Nanoelectronics

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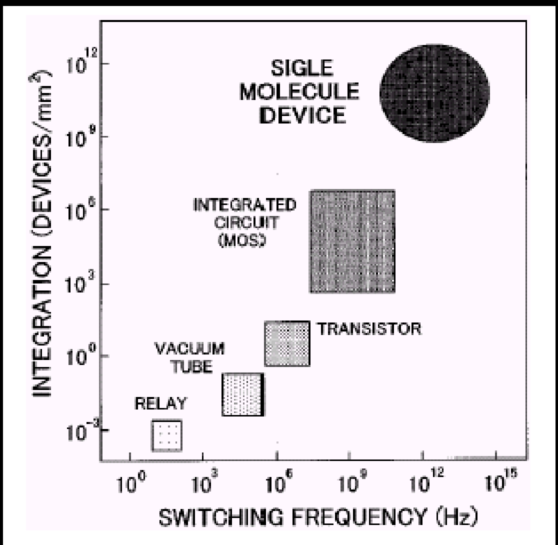
Electronic evolution

- Device
  - Vacuum tube
  - Transistor
  - Integration circuit (microelectronics)
  - Nanoelectronics
- Circuit
  - Analog
  - Digital
  - Fuzzy logic, neural network
- System
  - Hardware equipment
  - Microprocessor (software) based equipment
  - Digital process

Current Density Magnitude

		<—— Molecular Electronic Device ——>				
Quantity	Units	1,4-Dithiol Benzene	3-Ring Poly-phenylene Wire	Poly-phenylene RTD (5 rings)	Carbon Nanotube	Copper Wire
Applied Voltage	Volts	1	1	1.4 (peak)	1	2×10^{-3} (10 cm wire)
Current Measured in Experiment	Amperes	2×10^{-8}	3.2×10^{-5}	1.4×10^{-11}	1×10^{-7}	1 (approx.)
Current Inferred per Molecule	Amperes Electrons per Sec	2×10^{-8} 1.2×10^{11}	3.2×10^{-8} 2.0×10^{11}	1.4×10^{-14} 8.7×10^{4}	1×10^{-7} 6.2×10^{11}	– –
Estimated Cross-Sectional Area per Molecule	nm^2	~0.05	~0.05	~0.05	~3.1 (Radius ≈ 1 nm)	$\sim 3.1 \times 10^{12}$ (Radius ~ 1 mm)
Current Density	Electrons per Sec-nm^2	$\sim 2 \times 10^{12}$	$\sim 4 \times 10^{12}$	$\sim 2 \times 10^{6}$	$\sim 2 \times 10^{11}$	$\sim 2 \times 10^{6}$

Magnitude of Switching speed and integration

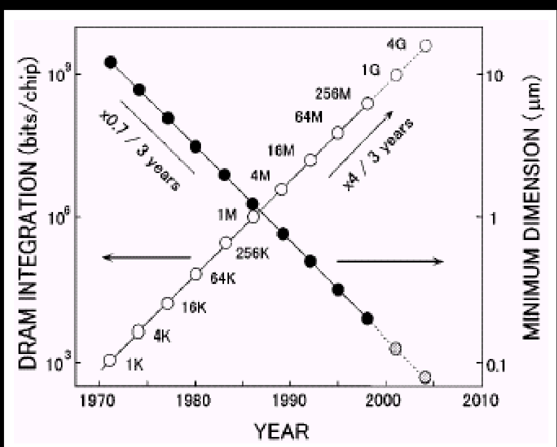


- Y. Wada, Proc.IEEE 89, 8, 1147-1171, 2001

Hardware

- Vacuum tube:
  - field control
  - heat power for filament
  - speed limit by large configuration
- Bipolar junction transistor:
  - - electron and hole conduction
- Unipolar transistor
  - Field effect transistor (FET)
  - Metal oxide semiconductor (MOS) transistor
  - low leak current, low power
  - high speed
  - minimization

Moore's laws and way out

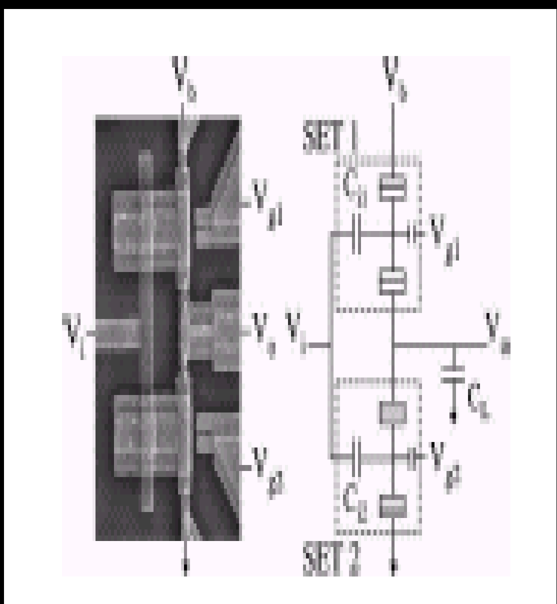


- Y. Wada, Proc.IEEE 89, 8, 1147-1171, 2001
- Integration has quadrupled every three year
- Minimum dimension has been scale by 0.7

Low dimensional devices

- Device size < 100nm close to the order of electron wavelength
- Quantum system
  - discrete energy
  - Tunneling through high barrier
- Quantum well: 2-D
- Quantum wire: 1-D
- Quantum dot: 0-D
- Metal dot: 3-D
- Resonant Tunneling diode: 2-D

Single Electron Inverter



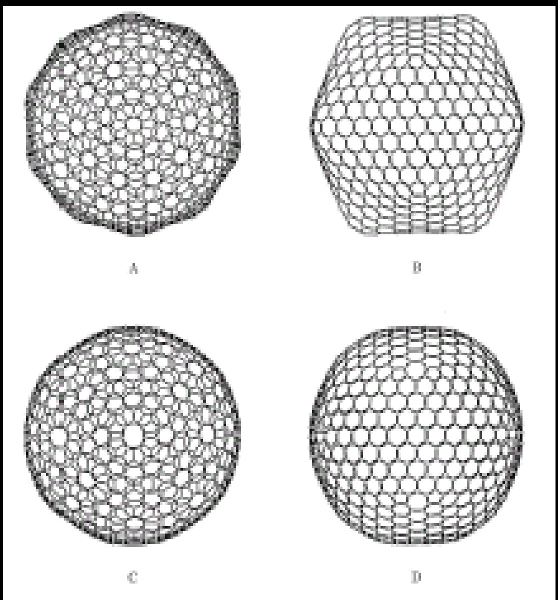
- C.P.Heij, P.Hadley and J.E.Mooij APL 78, 8, 1140, 2001
- Coulomb blockade
- Two SETs in series
- Pattern of 25nm thick Al film and 8nm thick AlxOy layer
- Gain 2.6 at 25mK, 1 at 140mK
- Magnetic field of 1T for superconductivity suppression

Carbon network

- 3D: diamond
- 2D: graphite
- 1D: nanotube
- 0D: bulky-ball

- 1D: conjugate polymer

Bulky Ball: 0-D carbon

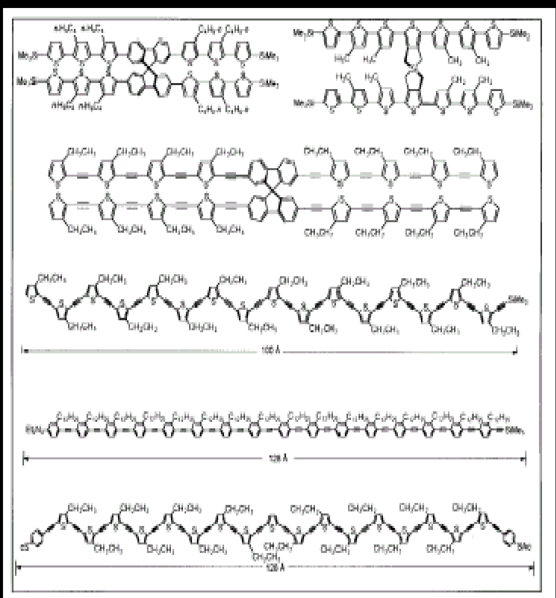


- Theor Chem Acc 99, 29-33, 1998
- C(960) (a and b)
- C(936) (c and d)

Molecular electronics

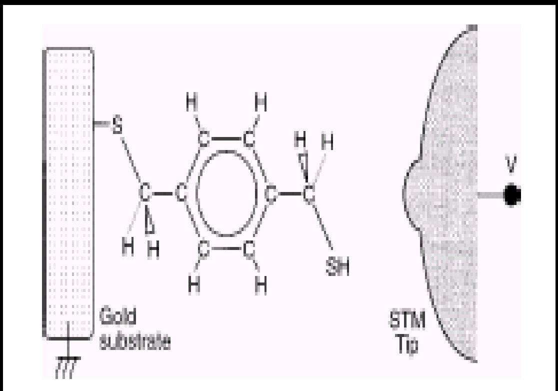
- Conjugate polymer
  - pi-bond: sp, sp^2, sp^3
  - PA, PVV, PVF
- Molecular switch
  - Conformation
  - Single electron
  - Moving atom
  - Adjusting potential

Molecular conductors



- M.A.Reed Proc. IEEE, 87, 4, 652-658, 1999
- Top three: with crossbar switch
- Bottom two rigid-rod conjugated oligomers with the thiol terminal

Molecular wire

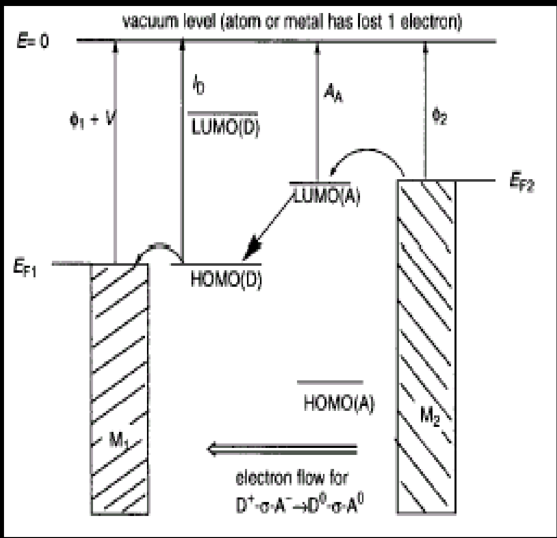


- J Chem Phys, 109, 7, 2874-2882, 1998
- Xylyl dithol
- Non-equilibrium Green Function method
- Open system

Molecular rectification

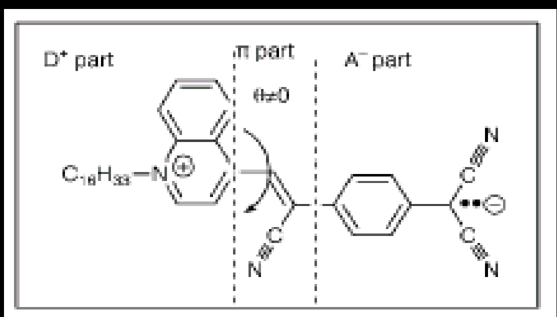
- J. Materials Chemistry, 9, 2271-2275, 1999.
- OHAPy-C_DNB
- Donor-sigma-acceptor
- LB film
- ab initio molecular modelling (local density functional code)

Aviram-Ratner model



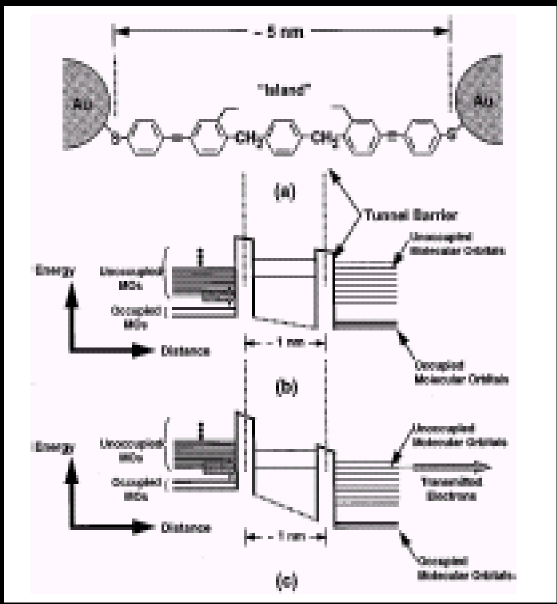
- J. Materials Chemistry, 9, 2027-2036, 1999
- Eledtron flow from the excited state D+-sigama- A- to the ground state D0-sigma-A0

D-pi-A Rectifier molecule



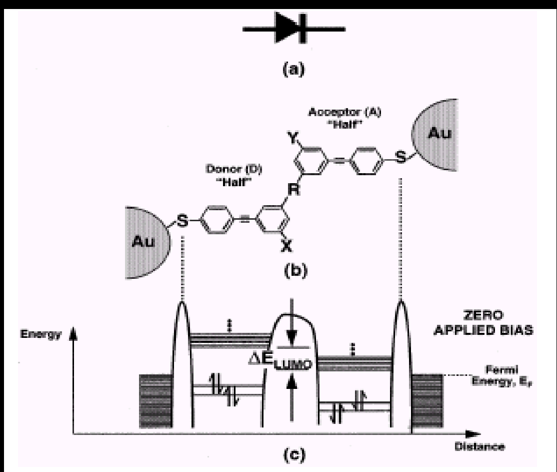
- J Am. Chem. Soc. 119, 10455, 1997
- (Ga/In)/Al/4 layer of LB/Al/(Ga/In)

Molecular resonant tunneling diode



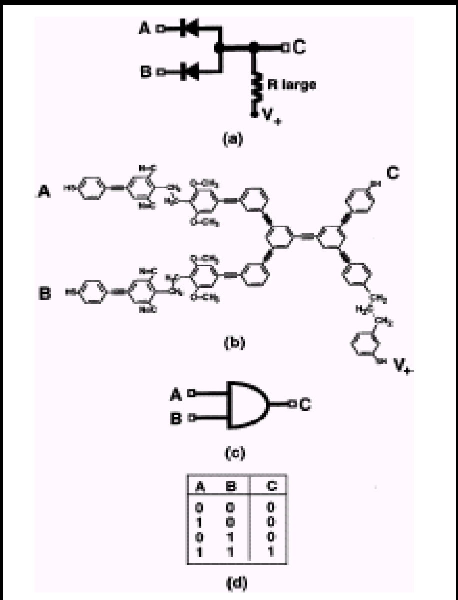
- M.A. Reed Proc.IEEE 87, 652-658, 1999

Proposed polyphenylene - based rectifier



- J.C. Ellenbogen, J. C. Love "Architectures for Molecular Electronic Computer" Proc. IEEE 88, 3, 2000

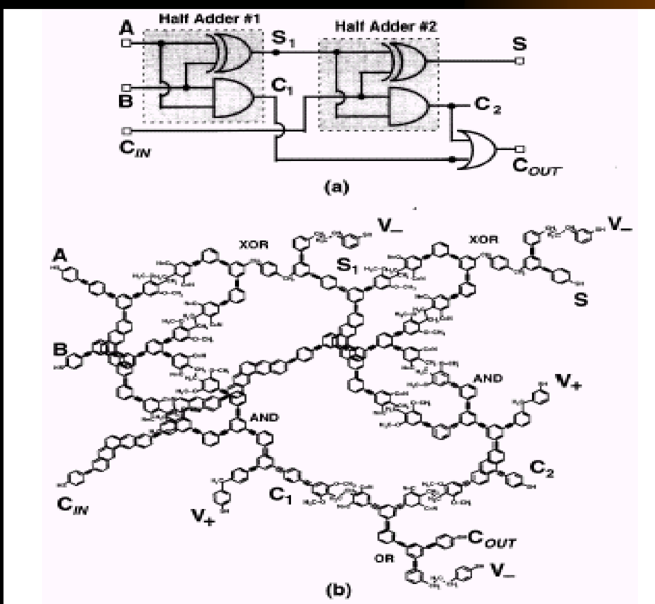
Proposed diode-diode type AND gate



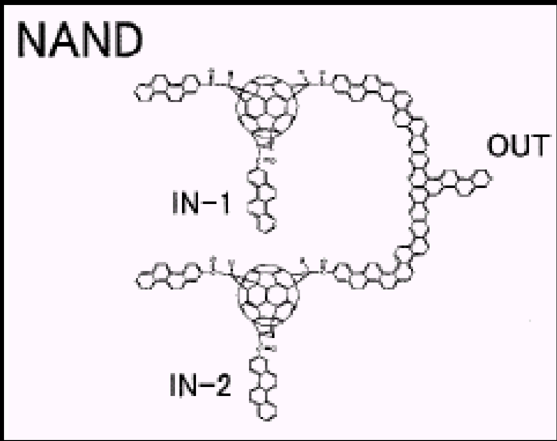
A	B	C
0	0	0
1	0	0
0	1	0
1	1	1

- J.C. Ellenbogen, J. C. Love "Architectures for Molecular Electronic Computer" Proc. IEEE 88, 3, 2000

Design for a molecular electronic full adder

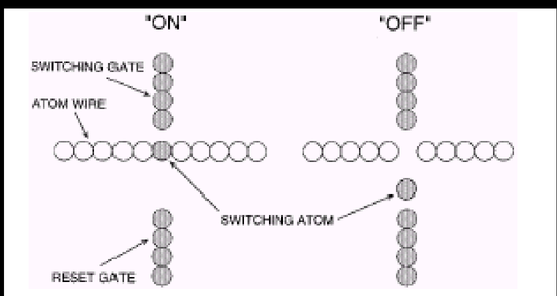


Mo lecular single electron transistor idea



- Y. Wada, Proc.IEEE 89, 8, 1147-1171, 2001
- MOSES: Two tunneling junction and one gate insulator

Atom relay transistor

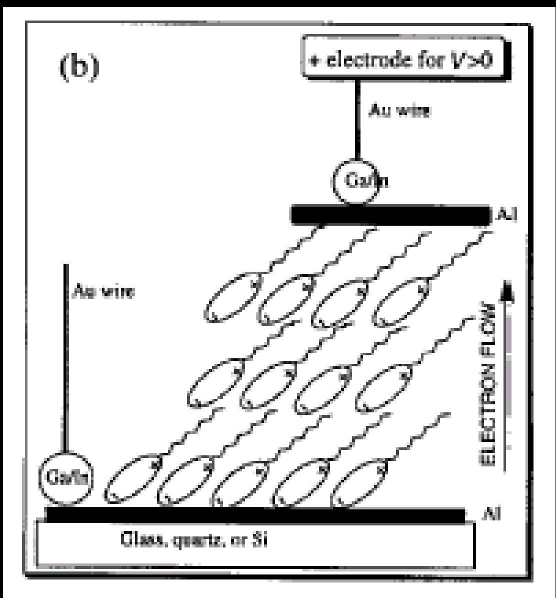


- Y. Wada, Proc.IEEE 89, 8, 1147-1171, 2001
- Mechanical motion of switch

Technology for Nanoelectronics

- Monoatomic-layer Thin film fabrication
  - Gas phase (Vacuum)
    - Molecular beam epitaxy (MBE)
    - Metal organic chemical vapor deposition (MOCVD)
  - Liquid (Hydrophobic/Hydrophilic: repel/attracted to water)
    - Langmuir-Blodgett (LB) film
- Patterning
  - Lithography
  - Self assembly
- Metal electrode
  - Scanning tunelling microscope STM
  - Surfer self assembly

Structure of LB monolayer thin film



Ways of Nanoelectronic

- Fix configuration
  - Programmable Logic Array (PLA)
  - Field Programmable Gate (FPGA)
  - Neural network
- Programming (Rule) -> Learning
- Other forms
  - DNA computer: molecular selection
  - Quantum computer: interaction between neighbor spin