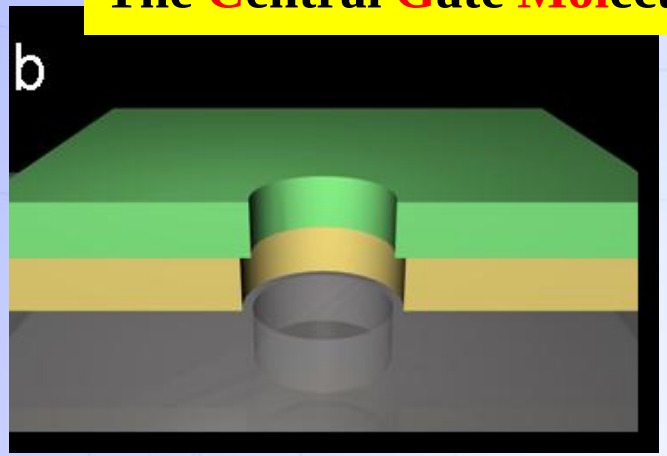
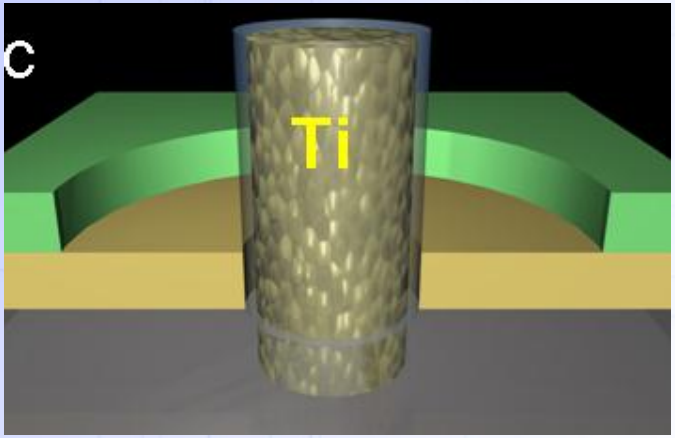
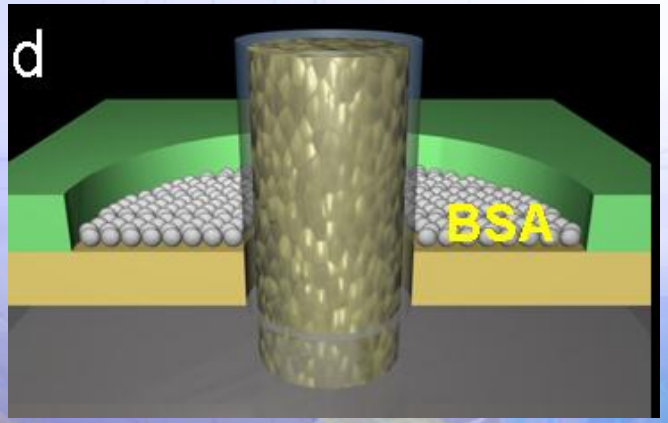
Our approach:
Transformation from two-leads device
to transistor structure- **Vertical Architecture**

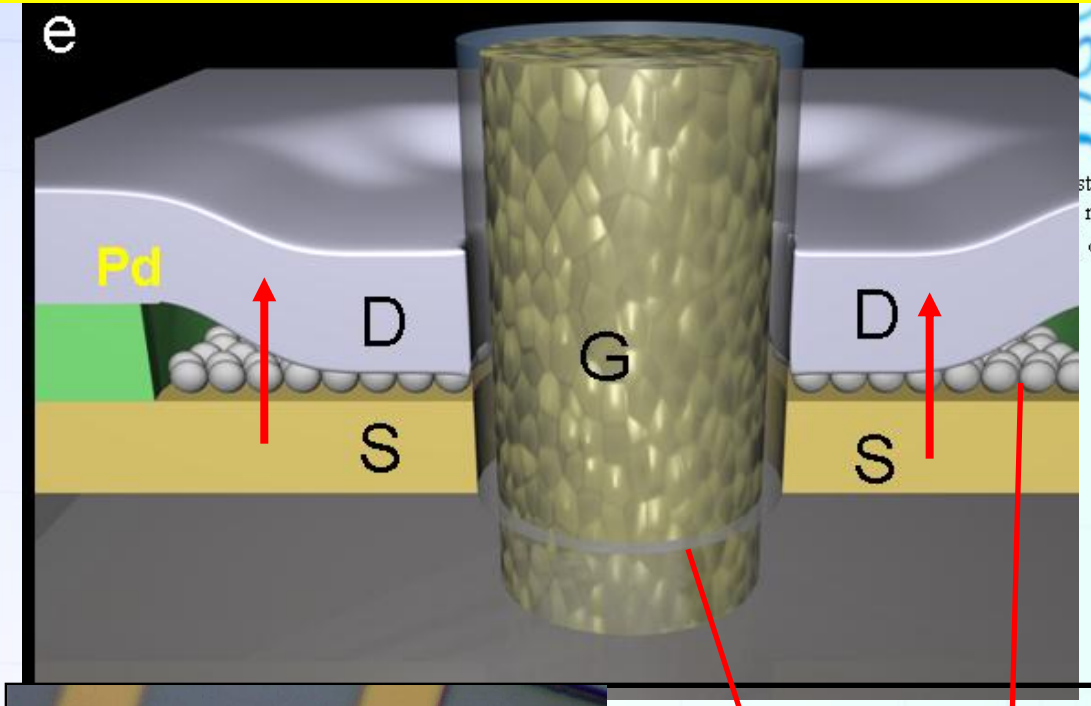


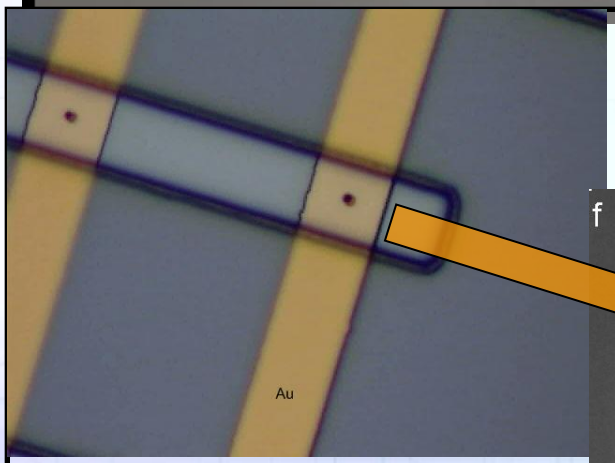
The Central Gate Molecular Vertical Transistor (C-Gate MolVet)

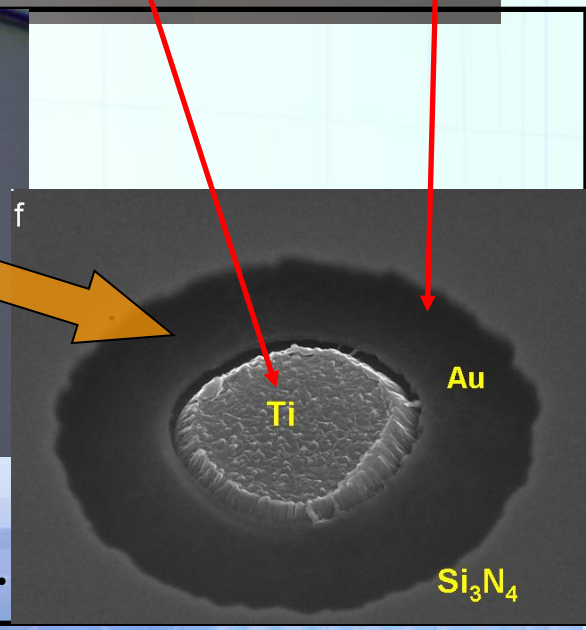








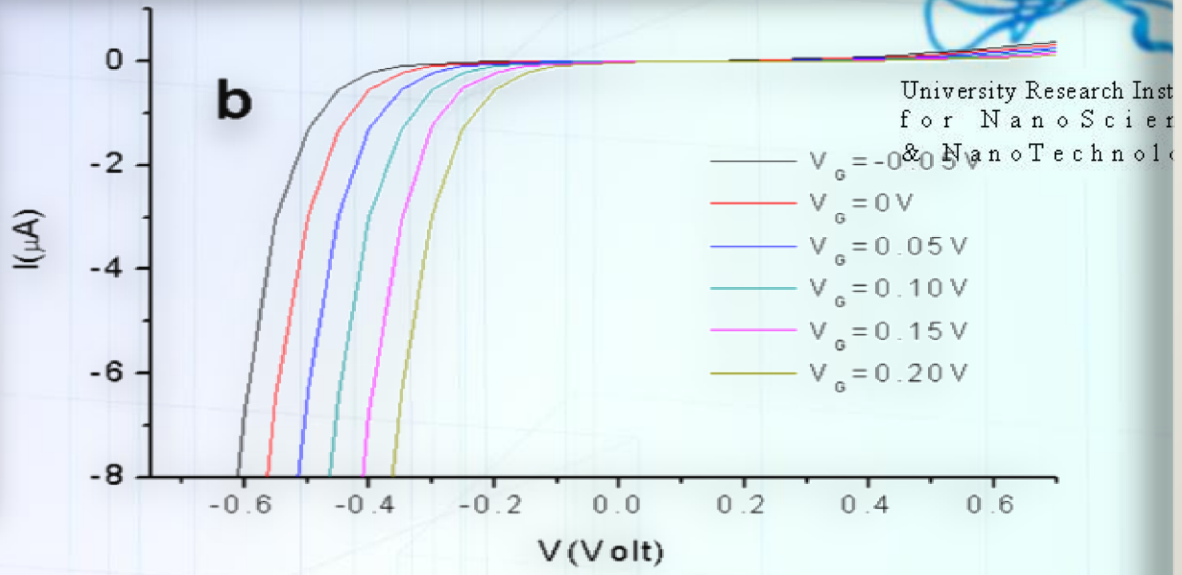


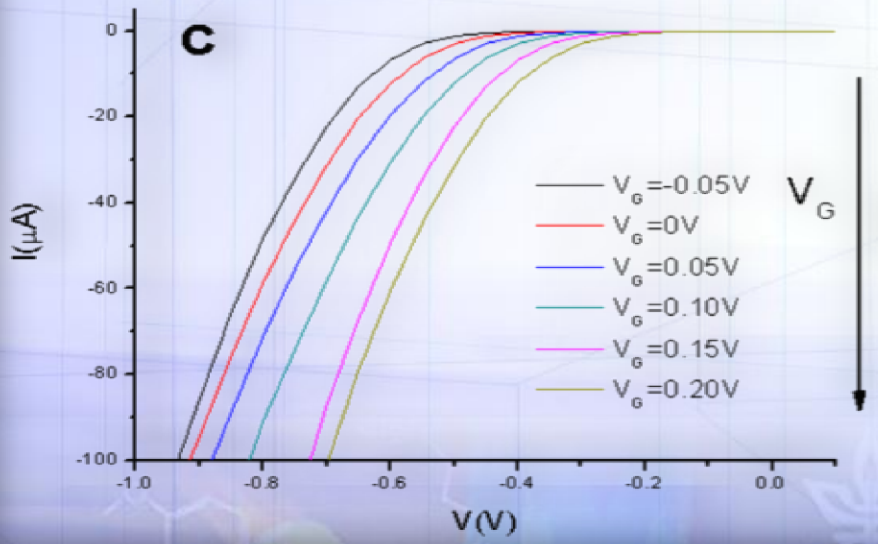


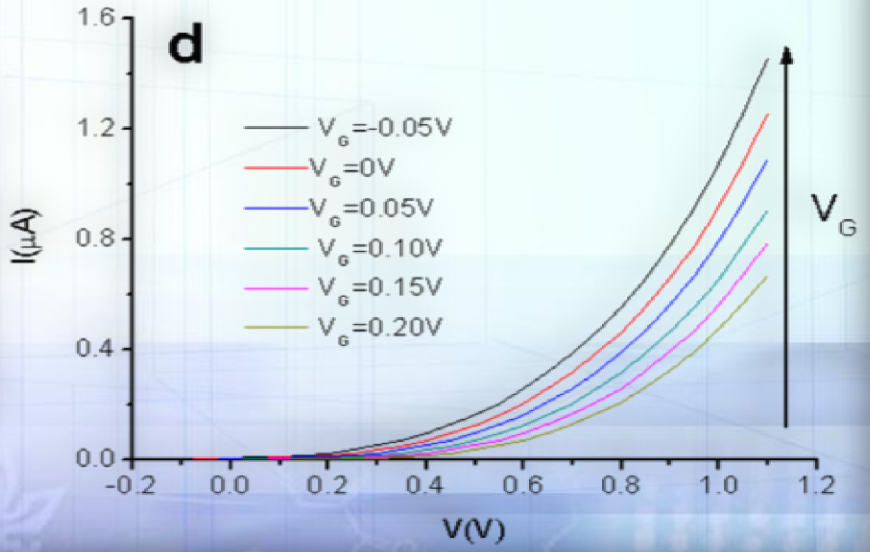
Nano Lett. (2009);9:1296

Adv Mater. (2010);22:2182.

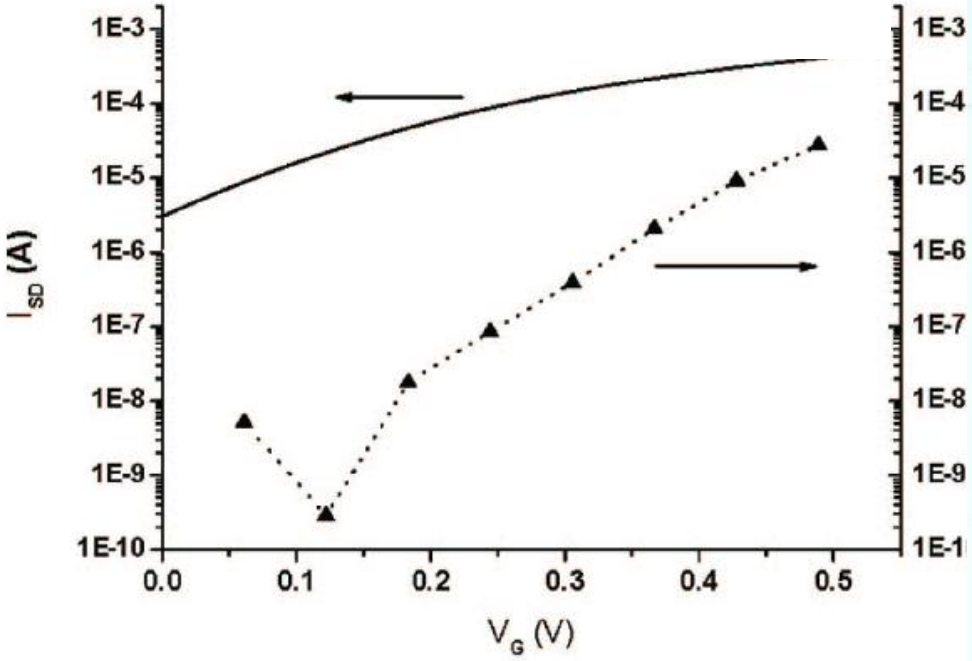
protein-4nm- channel molecular transistor

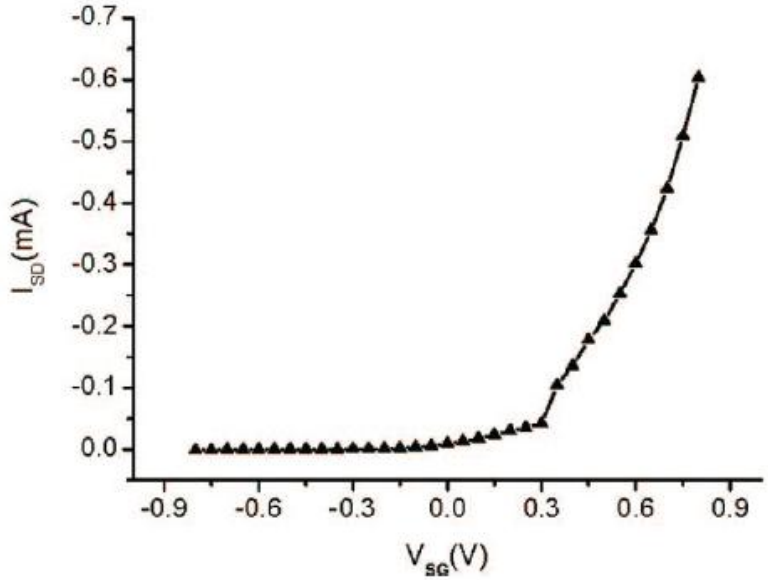






Nano lett 2009





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Other properties

- The fabrication is made using conventional process techniques- Un-limited amount of nm-sized devices can be constructed in parallel

- This is universal method- one use various types of molecules/materials

- Since the "channel length" is nm-sized (determined by the width of the molecular layer)- the transistor should be extremely fast
- **Technological applications: Memory, logic devices, optoelectronics , and new type of devices**

Molecular Design

Example: The design and measurement of Electroactive SAM

- An electroactive Molecule Can be charged (change its redox States during voltage application)
- Observation: electroactive molecule is accompanied by Negative Differntial resistance (NDR)
- One should detect this change by transport measurements (I/V curves)

The electroactive moiety should be “protected” by “barrier”-type moieties

Electron Transfer in electroactive molecules

Polaron Model (Nitzan, Ratner, Galperin) and Molecular Quantum Dot

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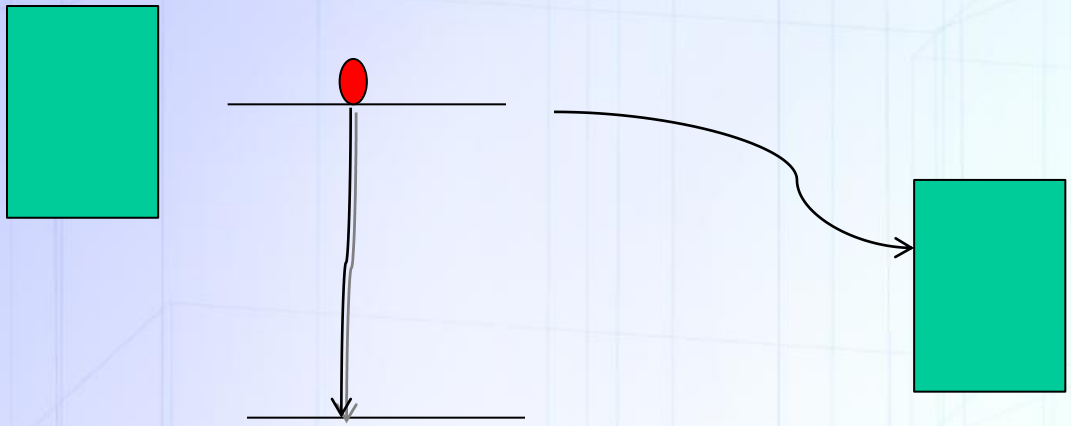
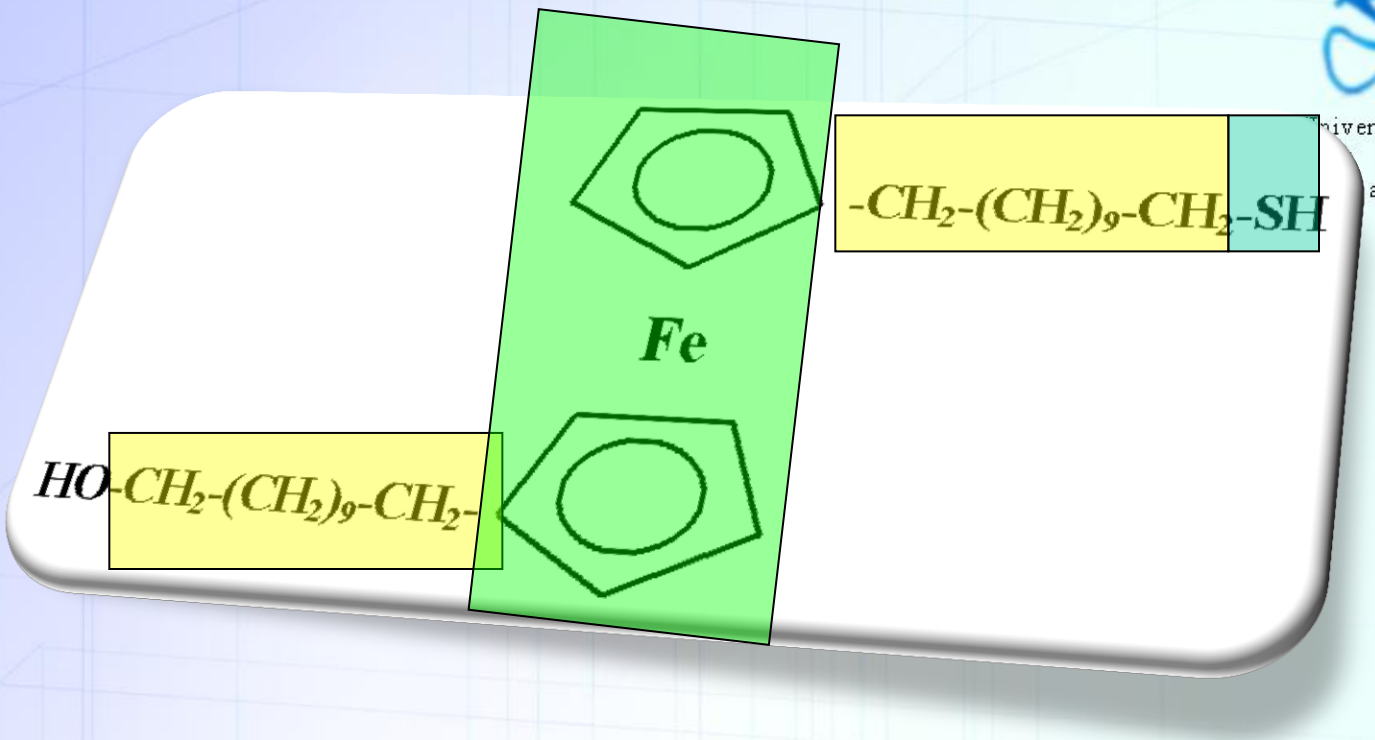


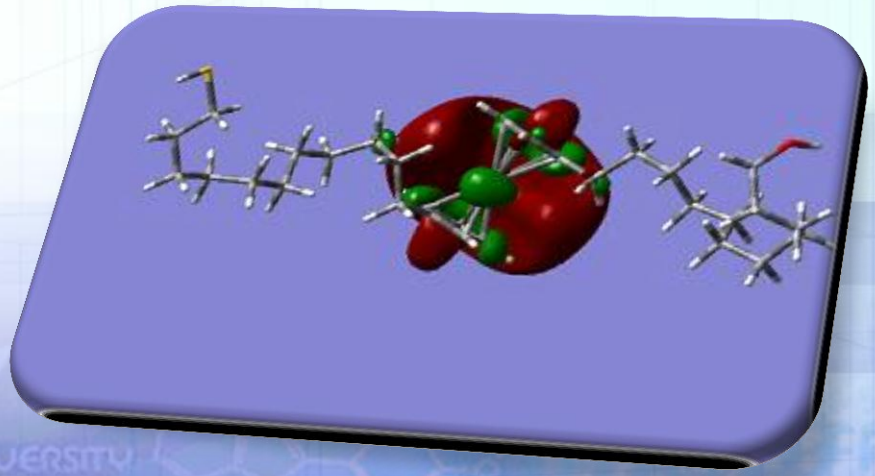
Strong e-ph coupling →Geometrical Relaxation→
Polaron Formation (MQD)

May explain Negative Differential Resistance (NDR), and Hysteresis

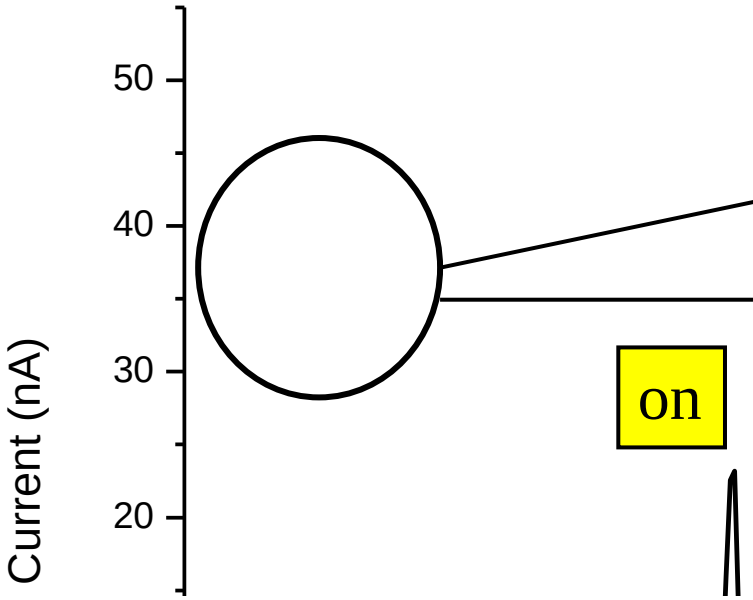
The Power of Organic Chemistry: Design of MQD (synthesis M. Gozin)



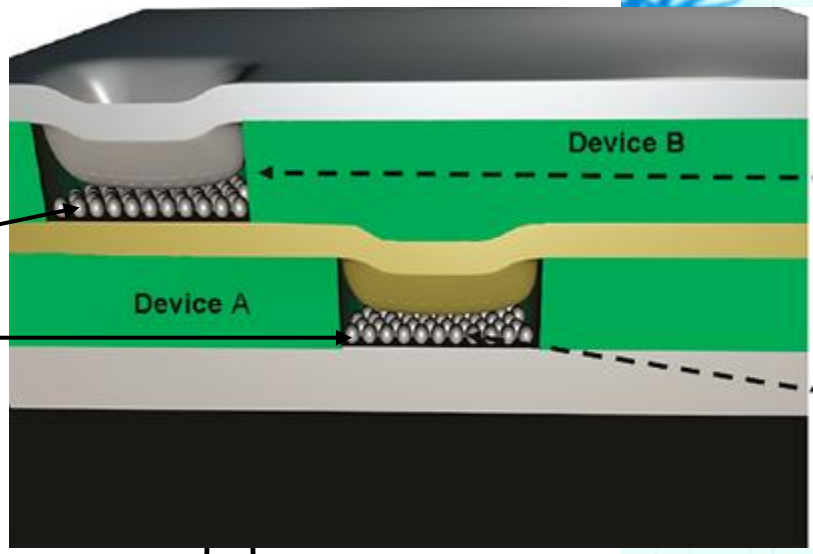
- **Central Conjugated unit/ redox center/ degeneracy**
- **Separation from electrodes by saturated chain**
- **Anchor group**

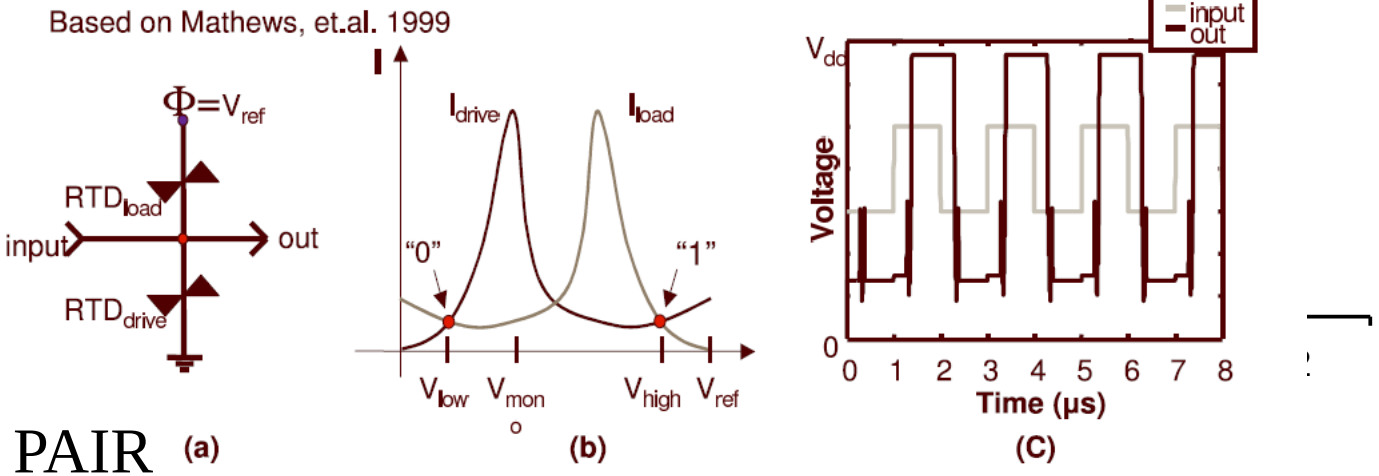


NDR asymmetric I/V as a basis for Logic circuit



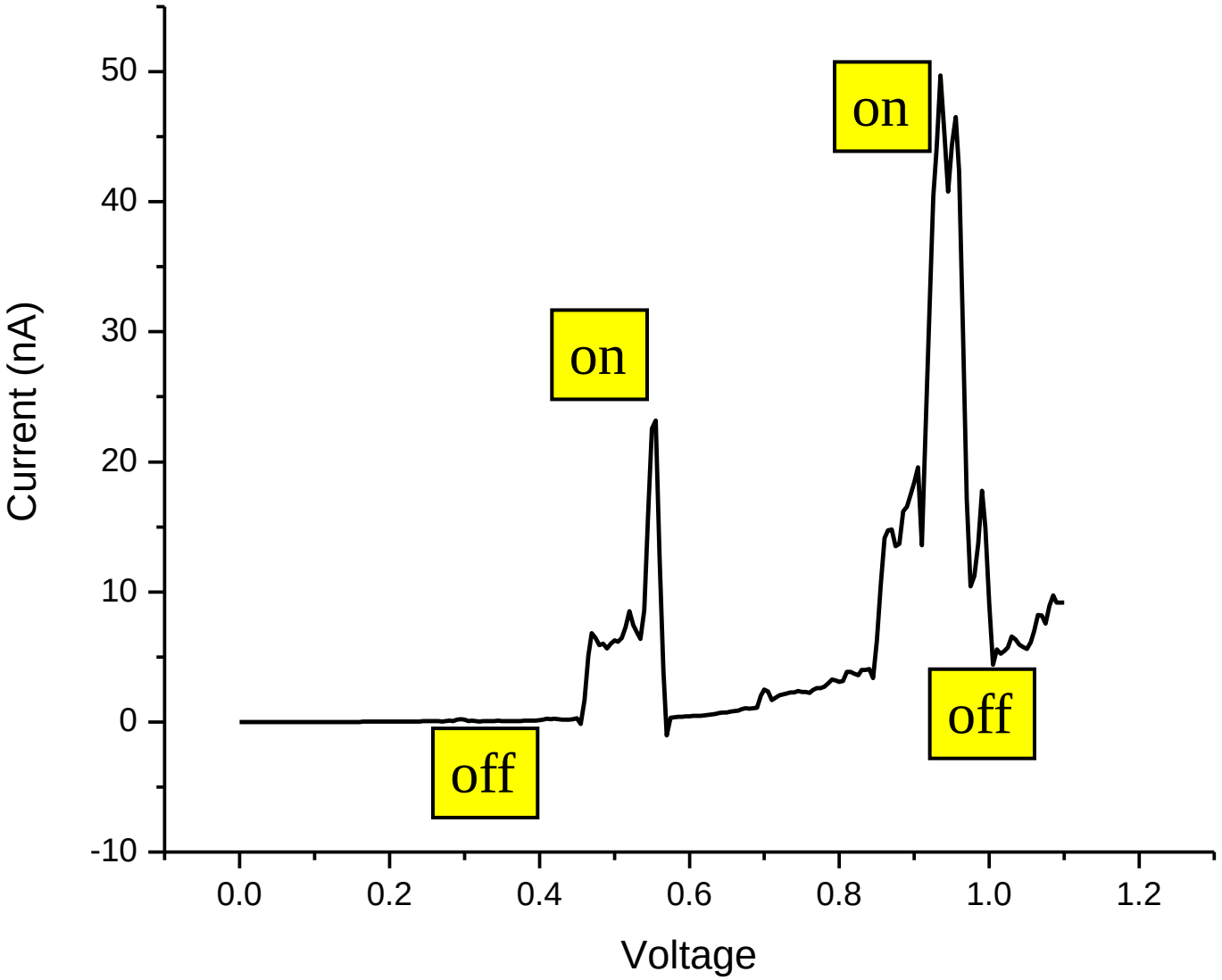
on



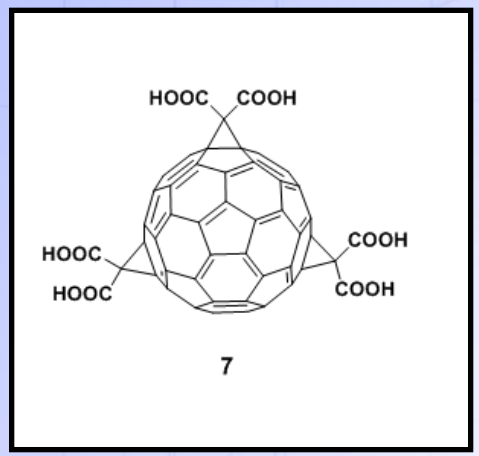


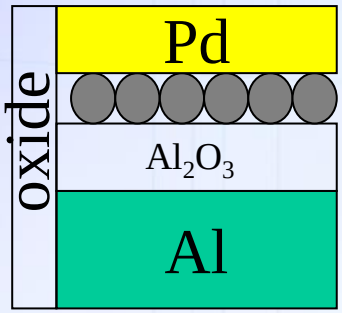
GOTO PAIR

NDR asymmetric I/V as a basis for Logic circuit

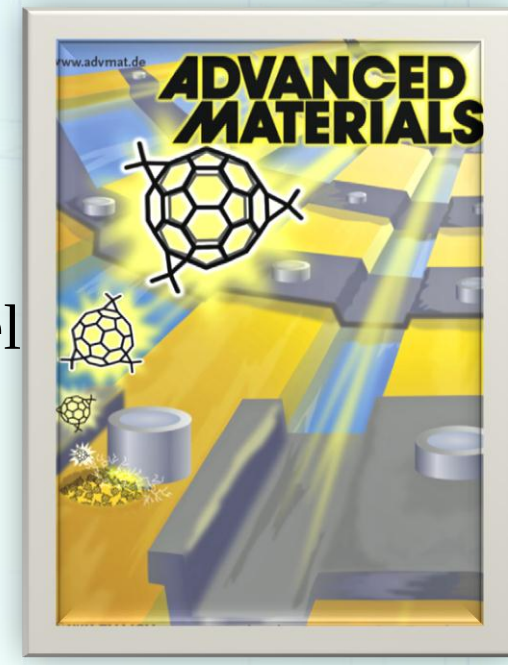


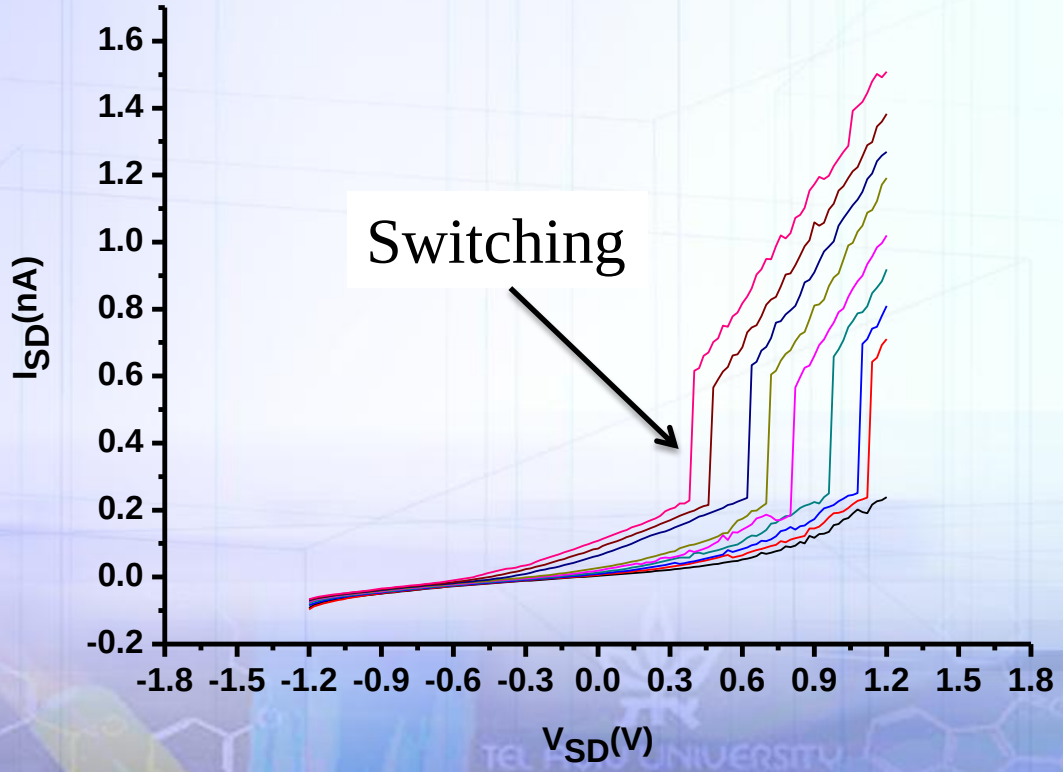
Molecular quantum dot transistor





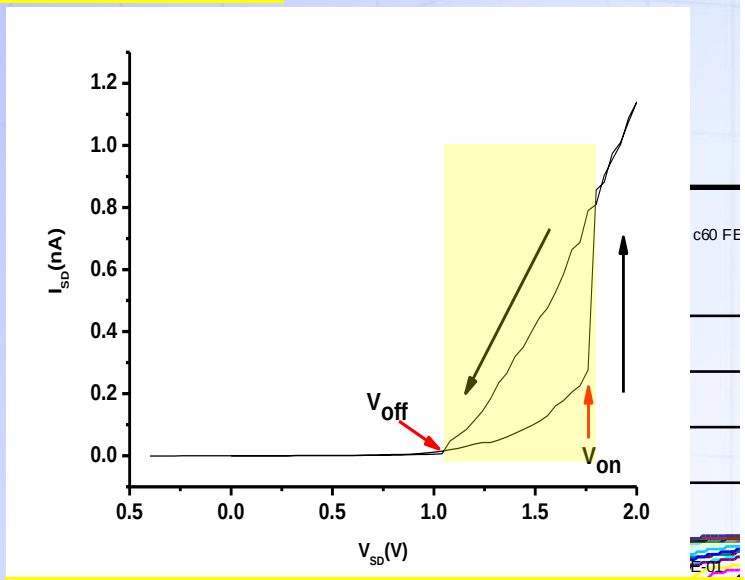
~ 1nm
Active channel
Transistor

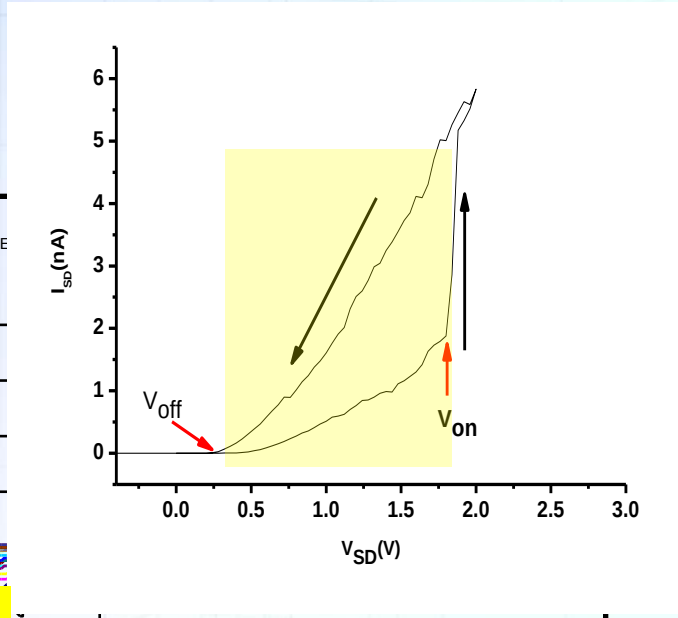




Gate-controlled switching

•Hysteresis





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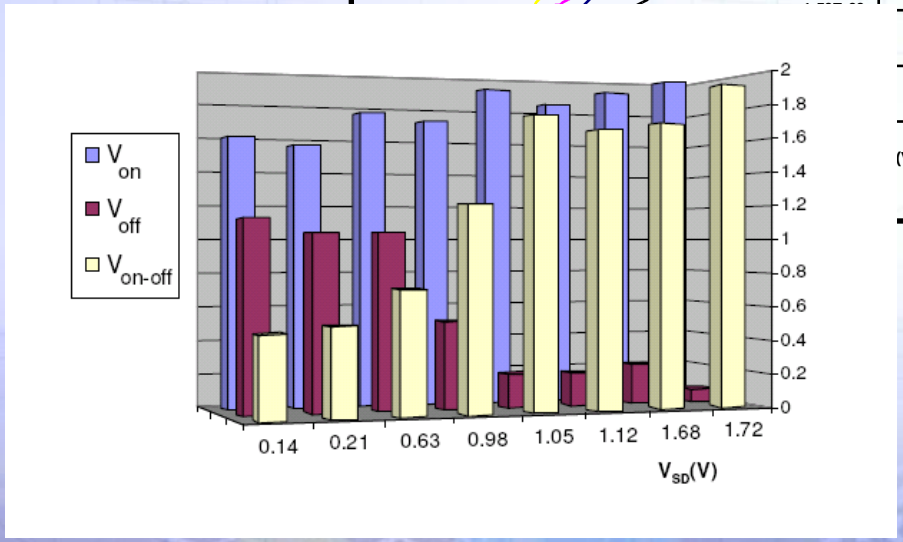
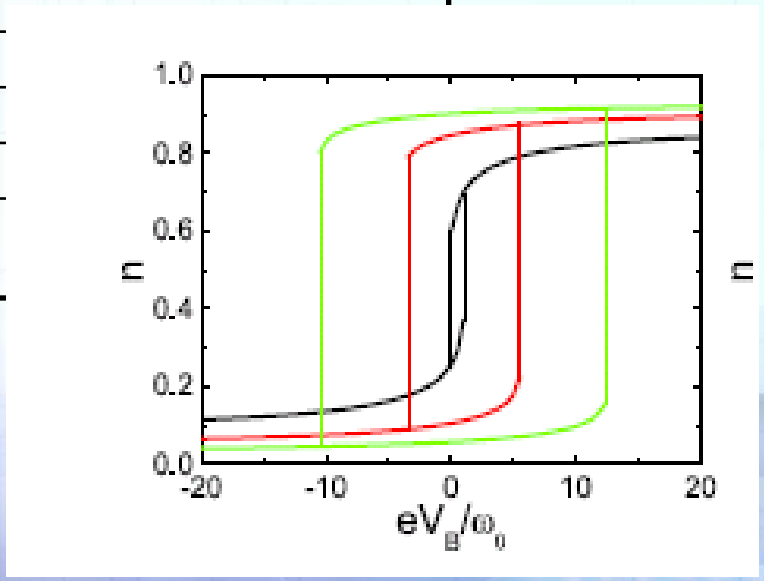
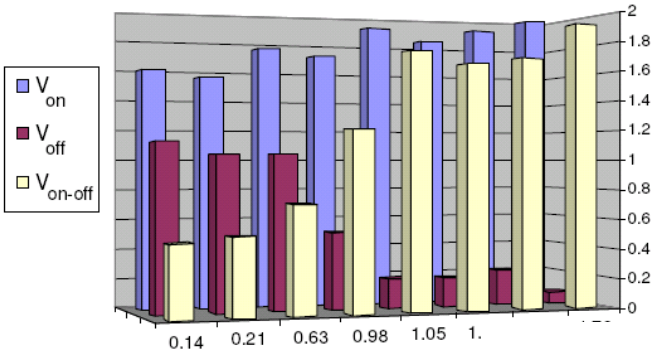
Gate Controlled Hysteresis

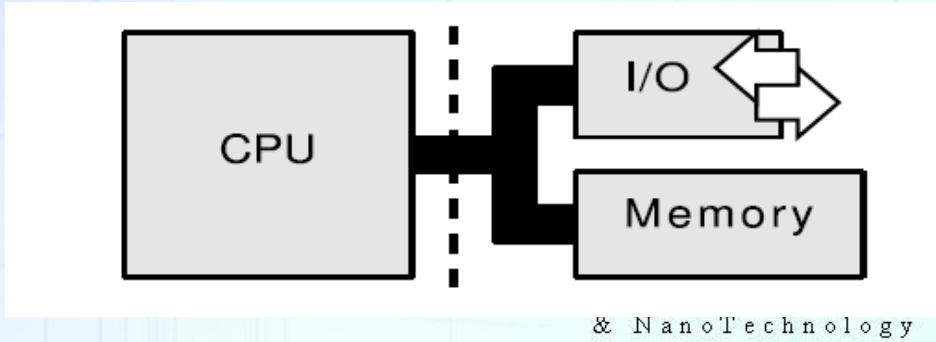




Thesis P. D'amico, Universit¨at Regensburg

Memory, Logic
And Von Neumann bottle-neck





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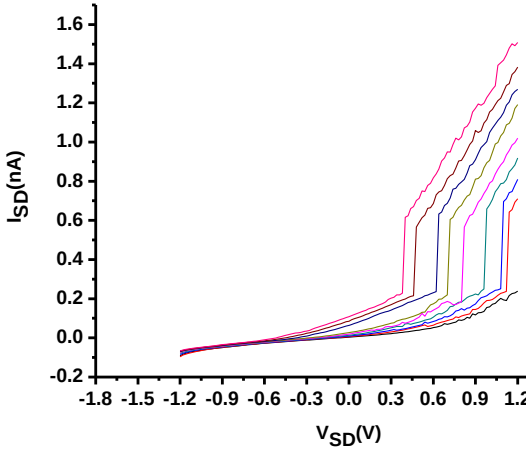
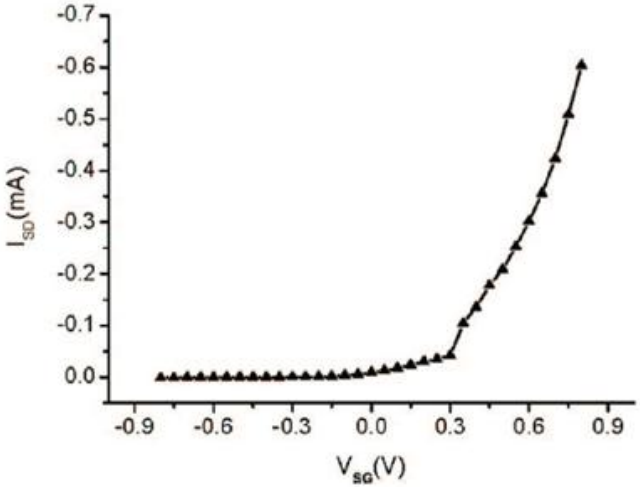
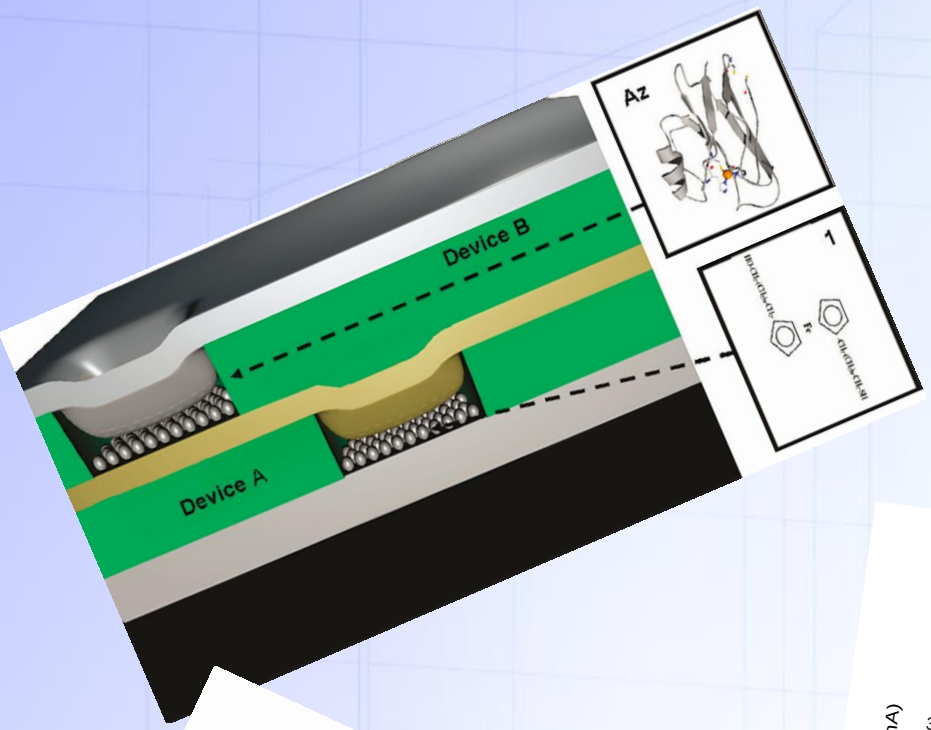
Hysteresis

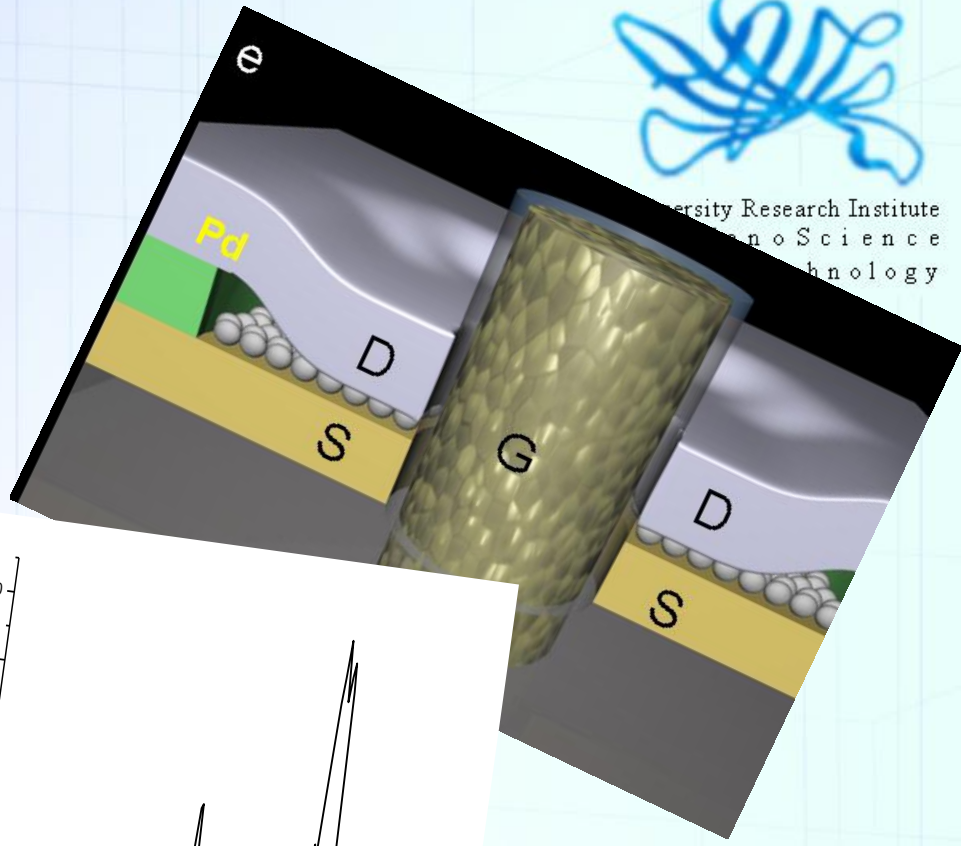


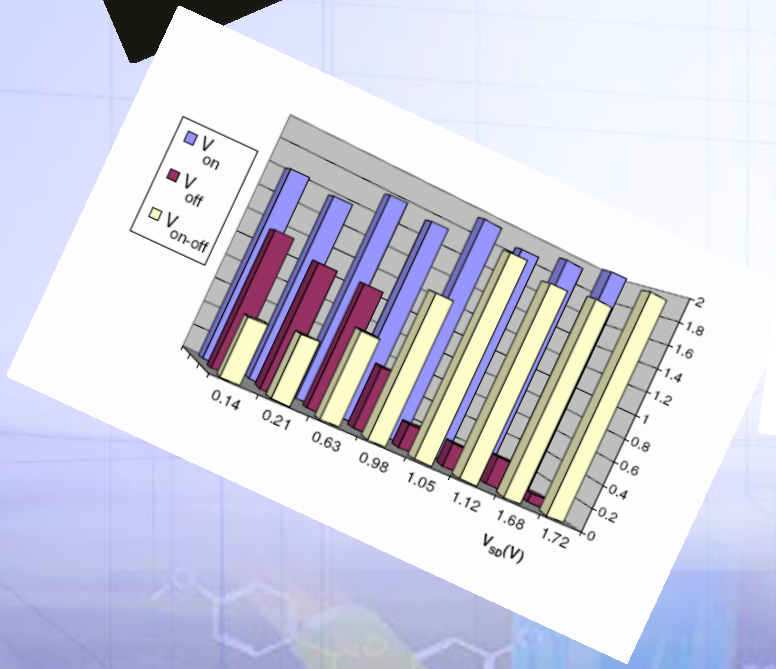
Switch

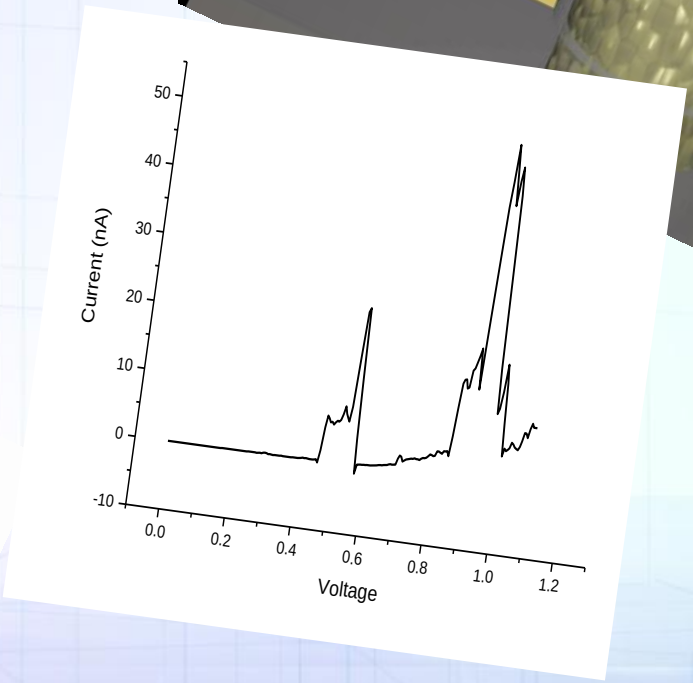


Transconductance









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- Yaron Fruchtman
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- Alex Ztukernik

- Ariel Caster
- Shai Li Moshe
- Simon Vergler
- Dr. Guilia Meshulam

- Prof. Chanoch Carmeli's group
- Dr. Itai Carmeli
- **Dr. Michael Gozin**
- Prof Andreas Hermann, University of Groningen

Prof. Abraham Nitzan

$$$.. ISF, DFG, Clal, US-Air force
James Franck Foundation