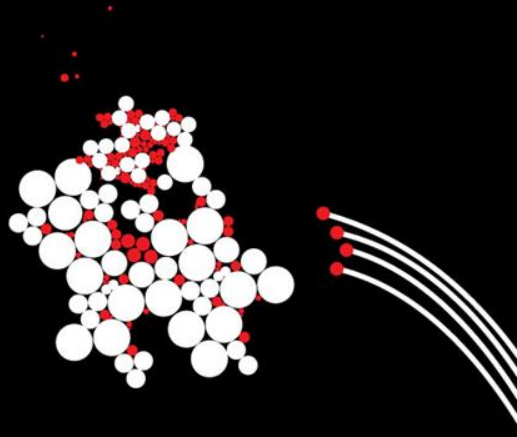
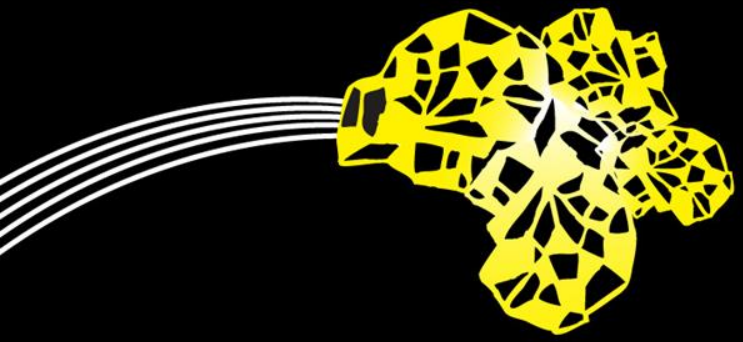
UNIVERSITY OF TWENTE.



State of the art in Microfabrication

Jurriaan Schmitz

j.schmitz@utwente.nl -- www.utwente.nl/ewi/sc



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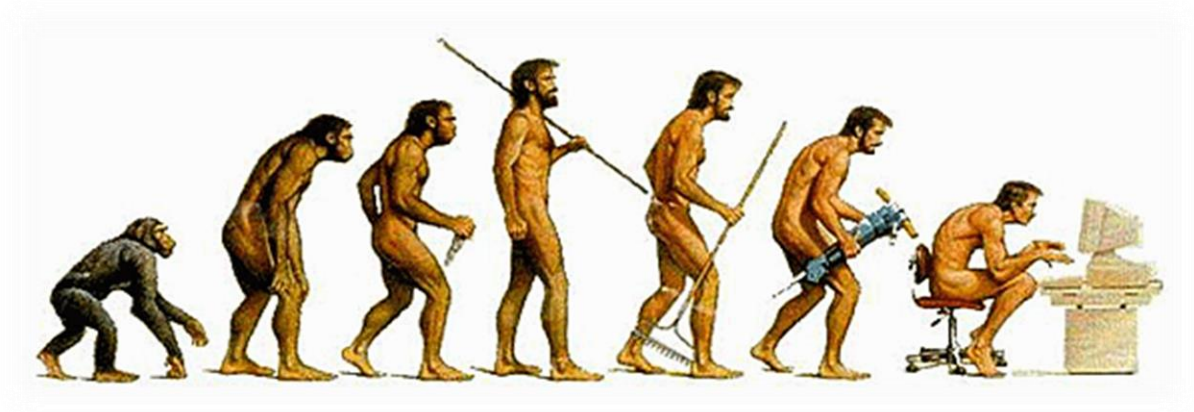
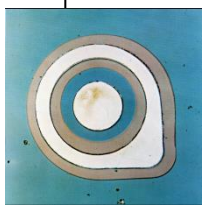
- Microelectronics: Moore's Law today
- Technology advances inside the microchip
- Other microfabricated devices
- Prospects for radiation imaging



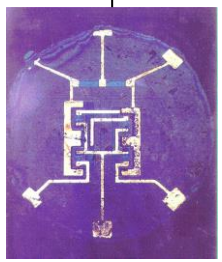
Images:
Computer history museum

The beginning: 1960s

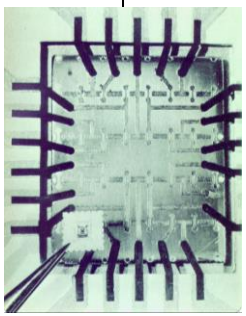
1958 Fairchild
First planar transistor



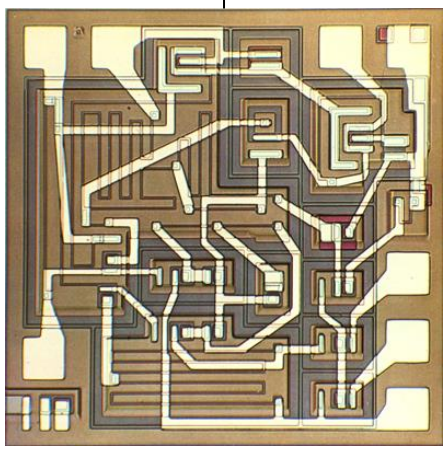
1961 Fairchild
4T5R flip-flop



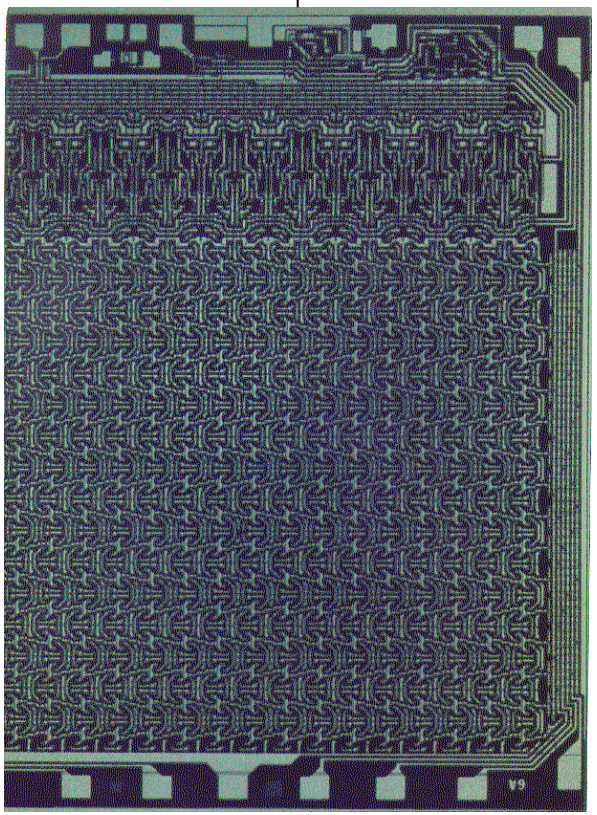
1962 RCA
16T logic chip



1965 Fairchild
opamp



1968 Fairchild
2kT SRAM chip



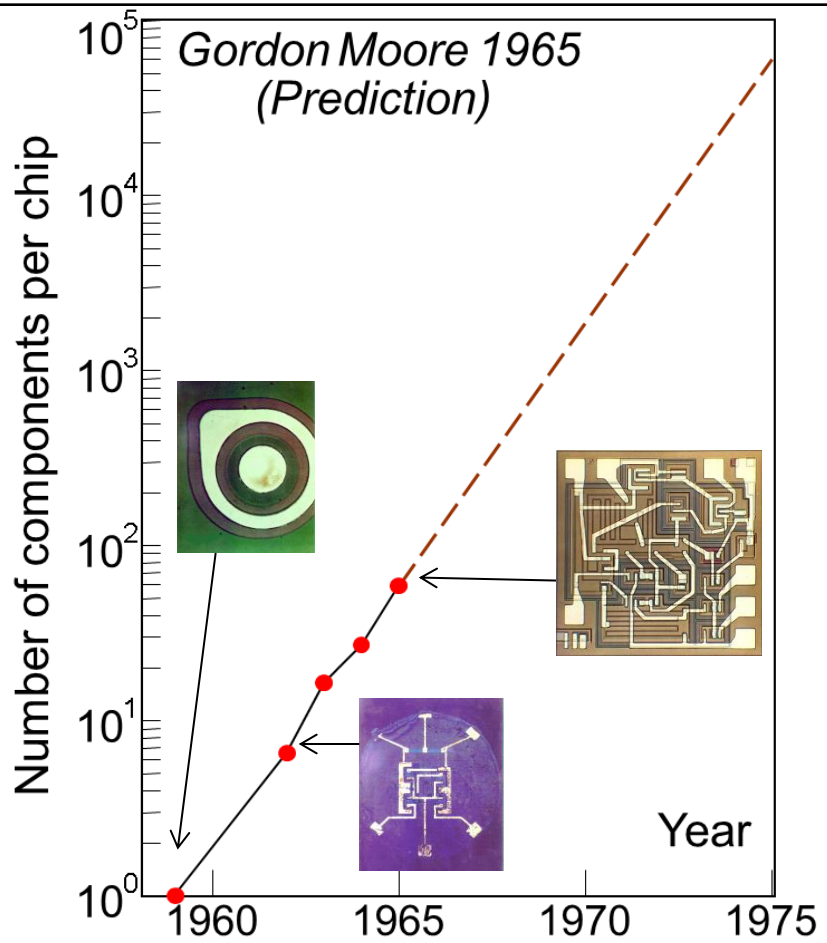
Gordon Moore 1965

Transistors keep getting cheaper!

- Smaller components
- Bigger chips & wafers
- Better skills

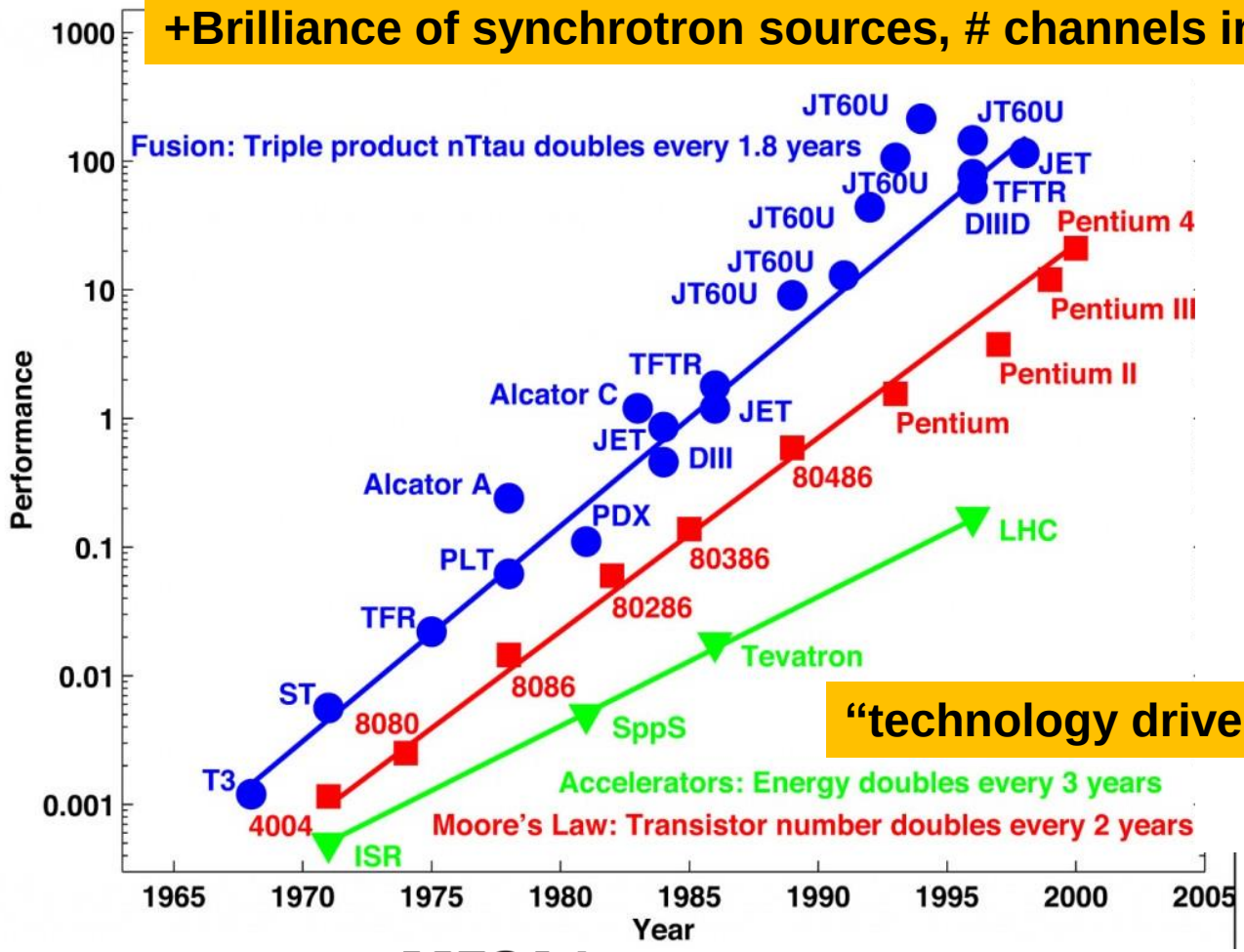
"Moore's Law":

The number of components on a chip doubles every year



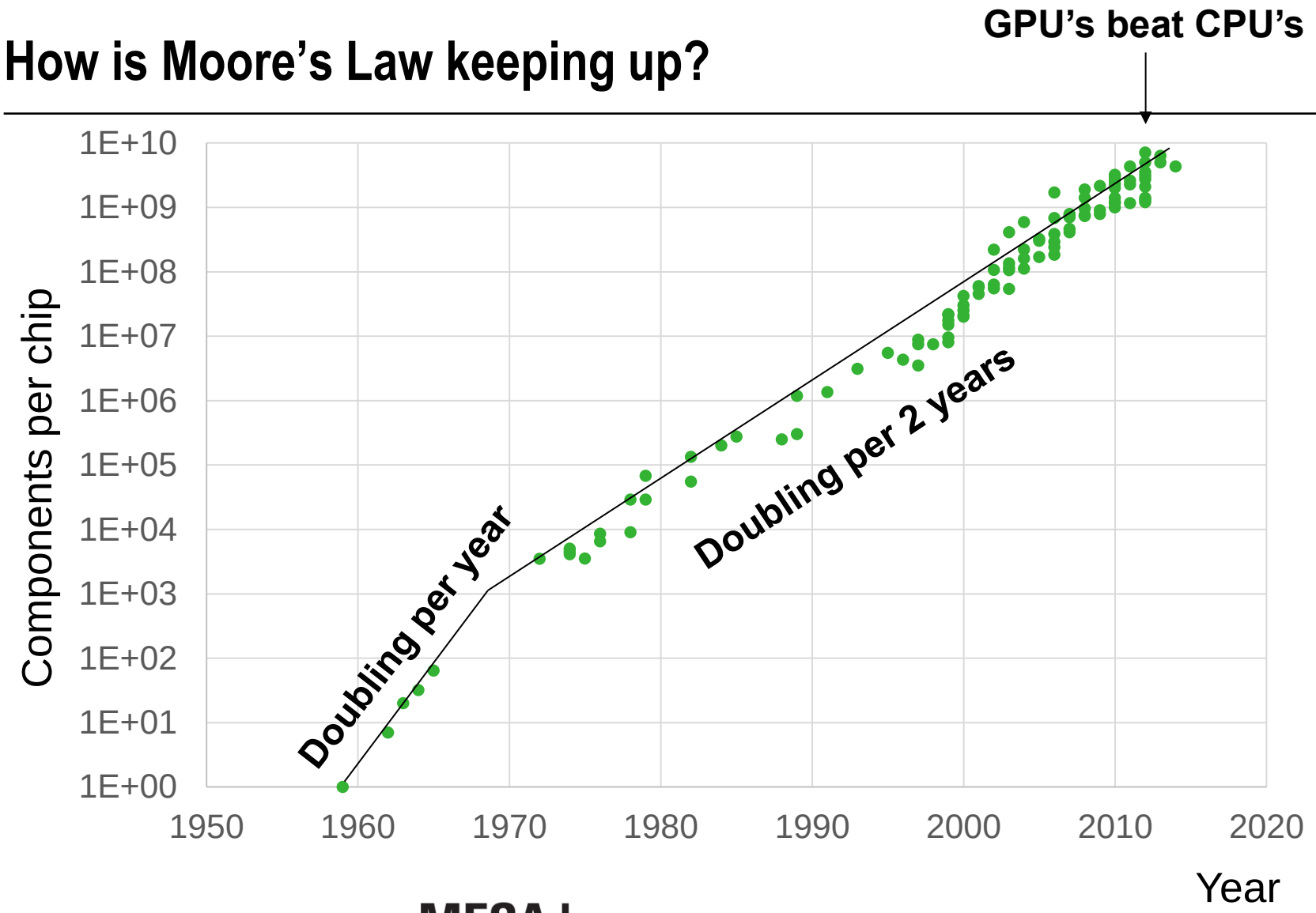
Moore's Law – chips, accelerators, fusion…

+Brilliance of synchrotron sources, # channels in trackers…



"technology driven progress"

How is Moore's Law keeping up?

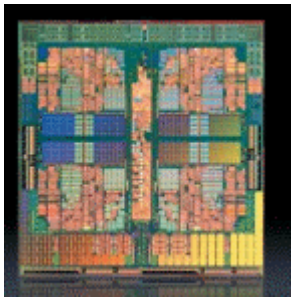


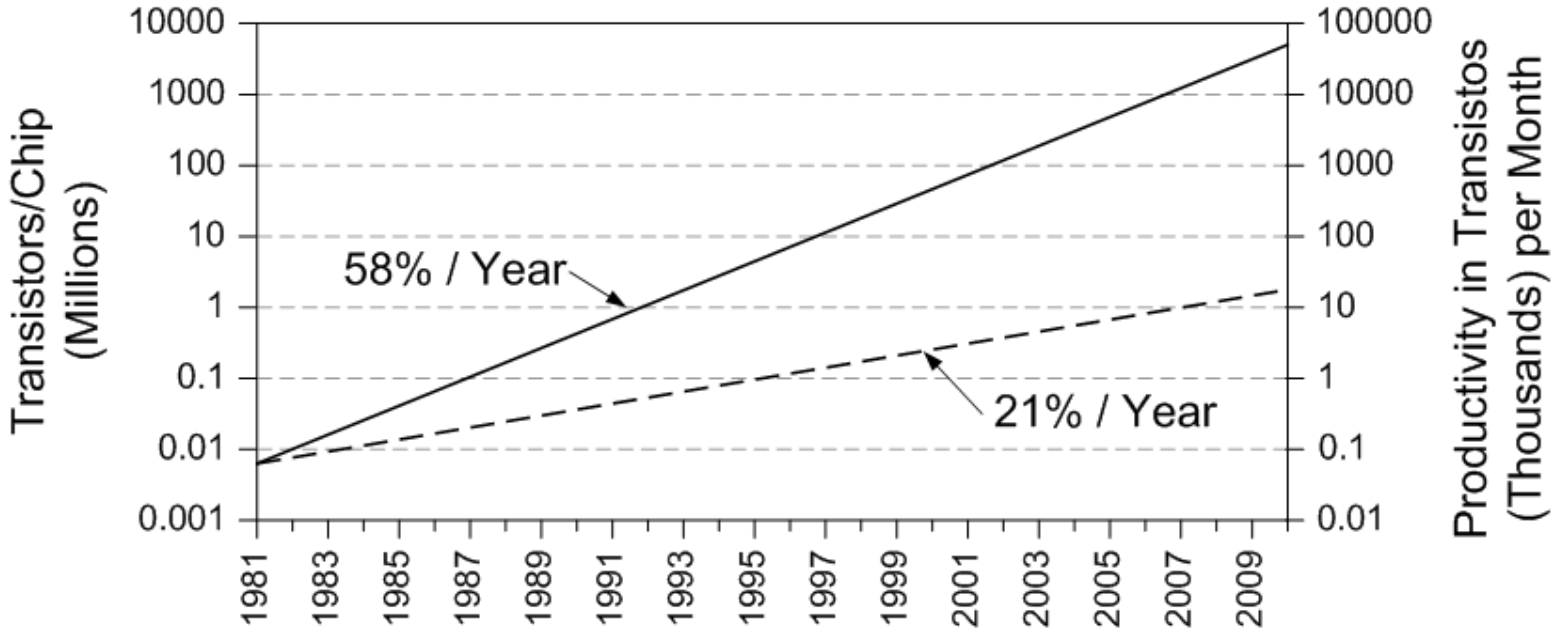
Moore's Law: perspective

- Transistor gate length scaling is slowing down (10% per generation)
- 300 → 450 mm transition is delayed to 2020
- ITRS roadmap: multiple breakthroughs required by 2018
- … what happens next?

Microchips keep getting better

- Design gap
- Multicore processors
- Transistor performance boosters





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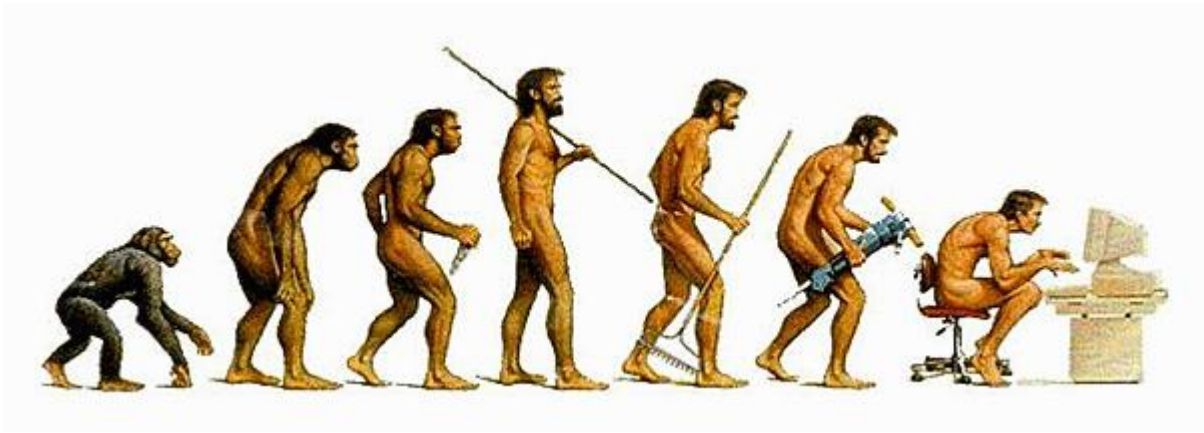
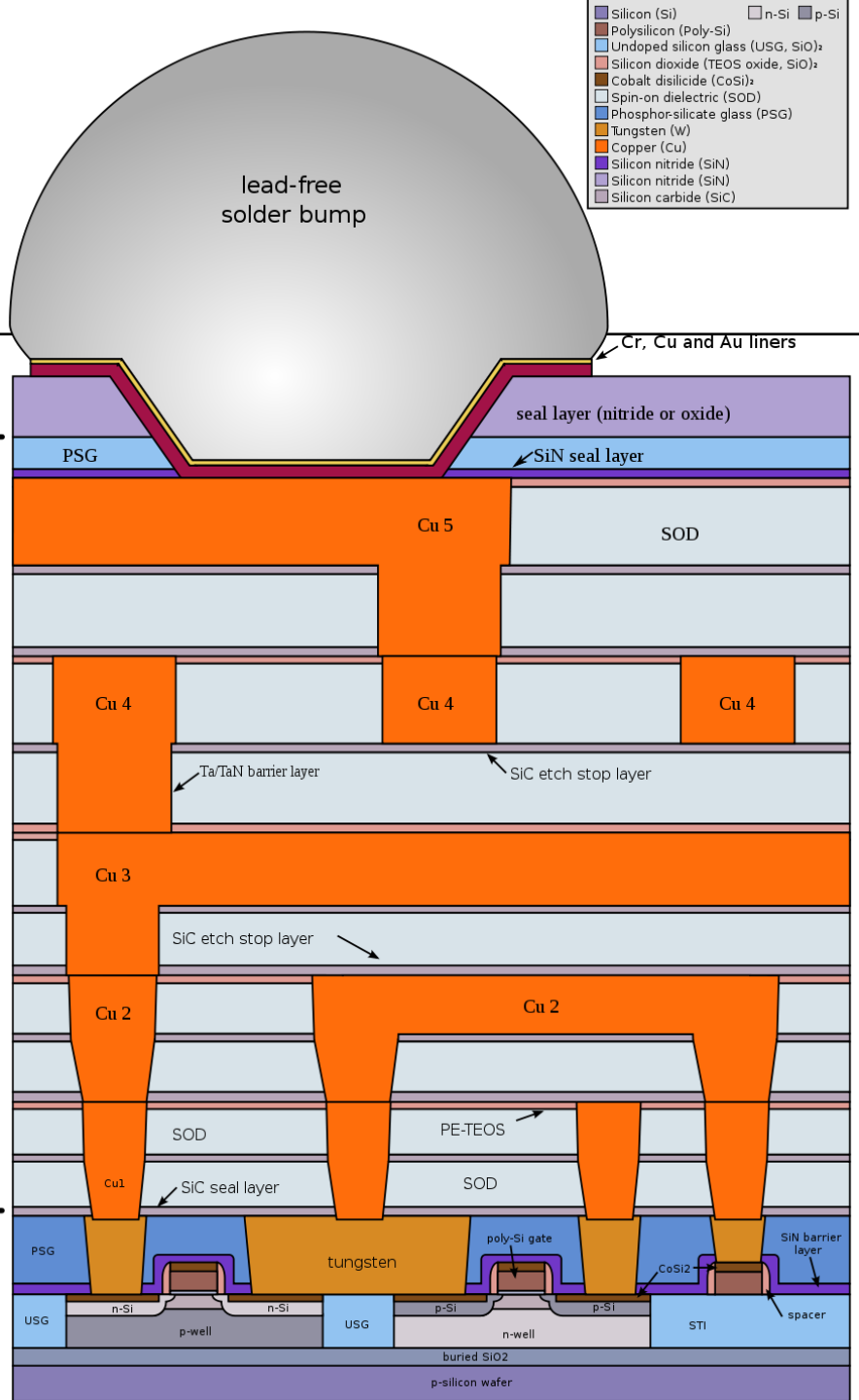


The CMOS chip

Complexity is more than transistors alone:

A cm^2 chip may contain
~20 km wires
~10^{10} contacts



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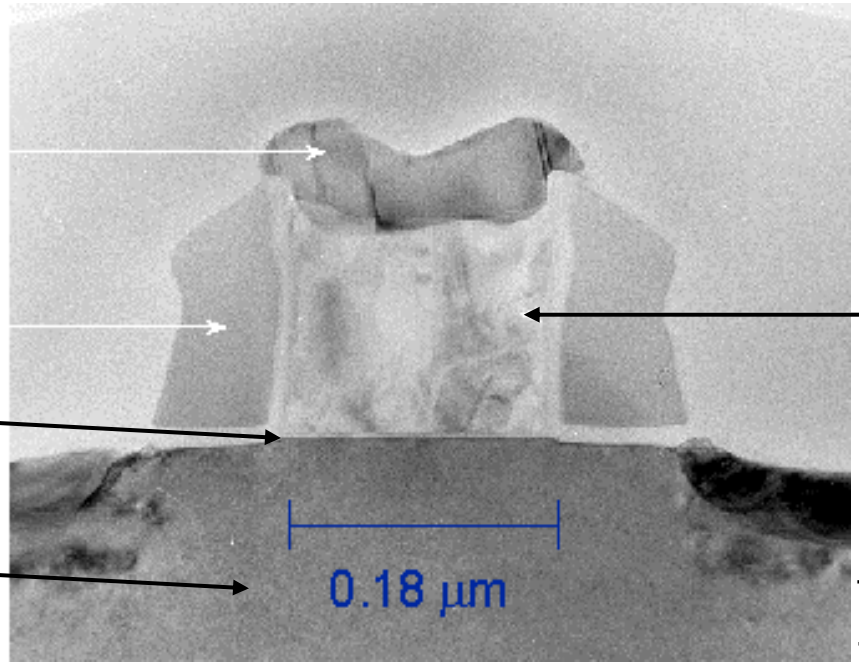
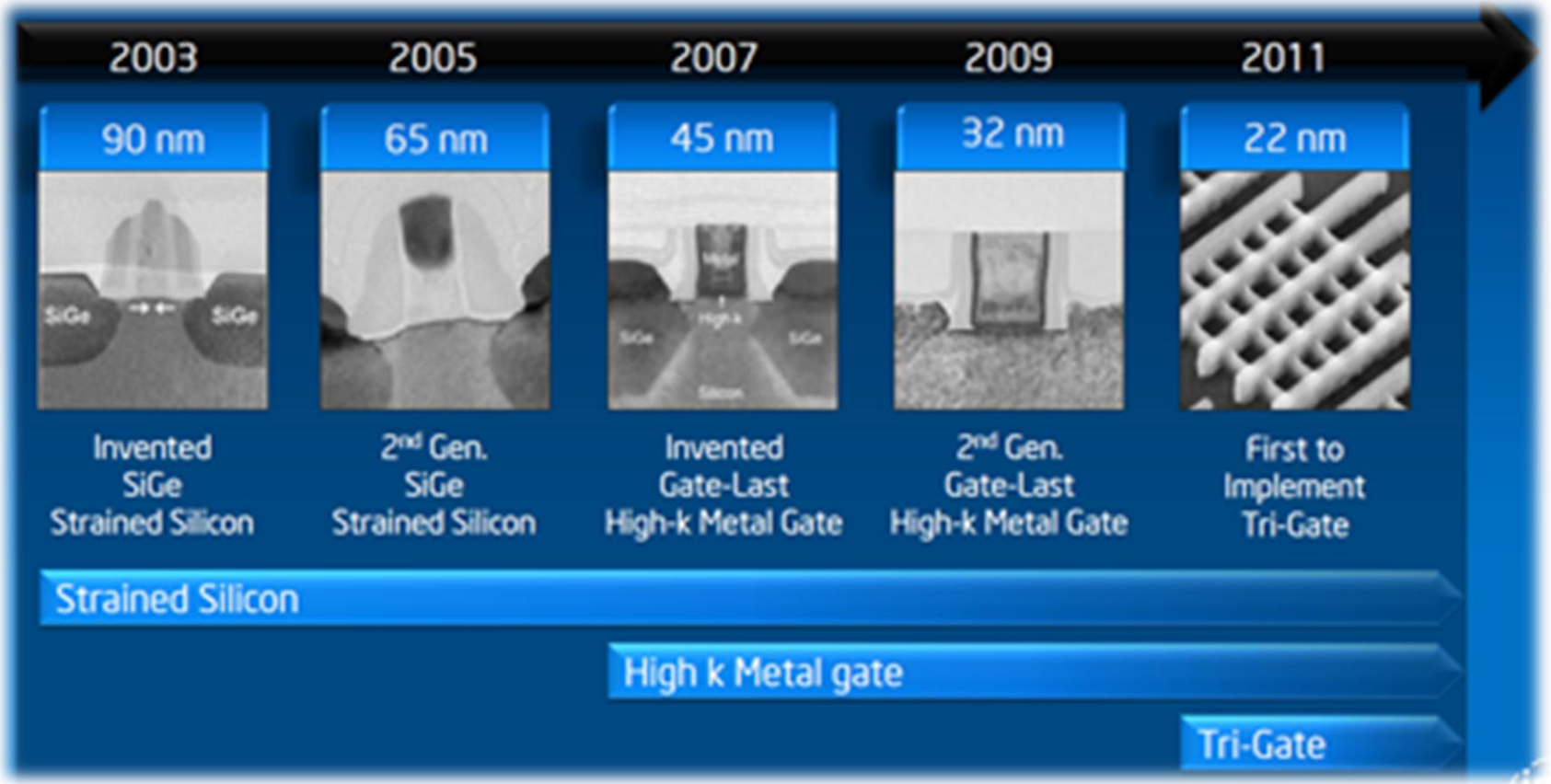
Transistor evolution
1970-2000: “the happy scaling era”

- Keep everything the same, only miniaturize it: $1/\sqrt{2}$ per generation



Transistor evolution (2)
2000-present: new technologies to boost performance



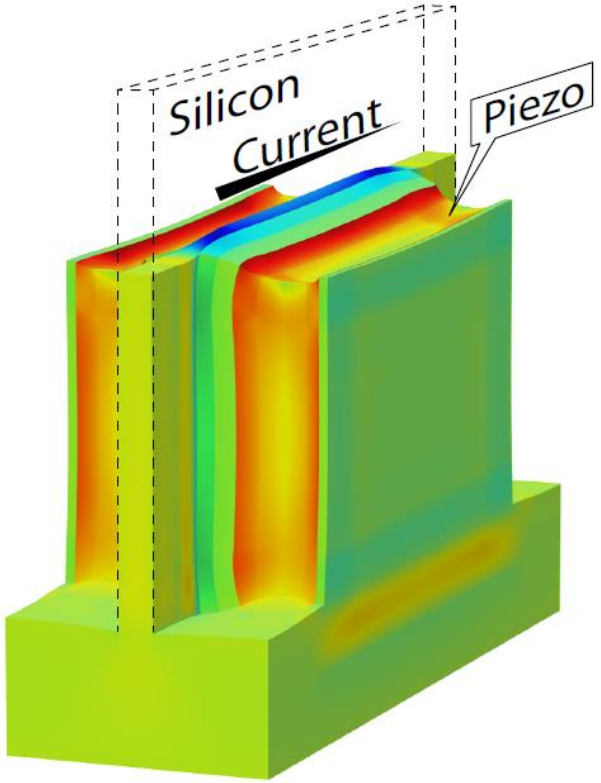
Intel

Another performance booster: Permanent strain → active strain modulation

- Switch strain on and off
- Use piezoelectric material (e.g. PZT)
- High on-current & low off-current

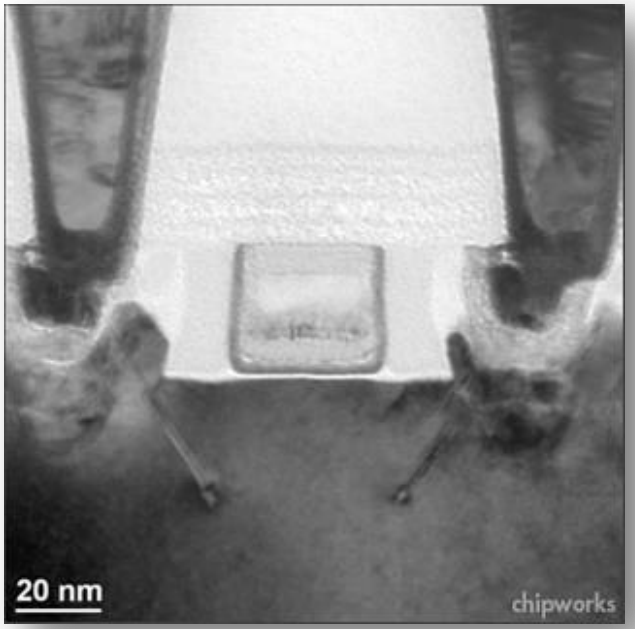
T. Van Hemert et al.., IEEE Trans. El. Dev. 2013

B. Kaleli et al., IEEE Trans. El. Dev. 2014



The art of microchips today

- 1-nm precision manufacturing
- Atomary sharp interfaces
- High-purity materials
- Best mastered:
  - Aluminum, copper, tungsten
  - Silicon; SiGe alloys
  - SiO_2, HfO_2, Si_3N_4

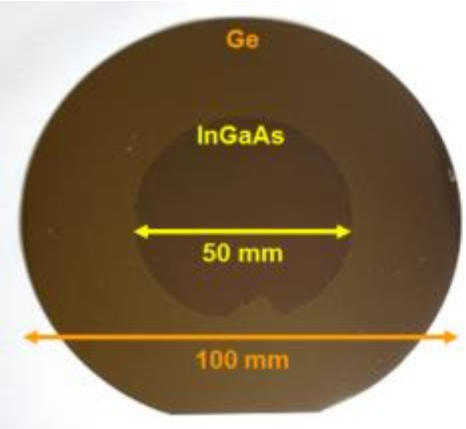


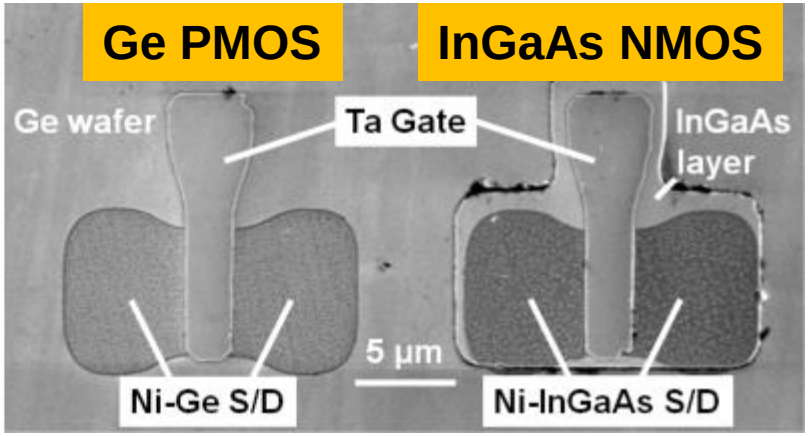
Conventional wisdom:

"If you can do it in CMOS, do it in CMOS"

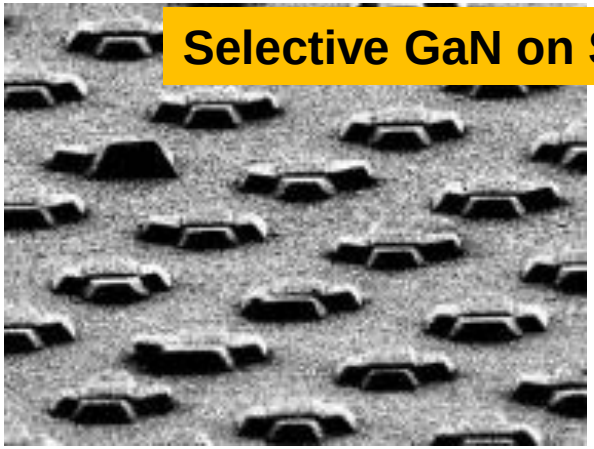
"If you can do it in silicon, do it in silicon"

Emerging technologies in microelectronics: Replacing good old silicon

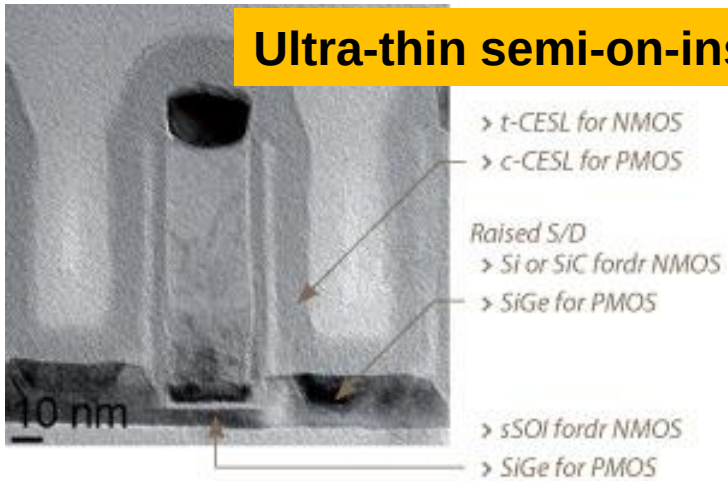




AIST

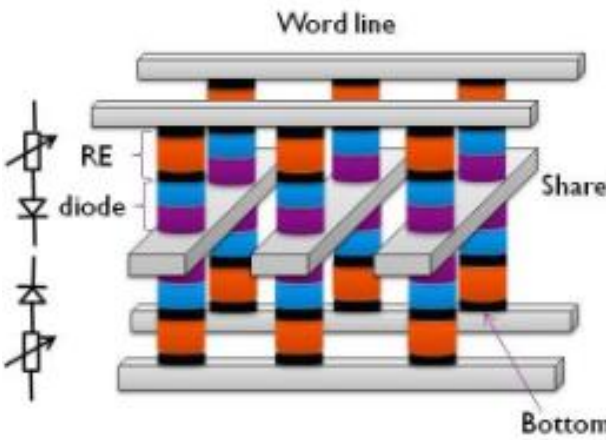


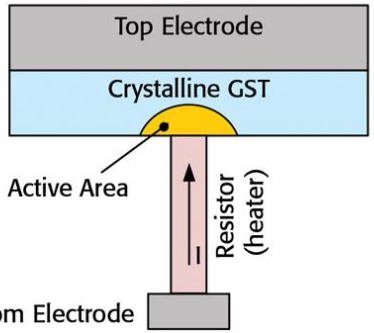
IBM

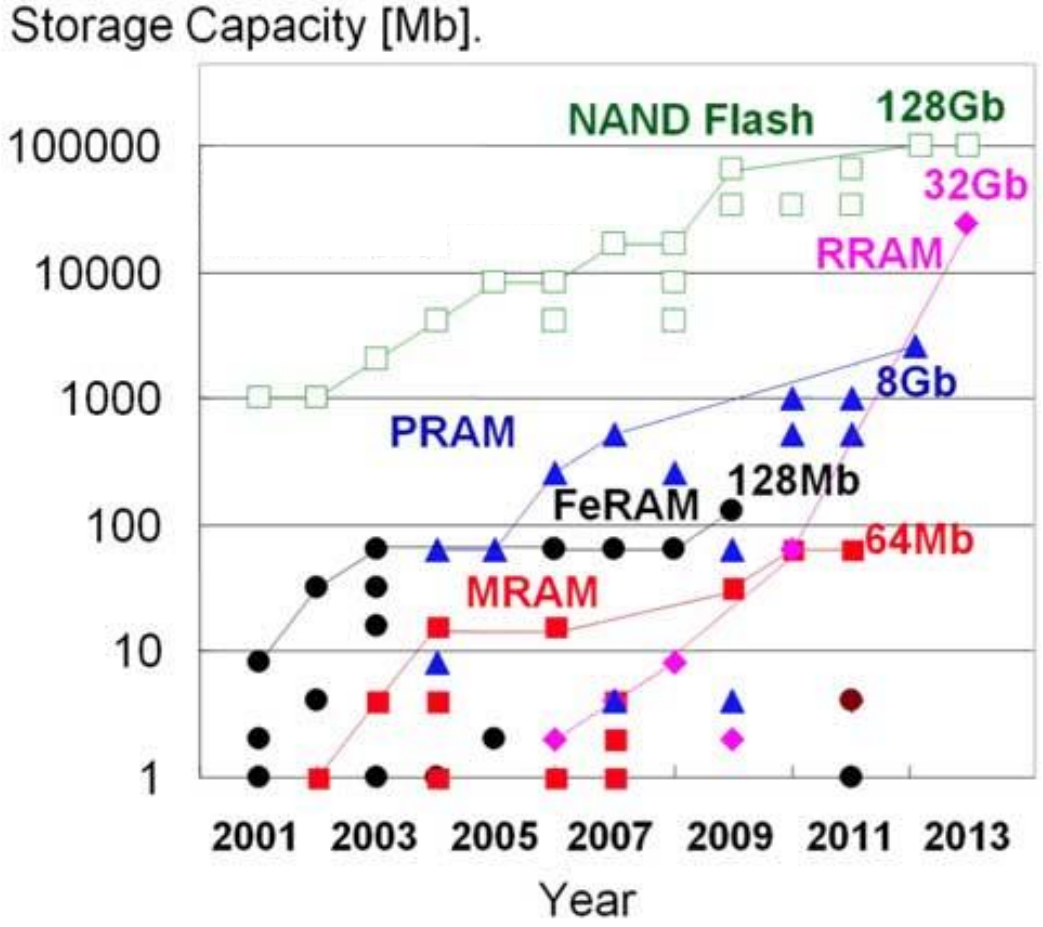


LETI

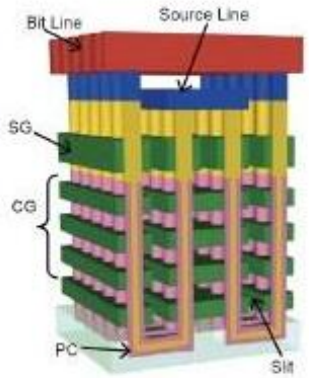
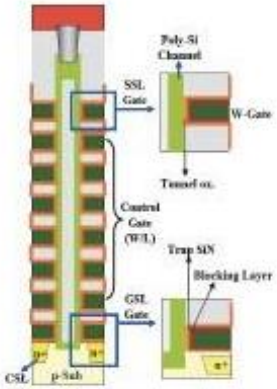
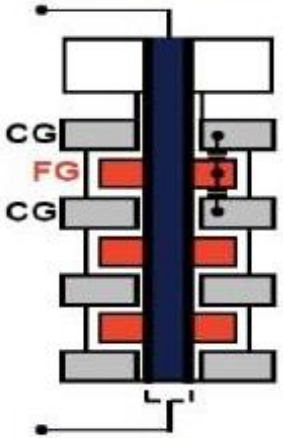
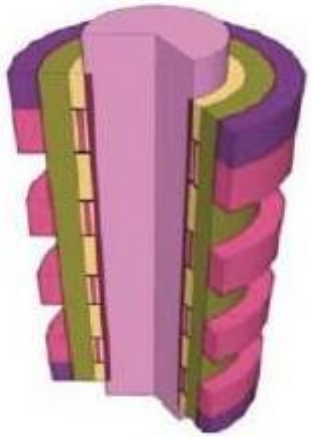
Emerging technologies in microelectronics: Replacing FLASH memory







But meanwhile, FLASH is going 3D

	p-BiCS (Toshiba)	TCAT (Samsung)	3D FG (Hynix)	Micron
Structure	 Tanaka. H, VLSIT 2007	 J. Jang, VLSIT 2009	 S. Whang, IEDM 2010	 G. Hawk, FMS 2011
Key Features	- P+ SONOS Cell	- TANOS Cell	- Floating Gate	?

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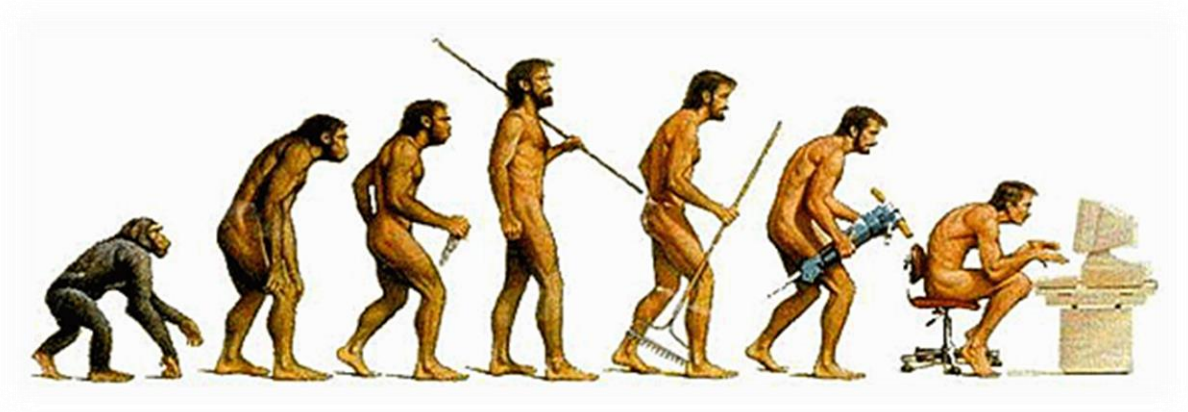
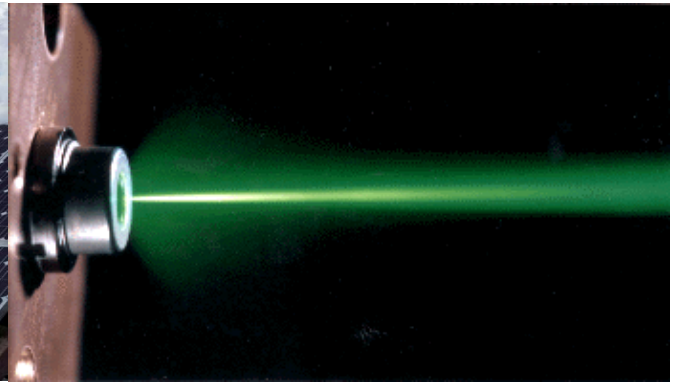


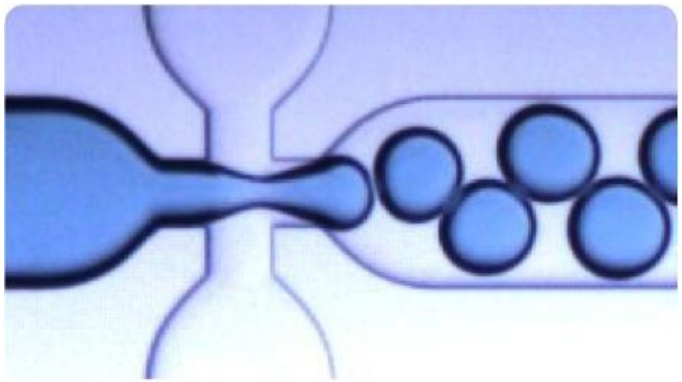
Microtechnology: more than chips

Light Emitting Diodes

Photovoltaics

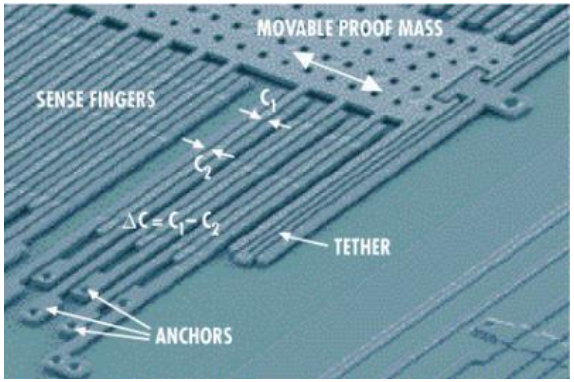


Semiconductor lasers



Microfluidics

Flat Panel Displays



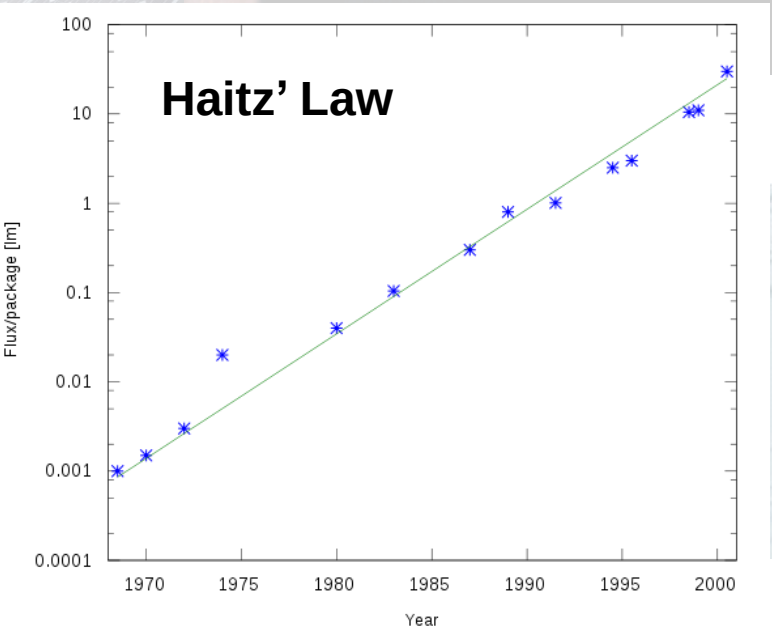
Sensors

Microtechnology: more than chips

Light Emitting Diodes

Steep market growth
GaN-based technology
Hetero-epitaxy

Photovolt



Microfluidics

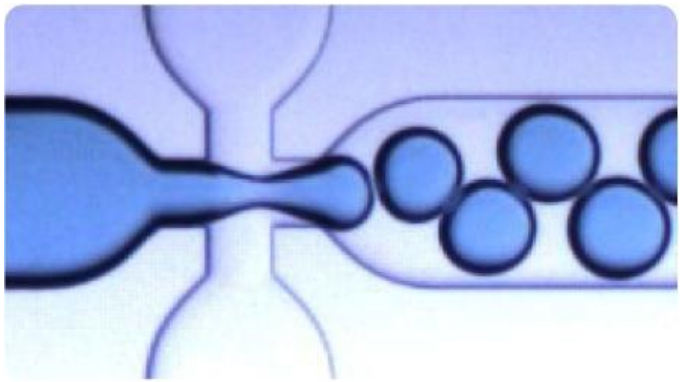
Flat P

Microtechnology: more than chips

Light Emitting Diodes

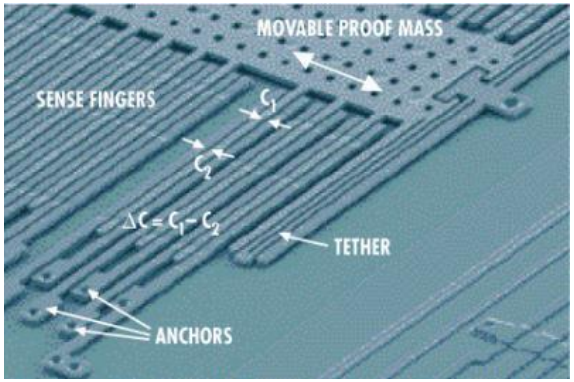
High potential:
Point-of-care medicine
Internet-of-things
Uses mainstream technology

iconductor lasers



Microfluidics

Flat Panel Displays

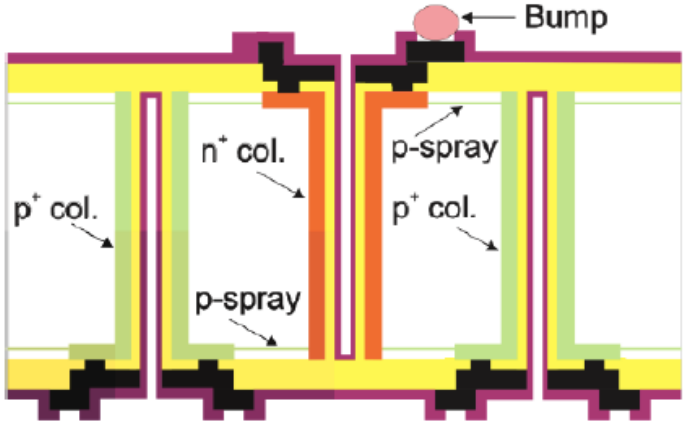


Sensors

…and sensors for radiation imaging!

Microfabricated sensors in particle physics:

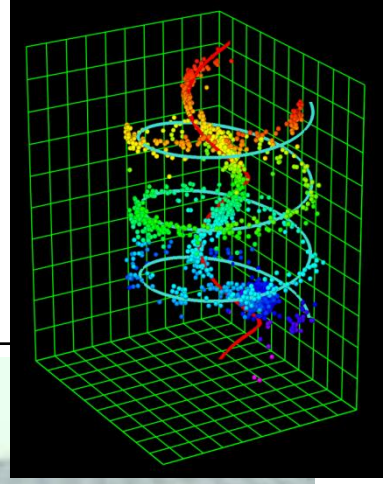
- Silicon detectors
- Charge-coupled devices
- Silicon photomultipliers
- CMOS-APS based detectors
- …

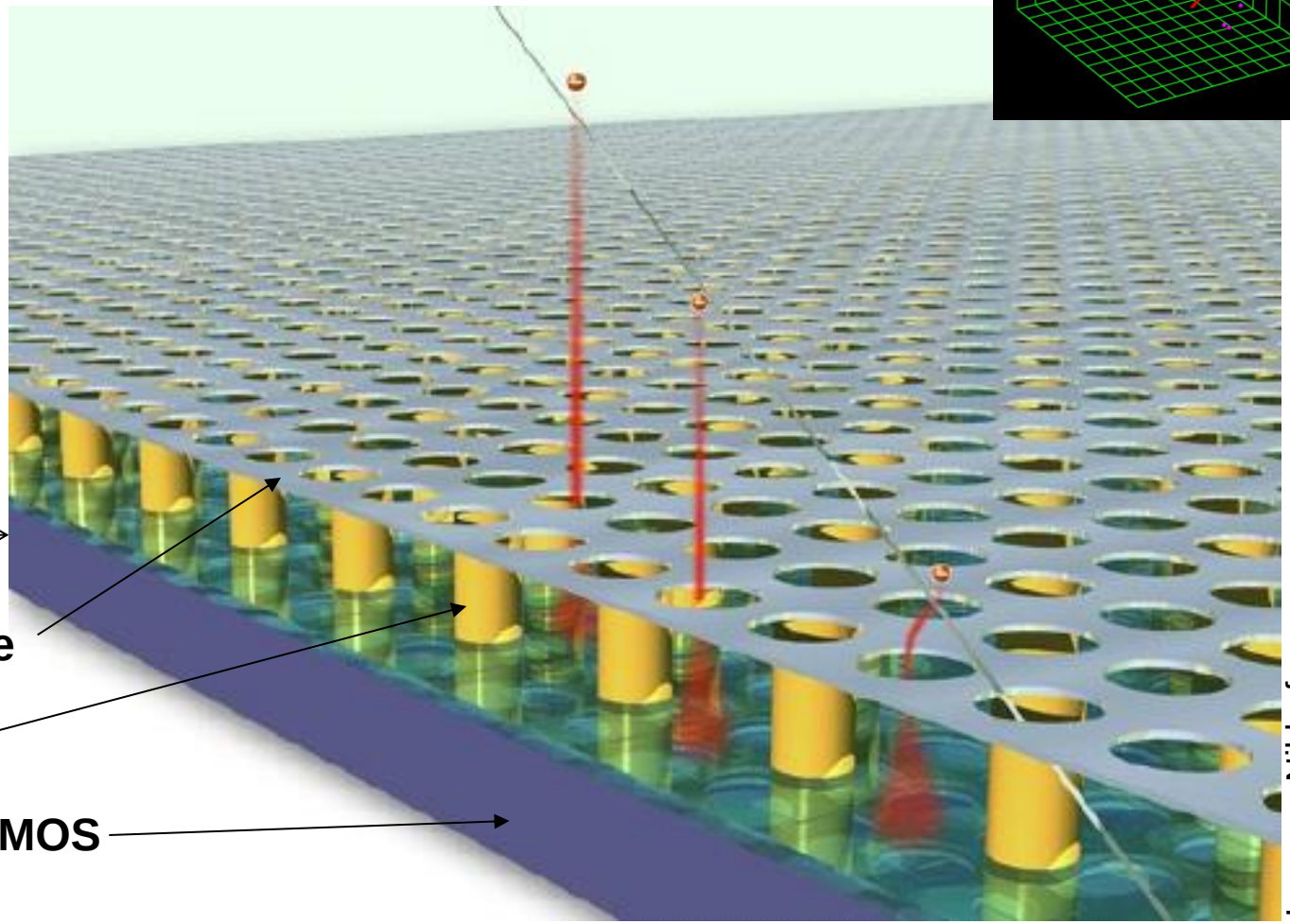


Focus on semiconductors for signal generation.

- Scintillators? Gas?

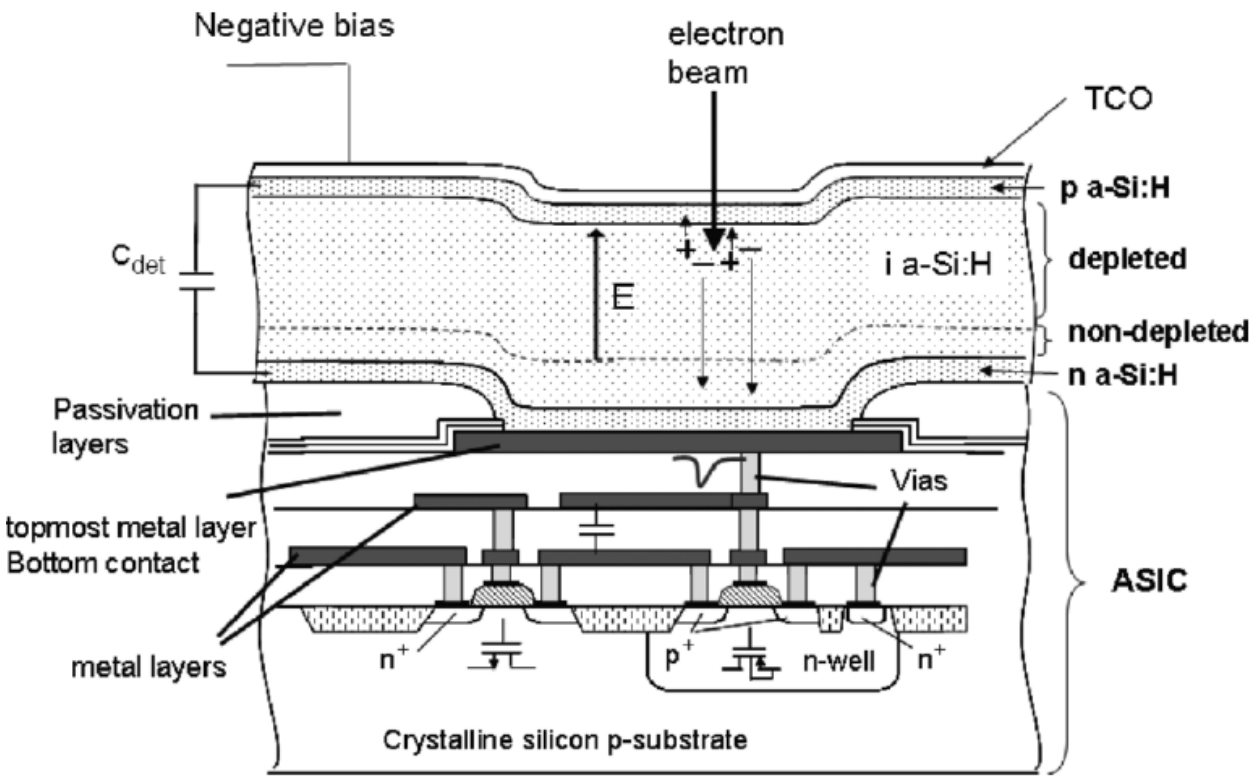
InGrid: a radiation imaging detector





Images: Nikhef

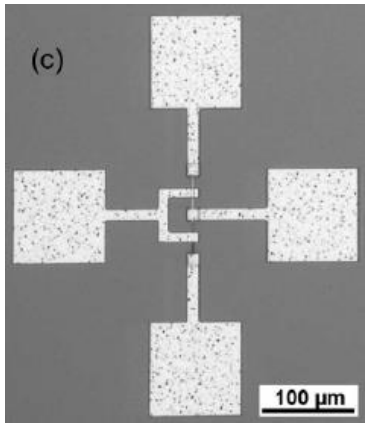
Semiconductors on top of CMOS



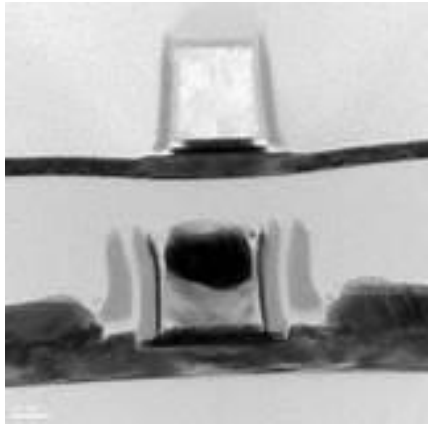
"TFA detector", Andrea Franco et al., IEEE Trans. Nucl. Sci. 2012

Or vice versa?

- Stack thin-film transistors on your sensor
- Monocrystalline: 3D electronics as developed e.g. by LETI (Batude et al.)
- Polycrystalline:
  e.g. I. Brunets et al.,
  IEEE Trans. El. Dev. 2009



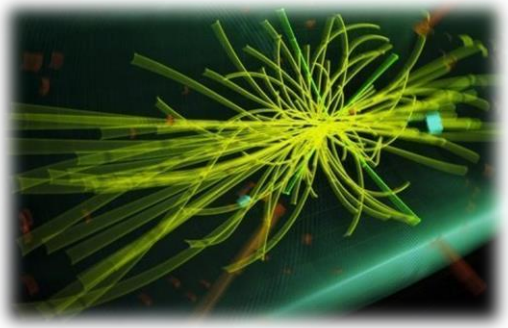
U.Twente


LETI

- Low temp fabrication (~400 °C)
- High interconnect density >> TSV's

Advances in microfabrication: Consequences for Particle Physics

- Miniaturized detector systems may boast
  - Improved resolution and speed
  - Reduced power consumption
  - Less X_0, lower mass
  - Onboard intelligence
  - “The interconnect benefit”
- IC Future: new materials & lower-power circuits
  - New semiconductor materials: GaN, InGaAs, Ge, …
  - Performance in radiation imaging?

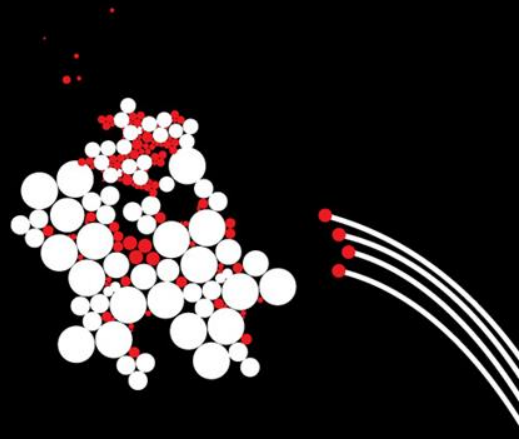


Thank you:

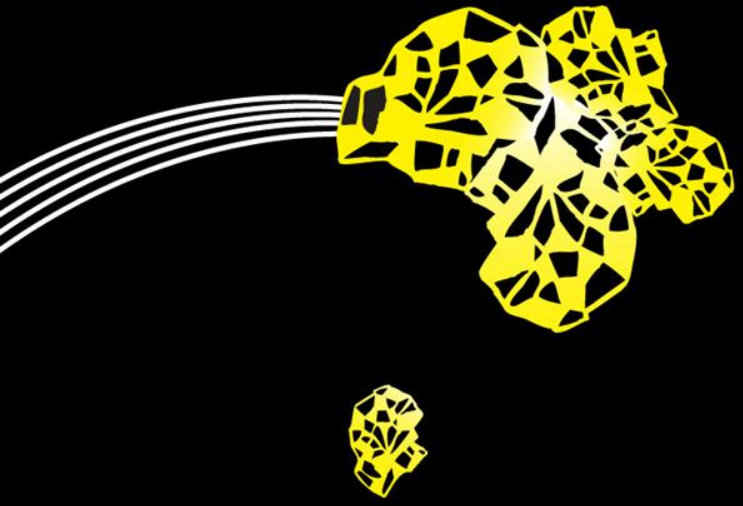
- My coworkers at the University of Twente
- Nikhef Detector R&D group
- TIPP organizers
- Dutch Technology Foundation STW, Min. Economic Affairs, FOM and EU

Ministerie van Economische Zaken

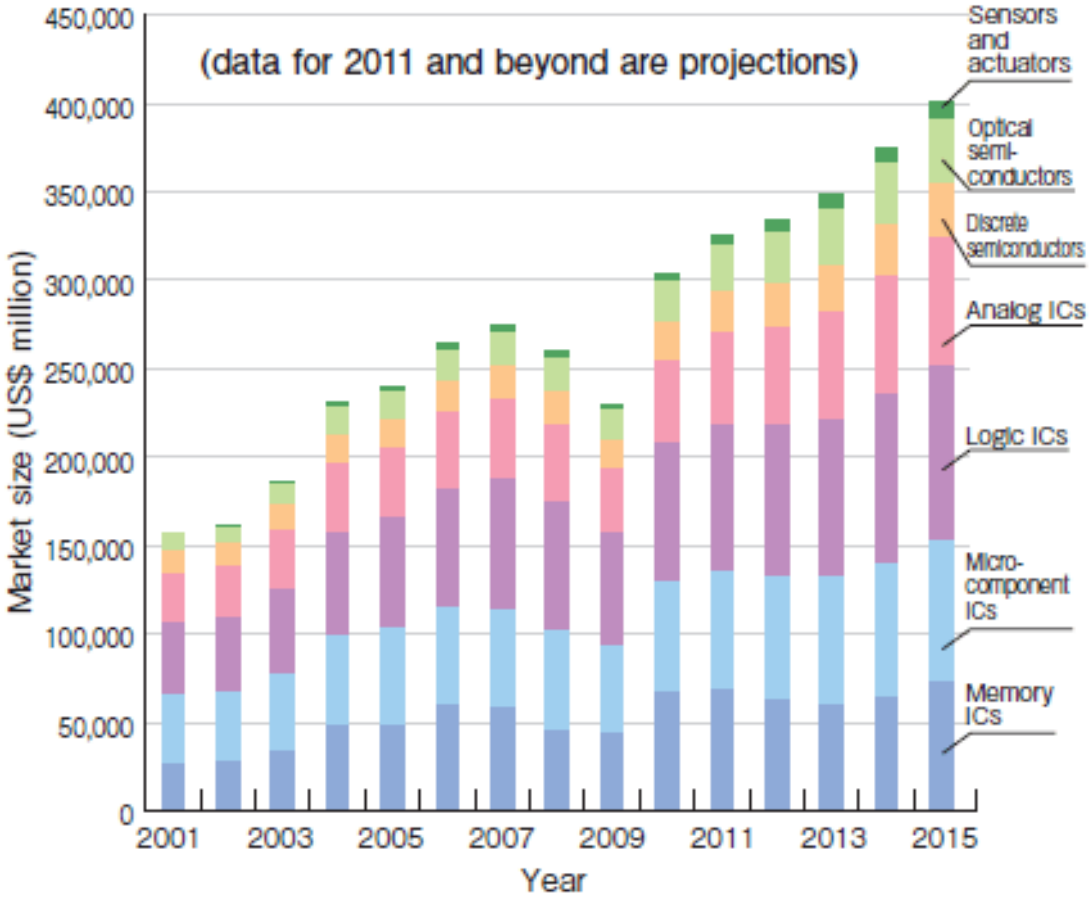
UNIVERSITY OF TWENTE.



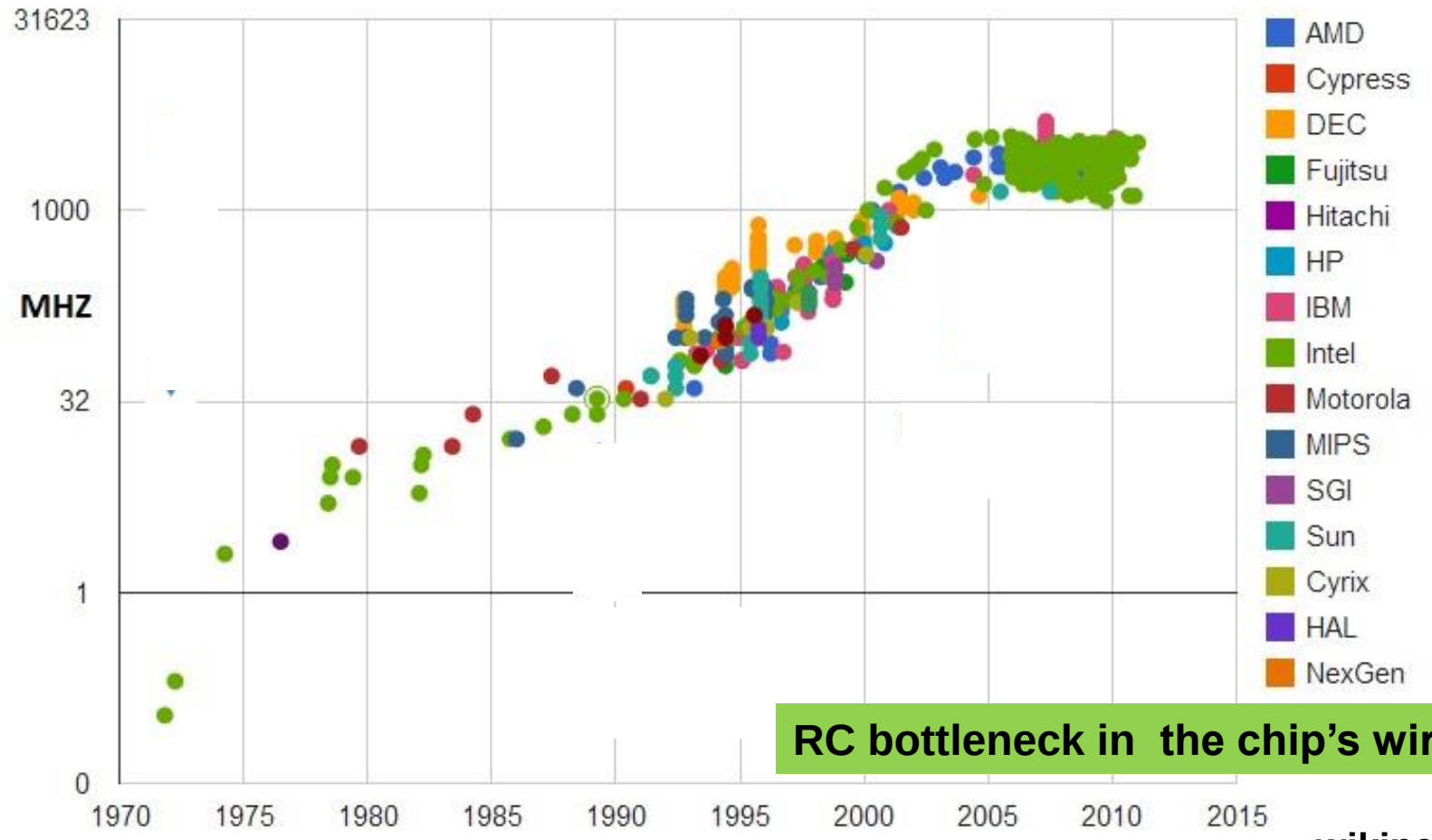
Questions?



Semiconductor market: arguably the largest industry



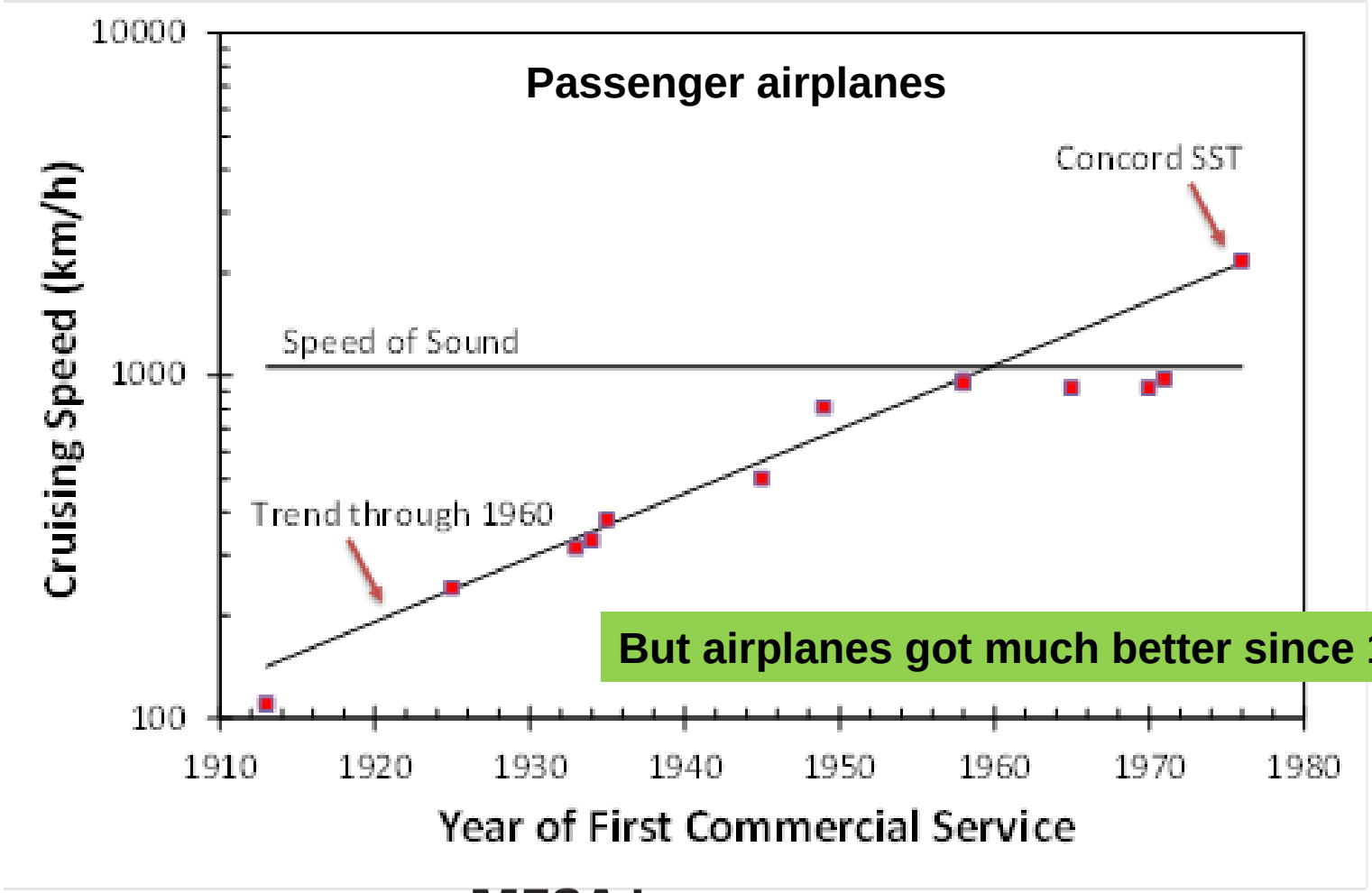
CPU clock frequency



RC bottleneck in the chip's wiring

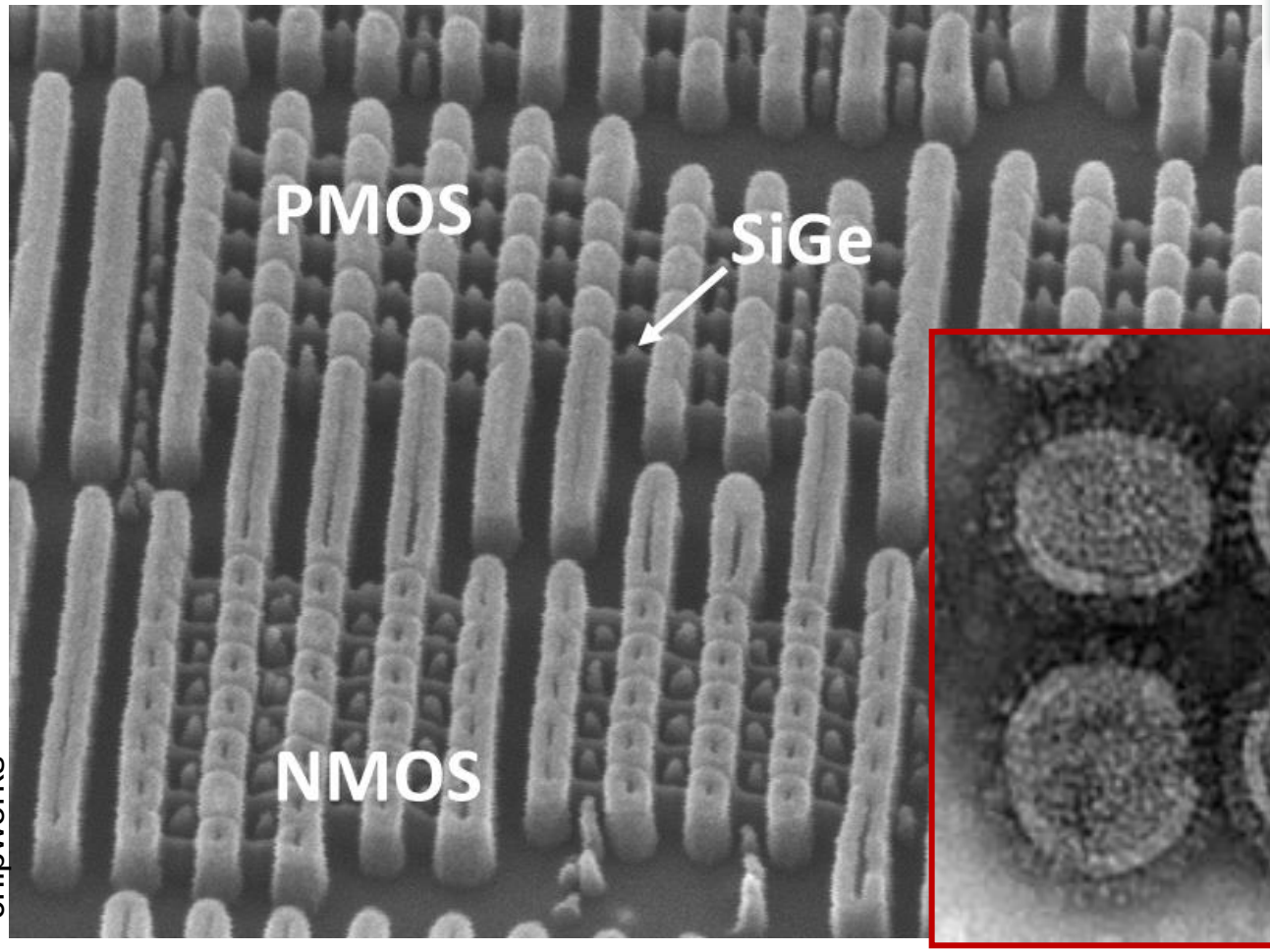
wikipedia

Trends like Moore's "Law" are not forever



But airplanes got much better since 1960!

Inside a TriGate chip



chipworks

H5N1 virus
(same scale)