

MOORE & More than MOORE



Centre for
Energy Research



Péter Fürjes

ELKH Centre for Energy Research
Institute of Technical Physics and Materials Science
Microsystems Laboratory

E-mail: [furjes.peter @ ek-cer.hu](mailto:furjes.peter@ek-cer.hu)

www.ek-cer.hu | www.mems.hu | www.biomems.hu

MEMS/NEMS INFRASTRUCTURE in CER MICROSYSTEMS LAB



RAITH 150 E-BEAM
Ultra high resolution (8nm)



Micromachining techniques:

- Patterning – mask design, laser pattern generator, 1 μ m photolithography, (double side) alignment, electron beam lithography (E-Beam), Focused Ion Beam processing – FIB milling, nanoimprinting
- Structured polymer layers – PMMA, PI, SU8 patterning, micromoulding, soft lithography – PDMS
- Wet chemistry – chemical wafer cleaning, isotropic and anisotropic etching techniques
- Dry etching – deep reactive ion etching, plasma etching techniques (DRIE, RIE)
- High temperature processes – thermal oxidation, diffusion, annealing, rapid thermal annealing (RTA)
- Physical thin film depositions – Thermal and electron beam evaporation, DC and RF Sputtering
- Chemical thin film depositions – Atmospheric and Low Pressure Chemical Vapour Deposition (CVD, LPCVD, LTO) thermal and plasma enhanced Atomic Layer Deposition (ALD)
- Liquid Phase Epitaxy (LPE) of III-V compound semiconductors (LED manufacturing)
- Wafer bonding – Si-glass, glass-glass, polymer-glass anodic and thermal bonding
- Chip dicing, wire bonding especially for sensor applications
- Special packaging techniques and methods
- multi-domain Finite-Element Modelling (FEM), and process simulation.

Characterisation techniques:

- optical (fluorescent) and electron microscopy (SEM / TEM and EDS), atomic force microscopy (AFM), profilometry, electrochemical impedance spectroscopy (EIS), mechanical vibration and climate test chambers, UV / VIS / IR / FTIR spectroscopy, etc.



Zeiss-SMT LEO 1540 XB SEM/FIB
SCIOS-2 type dual-beam SEM/FIB
nanoprocessing systems

- SEM with focused ion beam (FIB),
- gas injection system (GIS for EBAD/IBAD)

SILICON (silex)

THE

H 1 Hydrogen	He 2 Helium
Li 3 Lithium	Be 4 Beryllium
B 5 Boron	C 6 Carbon
N 7 Nitrogen	O 8 Oxygen
F 9 Fluorine	Ne 10 Neon
Na 11 Sodium	Mg 12 Magnesium
Al 13 Aluminum	Si 14 Silicon
P 15 Phosphorus	S 16 Sulfur
Cl 17 Chlorine	Ar 18 Argon
K 19 Potassium	Ca 20 Calcium
Sc 21 Scandium	Ti 22 Titanium
V 23 Vanadium	Cr 24 Chromium
Mn 25 Manganese	Fe 26 Iron
Ni 28 Nickel	Cu 29 Copper
Zn 30 Zinc	Ga 31 Gallium
Ge 32 Germanium	As 33 Arsenic
Se 34 Selenium	Br 35 Bromine
Kr 36 Krypton	Xe 54 Xenon
Rn 86 Radon	Uuo 118 Ununoctium

Radioactive elements

Photographs show samples of the pure or nearly pure element except as follows: At, Rn, Fr, Ac, Pa, and the transactinides. Some elements are shown as they appear in nature, while others are shown as they appear in the laboratory. The elements are arranged in order of increasing atomic number. The elements are arranged in order of increasing atomic number. The elements are arranged in order of increasing atomic number.

Periodic Table of Elements
Copyright © 2003 Theodore W. Gray. All rights reserved.

B 5 10.81 Boron	C 6 12.011 Carbon	N 7 14.007 Nitrogen
Al 13 26.982 Aluminum	Si 14 28.085 Silicon	P 15 30.974 Phosphorus
Ga 31 69.723 Gallium	Ge 32 72.64 Germanium	As 33 74.922 Arsenic

On the other side of this poster you will find a version with smaller pictures but with detailed technical data on each of the elements, plus trend plots.

More images and complete technical data can be found at periodictable.com

PERIODICTABLE.COM

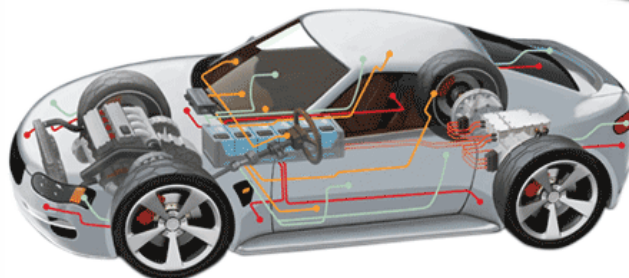
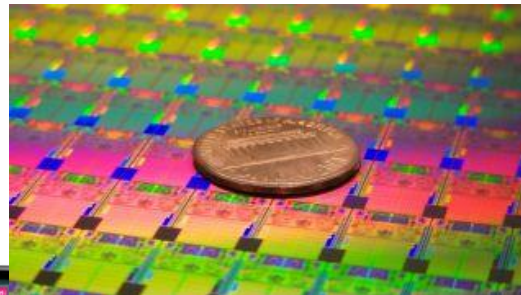
SILICON (silex)

Discoverer: Jons Berzelius
1823, Sweden

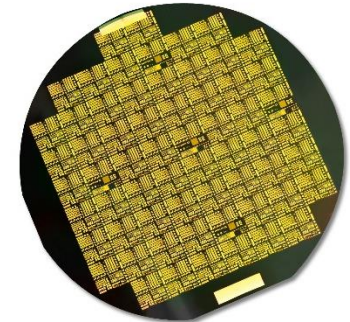
Natural presence:
granite, quartz, clay, sand

2nd in incidence in the Earth

Other applications...



SILICON – chemical element



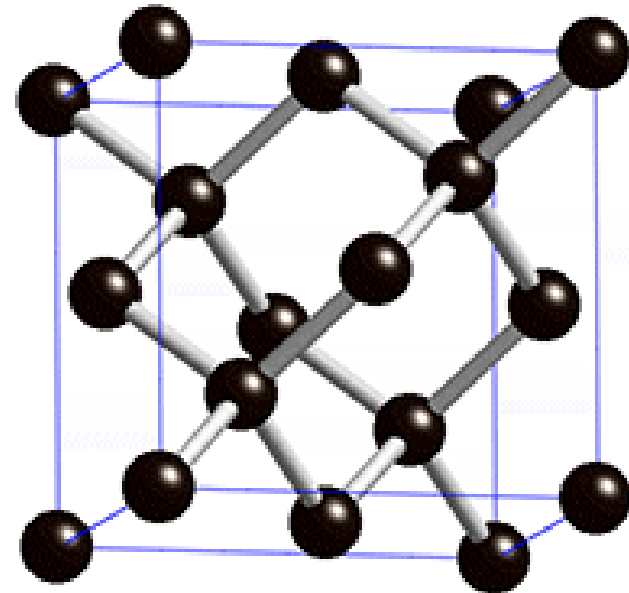
Properties: gray, metallic,
extremely hard material

Atomic number: 14 (1s² 2s² 2p⁶ / 3s² 3p²)

4th group / tetravalent metalloid

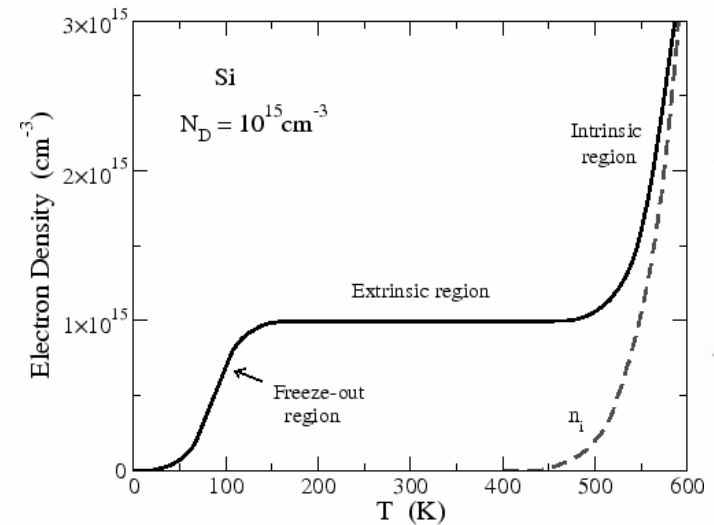
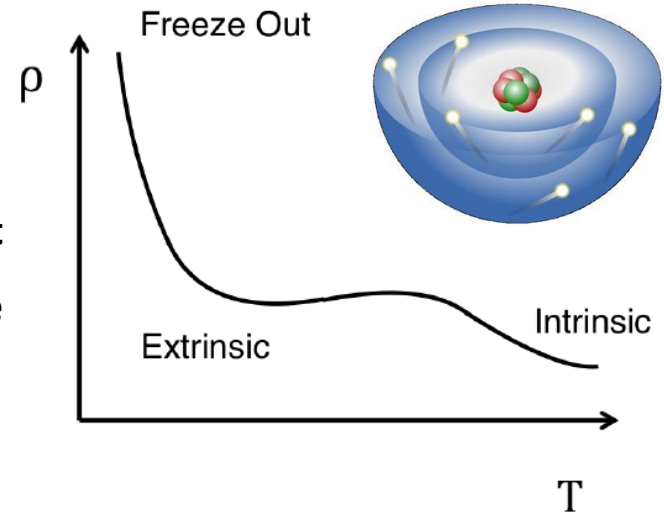
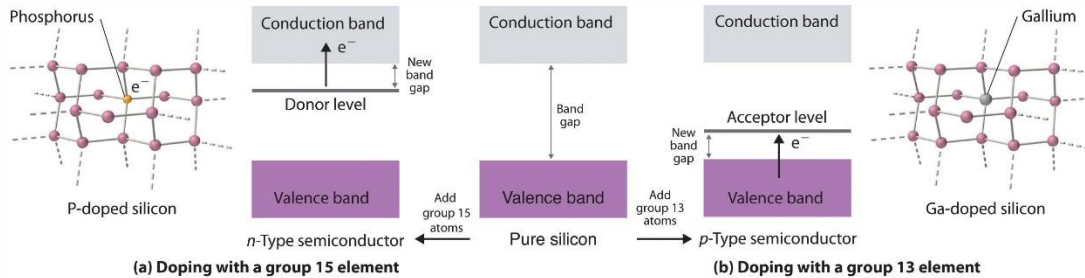
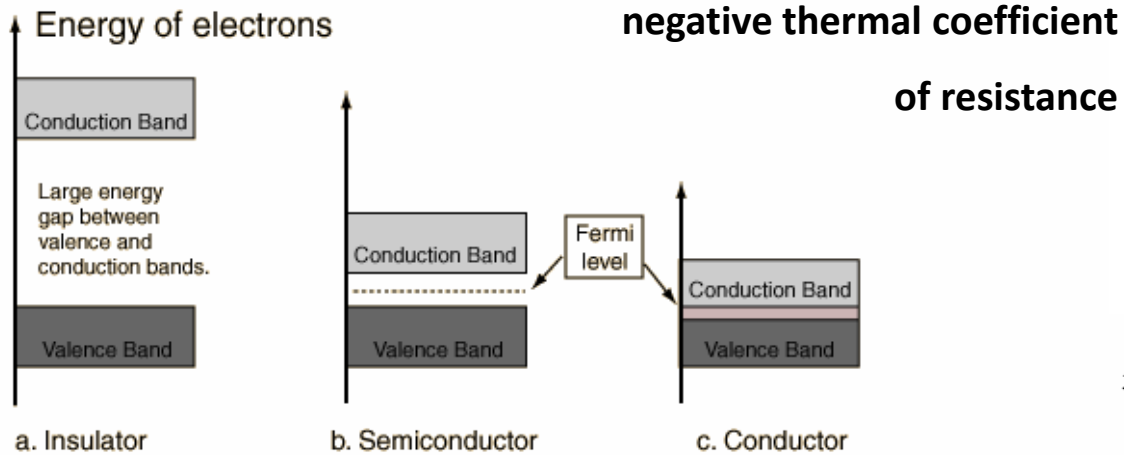
Crystal: similar to diamond

Electronic property: semiconductor



Resistance of semiconductors: $10^{-9} - 10^3 \text{ } \Omega\text{cm}$

How does the resistance change with the temperature?



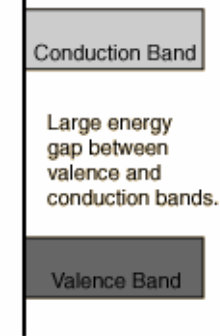
SEMICONDUCTORS

Resistance of semiconductors: $10^{-9} - 10^3 \text{ } \Omega\text{cm}$

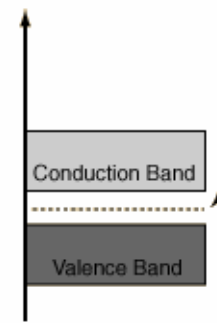
How does the resistance change with the temperature?

negative thermal coefficient of resistance

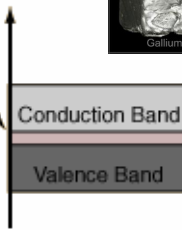
Energy of electrons



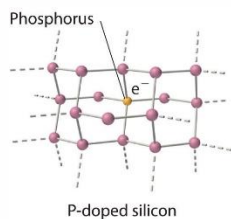
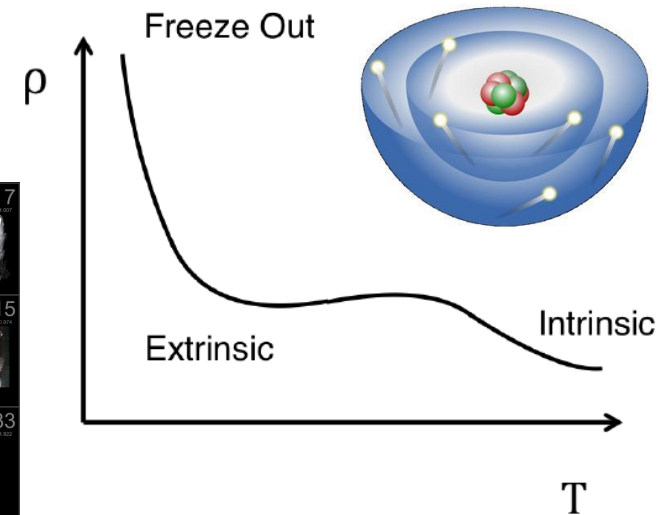
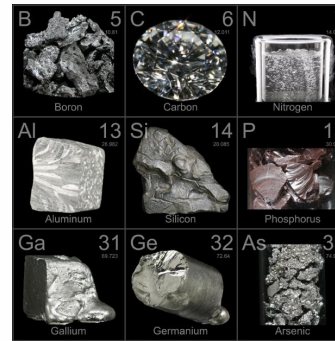
a. Insulator



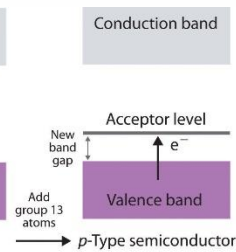
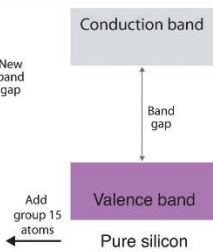
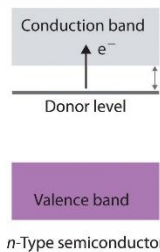
b. Semiconductor



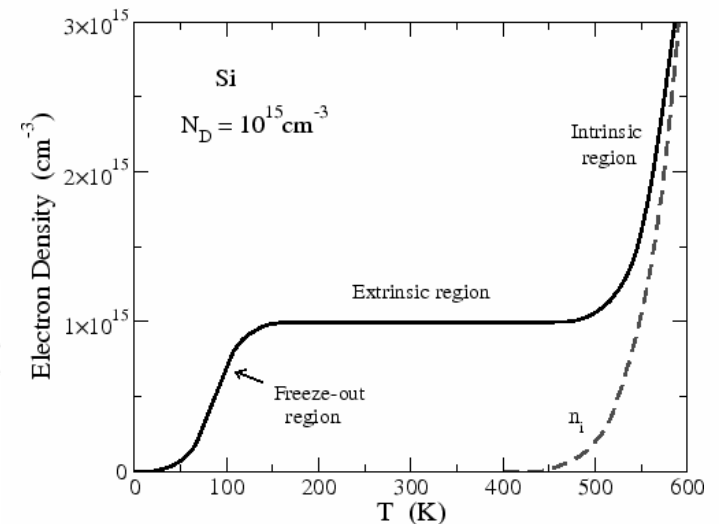
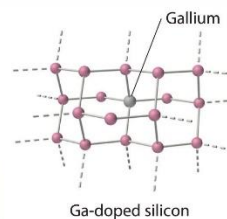
c. Conductor



(a) Doping with a group 15 element

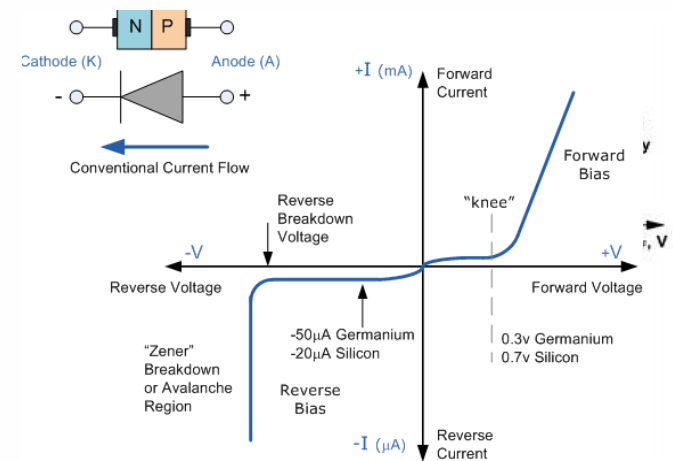
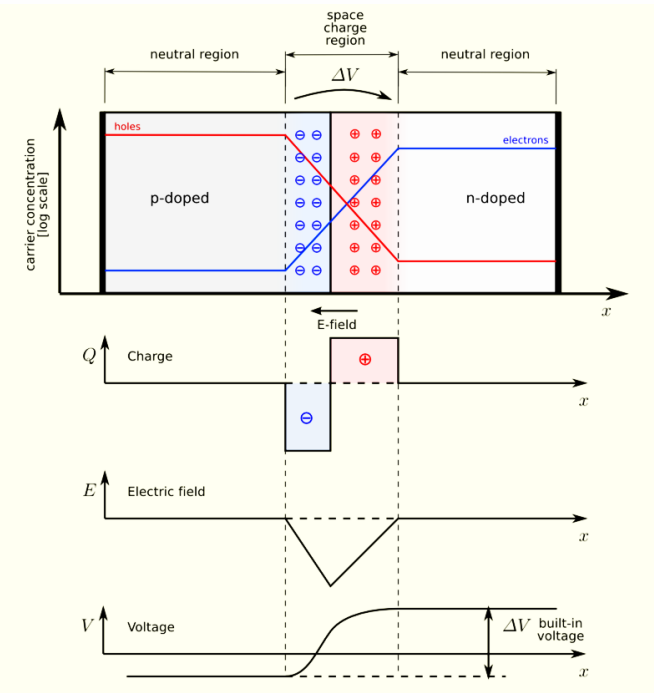
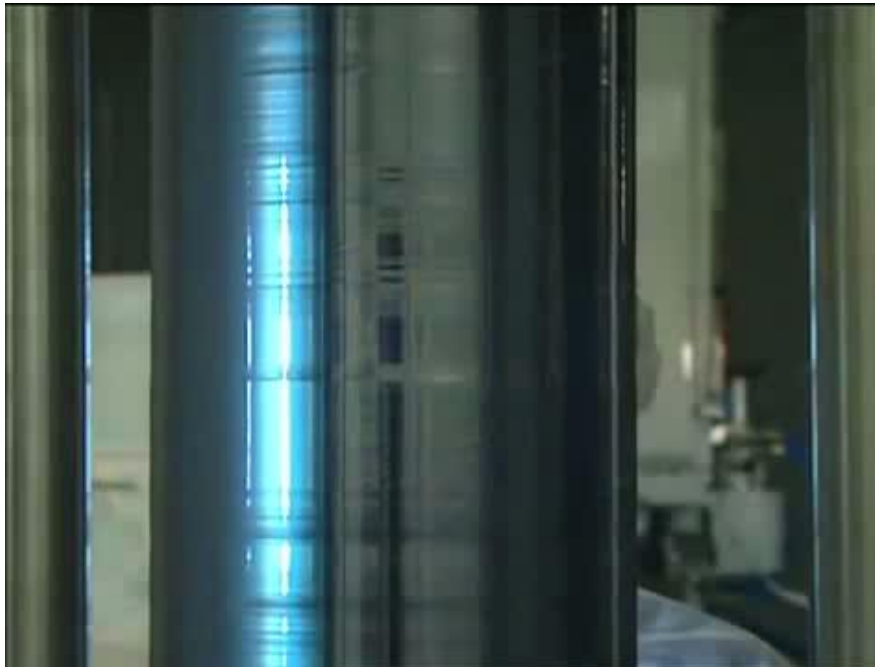
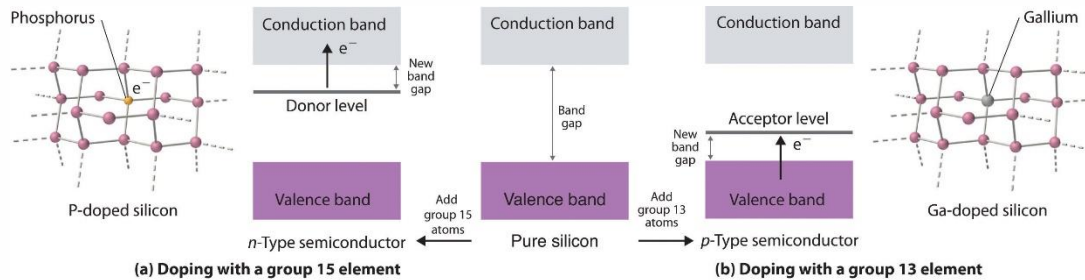


(b) Doping with a group 13 element



DIODE

Doped semiconductors: n (electron) and p (hole) type



TRANSISTOR



The Nobel Prize in Physics 1956



William Bradford Shockley
Prize share: 1/3



John Bardeen
Prize share: 1/3

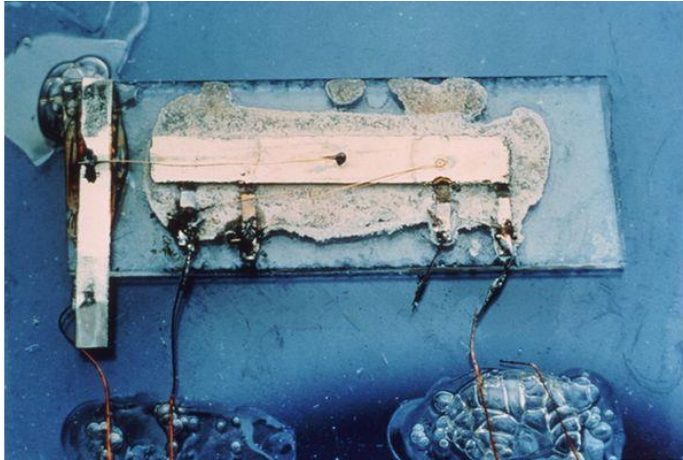


Walter Houser Brattain
Prize share: 1/3

The Nobel Prize in Physics 1956 was awarded jointly to William Bradford Shockley, John Bardeen and Walter Houser Brattain *"for their researches on semiconductors and their discovery of the transistor effect"*.

Substitution of vacuum (electron) tube
Functions: switching / amplification / voltage stabilisation

THE FIRST INTEGRATED CIRCUIT



- Transistor: solution for the problems of the vacuum (electron) tube (dissipation, reliability).
- Solution for connecting discrete devices (space saving).

The Nobel Prize in Physics 2000



Zhores I. Alferov

Prize share: 1/4



Herbert Kroemer

Prize share: 1/4



Jack S. Kilby

Prize share: 1/2

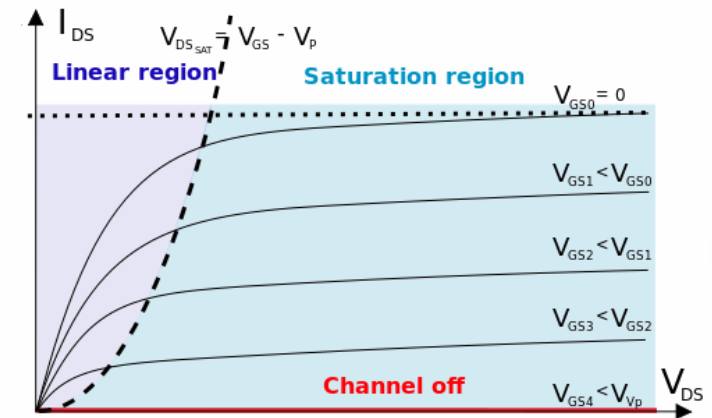
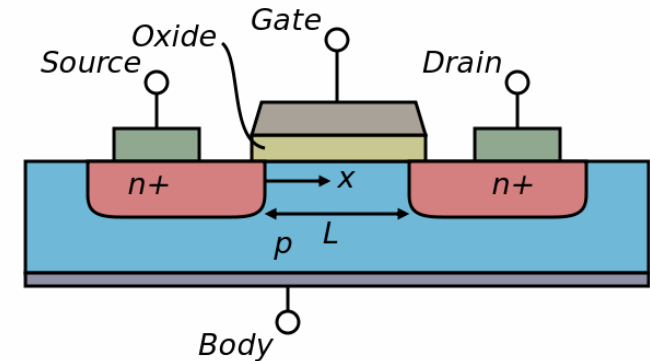
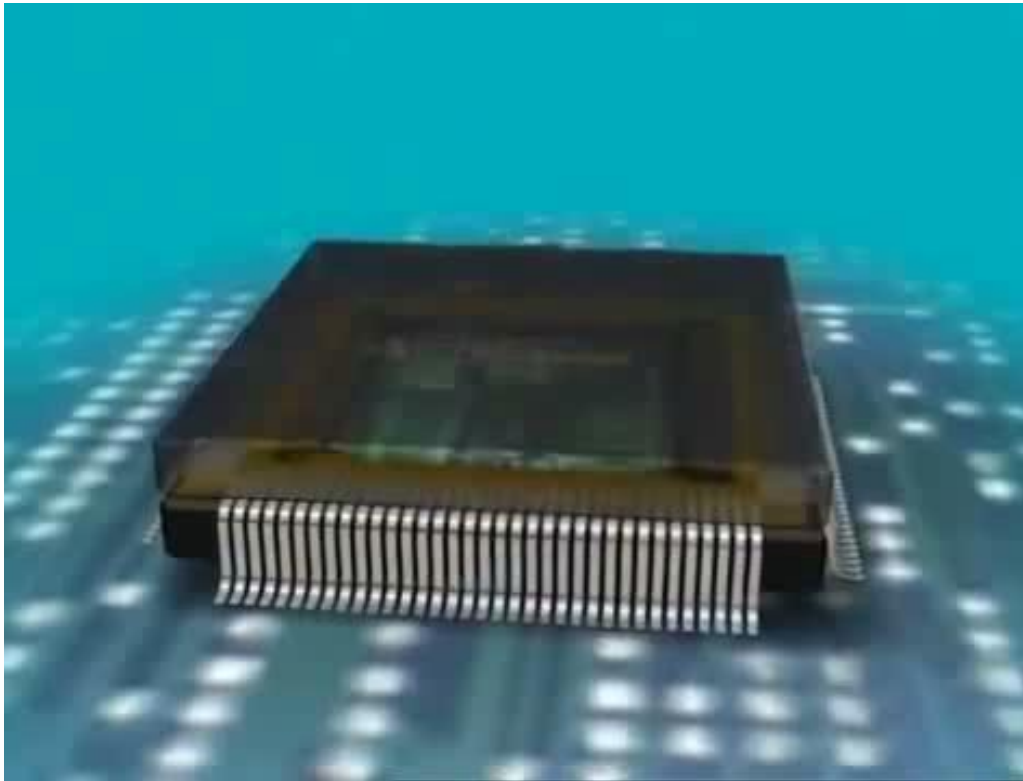
The Nobel Prize in Physics 2000 was awarded "*for basic work on information and communication technology*" with one half jointly to Zhores I. Alferov and Herbert Kroemer "*for developing semiconductor heterostructures used in high-speed- and optoelectronics*" and the other half to Jack S. Kilby "*for his part in the invention of the integrated circuit*".

Photos: Copyright © The Nobel Foundation

FIELD EFFECT TRANSISTOR (FET)

Main building block of CPU and memory

Functions: amplification (analog signals), switching

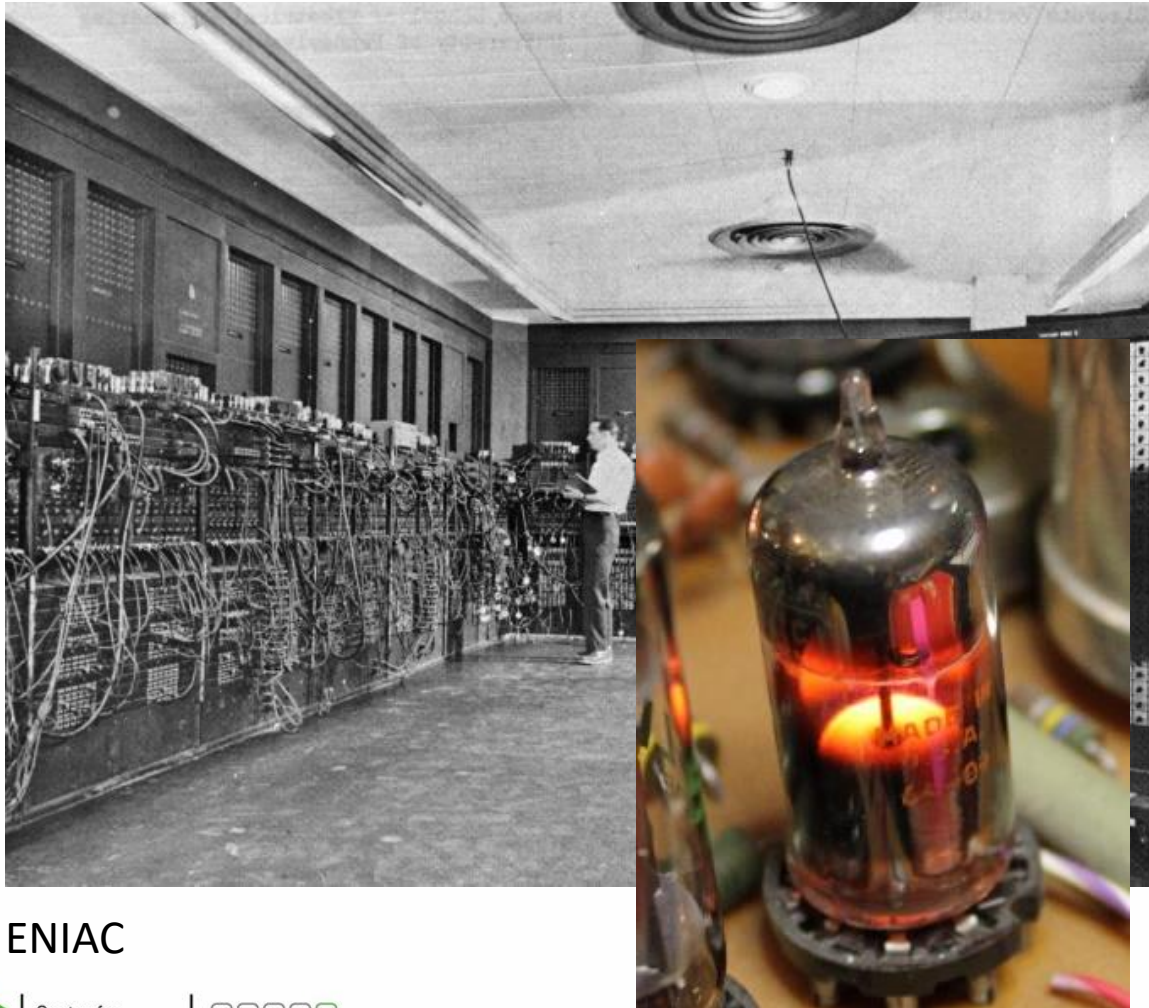


COMPUTATION



The FIRST COMPUTER

Von Neumann, János (1903-1957)



ENIAC



Development of the logical architecture of the electronic computers, based on the binary system.

Basic elements: memory, program storage, command system

DEVELOPMENT of THE COMPUTATIONAL CAPACITY

1 The accelerating pace of change ...



2 ... and exponential growth in computing power ...

Computer technology, shown here climbing dramatically by powers of 10, is now progressing more each hour than it did in its entire first 90 years



Colossus

The electronic computer, with 1,500 vacuum tubes, helped the British crack German codes during WW II



UNIVAC I

The first commercially marketed computer, used to tabulate the U.S. Census, occupied 943 cu. ft.



Apple II

At a price of \$1,298, the compact machine was one of the first massively popular personal computers

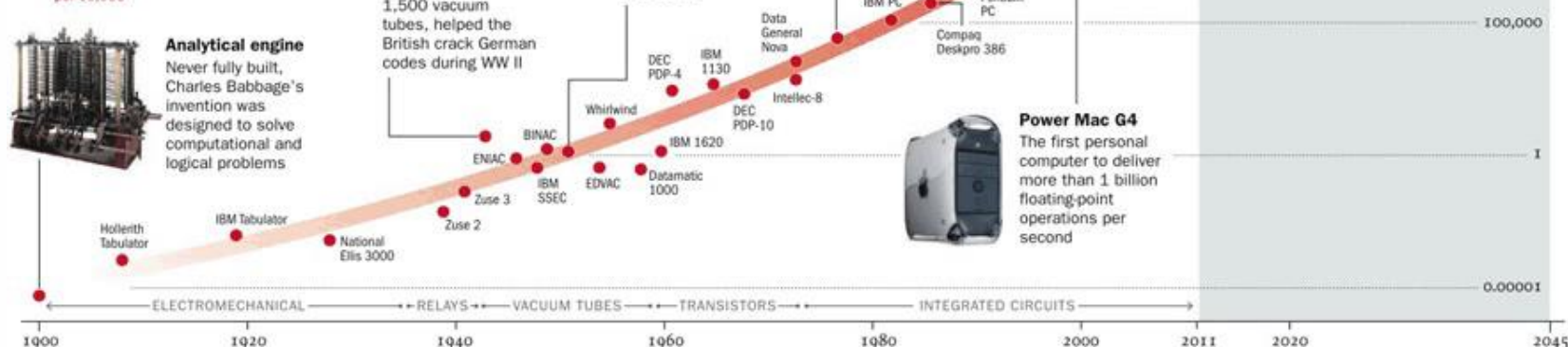
3 ... will lead to the Singularity

COMPUTER RANKINGS

By calculations per second per \$1,000



Analytical engine
Never fully built, Charles Babbage's invention was designed to solve computational and logical problems



Power Mac G4

The first personal computer to deliver more than 1 billion floating-point operations per second



HOW MANY TRANSISTOR CAN BE PLACED ON A CHIP?

THE MOORE LAW

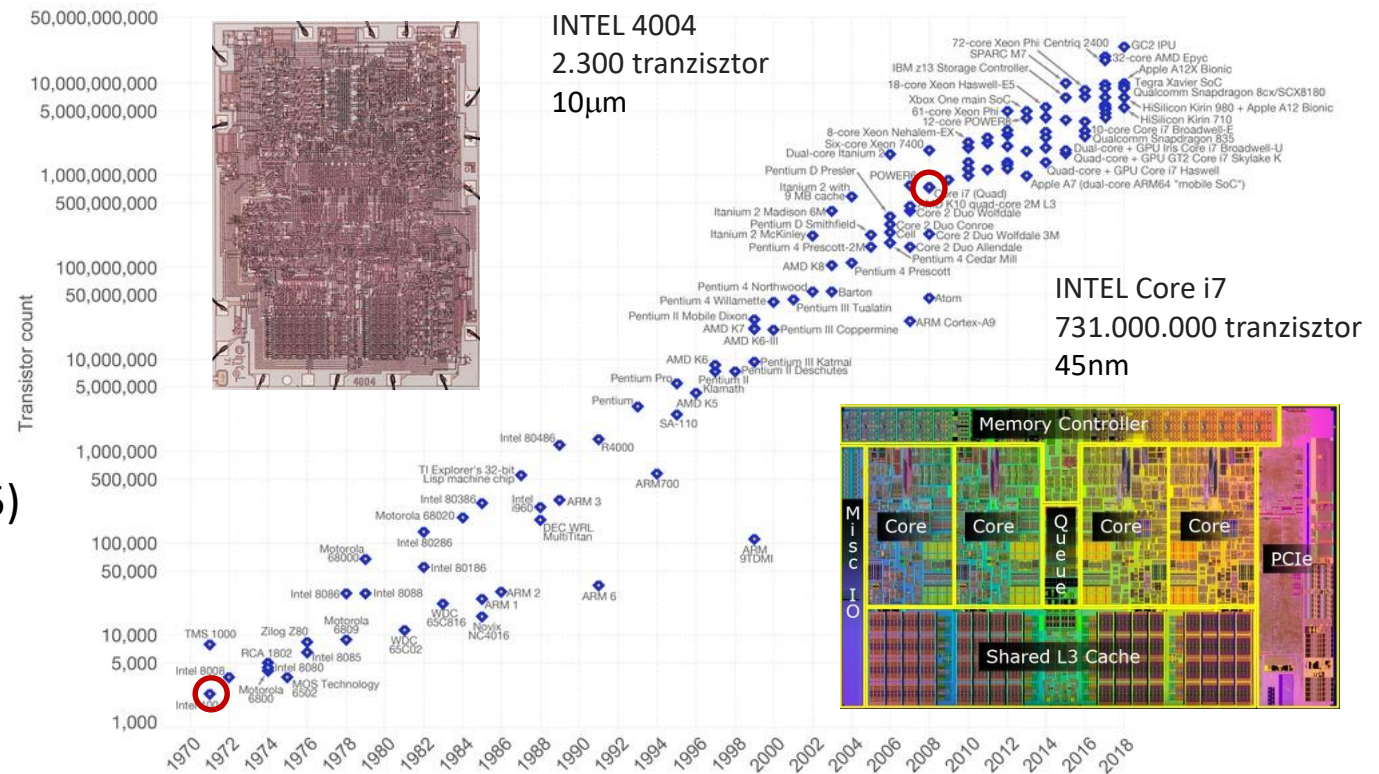


Gordon Moore (1965)

Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

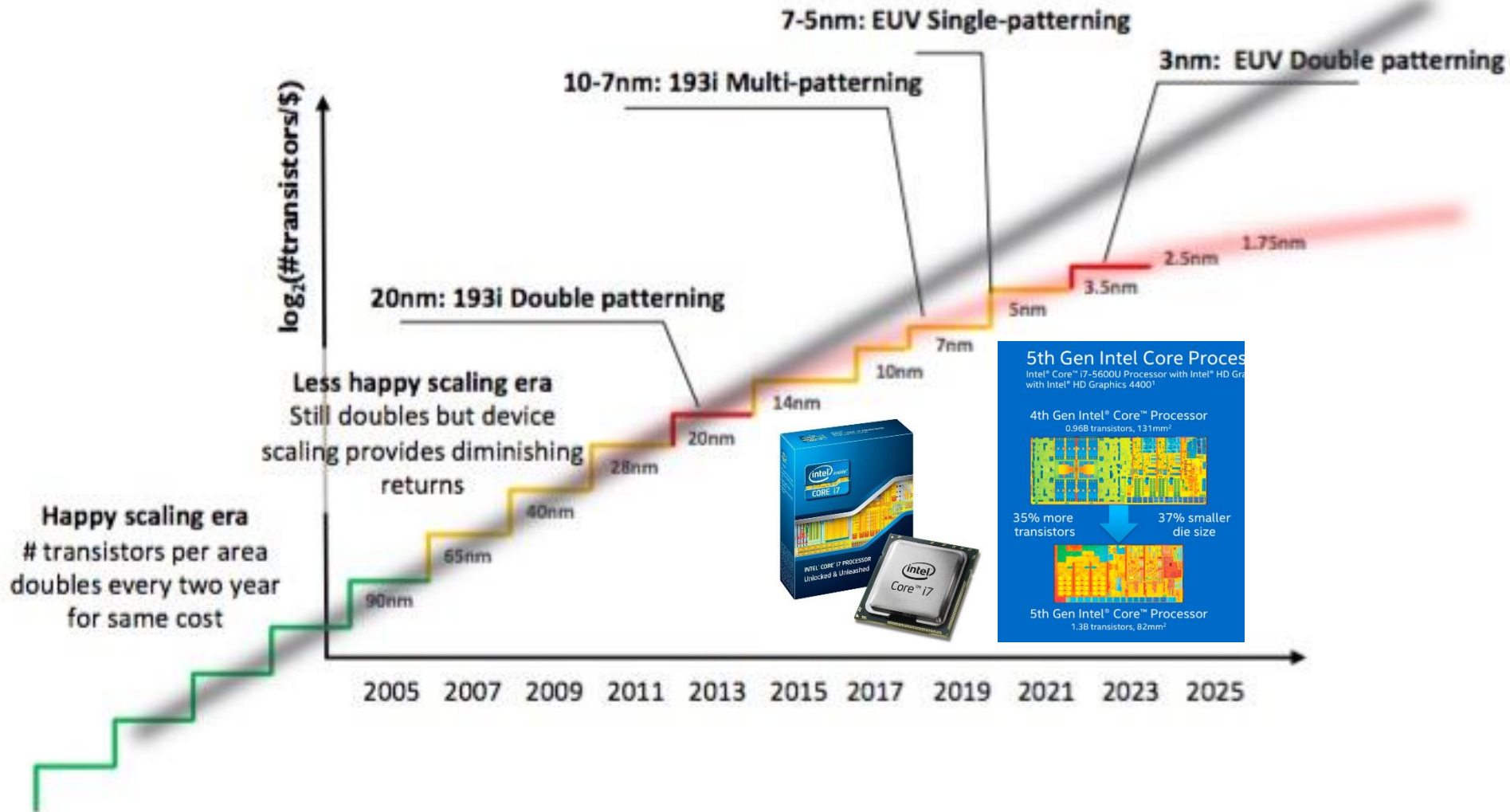
Our World
in Data



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at [OurWorldInData.org](https://www.ourworldindata.org). There you find more visualizations and research on this topic.

Licensed under CC-BY-SA by the author Max Roser.

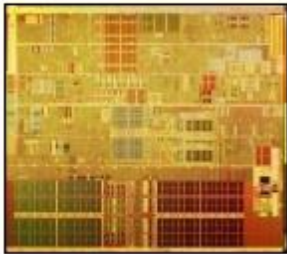
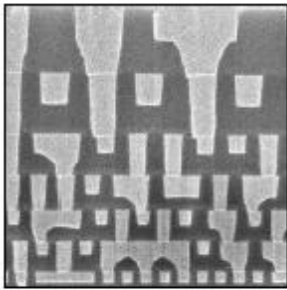
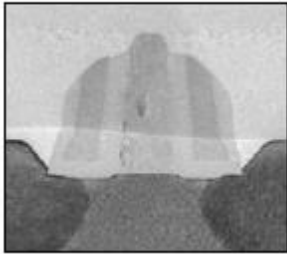
TECHNOLOGY DEVELOPMENT



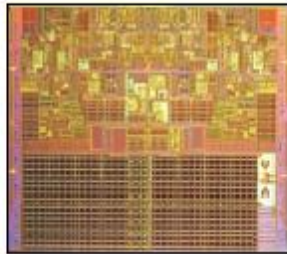
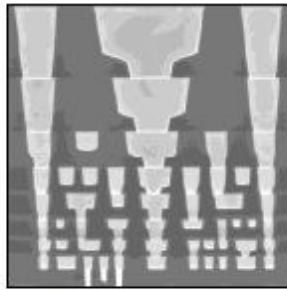
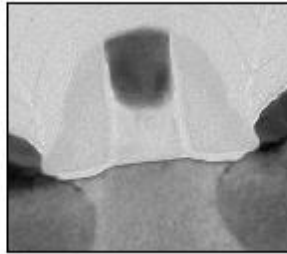
TECHNOLOGY: from SAND to PROCESSOR

INTEL 2003 - 2011

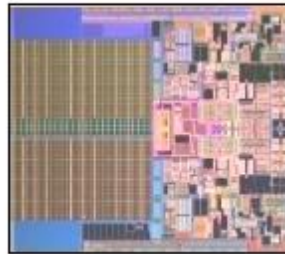
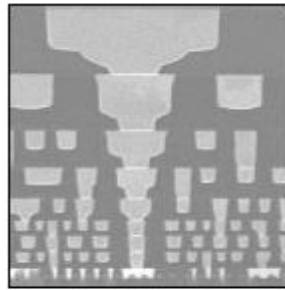
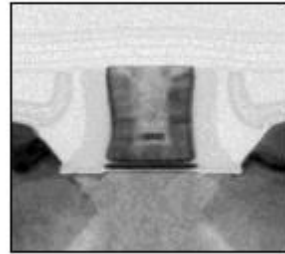
90 nm
2003



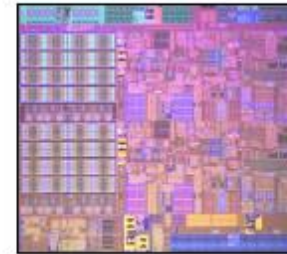
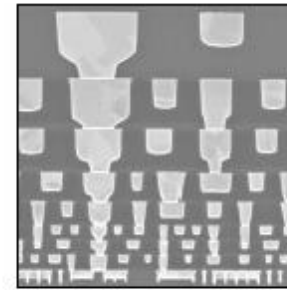
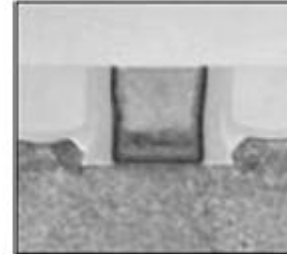
65 nm
2005



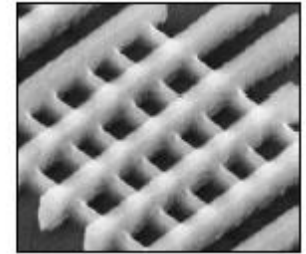
45 nm
2007



32 nm
2009



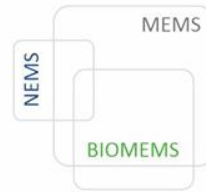
22 nm
2011



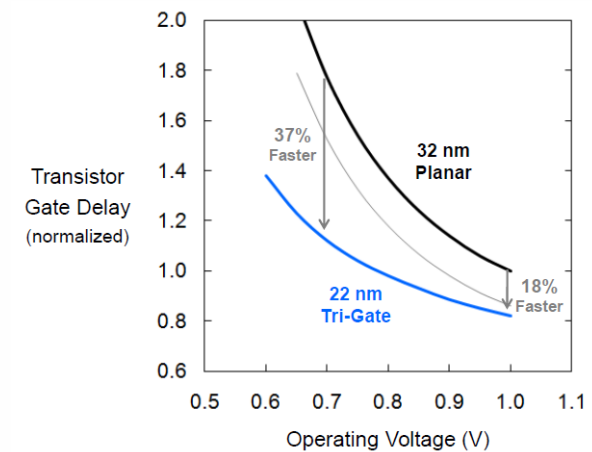
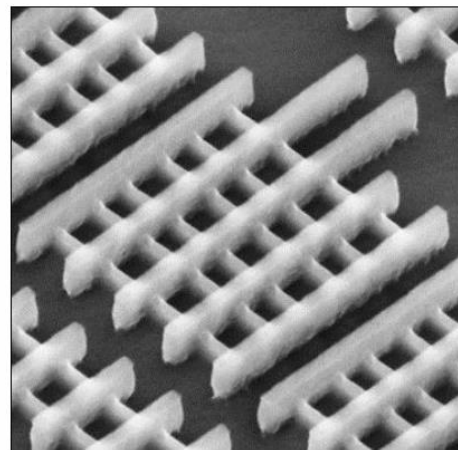
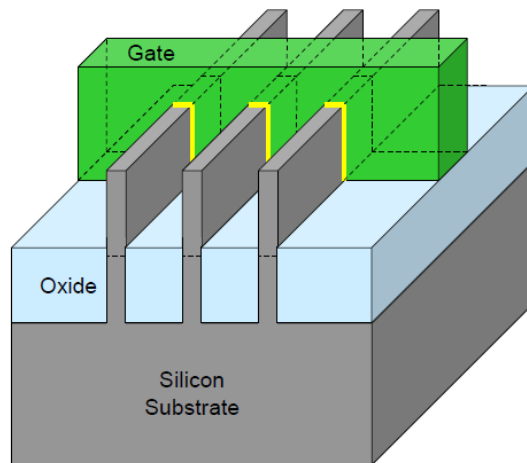
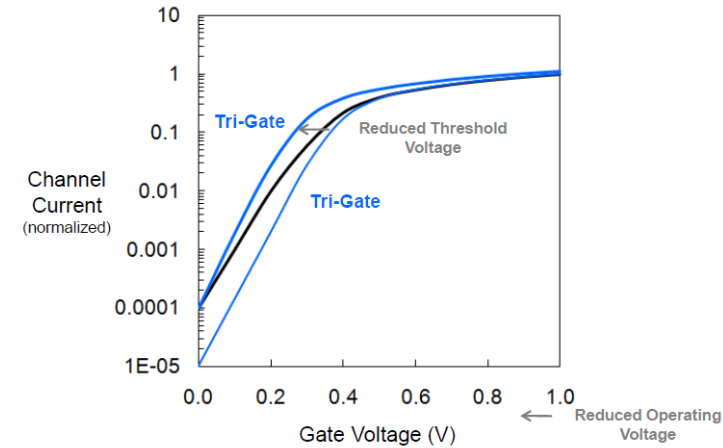
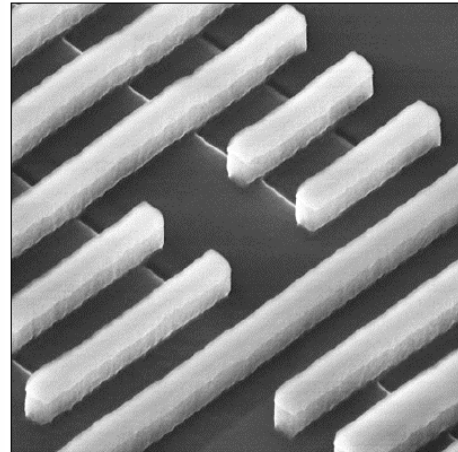
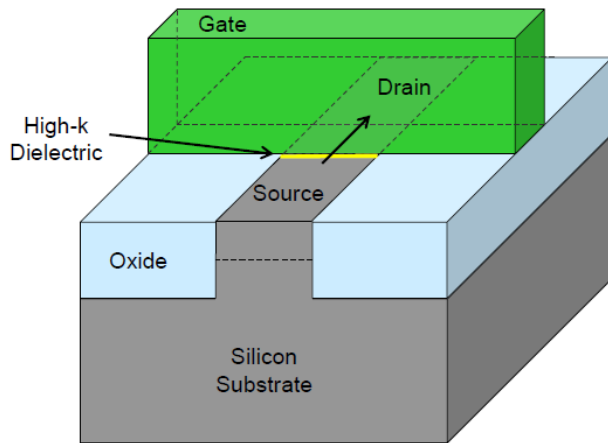
3D TRI-GATE transistor



PLANAR vs. 3D TRANSISTOR



iomems.hu



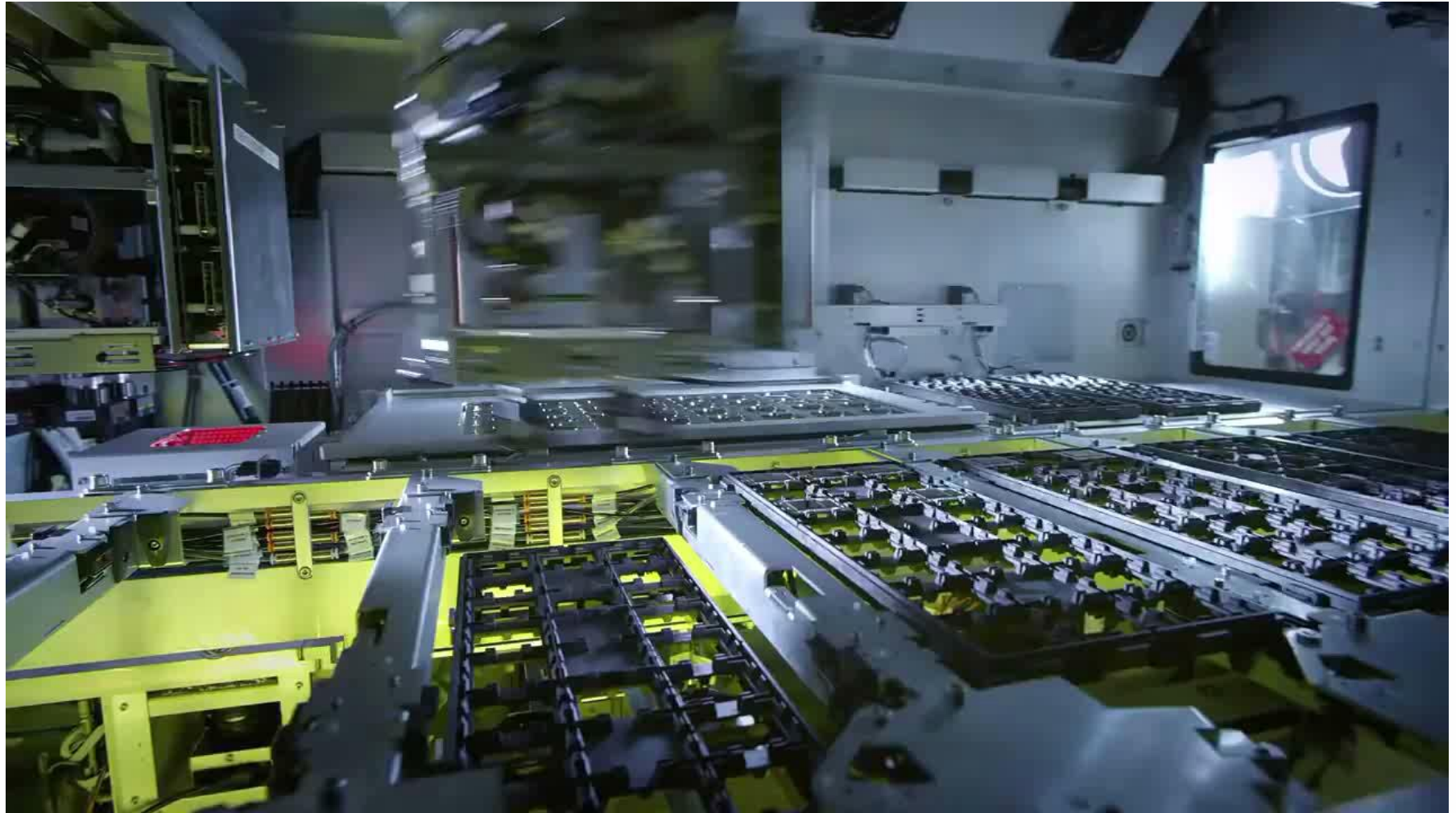
ELKH | Centre for Energy Research | Institute of Technical Physics and f

TECHNOLOGY: from SAND to PROCESSOR

(2011 - 3D TRI-GATE MOS)

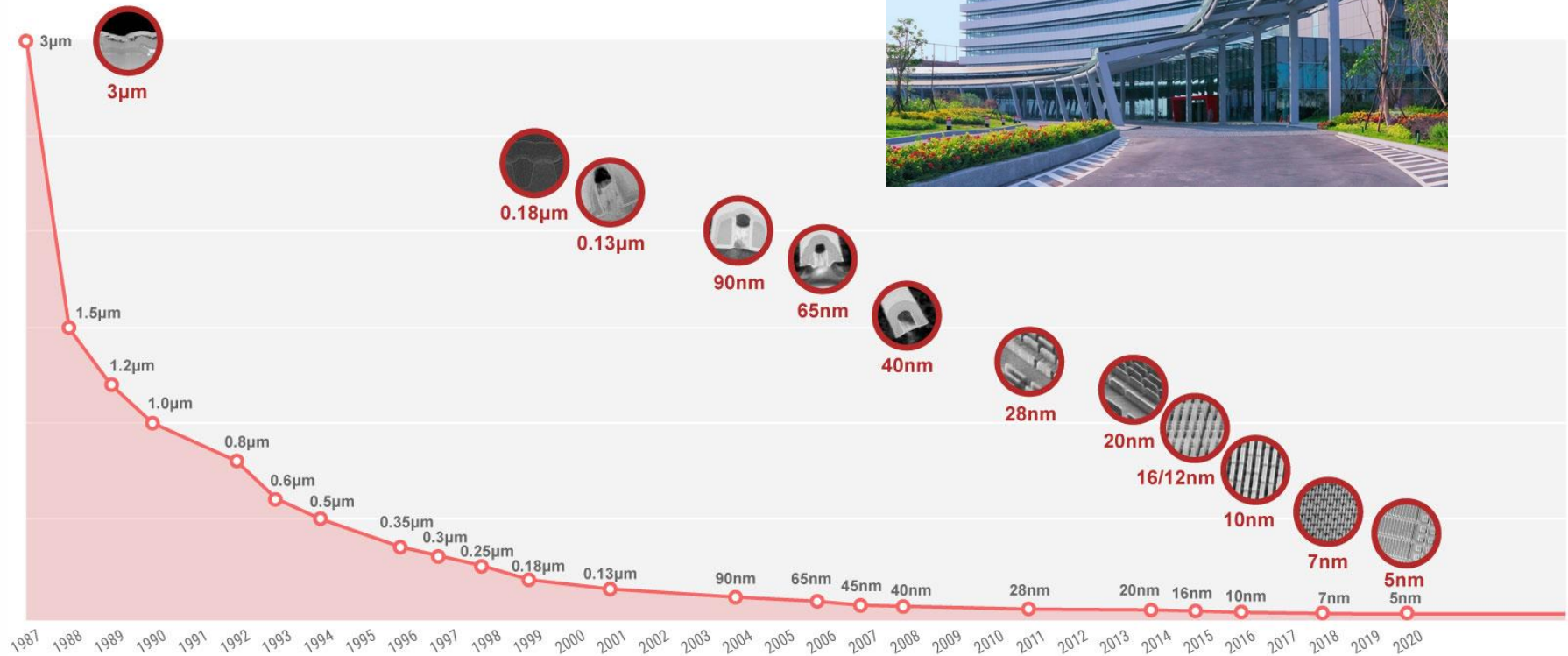


INFRASTRUCTURE – MICRO / NANO – INTEL FAB



TSMC 1987 - TODAY

TSMC's 5nm (N5) Fin Field-Effect Transistor (FinFET) technology successfully entered volume production in the second quarter of 2020.



Revenue for January through September 2021 totaled NT\$1,149.23 billion, an increase of 17.5 percent compared to the same period in 2020.

BEYOND MOORE LAW ...

MOBILE

TSMC to Use 4nm Process For A16 Bionic Chips on iPhone 14

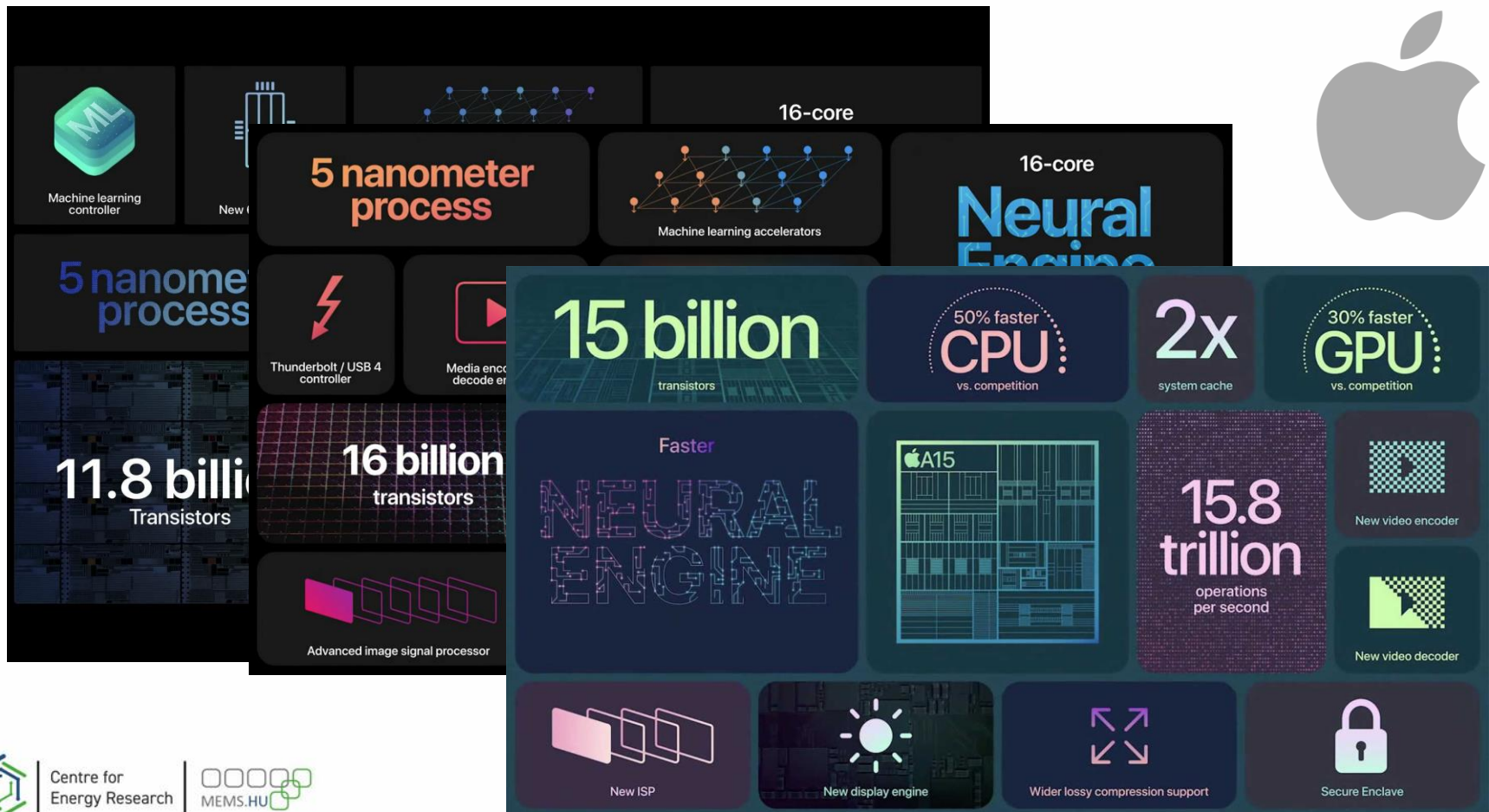
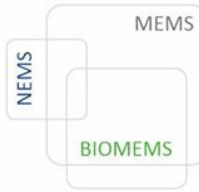
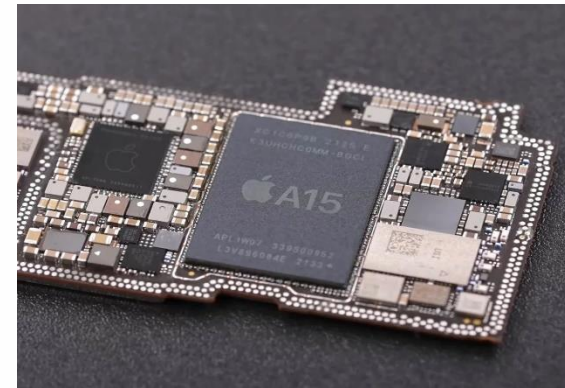
By Ali Salman

Nov 3, 2021 14:29 EDT

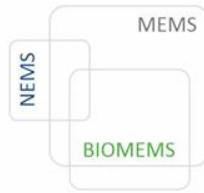
f SHARE

t TWEET

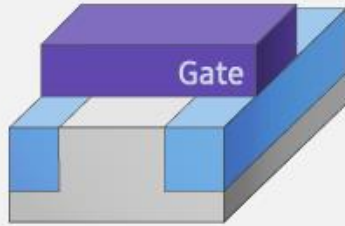
o SUBMIT



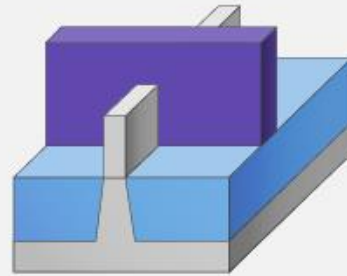
TECHNOLOGY: BEYOND 3D TRI-GATE



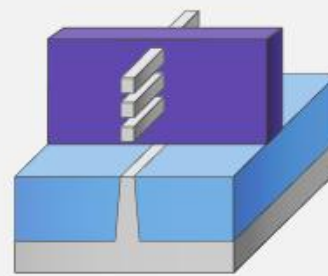
Multi-Bridge Channel FET (MBCFET)



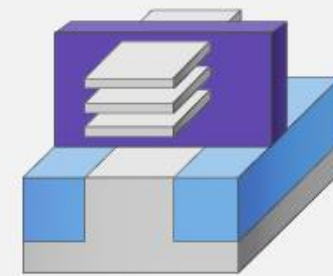
Planar FET



FinFET

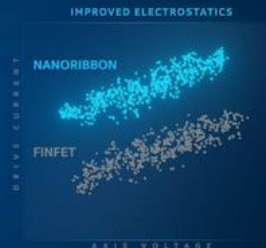
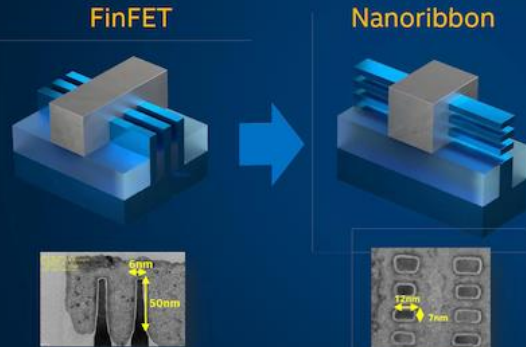


GAAFET
(Nanowire)

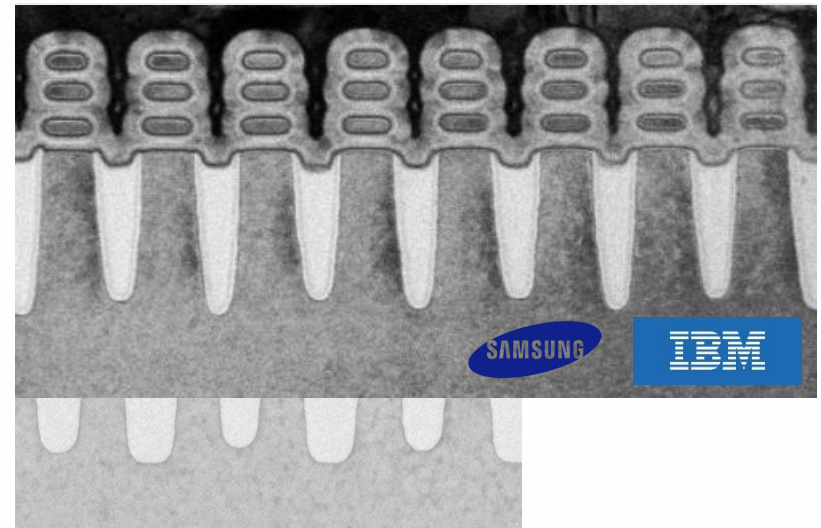


MBCFET™
(Nanosheet)

FINFET CHANGING TO NANOWIRE/NANORIBBON

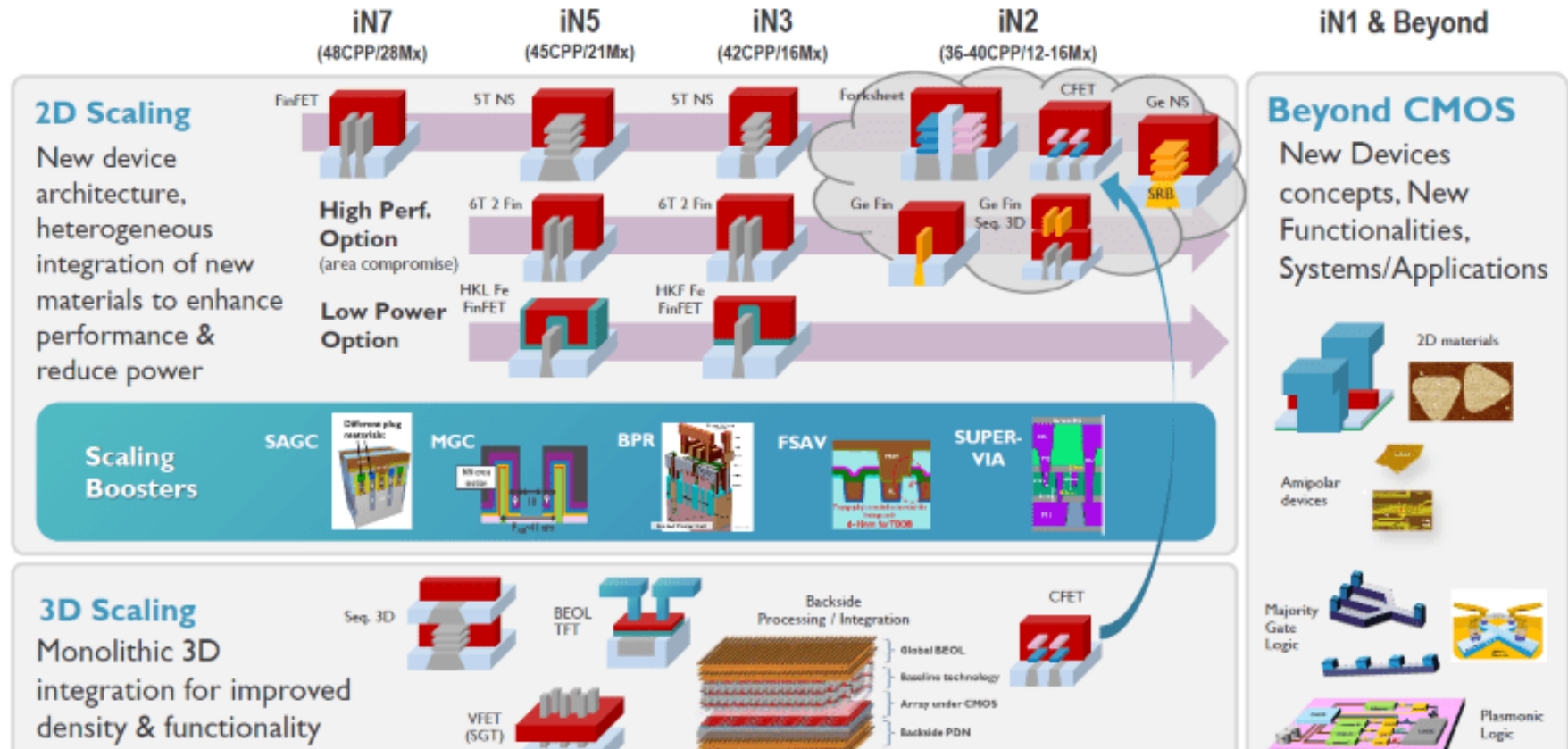


Gate-All-Around Field Effect Transistor (GAAFET)



CMOS AND BEYOND CMOS

IMEC VIEW OF LOGIC ROADMAP

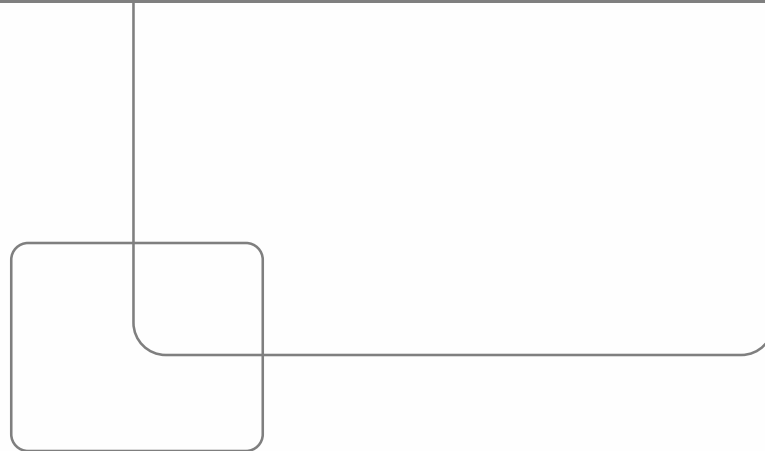


Alternative technologies:

Superconducting technology
Spintronics

Quantum Computing
Photonics

MORE THAN MOORE REVOLUTION of MEMS

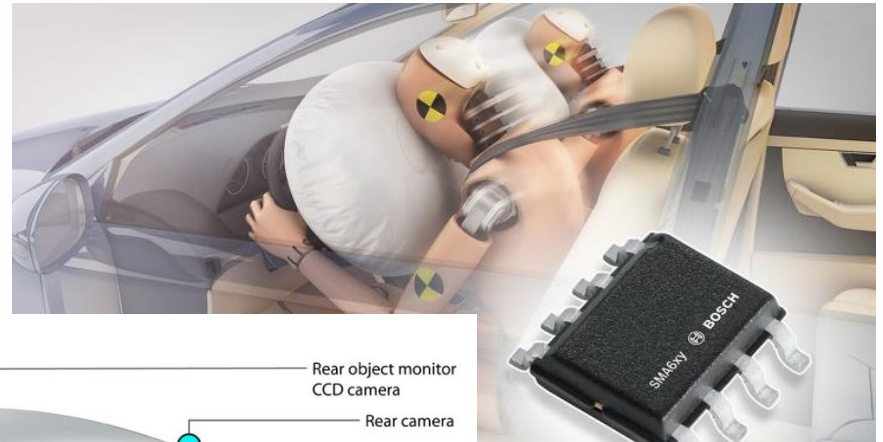


MEMS: SI (SOLID STATE) MICROSENSORS

MEMS: micro-electromechanical systems

Example: automotive applications

- Engine / gear diagnostics and control
- Life- and traffic safety
- Comfort



Vehicle Sensors

Lane departure system

Night vision

Front object CCD camera

Front airbag sensors

ASCD

Nighttime pedestrian warning

Drowsiness sensors

Front object laser radar

Nighttime pedestrian warning IR sensor

Active park assist

Tire pressure sensor

Rear object monitor CCD camera

Rear camera

Side curtain sensor

Blind spot detection

Cross traffic alert

Central computer

Rear object laser radar

Wheel speed sensor

Tire pressure sensor

Collision sensor

Side airbag SRS

Adaptive cruise control

Steering Angle sensor

Automatic brake actuator

Wheel speed sensor

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GUESS WHO?

Steve Jobs
APPLE



Apple II (1977):



Lisa (1983):



Macintosh (1984):



NeXT (1989):



iMac (1998):



iPod (2001):



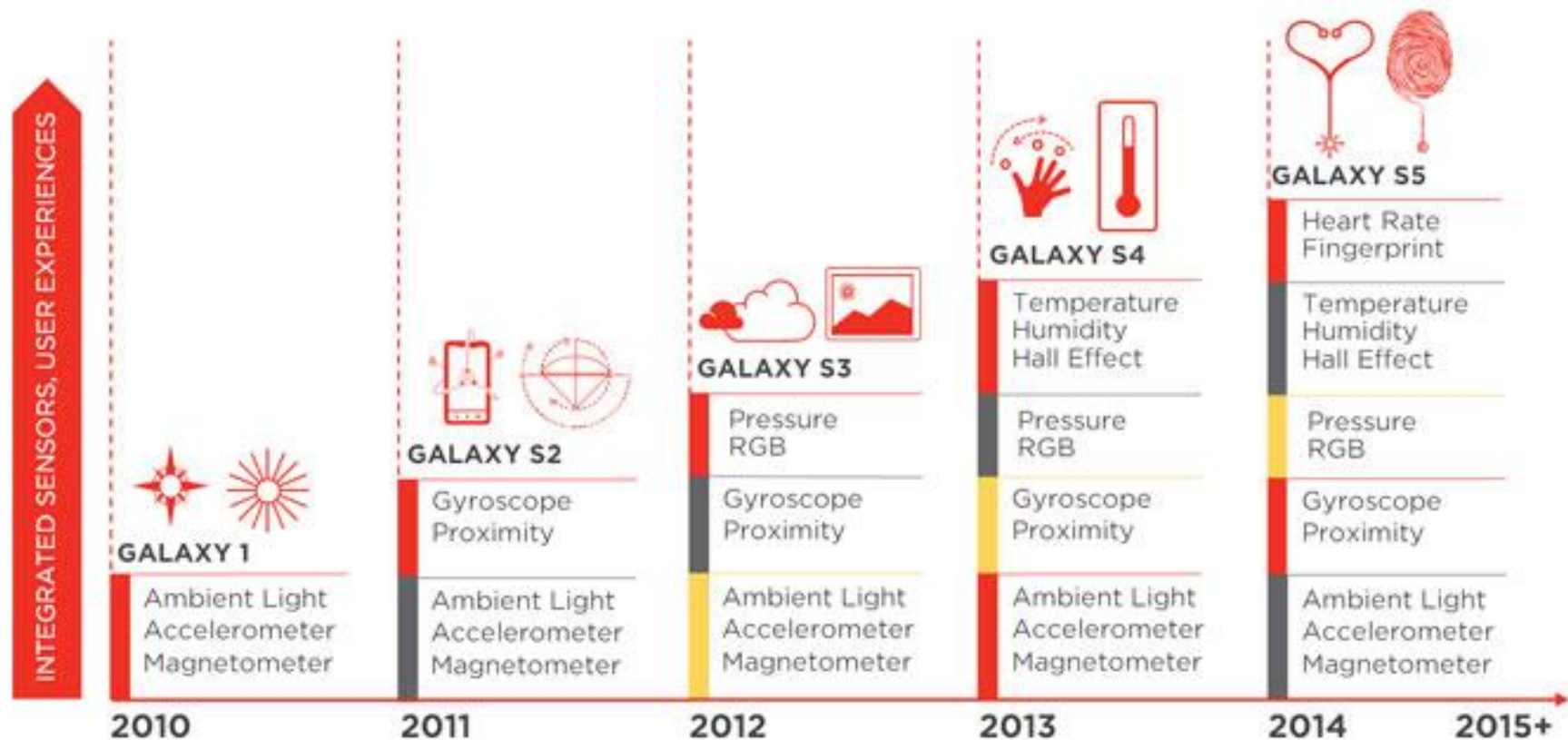
iPhone (2007):



iPad (2010):

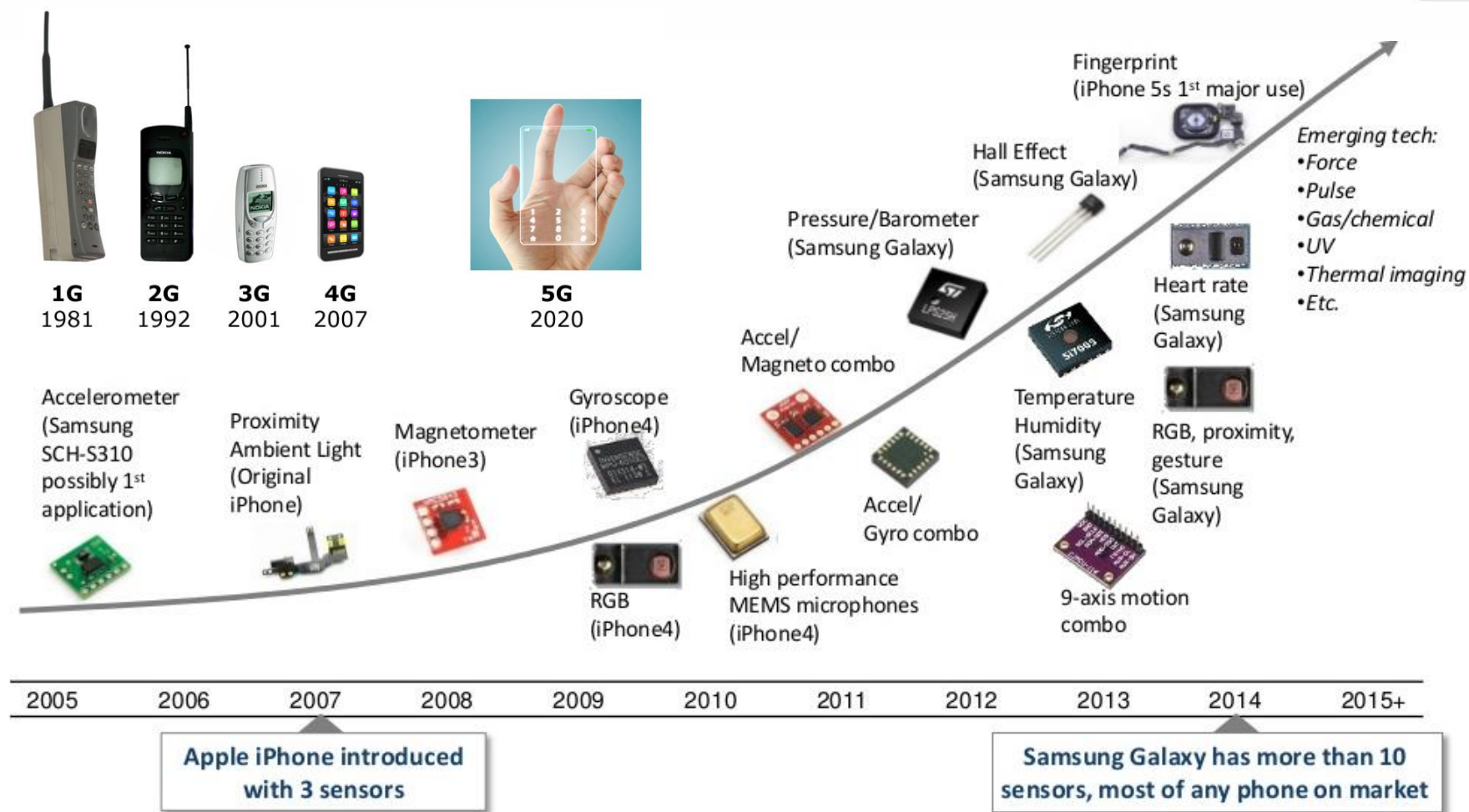
DISASSEMBLE OUR VIRTUAL SMARTPHONE

SENSOR GROWTH IN SMARTPHONES



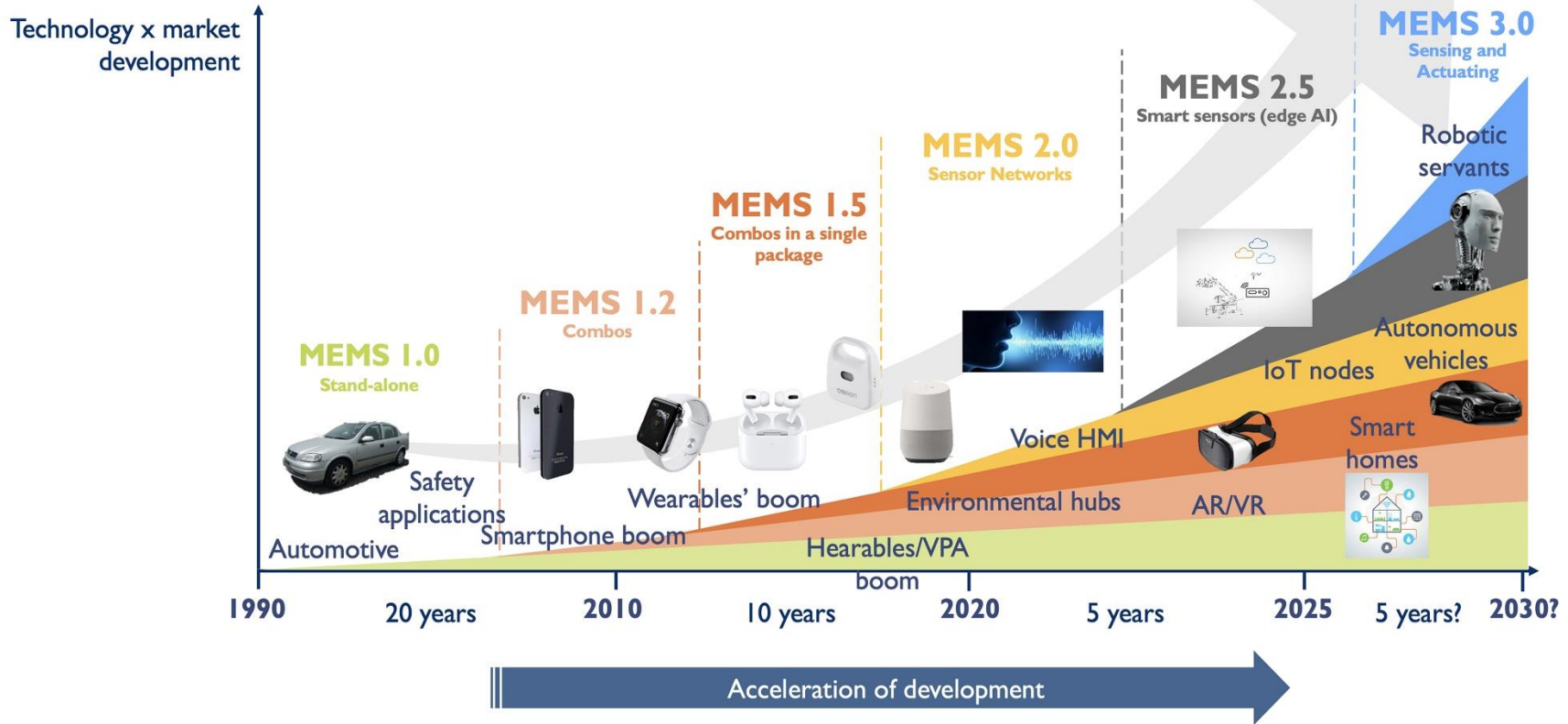
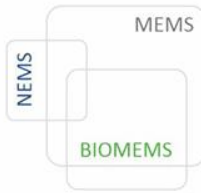
Sources: Driven by Apple and Samsung, Light Sensors Achieve Double-Digit Revenue Growth, IHS, June 30, 2013; MEMS: Looking back at 2014 and 5 years outlook, IHS, November 2014; Light and Proximity Sensors - A Market Ready for Explosive Growth, Tony Rizzo, Mobility TechZone, July 30, 2013; iPhone 6 Teardown, iFixit, 2014; Apple 3GiPhone Teardown Report, Portelligent, 2008; MEMS Microphone Market Tops 2 Billion Units, Mobile Dev Design, March 4, 2013

SMARTPHONE'S FUTURE

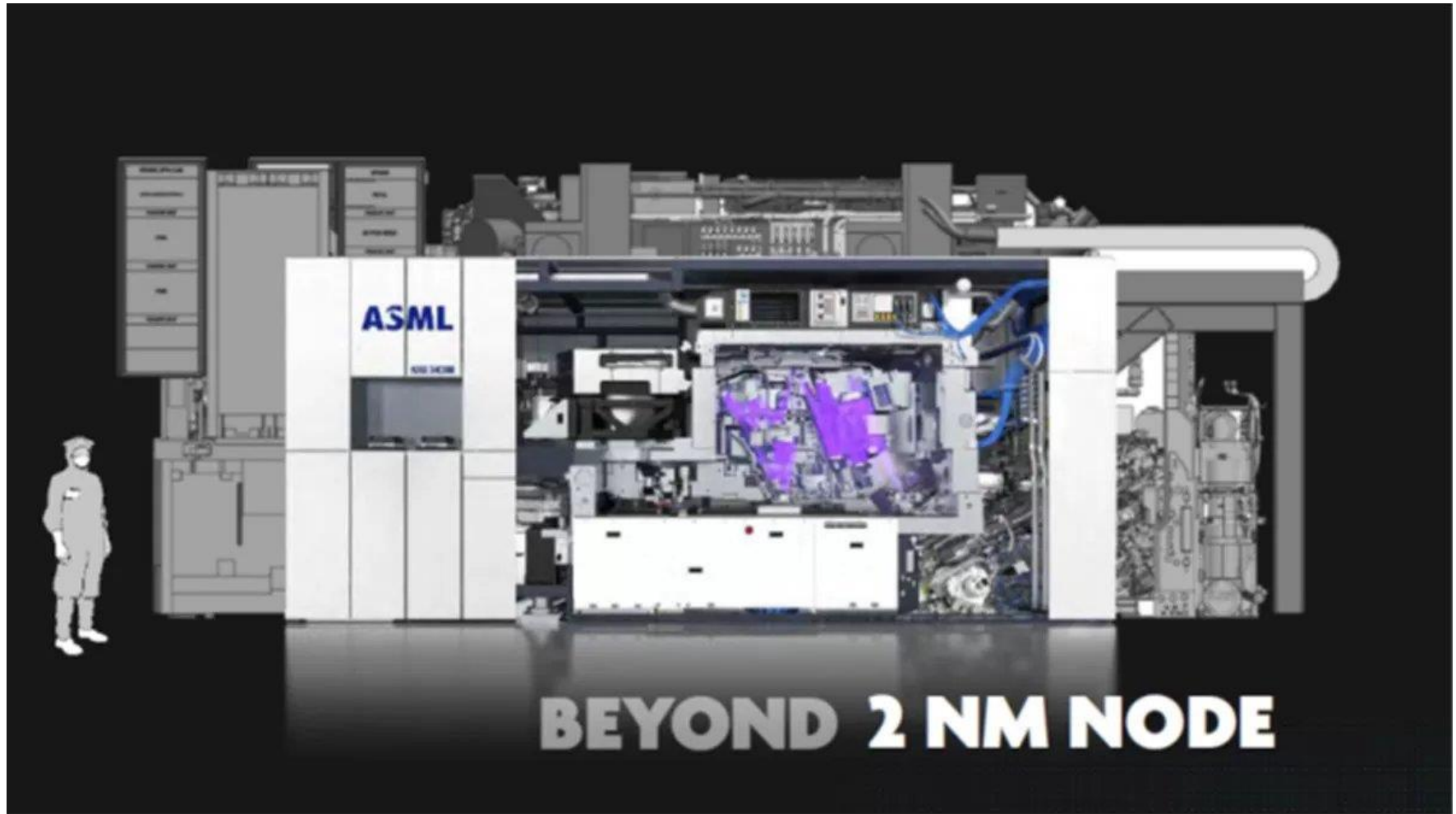


Sources: This little motion sensor went to the market..., Sonja Thompson, IT News Digest, March 22, 2007; Willie D. Jones, IEEE Spectrum, A Compass in Every Smartphone, January 29, 2010; Consumers boost MEMS combo sensors, Electronic Product Design and Test, March 19, 2014; Samsung Turns up the Pressure on Competition with Pressure Sensor in Galaxy S4, IHS, March 20, 2013; Behind the sixth sense of smartphones: the Snapdragon processor sensor engine, Qualcomm, April 24, 2014; MEMS for Cell Phones & Tablets, Yole Developpement, May 2012; Fairchild, Emergence of a \$Trillion MEMS Sensor Market, SensorCon, 2012; MEMS Microphone Market Tops 2 Billion Units, Mobile Dev Design, March 4, 2013

„SMART” EVOLUTION



STATE OF THE ART



THX FOR ATTENTION!