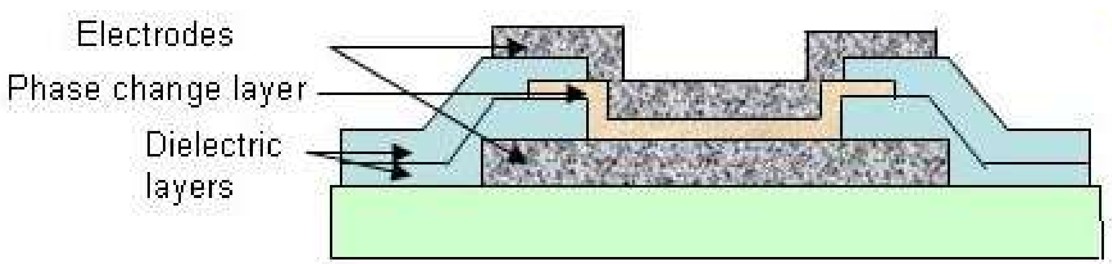
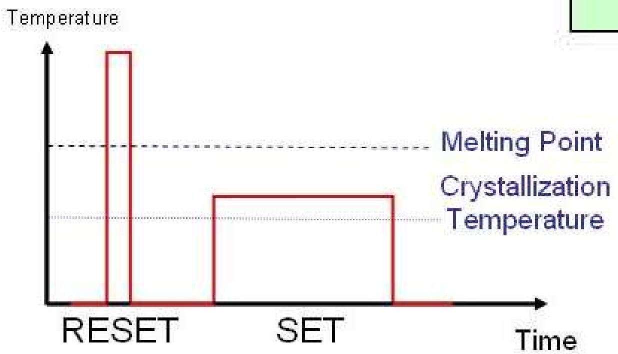
MOSFETs and the future of microelectronics

Phase change memory

Phase-change memory (PCM) uses chalcogenide materials. These can be switched between a low resistance crystalline state and a high resistance amorphous state.

GeSbTe is melted by a laser in rewritable DVDs and by a current in PCM.

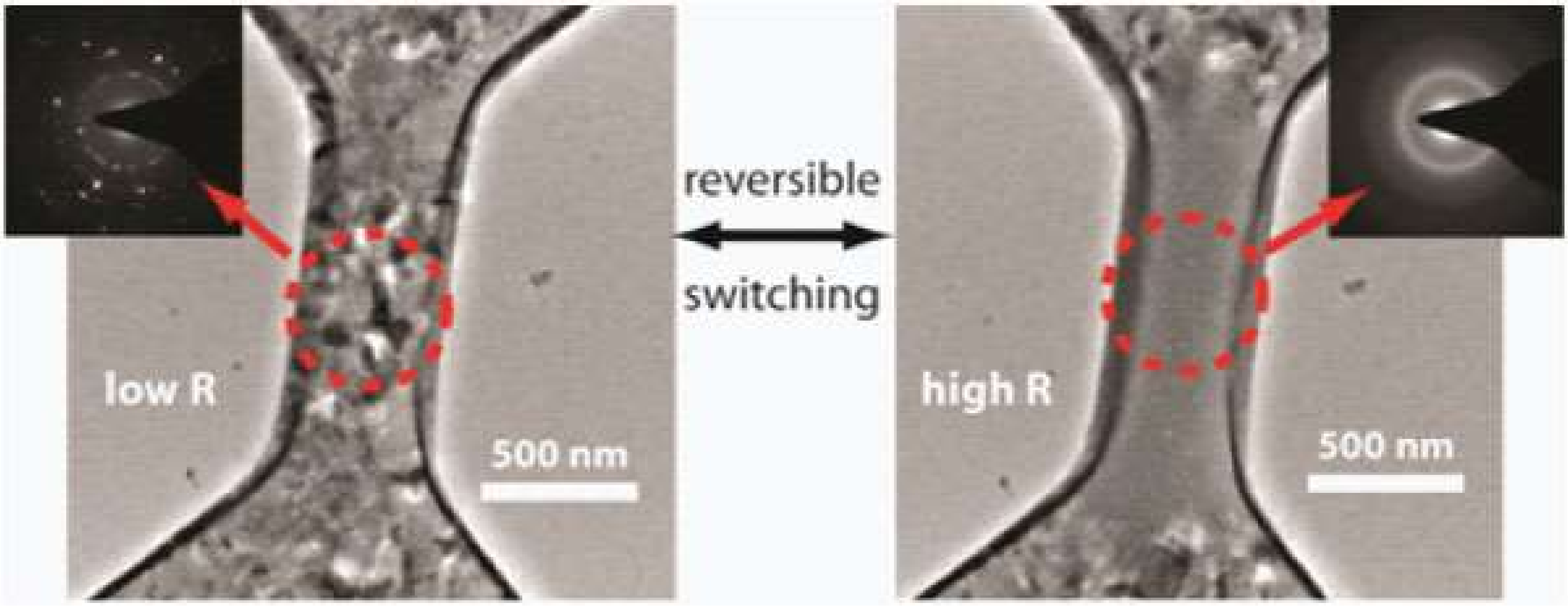




nonvolatile

Phase change material

Electron diffraction in a TEM of a GeSbTe alloy.

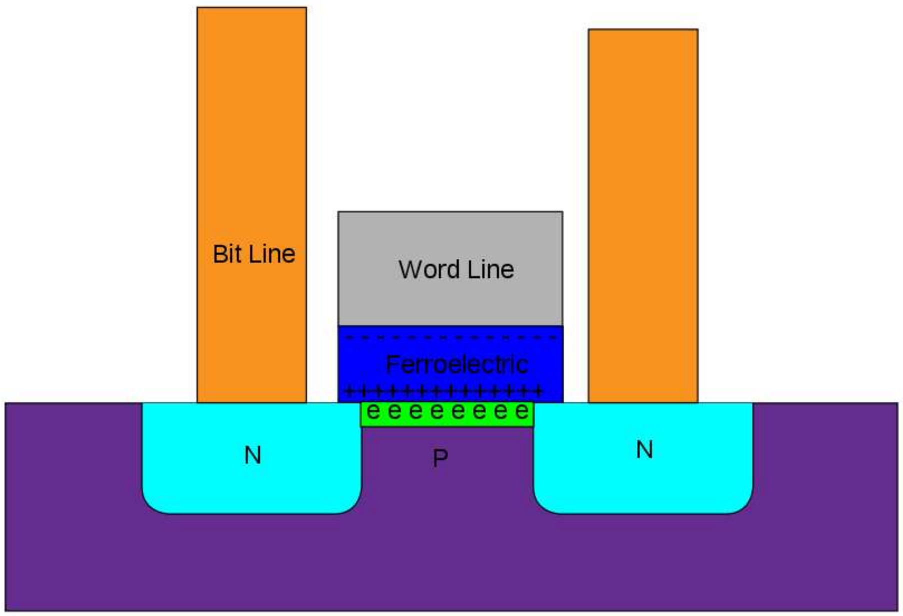


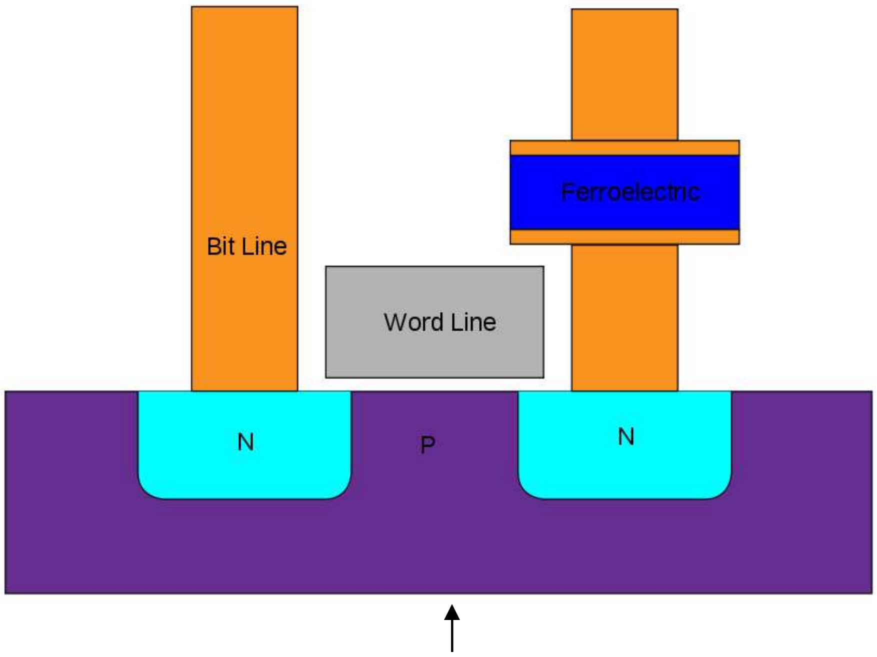
http://web.stanford.edu/group/cui_group/research.htm

Ferroelectric RAM

FeRAM uses a Ferroelectric material like PZT to store information.

Sometimes used in smart cards.



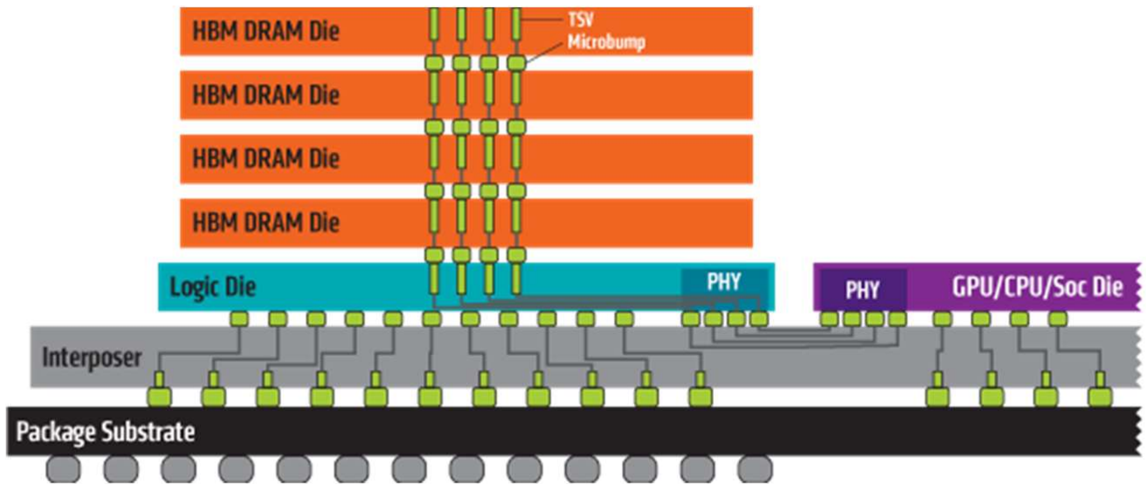


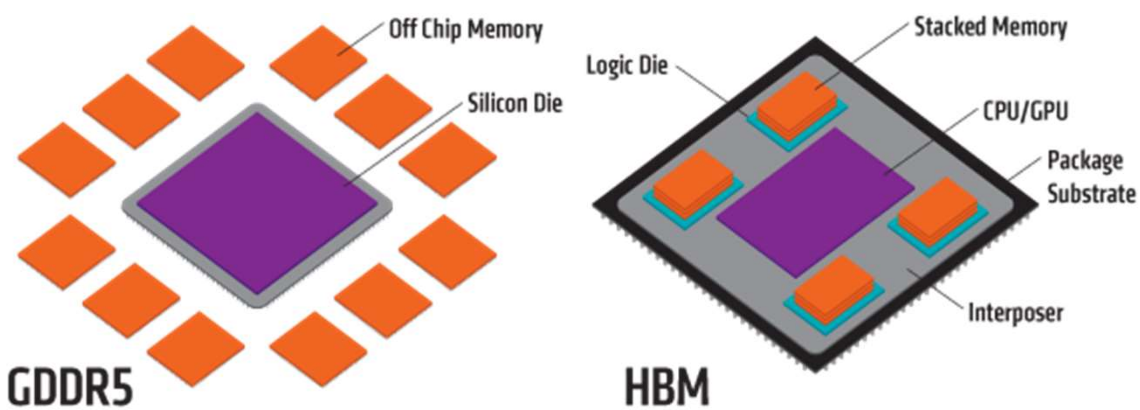
nonvolatile

To read, try to write a 0,
if a current flows, it was a 1.

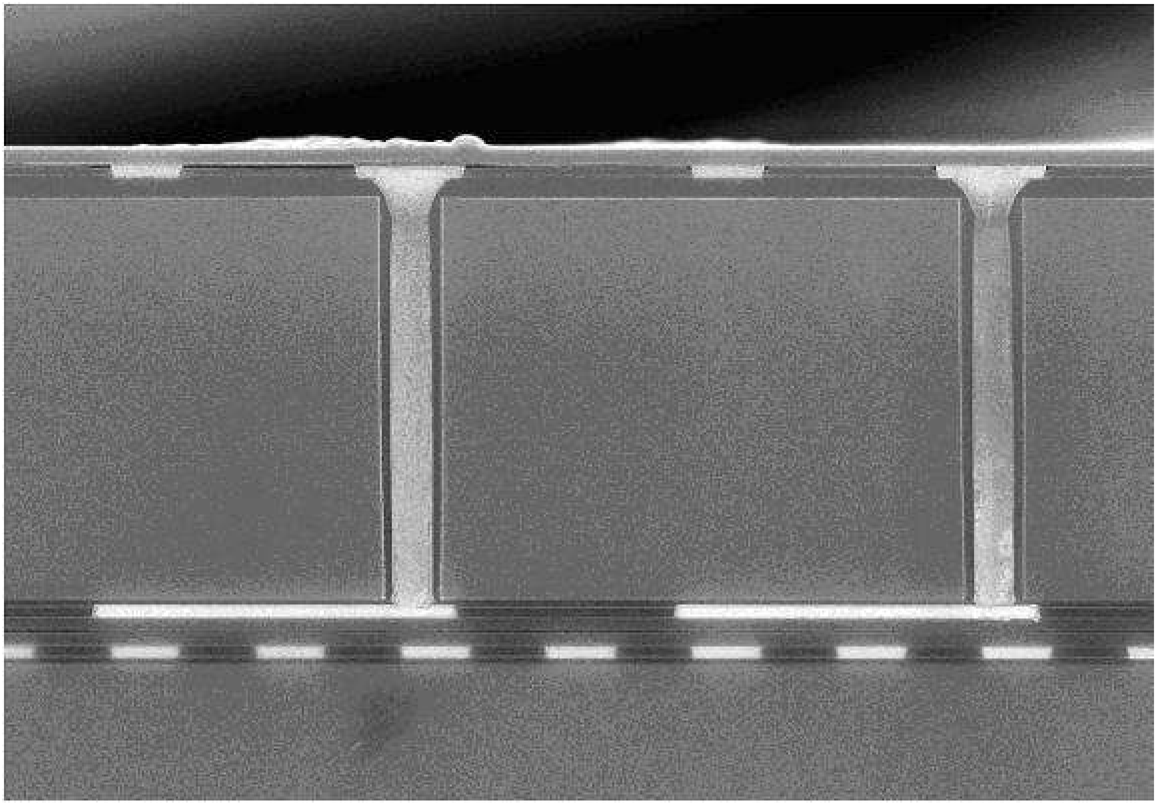
High Bandwidth Memory

AMD to launch its HBM graphics cards on 16 June 2015.





Through-Silicon Via (TSV)

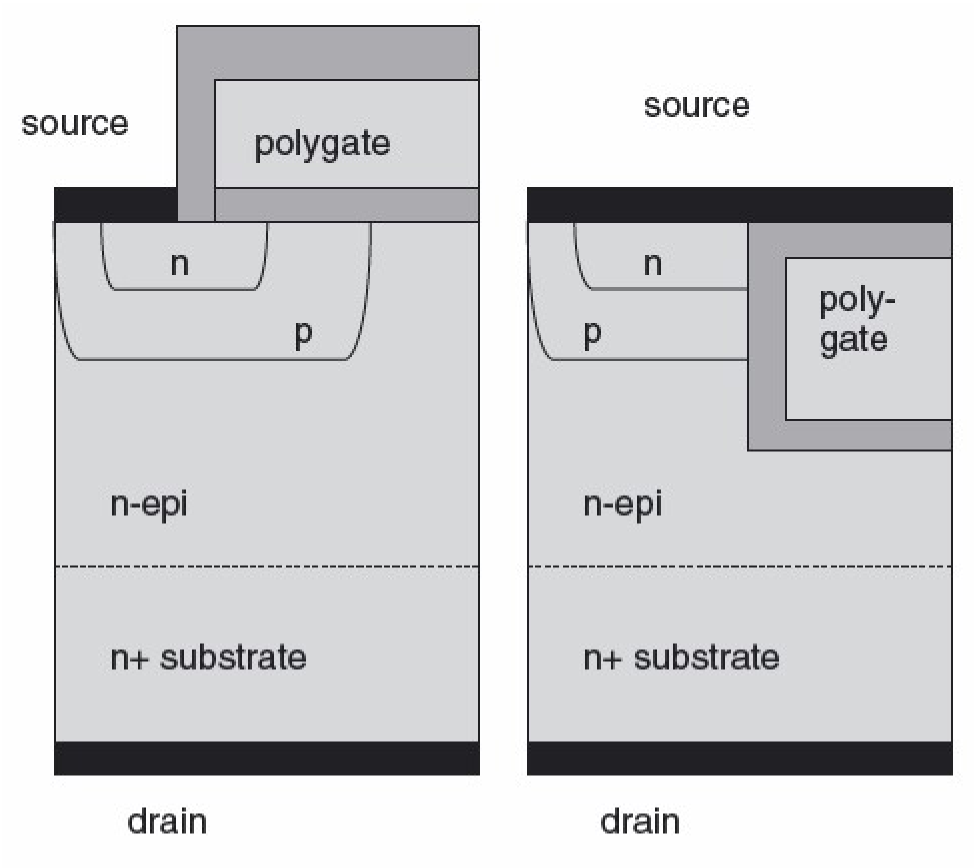


A vertical electrical connection (via) passing completely through a silicon wafer.

Used in 3D integration.

http://javier.esilicon.com/2011/01/30/thru-silicon-vias-current-state-of-the-technology/

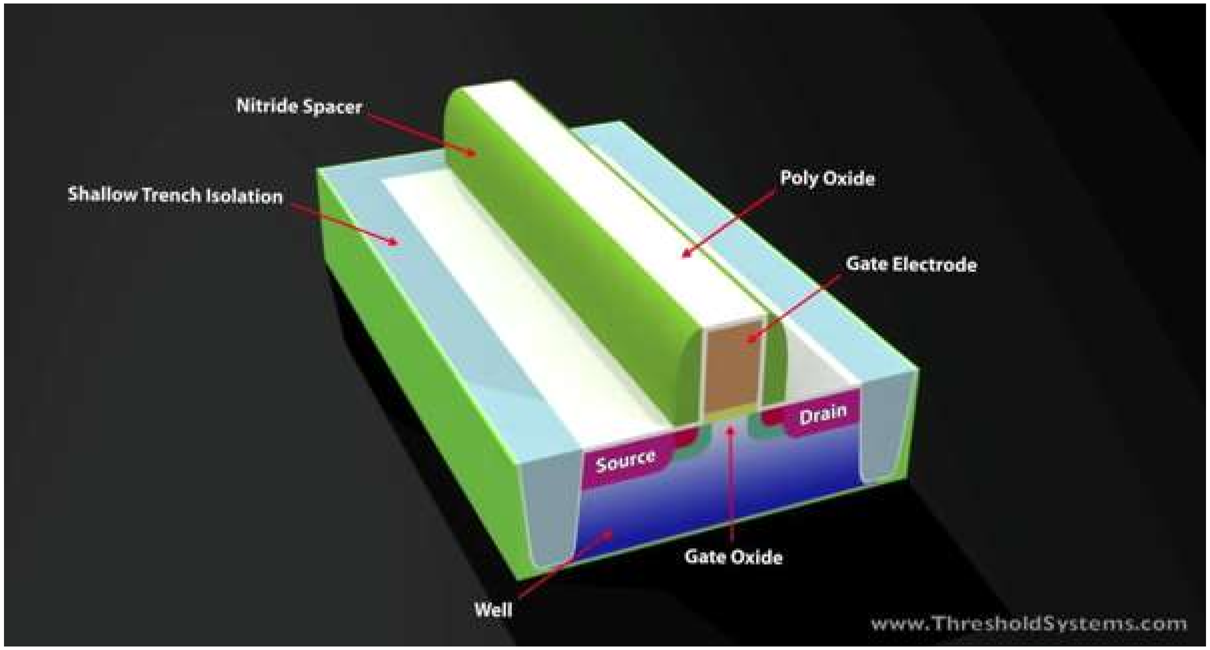
U-MOSFET and D-MOSFET

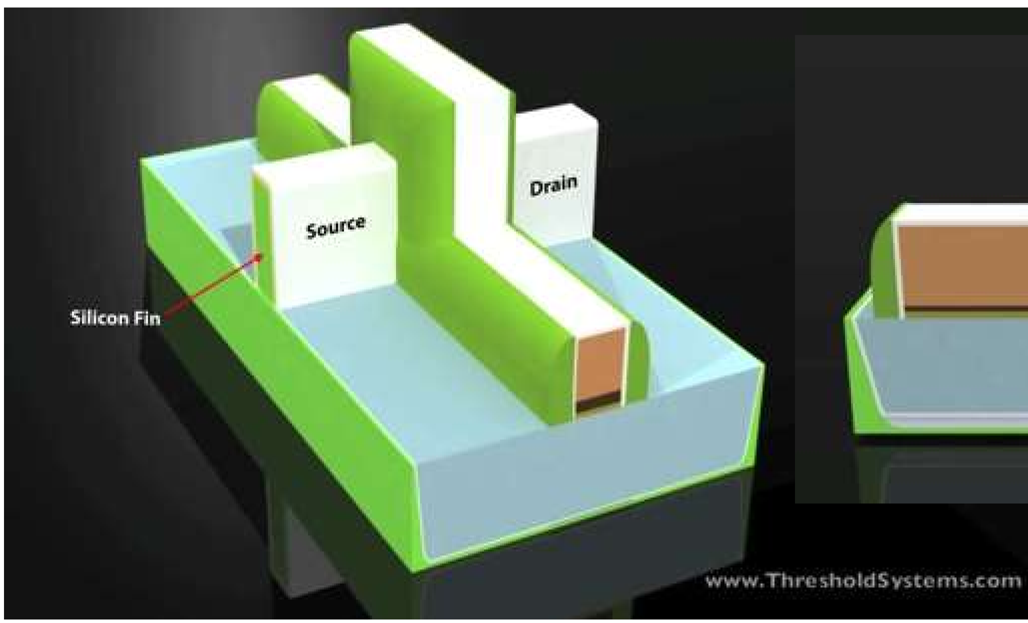


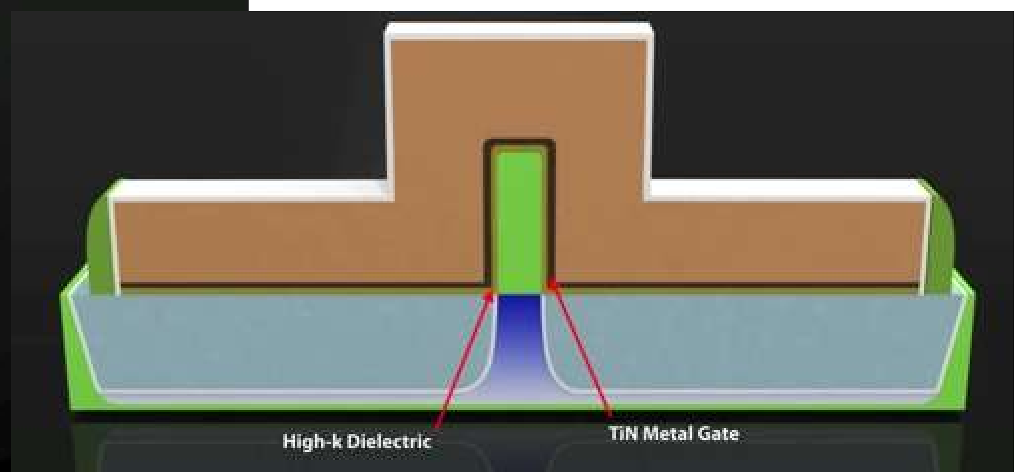
Fransila

Power transistors

FinFET

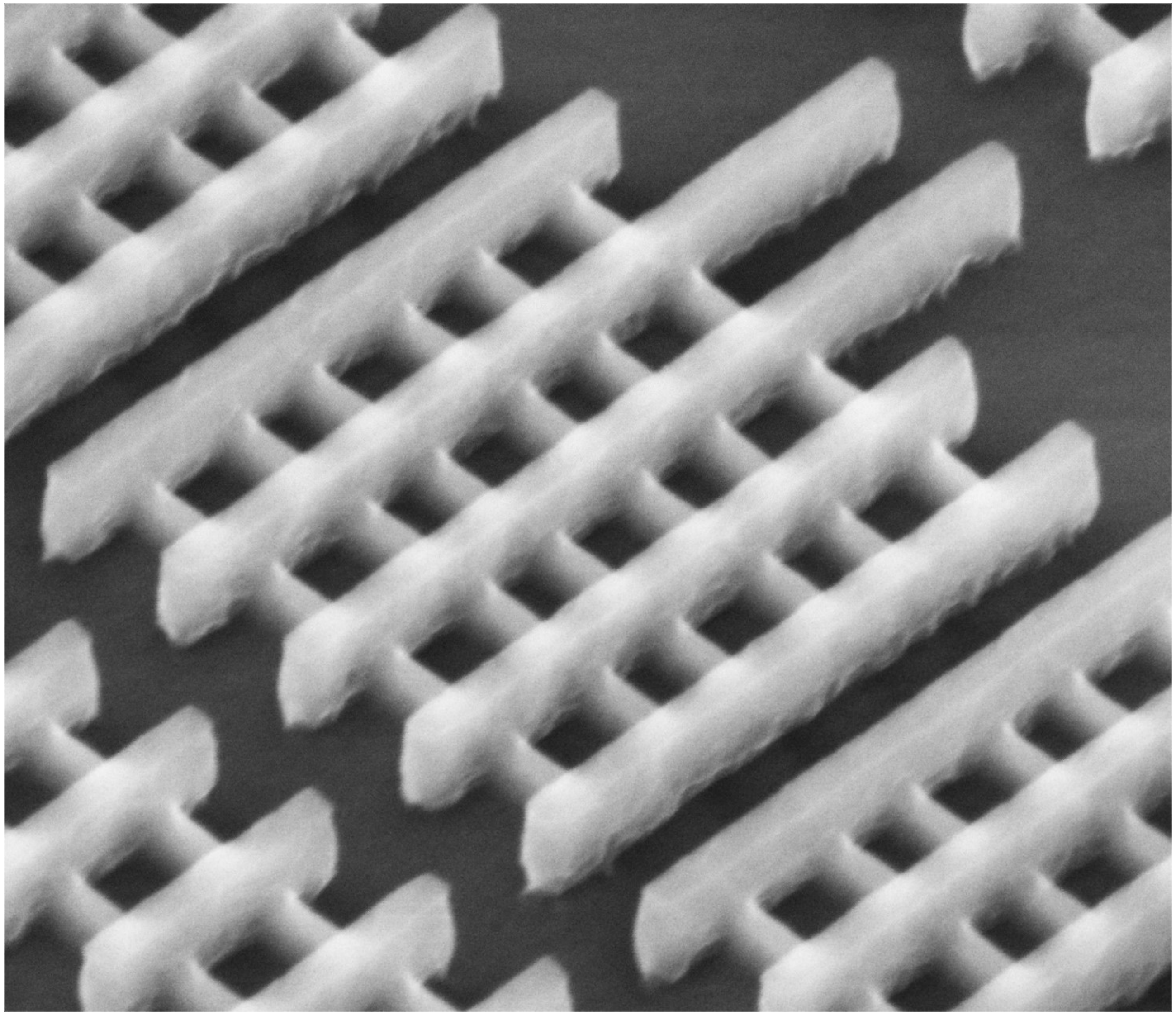






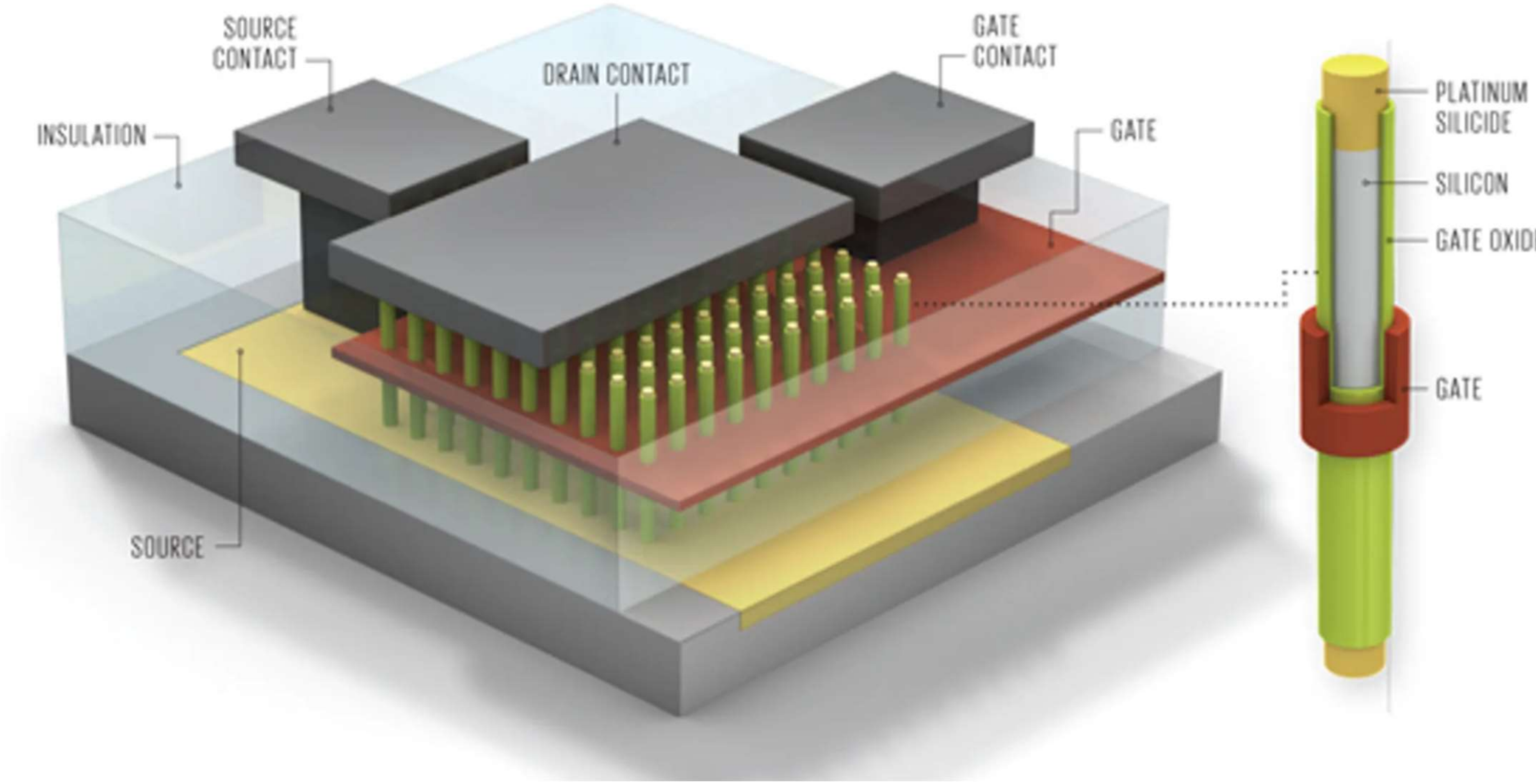
https://www.youtube.com/watch?v=Jctk0DI7YP8

Intel 22nm 3D tri-gate transistor



http://download.intel.com/newsroom/kits/22nm/gallery/images/Intel-22nm_Transistor.jpg

Gate All Around (GAA)



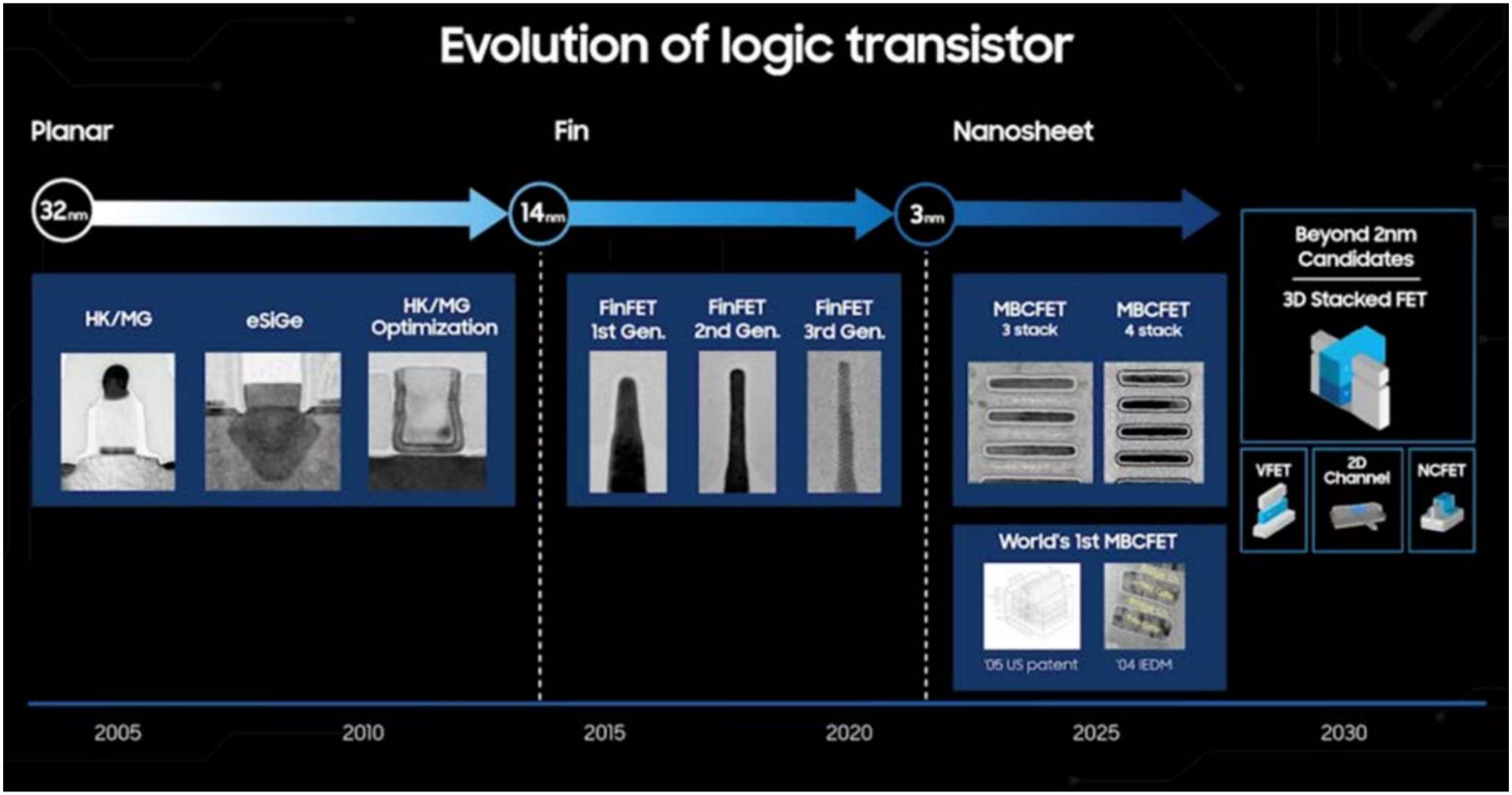
IEEE Spectrum, 29 Apr. 2013

INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

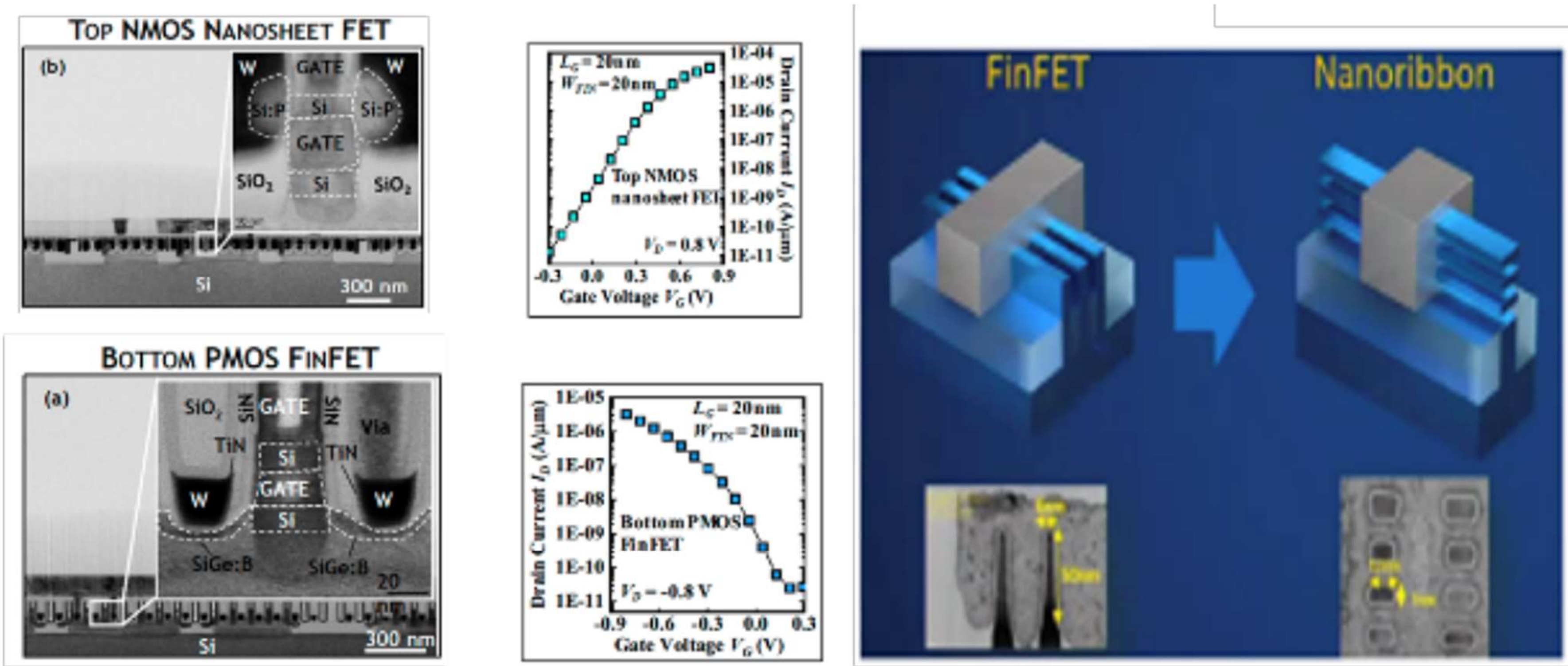
2022 EDITION

EXECUTIVE SUMMARY



https://irds.ieee.org/editions/2022/executive-summary

INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

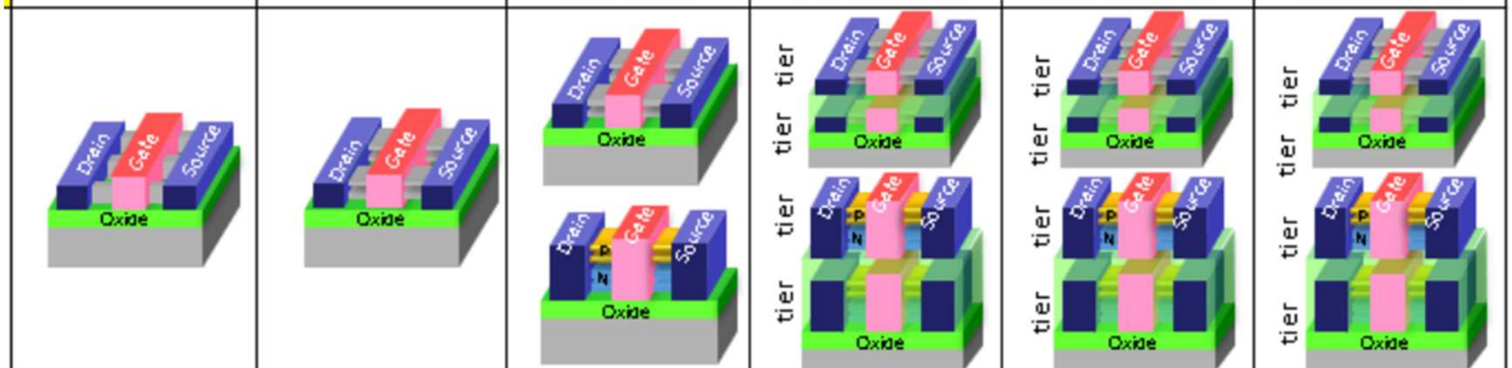


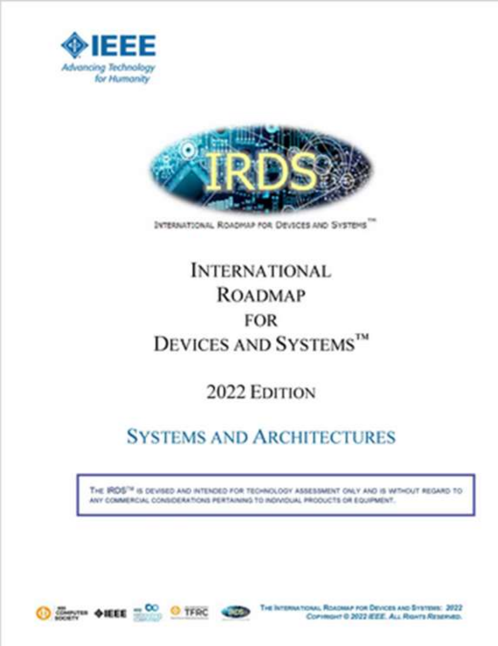
Source: IMEC and Intel

Figure ES11 D. *Vertical transistors and nanoribbons are progressively entering the logic technology arsenal*

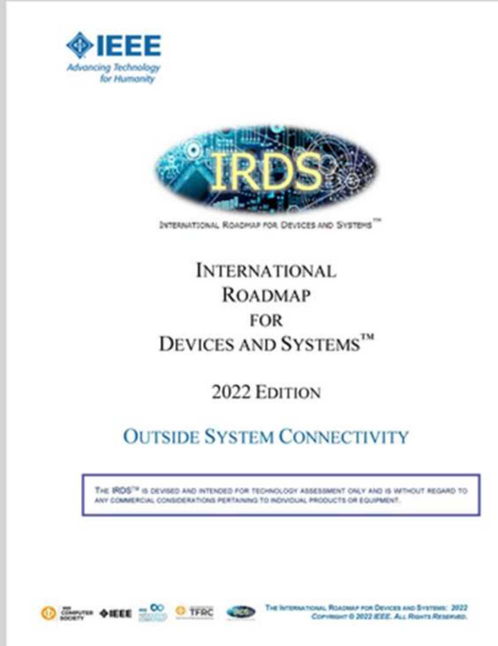
https://irds.ieee.org/editions/2022/executive-summary

2022 Roadmap

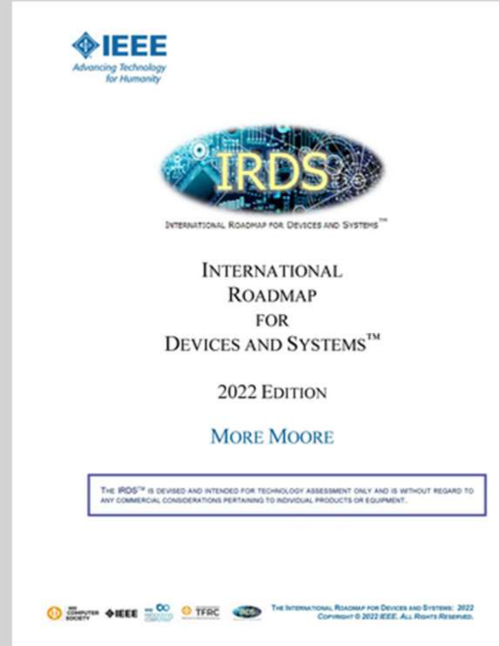
	2022	2025	2028	2031	2034	2037
	G48M24	G45M20	G42M16	G40M16/T2	G38M16/T4	G38M16/T6
	"3nm"	"2nm"	"1.5nm"	"1.0nm eq"	"0.7nm eq"	"0.5nm eq"
	Stacking	Stacking	Stacking	3DVLSI	3DVLSI	3DVLSI
	finFET LGAA	LGAA	LGAA CFET-SRAM	LGAA-3D CFET-SRAM	LGAA-3D CFET-SRAM	LGAA-3D CFET-SRAM
	finFET	LGAA	LGAA CFET-SRAM	LGAA-3D CFET-SRAM-3D	LGAA-3D CFET-SRAM-3D	LGAA-3D CFET-SRAM-3D
						
Mx pitch (nm)	32	24	20	16	16	16
M1 pitch (nm)	32	23	21	20	19	19
M0 pitch (nm)	24	20	16	16	16	16
Gate pitch (nm)	48	45	42	40	38	38
Lg: Gate Length - HP (nm)	16	14	12	12	12	12
Lg: Gate Length - HD (nm)	18	14	12	12	12	12
Channel overlap ratio - two-sided	0.20	0.20	0.20	0.20	0.20	0.20
Spacer width (nm)	6	6	5	5	4	4



Systems and Architectures

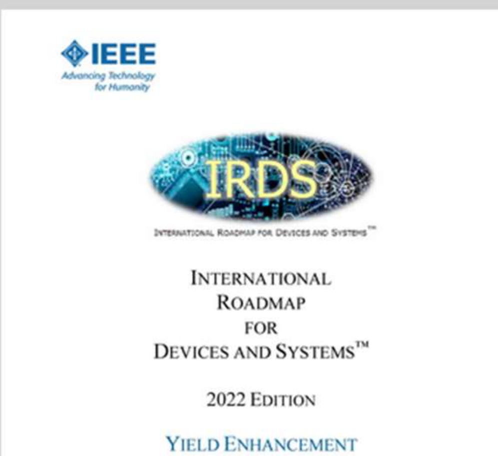


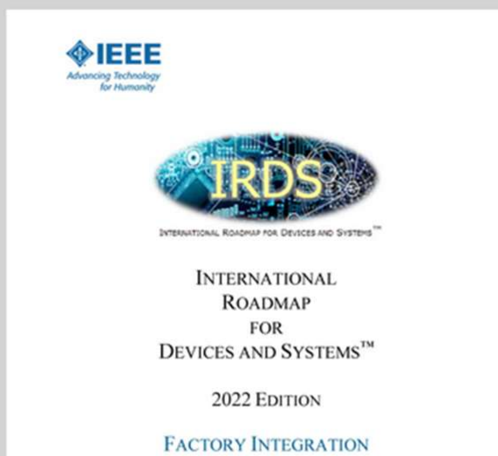
Outside System Connectivity

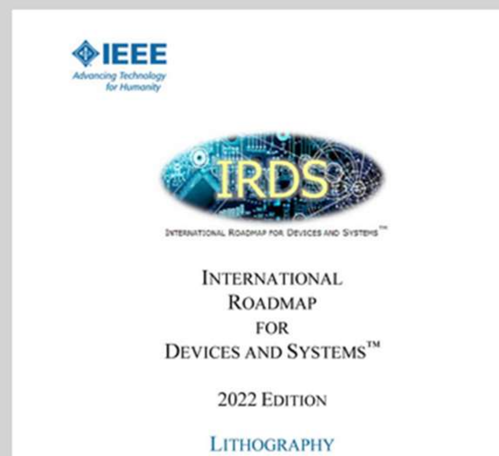


More Moore

https://irds.ieee.org/editions/2022







INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

2022 EDITION

BEYOND CMOS AND EMERGING MATERIALS INTEGRATION

Organic microprocessor

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

Miniaturization ends with CMOS

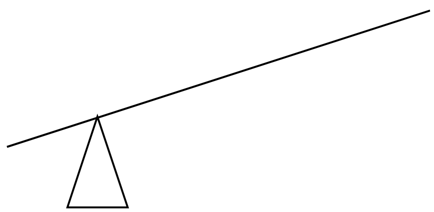
There are no technologies (single electron transistors, molecular electronics, superconducting electronics, spintronics, NEMs...) that can provide performance similar to CMOS at a **much** smaller size scale.

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

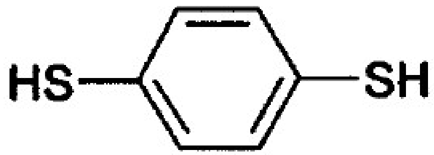
There are two lengths in an amplifier.

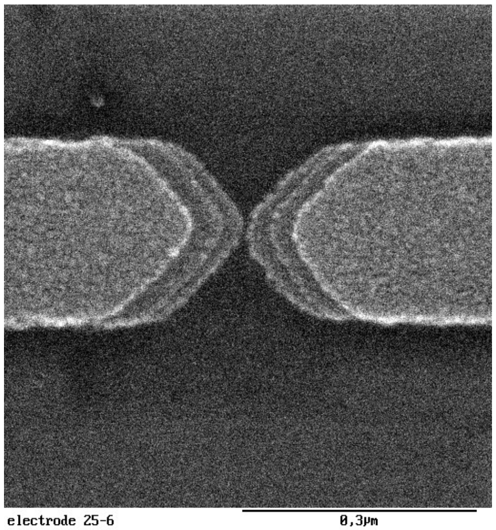


In CMOS the gate insulator is much thinner than the gate length.

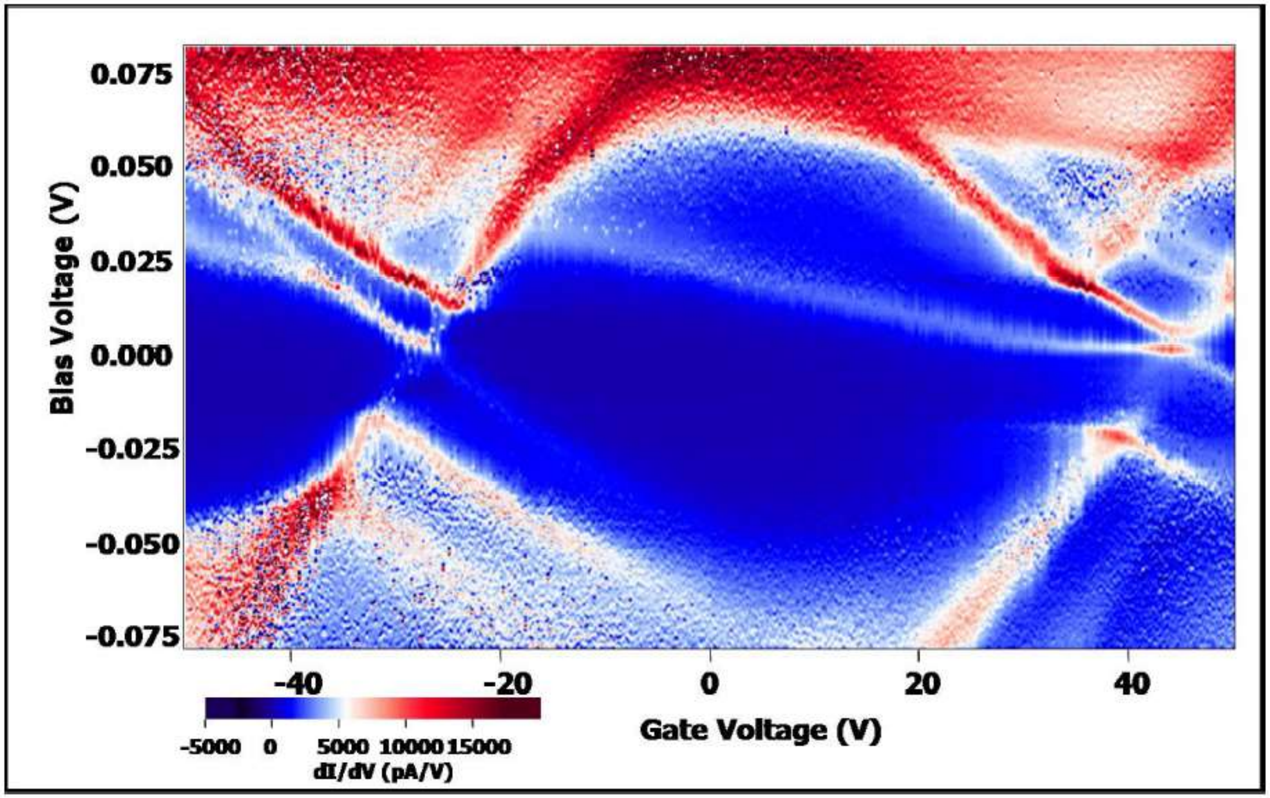
If the short length is 1 nm, the long length is 10 nm.

Measuring molecules



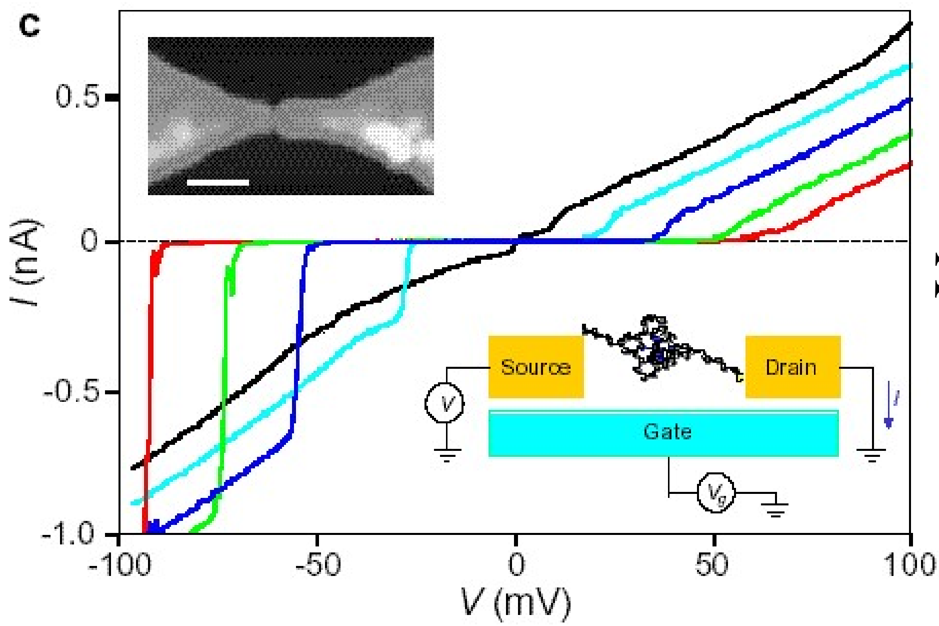


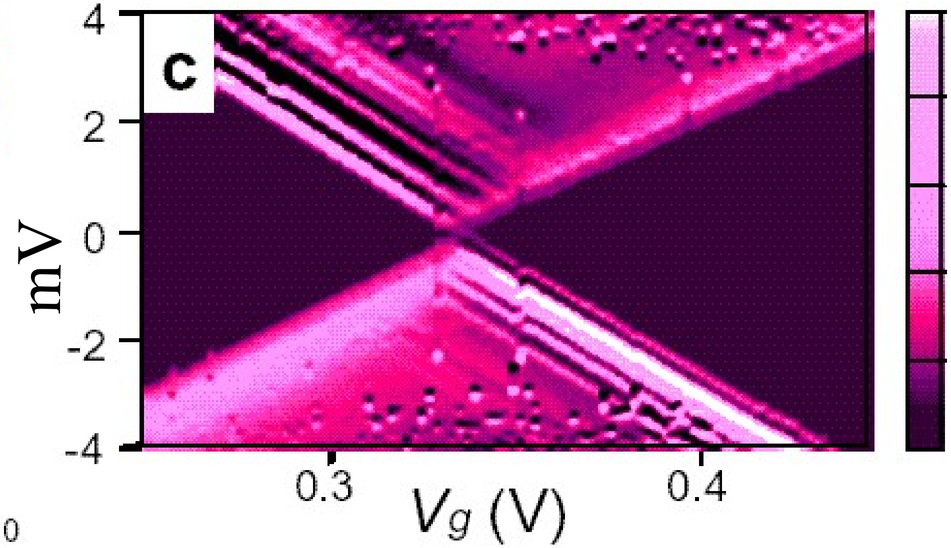
1,4-benzenedithiol



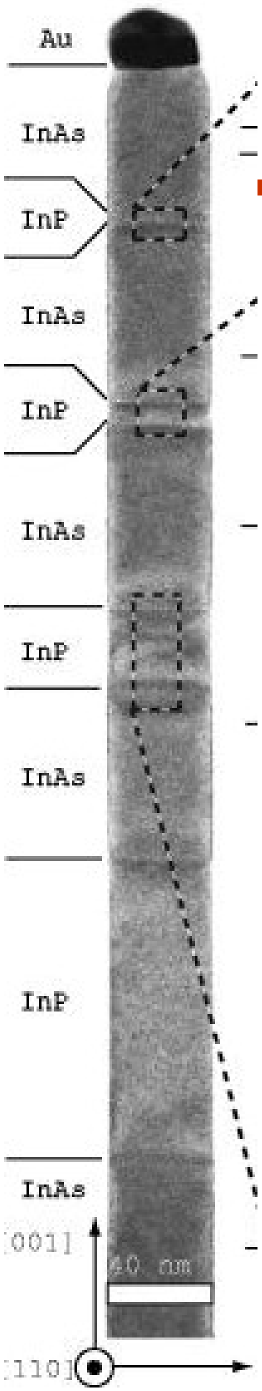
Results are unreproducible

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).

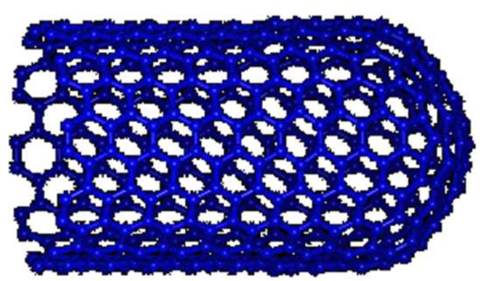


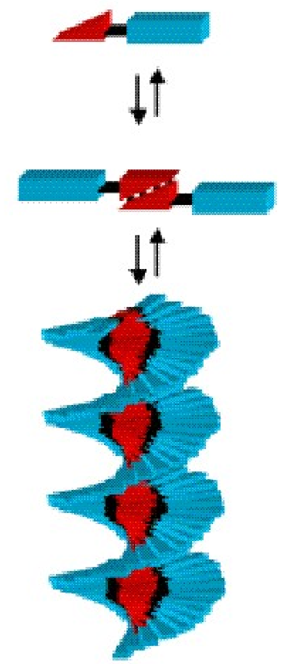
Use big 'molecules' as electronic components

Easier to make reproducible contacts.

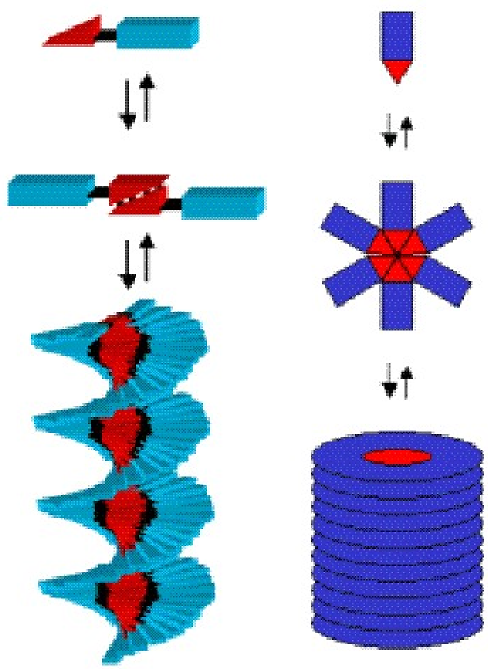
Imaging of individual molecular assemblies possible

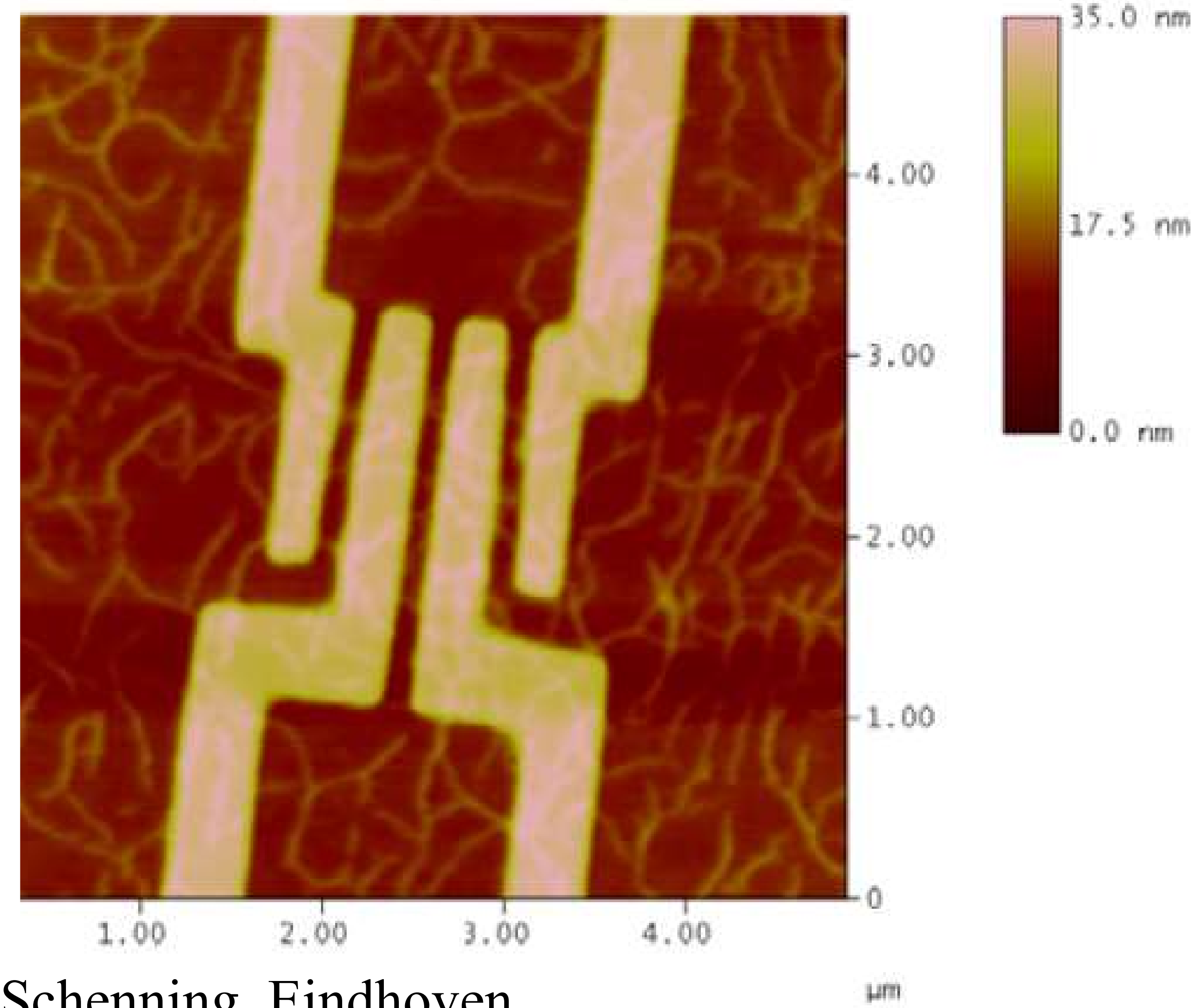
Nanowires or nanocrystals of conventional semiconductors





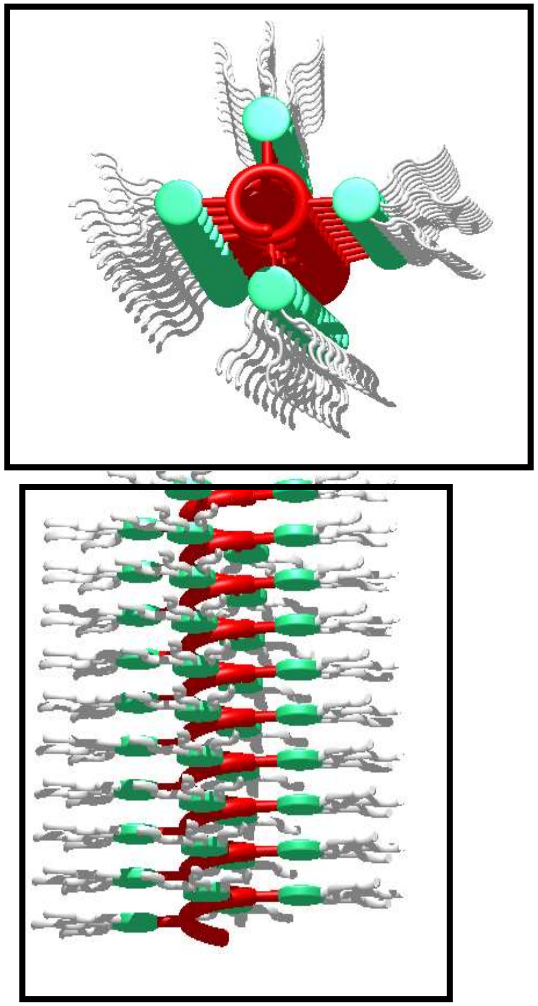
AFM image of MOPV4 fibers

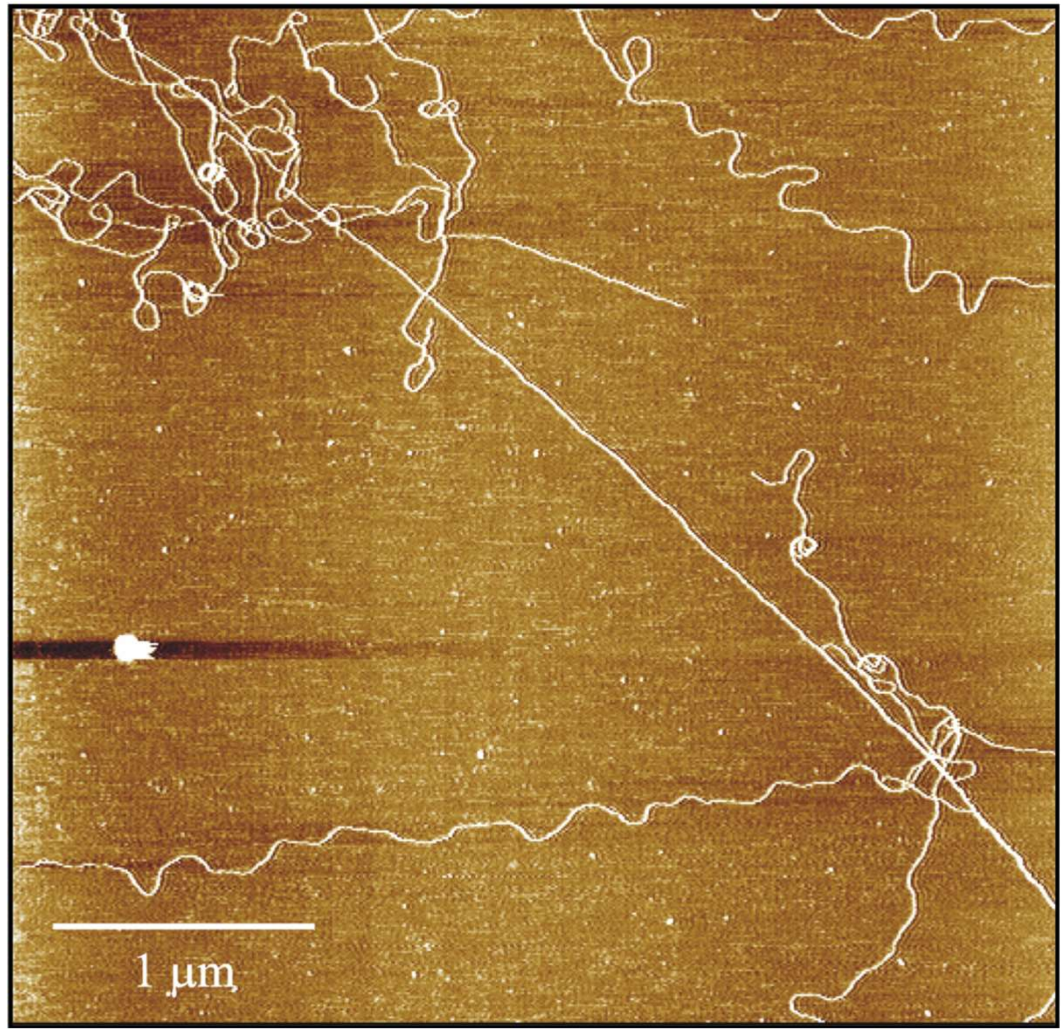




Albert Schenning, Eindhoven

Using templates for self-assembly

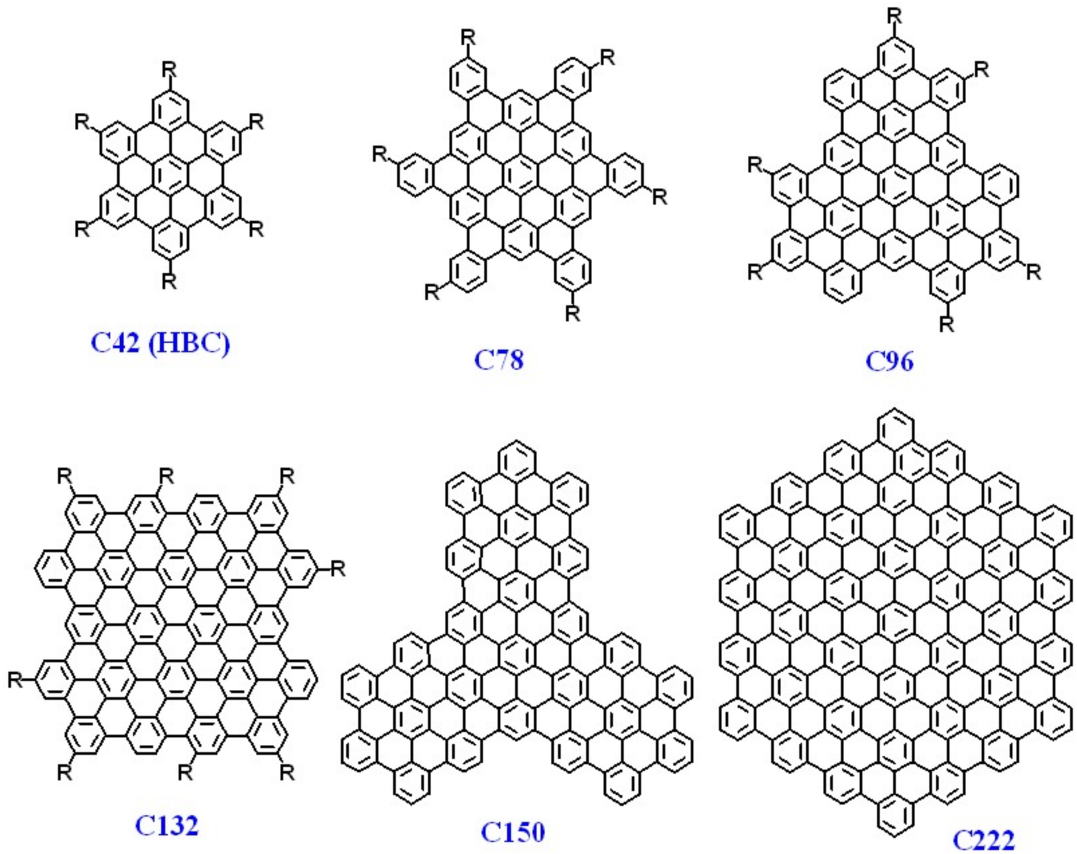


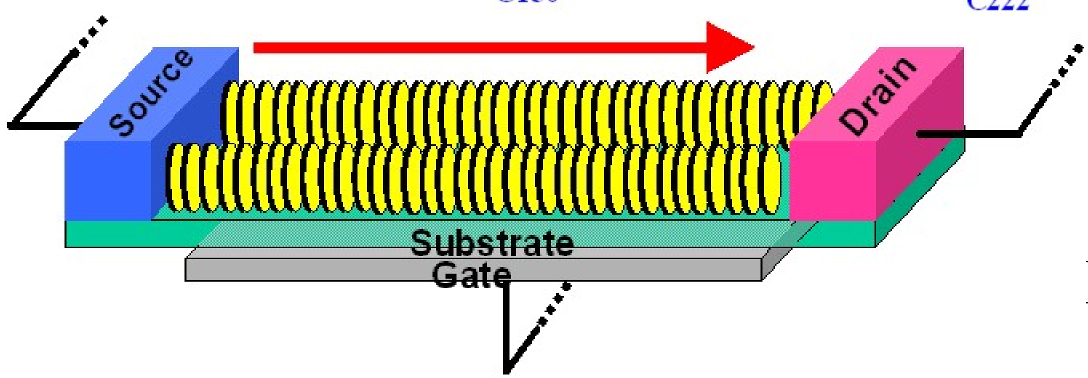


Alan Rowan, Nijmegen

Phthalocyanine Polyisocyanides

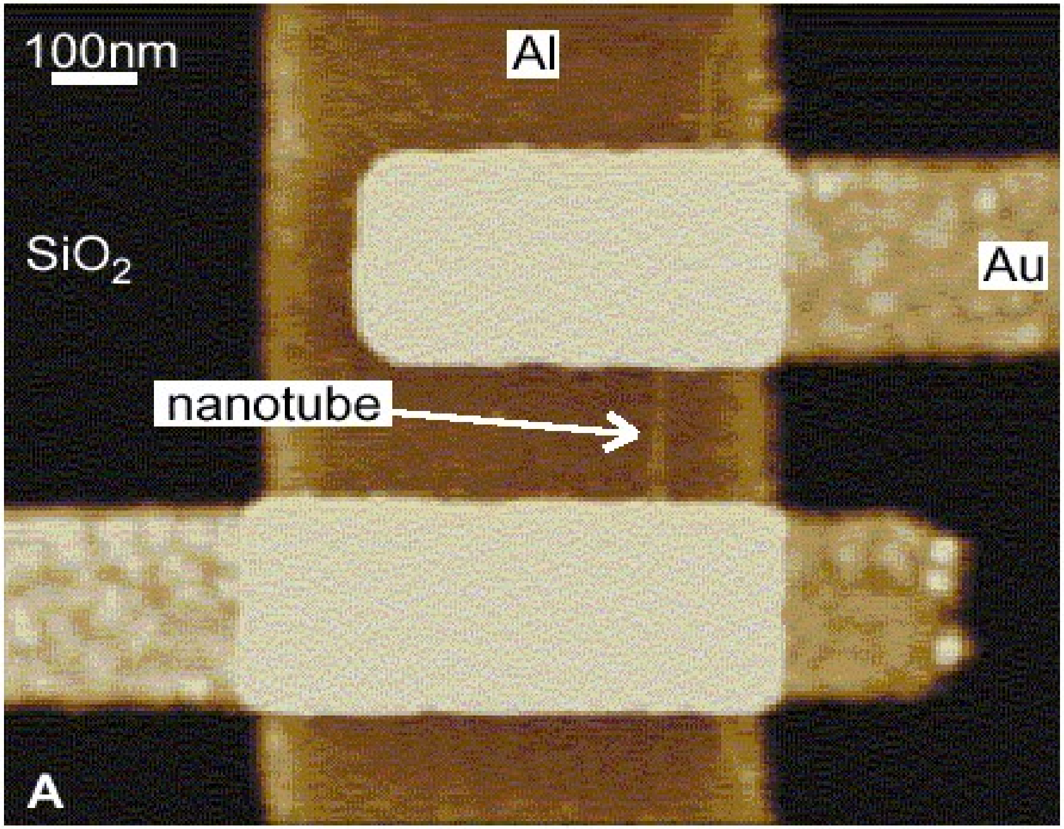
hexabenzocoronenes

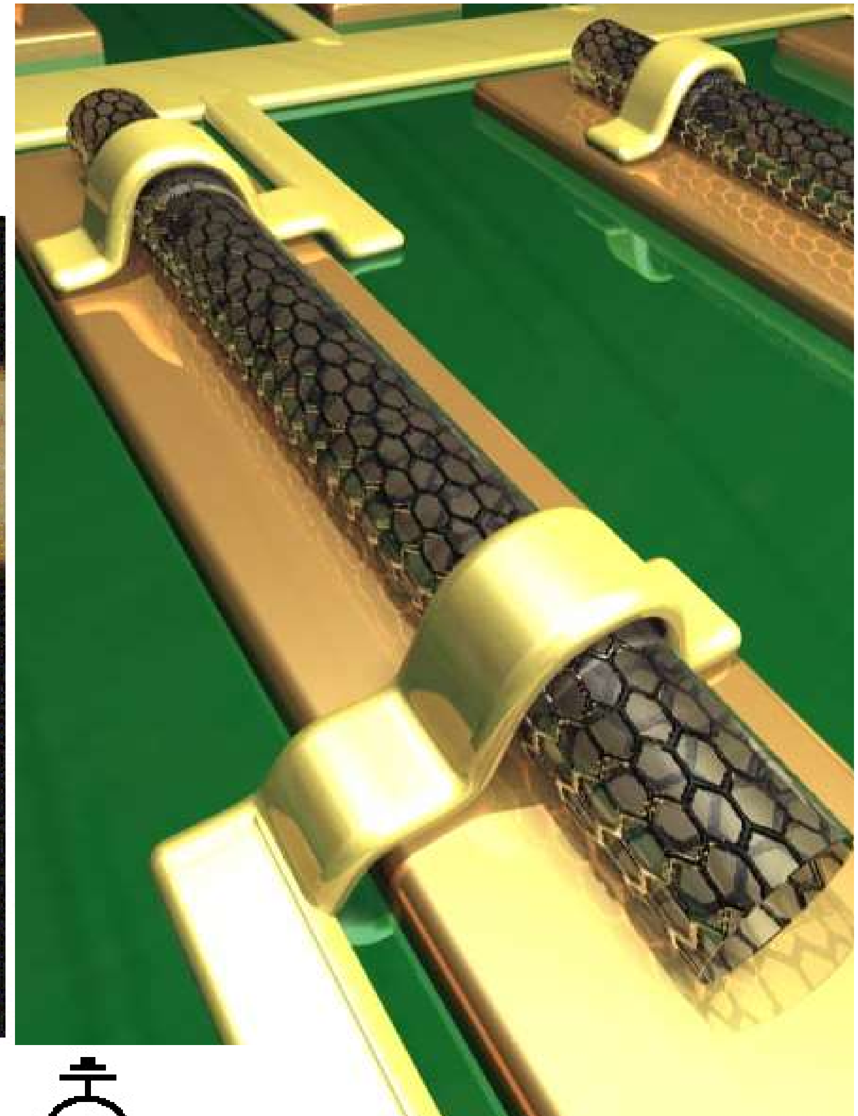


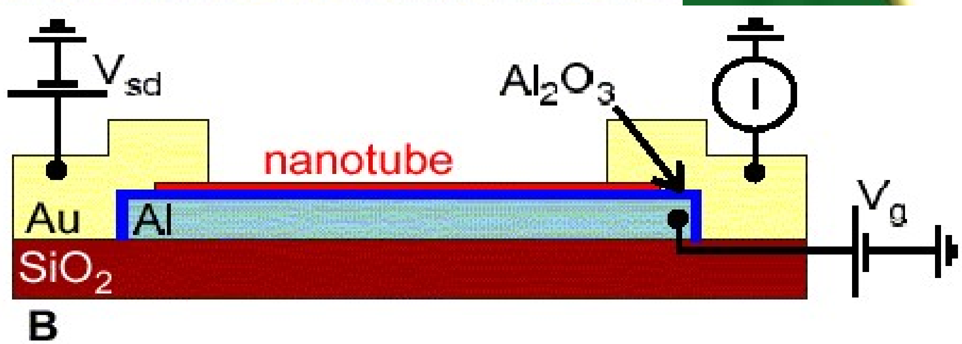


Müllen, Mainz

Carbon nanotube transistors







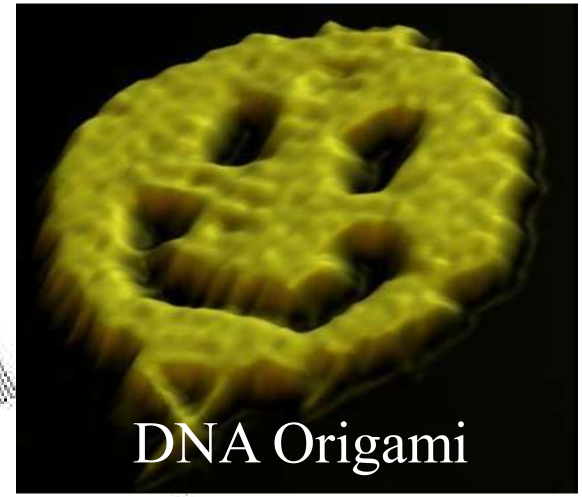
International Technology Roadmap for Semiconductors

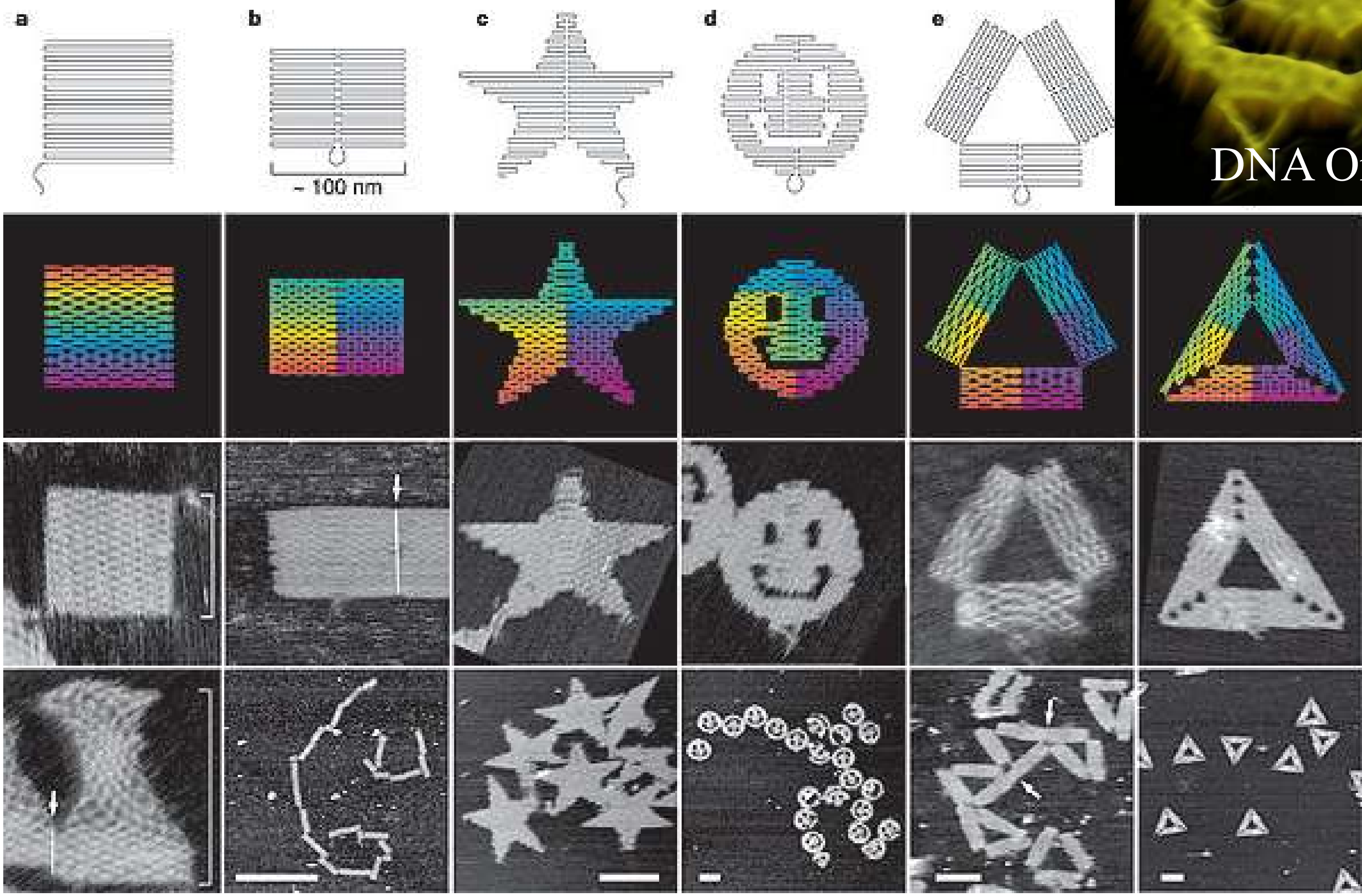
2009 Edition

"The first three editions of the ERD Logic section have evaluated alternative logic technology entries in terms of their potential to displace scaled CMOS devices in high performance general purpose computing. The conclusion reached in those editions was that none of the alternative technologies surveyed had a high potential for displacing scaled CMOS devices on the ITRS roadmap scheduled for the 2020's."

Lots of hype in the press. Read ITRS for a more balanced evaluation.

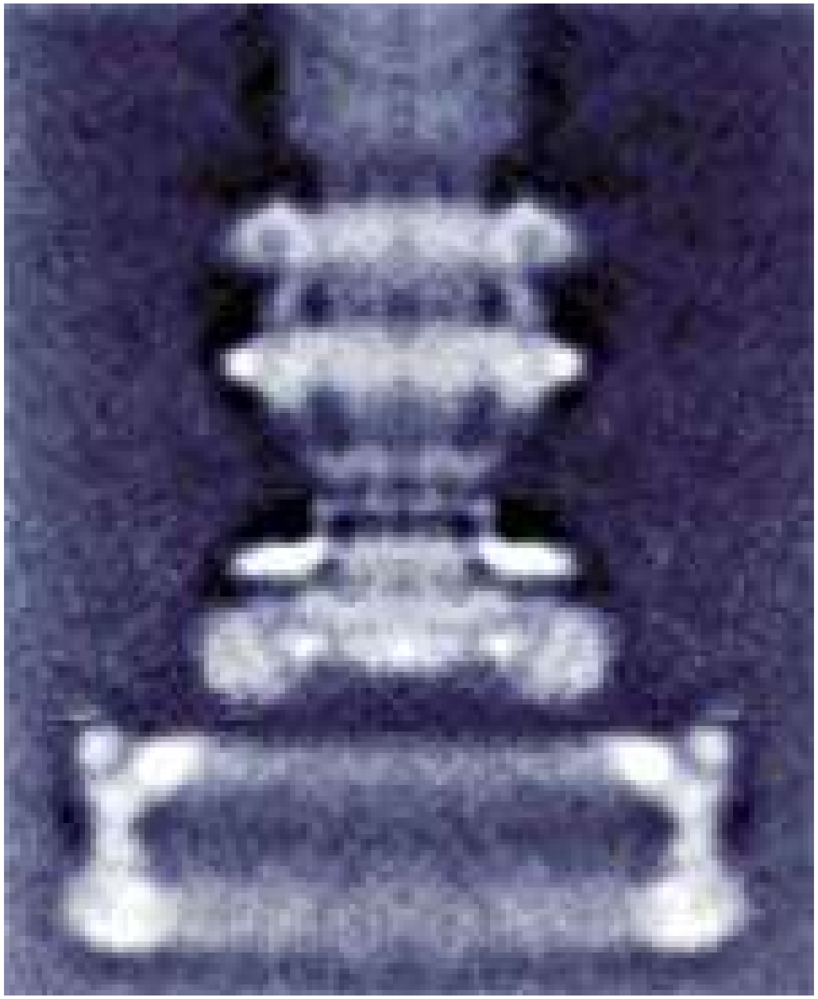
Bottom-up technology

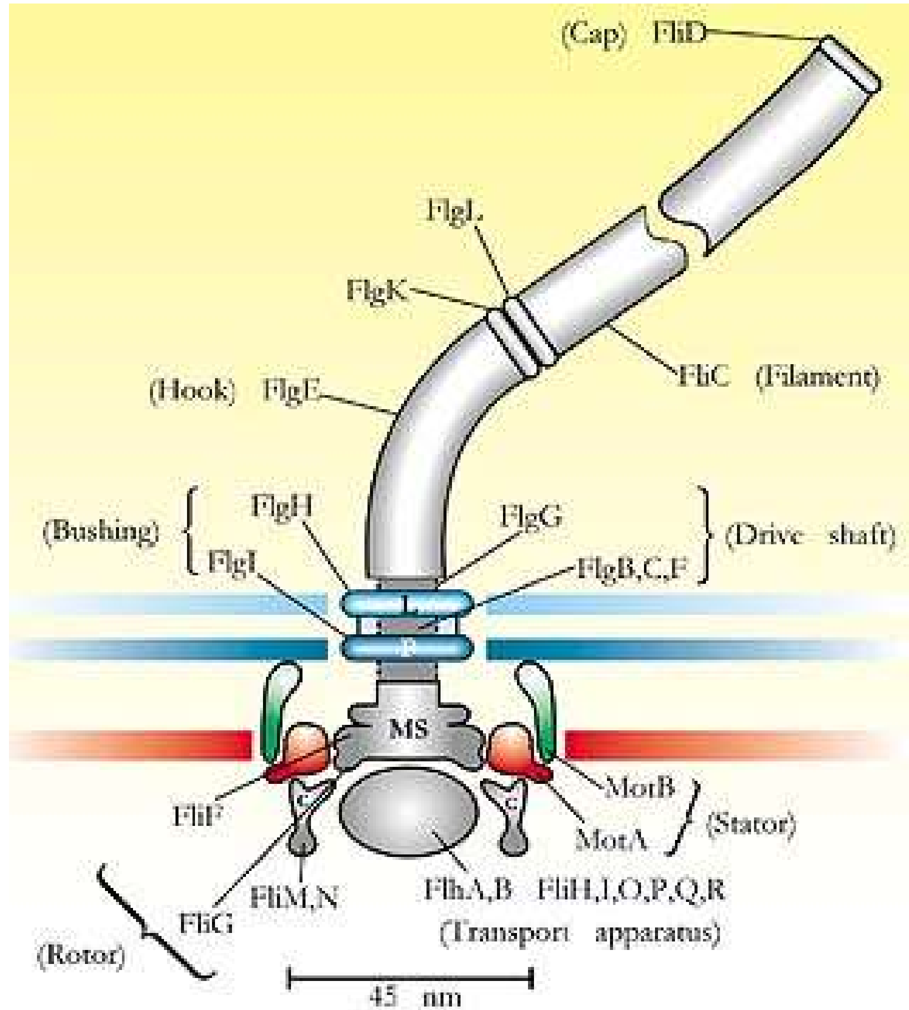




(Images: Paul Rothemund)

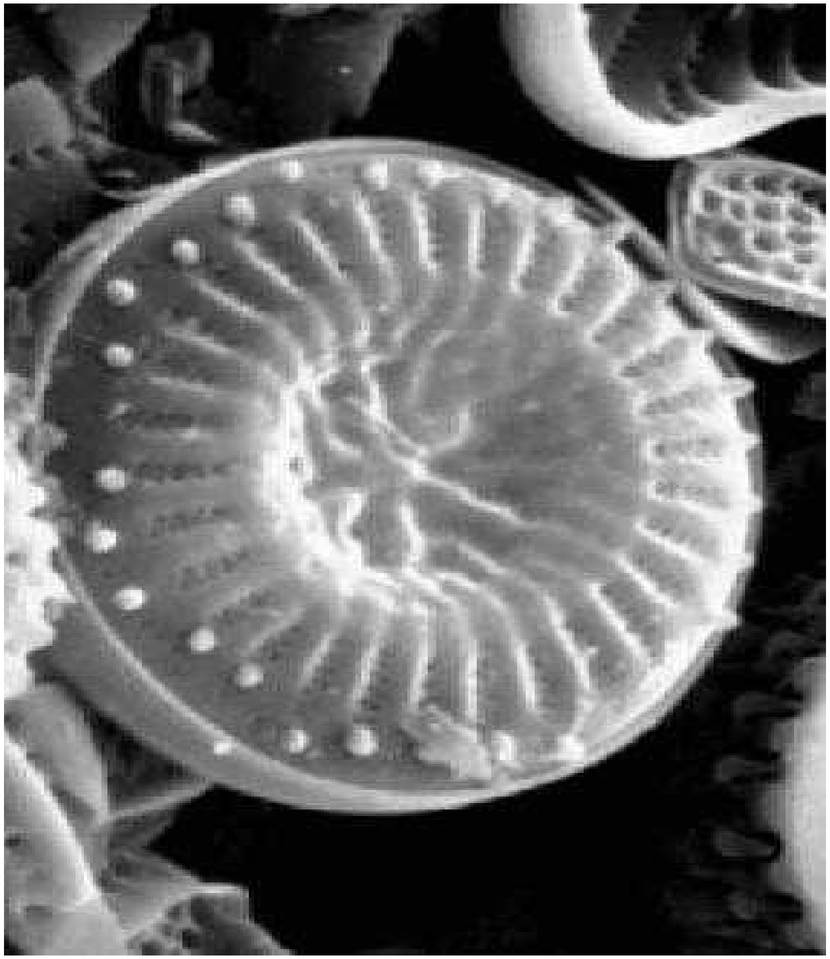
Bottom-up technology



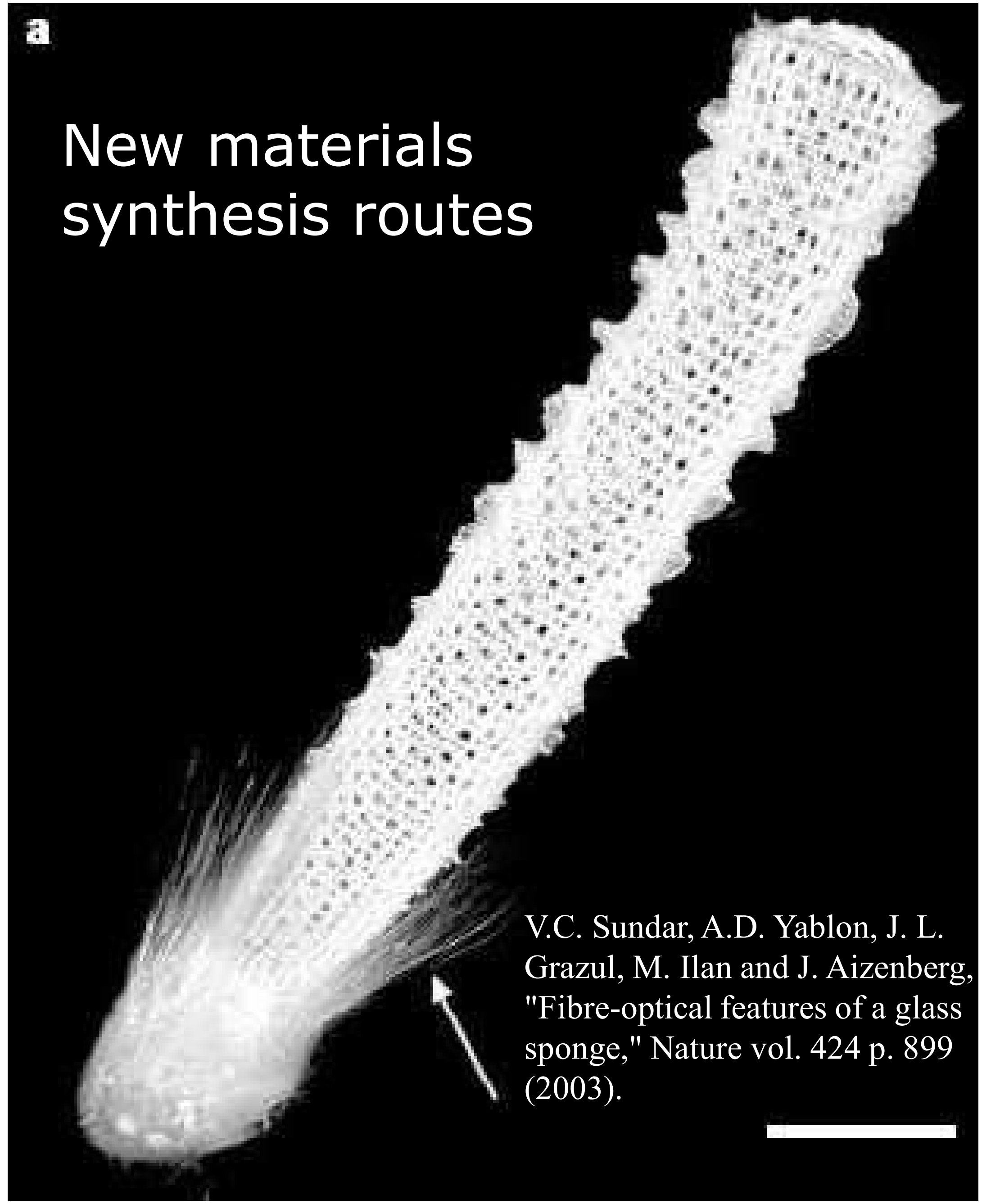


Bacterial motor

New materials synthesis routes



Produced at room temperature from sunlight and seawater.



V.C. Sundar, A.D. Yablon, J. L. Grazul, M. Ilan and J. Aizenberg, "Fibre-optical features of a glass sponge," Nature vol. 424 p. 899 (2003).

Self-assembly of devices will be a key competence

- Self organization of structures from 100 microns to 0.1 nm
- Learn chemistry from biology
- Exploit biological infrastructure
  - Trees = self assembled solar cells, batteries
- Self assemble lithographically produced devices
  - lighting panels, solar cells