A future UK semiconductor industry

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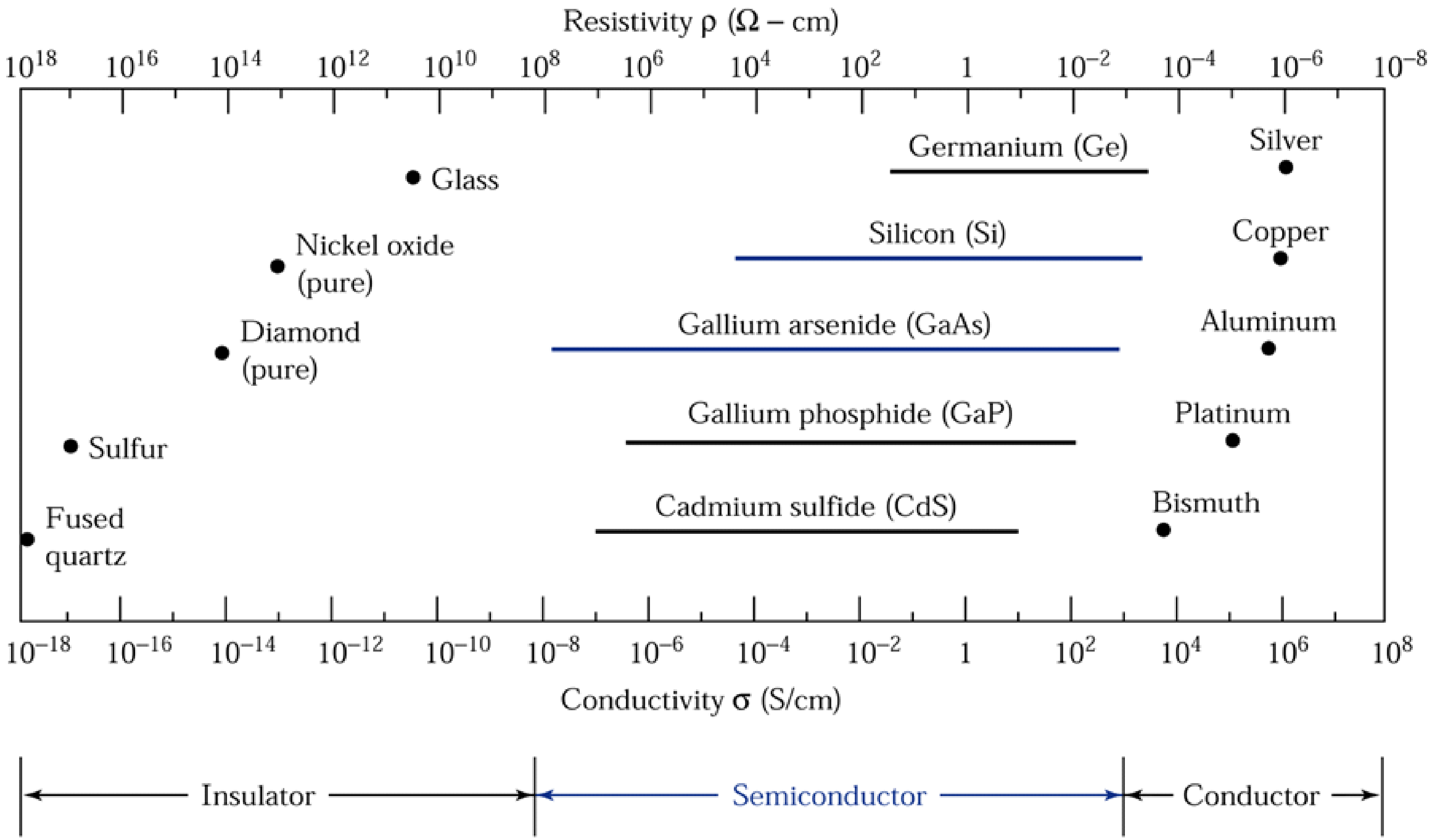
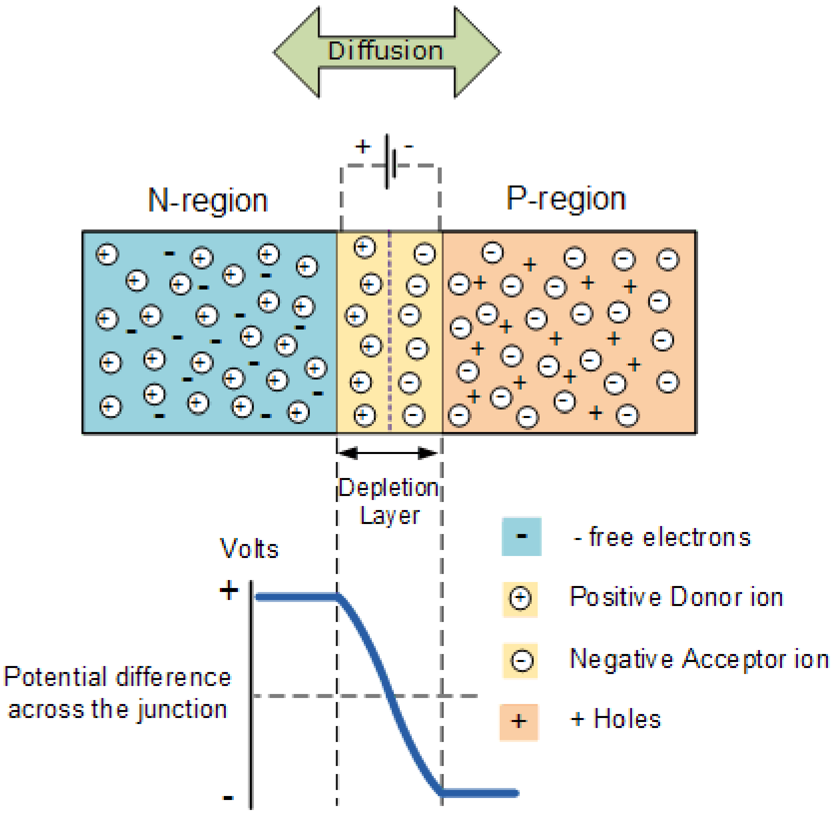
Semiconductor Properties: doping

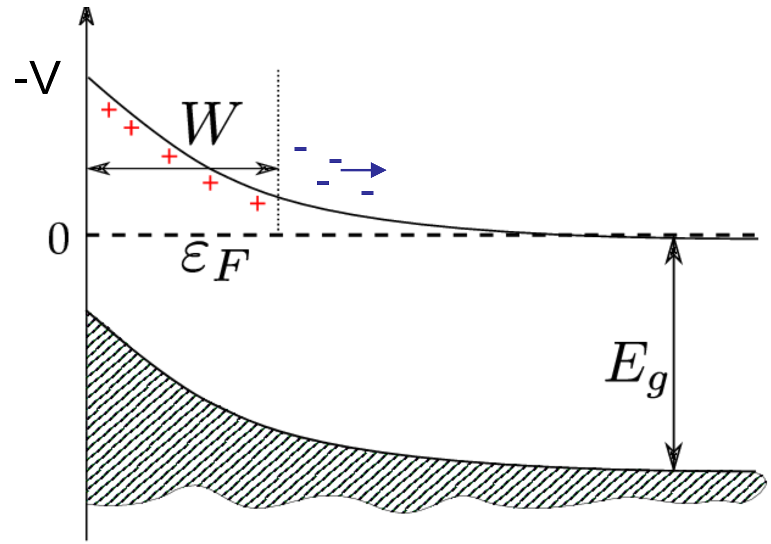
- Doping → engineer conductivity



Semiconductor Properties: voltage

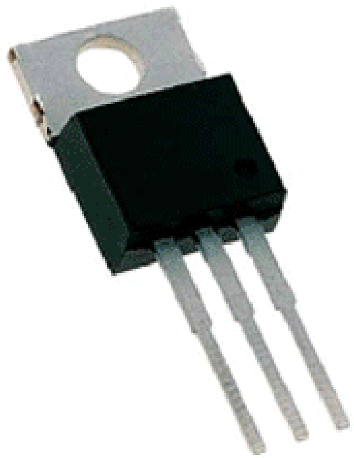
- voltage → engineer conductivity
- voltage can be internal (pn junction) or applied externally

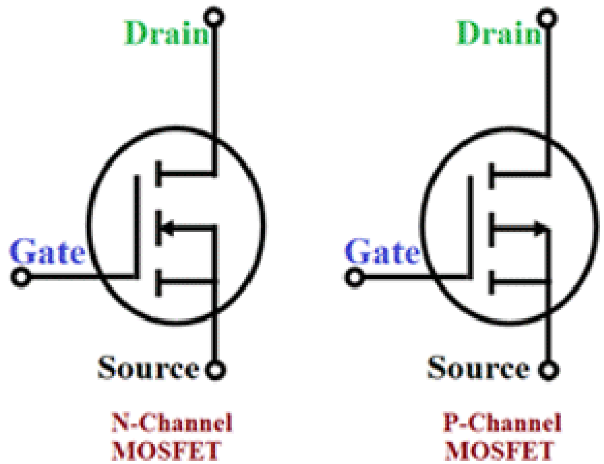


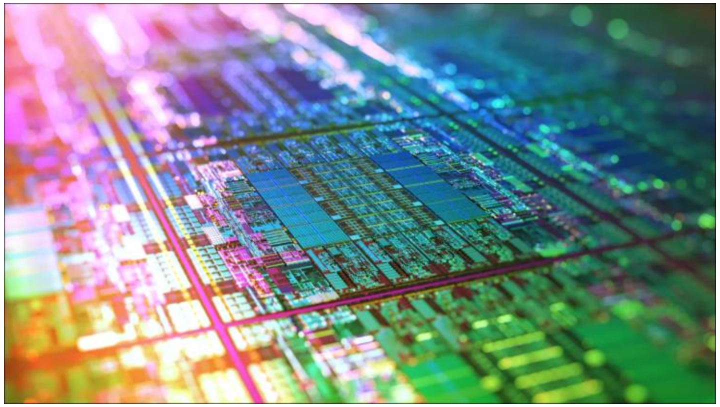


MOSFET

1959 Mohamed Atalla, Dawon Kahng





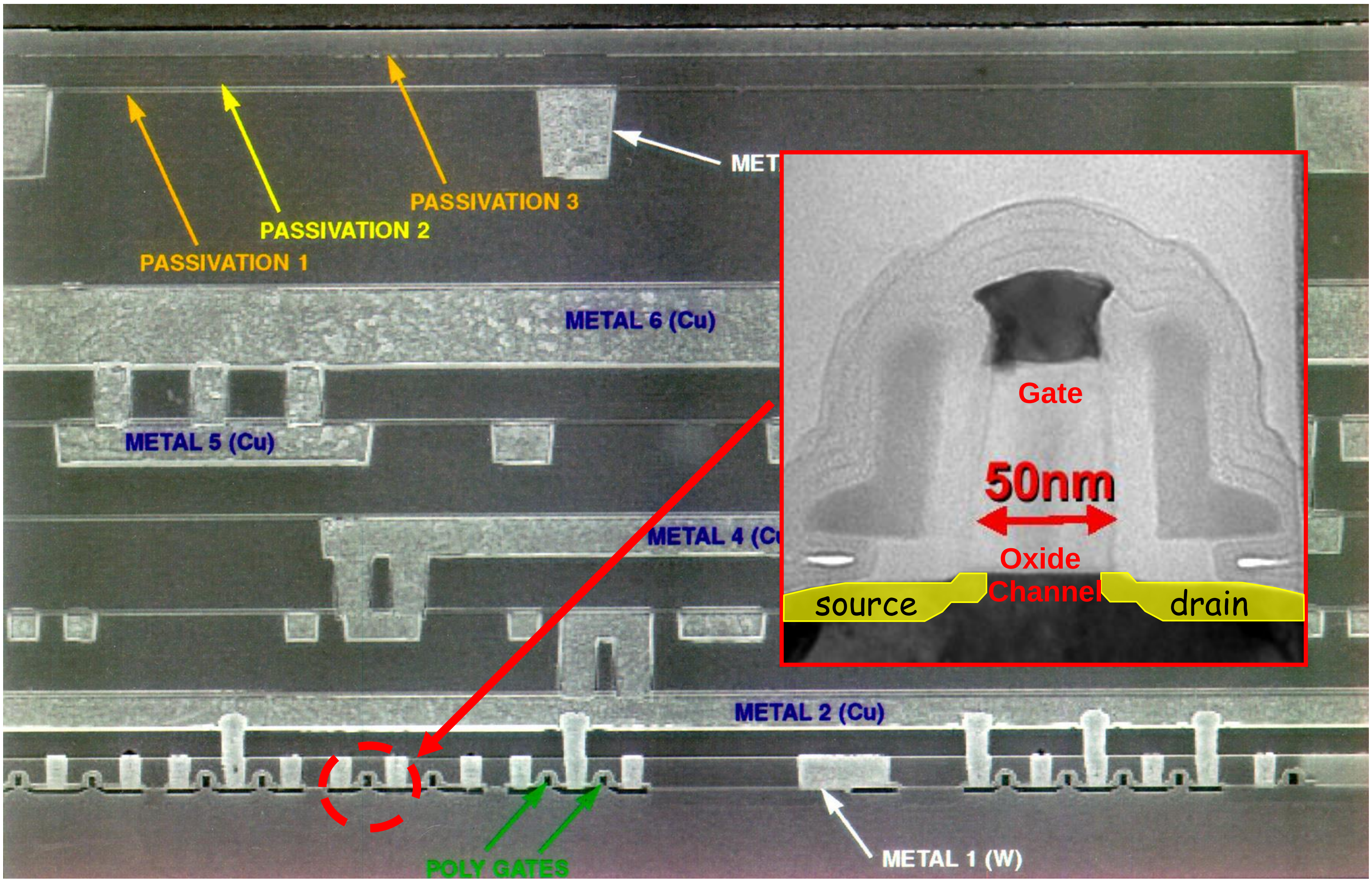


100V Power
MOSFET

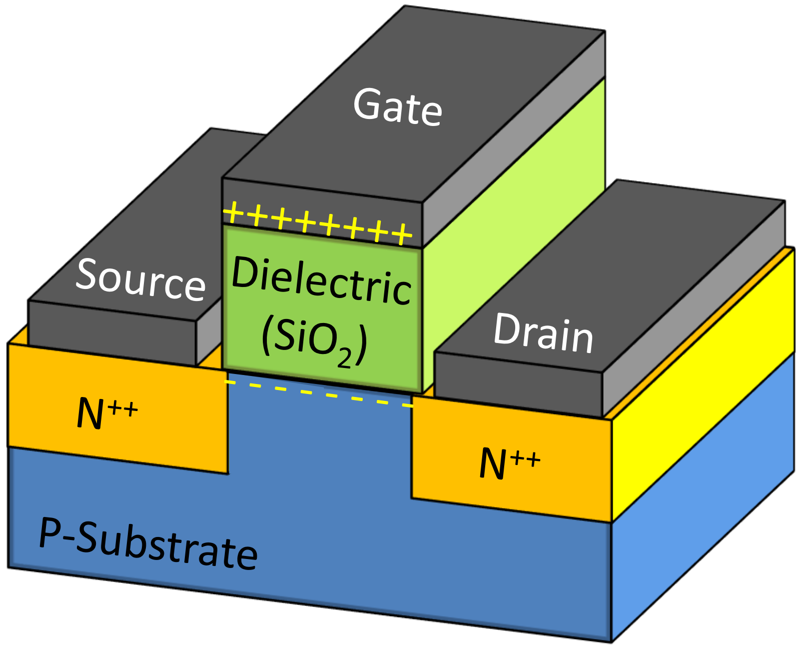
Circuit symbol

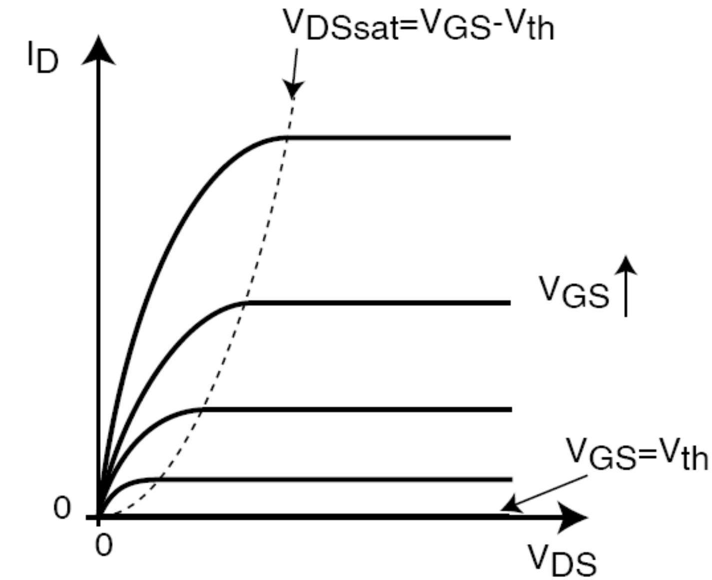
Billions of 5 nm
MOSFETs on microchip

Silicon microchip (cross section)



(planar) NMOSFET operation

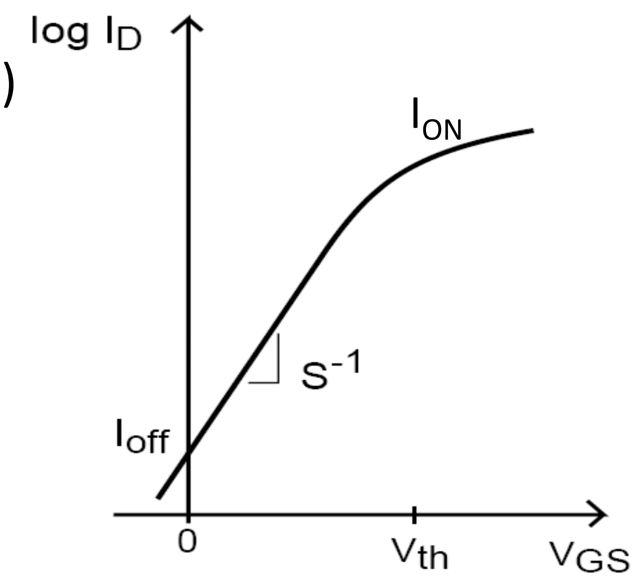




- +ve Gate voltage (V_{GS}) → -ve charge in Si
- creates "inversion layer" channel ($V_{GS} > V_{th}$)
- Drain voltage (V_{DS}) → drain current (I_D)
- If $V_{GS} < V_{th}$ → subthreshold current:

$$I_D \propto \exp \frac{q(V_{GS} - V_t)}{nkT}$$

- subthreshold slope > 60 mV/dec



1965
Moore’s Law

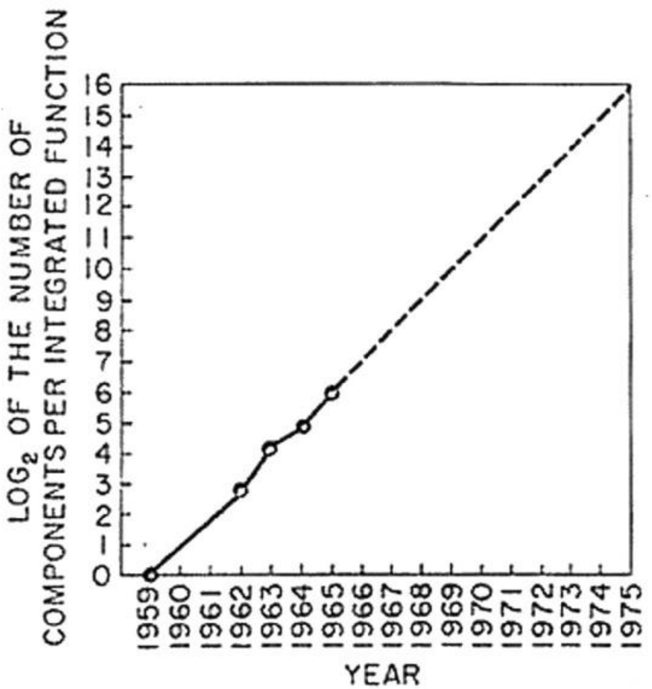


Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.

2^6 = 64 components on single chip by 1965

2^{16} = 65,536 components on single chip by 1975

The experts look ahead

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

But the biggest potential lies in the production of large systems. In telephone communications, integrated circuits in digital filters will separate channels on multiplex equipment. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in completely different ways. For example, memories built of integrated electronics may be distributed throughout the machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turn-around.

Present and future

By integrated electronics, I mean all the various technologies which are referred to as microelectronics today as well as any additional ones that result in electronics functions supplied to the user as irreducible units. These technologies were first investigated in the late 1950's. The object was to miniaturize electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including microassembly techniques for individual components, thin-film structures and semiconductor integrated circuits.

Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future to be a combination of the various approaches.

The advocates of semiconductor integrated circuitry are already using the improved characteristics of thin-film resistors by applying such films directly to an active semiconductor substrate. Those advocating a technology based upon films are developing sophisticated techniques for the attachment of active semiconductor devices to the passive film arrays.

Both approaches have worked well and are being used in equipment today.

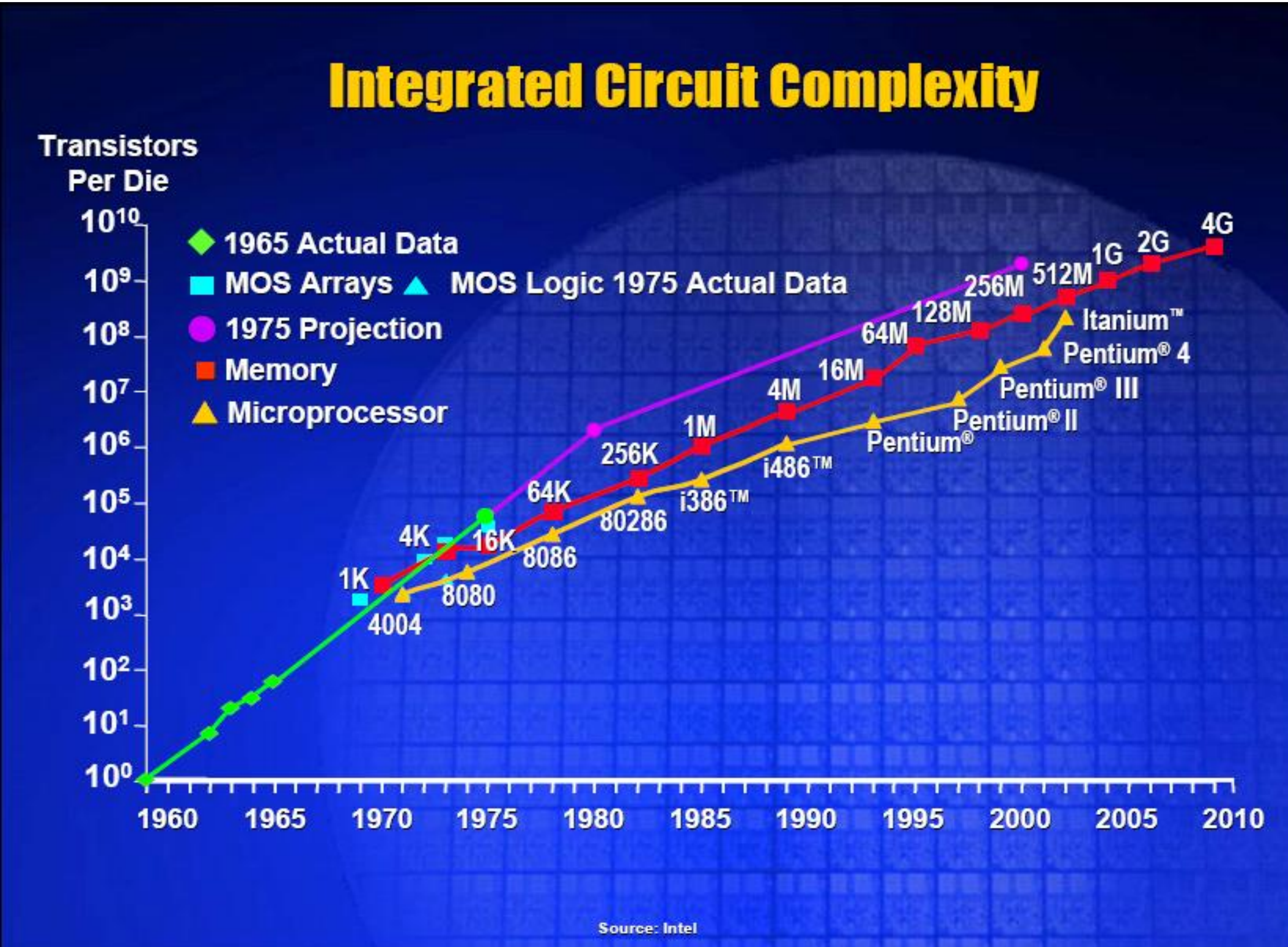
The author

Dr. Gordon E. Moore is one of the new breed of electronic engineers, schooled in the physical sciences rather than in electronics. He earned a B.S. degree in chemistry from the University of California and a Ph.D. degree in physical chemistry from the California Institute of Technology. He was one of the founders of Fairchild Semiconductor and has been director of the research and development laboratories since 1959.

Electronics, Volume 38, Number 8, April 19, 1965

Year	Processor Name	Transistor Count	Process Technology (μm)
1971	4004	2,300	10
1972	8008	3,500	10
1974	8080	6,000	6
1976	8085	6,500	3
1978	8086	29,000	3
1982	80286	134,000	1.5
1985	80386	275,000	1.5
1989	Intel486	1,200,000	1
1993	Pentium	3,100,000	0.8
1995	Pentium Pro	5,500,000	0.6
1997	Pentium II	7,500,000	0.35
1999	Pentium III	9,500,000	0.25
2000	Pentium IV	42,000,000	0.18
2002	Pentium IV (Northwood)	55,000,000	0.13
2004	Pentium IV (Prescott)	169,000,000	0.09
2005	[illegible]	230,000,000	0.09
2006	Core 2	291,000,000	0.065

~ 6,000 components
on processor chip by 1974

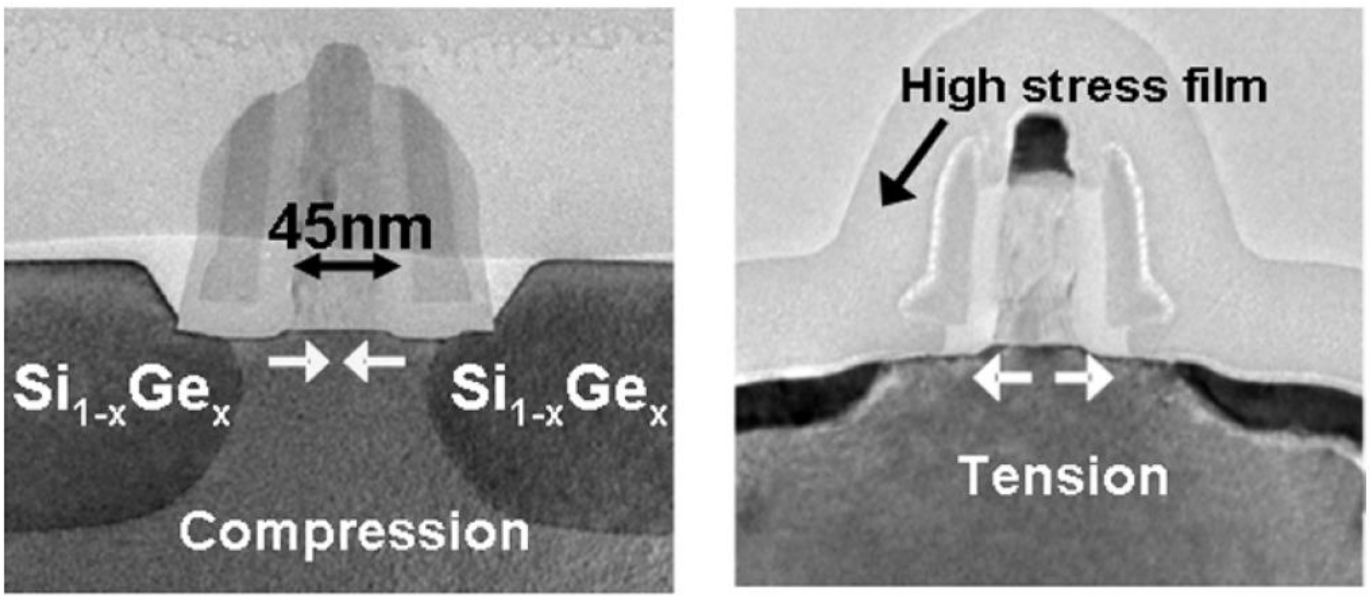

Integrated Circuit Complexity
Transistors Per Die
1965 Actual Data
MOS Arrays
MOS Logic 1975 Actual Data
1975 Projection
Memory
Microprocessor
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
1K
4K
16K
64K
256K
1M
4M
16M
64M
128M
256M
512M
1G
2G
4G
4004
8080
8086
80286
i386™
i486™
Pentium®
Pentium® II
Pentium® III
Pentium® 4
Itanium™
Source: Intel

More of Moore 1970 - 2002

- **Classic Silicon Scaling**
  - Reduce dimensions, constant E field → electrostatic integrity
  - Modifications for short channel effects
  - stopped at 130 nm

90 nm Technology Generation – 2003 (Intel)

Equivalent scaling 1: Strained silicon



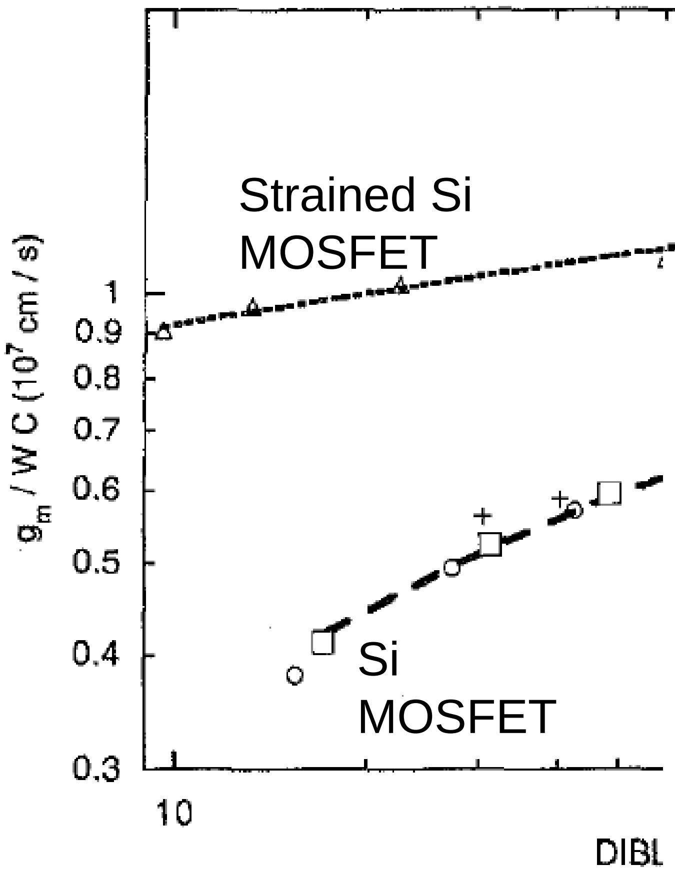
pMOSFET nMOSFET

Major change in technology:

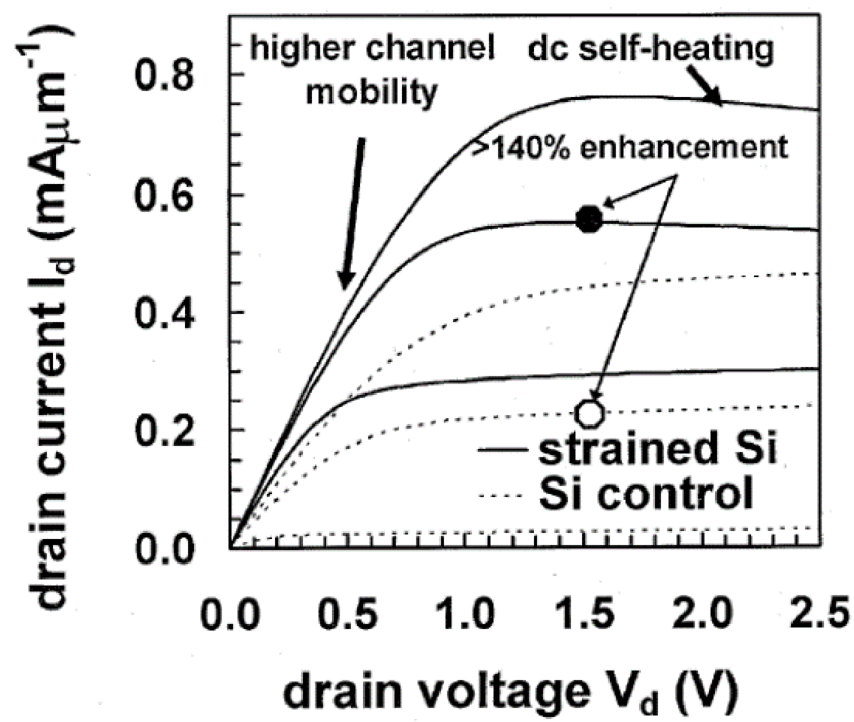
- strained silicon: improved speed with no extra power and no loss of electrostatic integrity (gate control)

Deep Submicron CMOS Based on Silicon Germanium Technology

A. G. O'Neill and D. A. Antoniadis, *Fellow, IEEE*



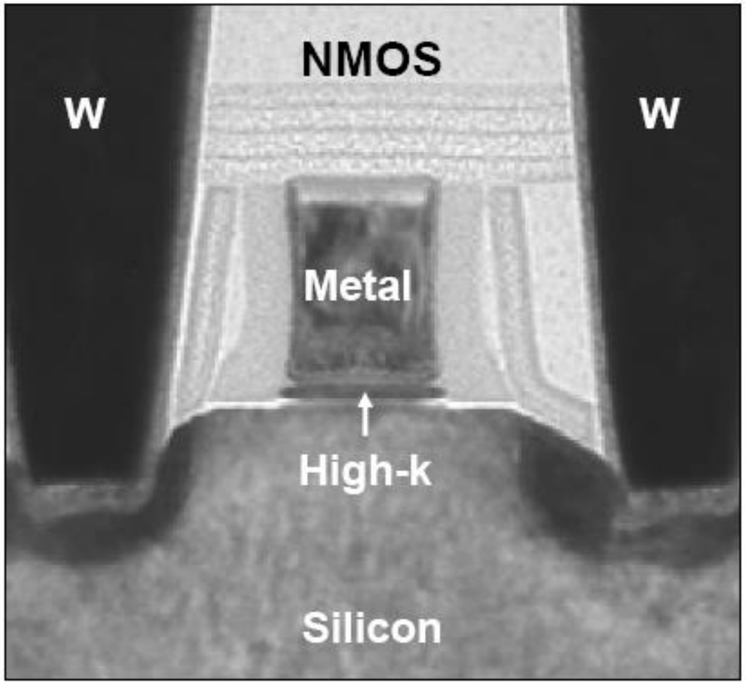
:n device speed, described
ınel length as an implicit
idth and C_{ox} is the gate
is relationship was found
:s such as oxide thickness.

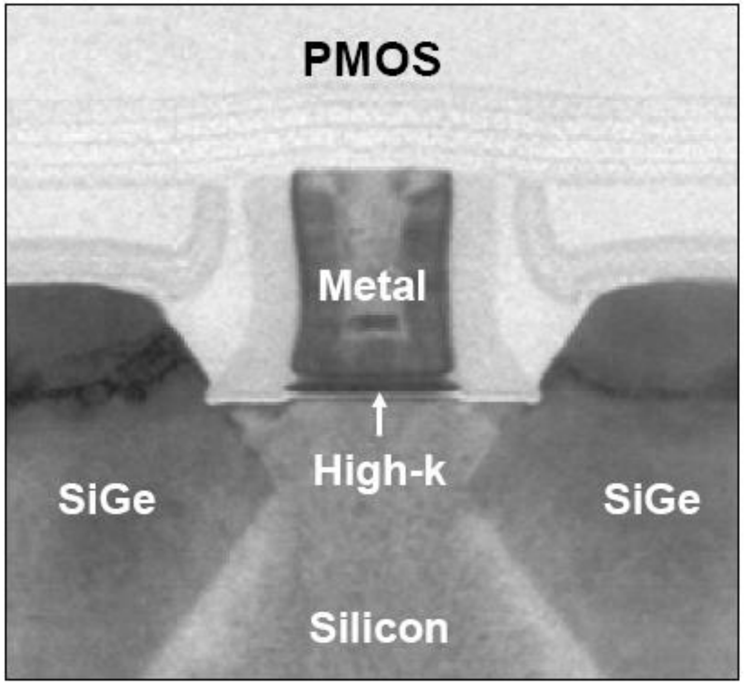


0.1 μm NMOSFET's and 67 GHz for 0.1 μm PN
Elsewhere, Yan *et al.* [3] report a f_t of 116 GHz for (
89 GHz for 0.15 μm NMOSFET's and at the same
Lee *et al.* [4] demonstrated 0.1 μm PMOSFET's o

45 nm Technology Generation – Sep 2007 (Intel)

Equivalent scaling 2: High-k dielectric



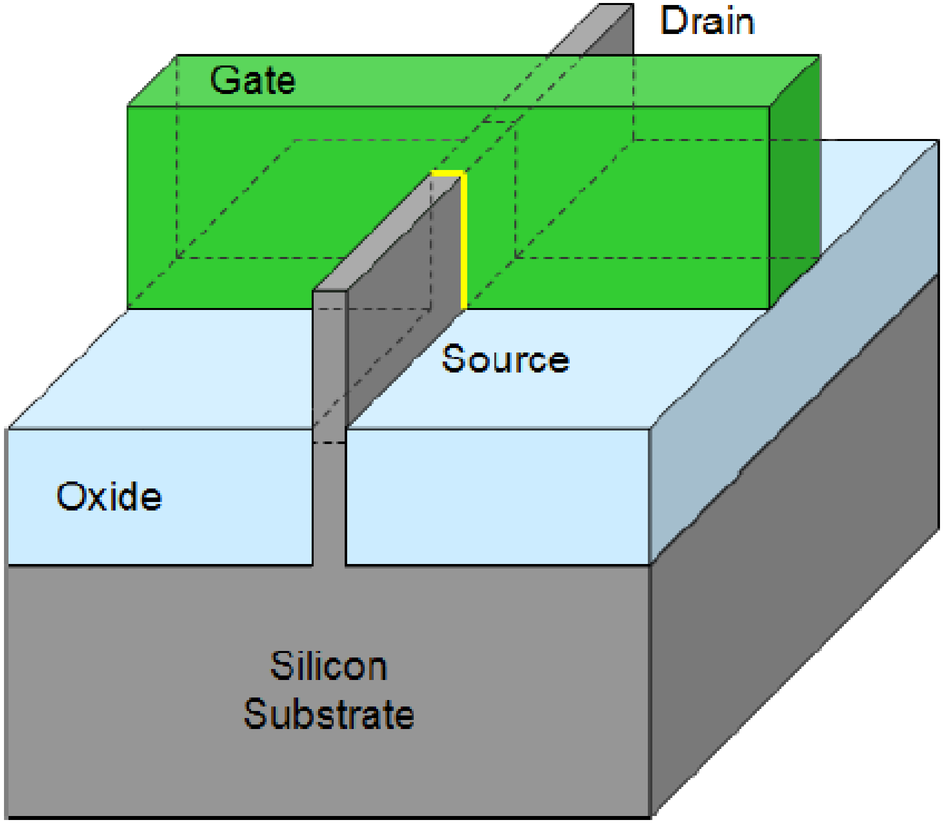


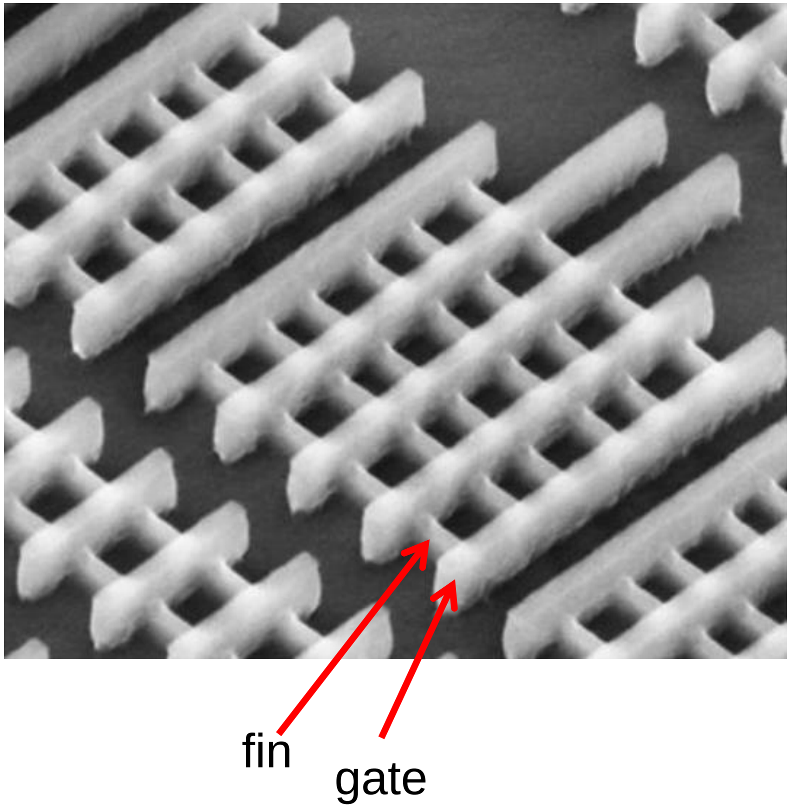
Major changes in technology:

- new gate dielectric with high permittivity → “effective” oxide < 3 nm
- return to Al metal gate (with liners to adjust workfunction)

22 nm Technology Generation 2011

Equivalent scaling 3: FinFET (for gate control)

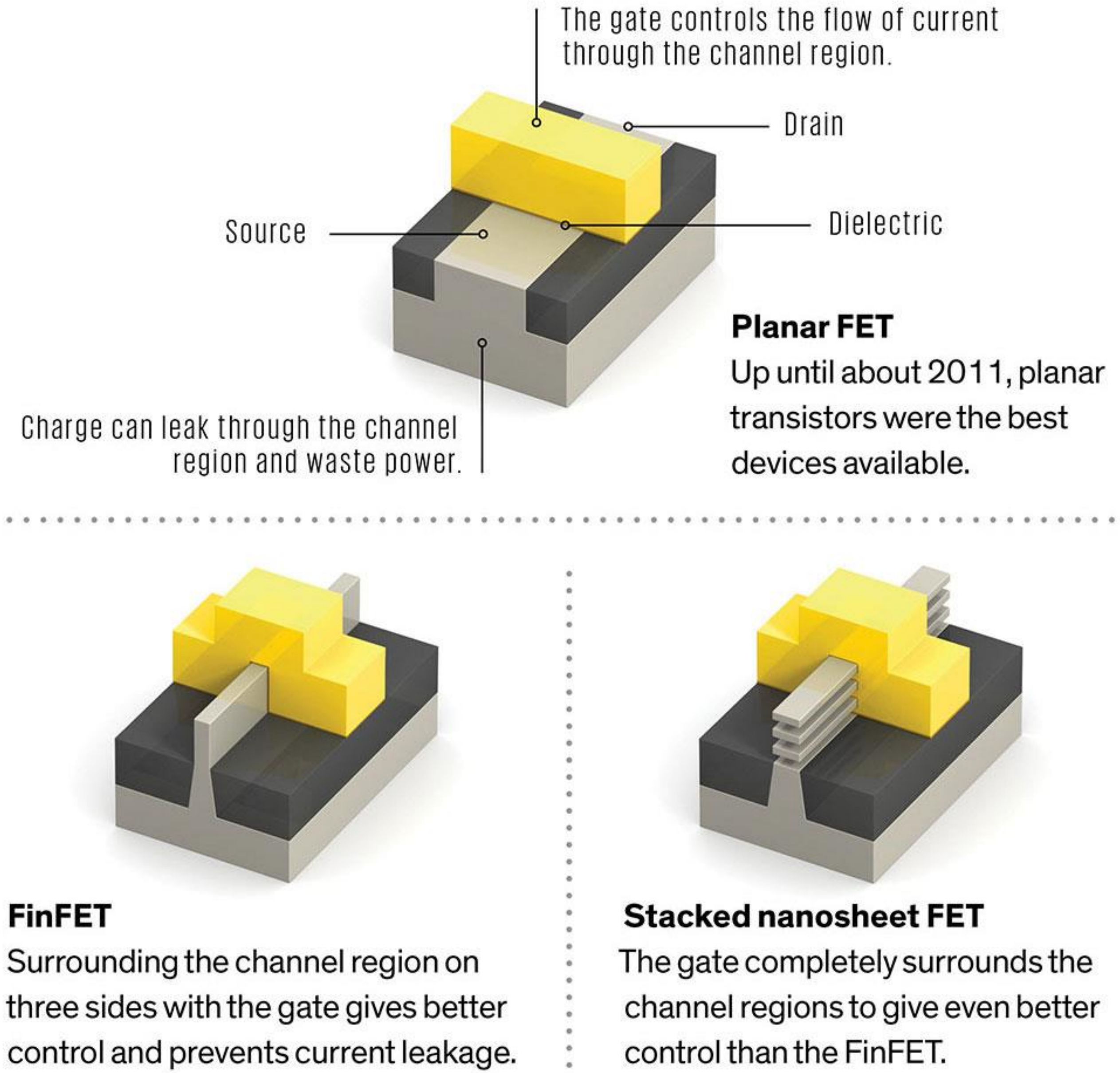




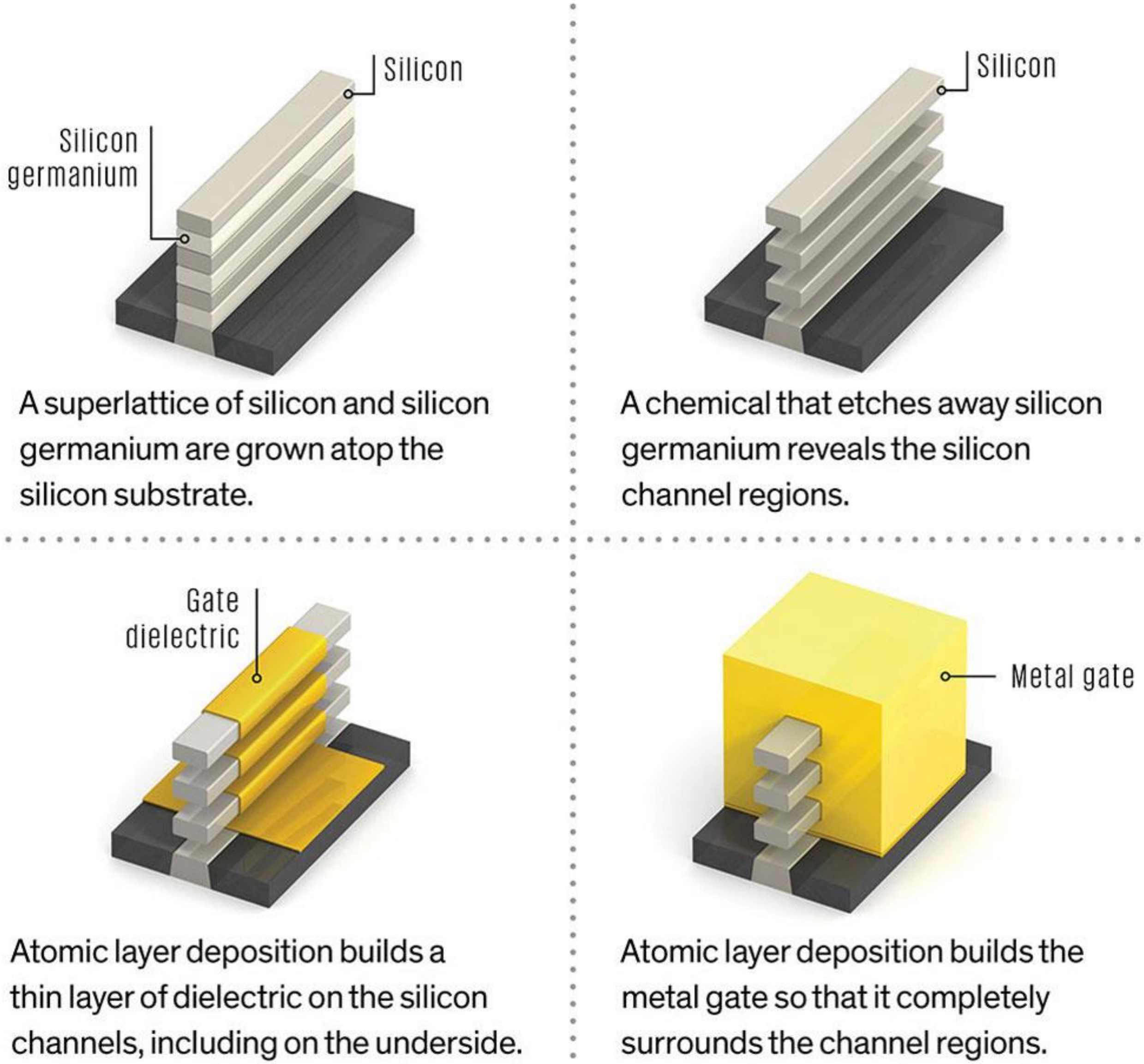
- Tri-gate (FinFET) transistors,

Multiple fins

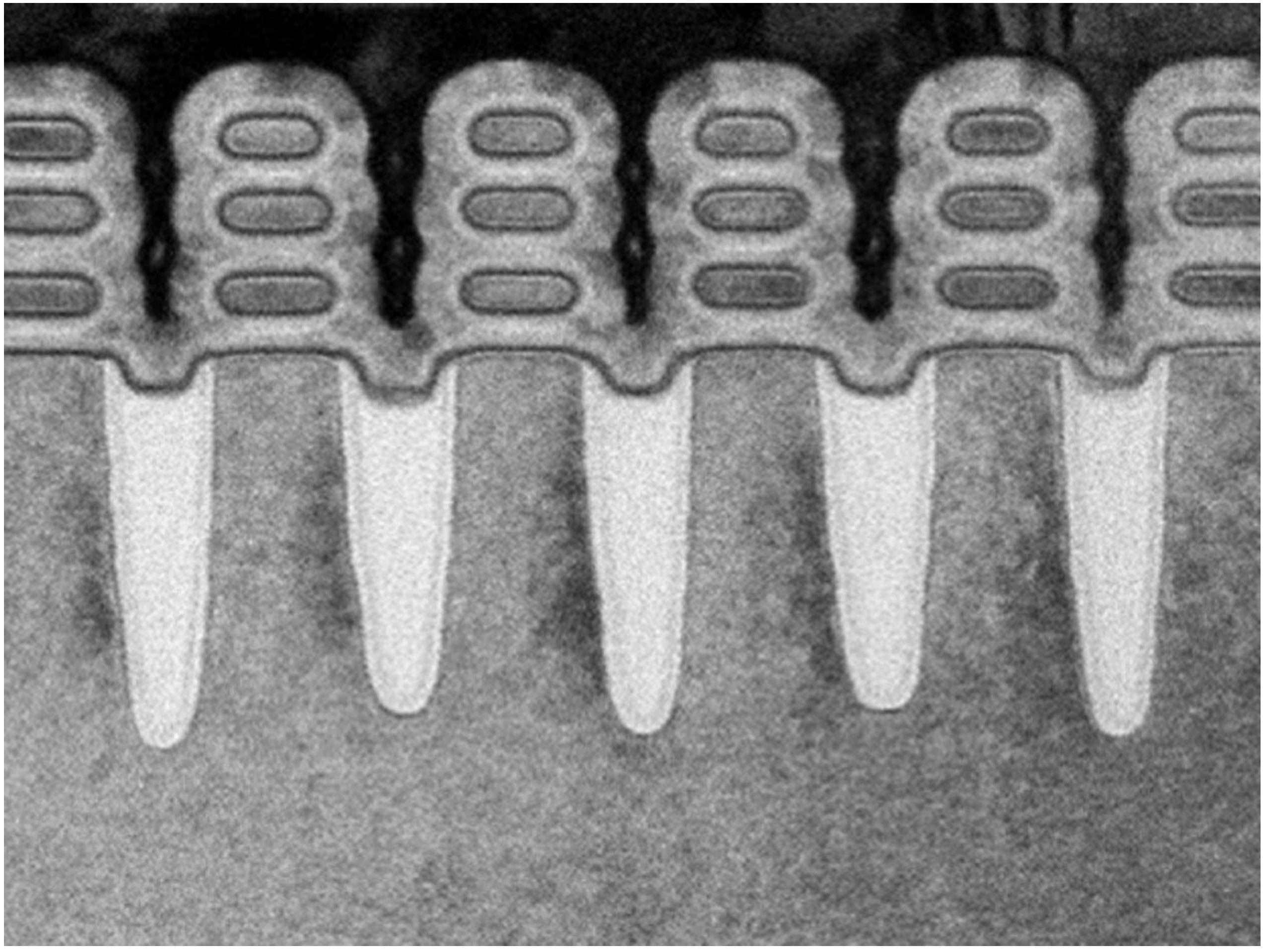
Electrostatic integrity (gate control)



Electrostatic control (integrity)



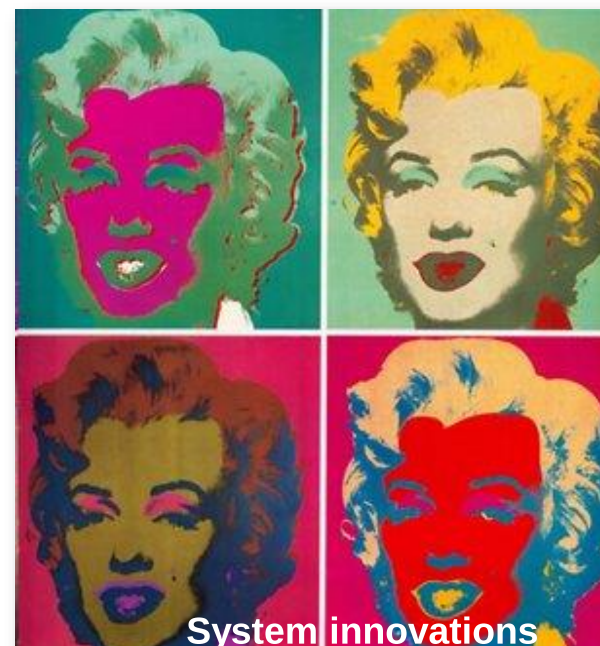
Gate all around nanosheet FET



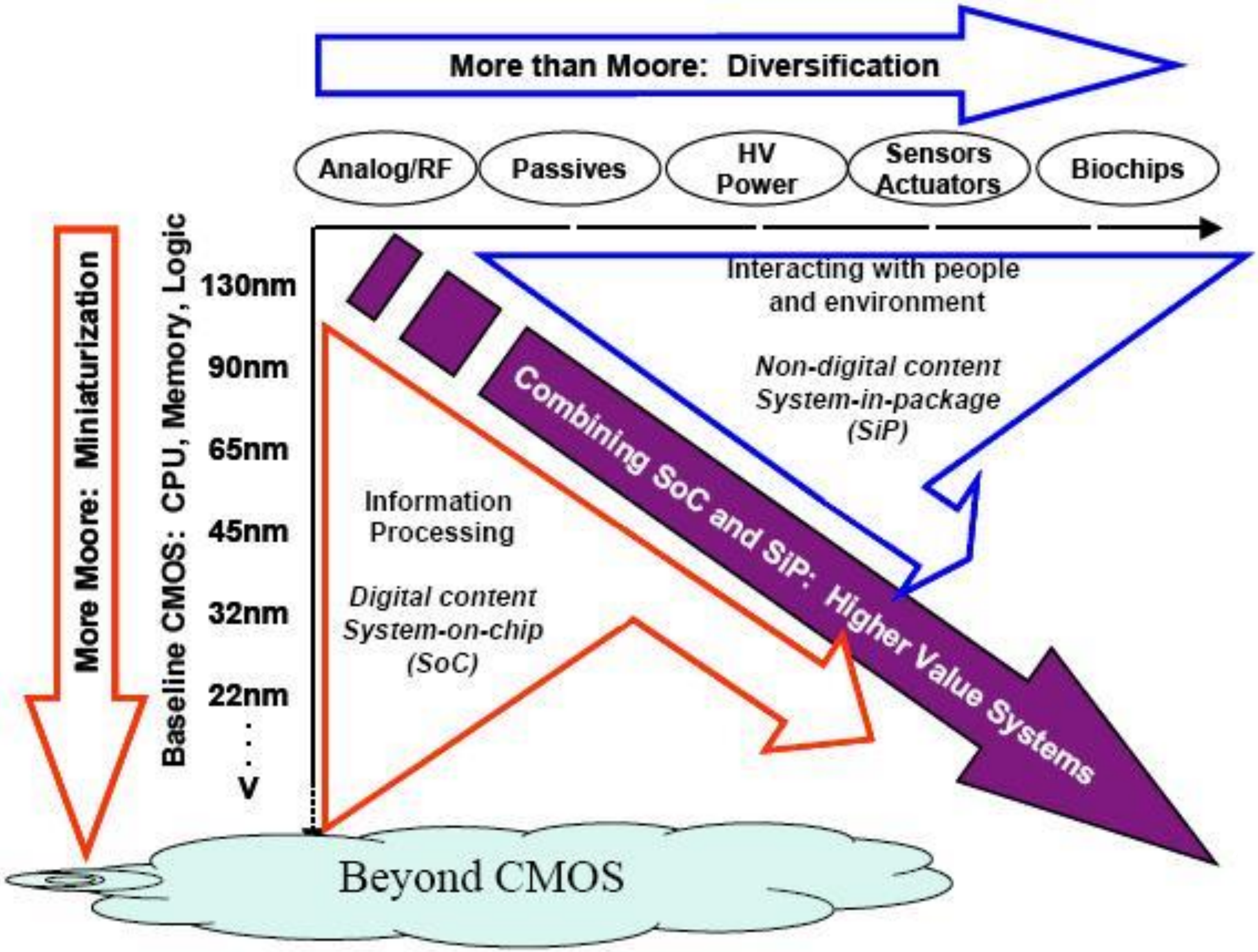
- 3 nm Technology Generation and below
- Current flows through multiple stacks of semiconductor completely surrounded by gate

More of Moore

- **Classic Silicon Scaling**
  - Reduce dimensions, constant E field
  - Modifications for short channel effects
  - stopped at 130nm
- **Equivalent scaling**
  - Reduce dimensions less
  - Strain, hi-k dielectric, finFET, nanosheet
- **System innovations**
  - Multi-core
  - Mixed technology platforms

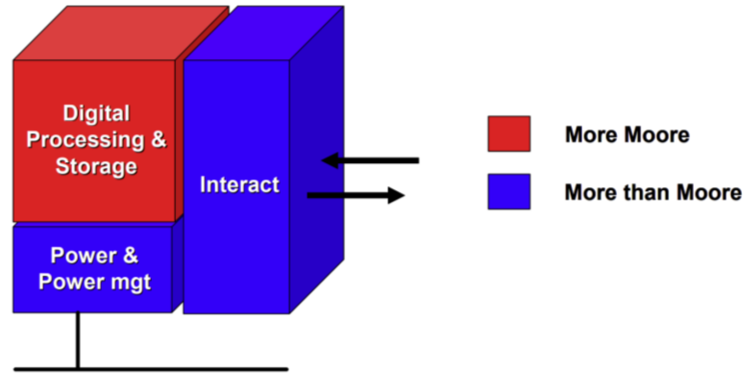


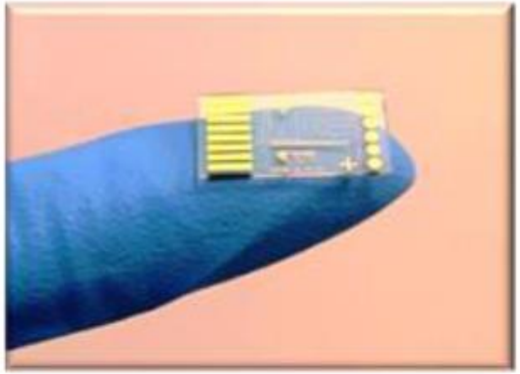
More than Moore

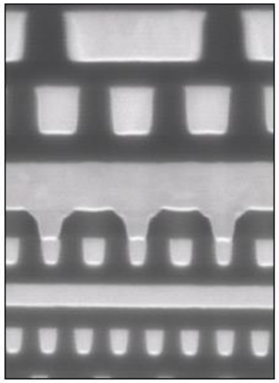


More than Moore

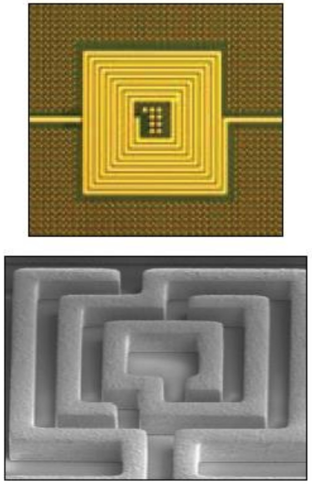
- Sensors
  - Motion, pressure, drive, environment, agri-food, biomedical, molecular diagnostics, CMOS interface
- Passives
  - mixed signal and RF circuits
- Power
  - Si, SiC, GaN, smart power
- Energy harvesting
  - Electromagnetic, thermal, mechanical
- Wearable, flexible
  - Thin substrates





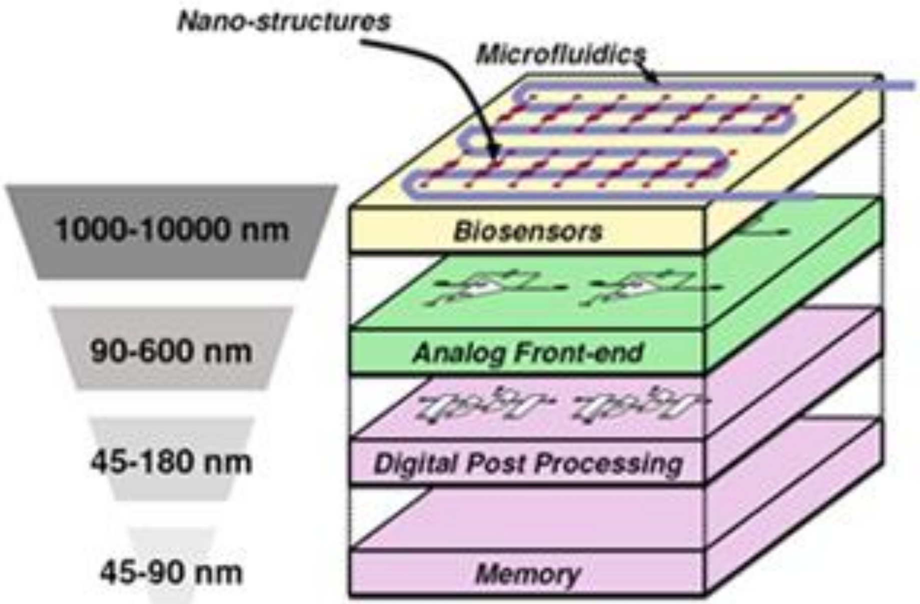


Finger Capacitors

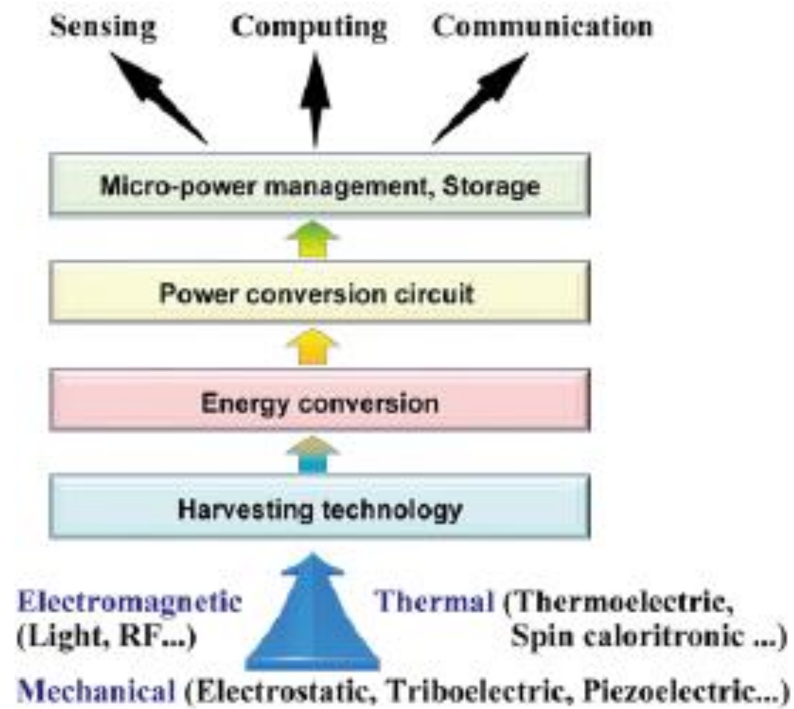


High-Q Inductors

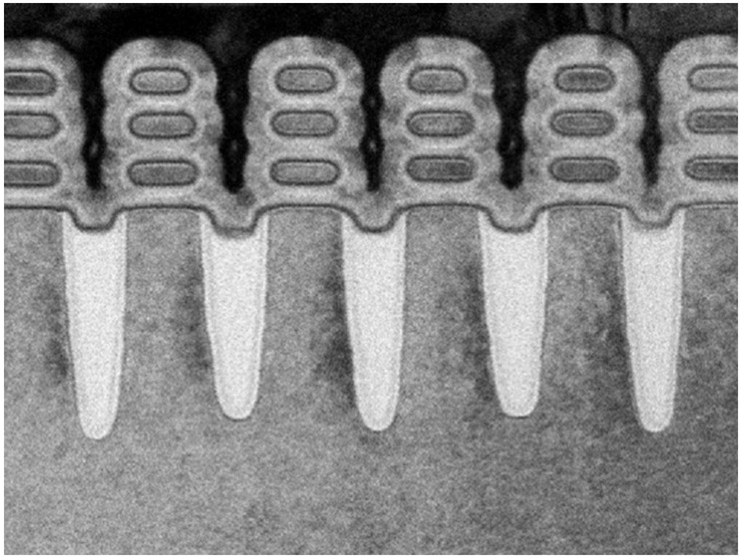
More than Moore

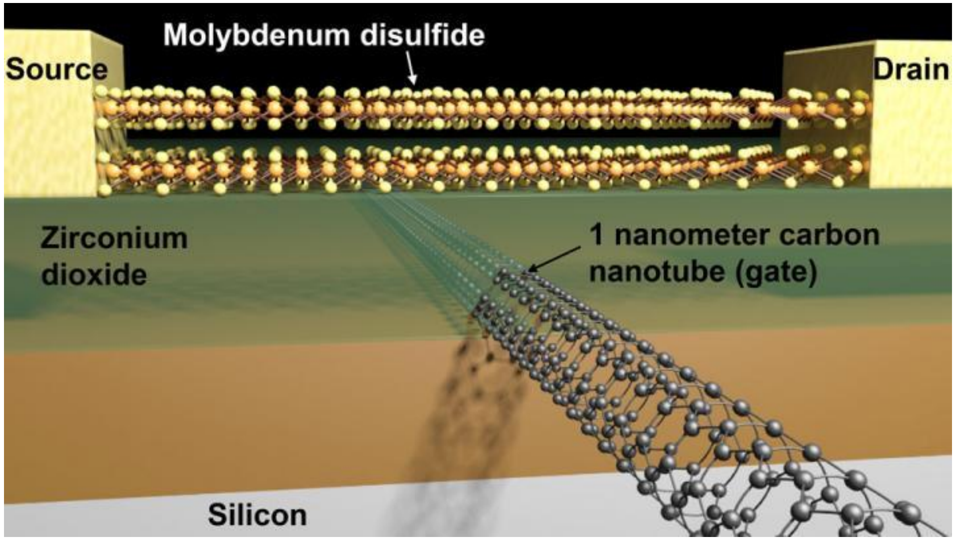


Heterogeneous 3D Integration



Beyond silicon?





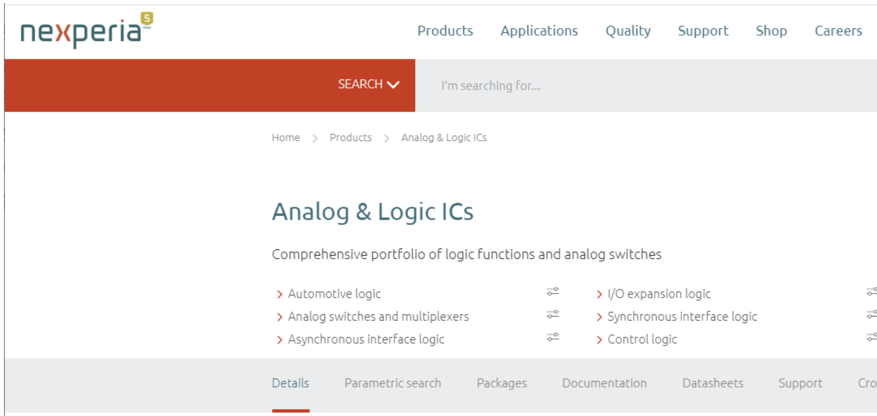
- **Silicon / CMOS is *really* good!**
  - Si is abundant, an element
  - SiO_2 is stable oxide giving excellent isolation (> 3nm)
  - Si/SiO_2 interface is monolayer, low defects
  - MOSFET $I_{ON} / I_{OFF} > 10^6$
  - CMOS only consumes power when switching states
  - Si industry is mature AND innovative

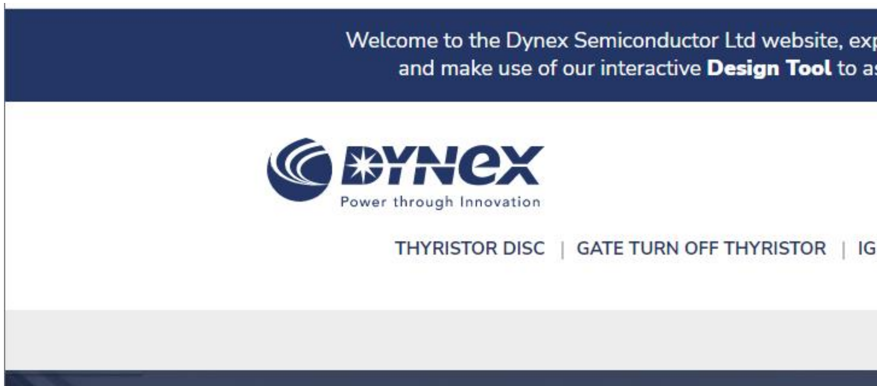
A global perspective of semiconductors

- The global semiconductor industry is one of the largest in the world
  - behind oil, automotive and telecoms,
  - revenue from semiconductors was 0.5% of global GDP in 2020
- In 2021, 1.1 trillion microchips produced
  - 125 microchips per person on Earth
  - Global microchip market was $614 Billion
  - Bigger than global software market of $569 Billion
  - Global power semiconductor market was $39.5 Billion
  - Around 80% of the market is silicon
  - Around 0.5% of the market is from UK
- 1990’s: 80% of manufacturing was in the US or Europe – including UK.
- Today: Taiwan (TSMC) and Korea (Samsung) account for 83% of processor chips and 70% of memory chips.

A UK perspective of semiconductors

- The Newport Wafer Fab is the UK's largest chipmaking facility. In July 2021 it was sold for £63 million ($111,500,000) to Dutch company Nexperia, which itself became a subsidiary of Chinese outfit Wingtech Technology in 2018.
- Semefab. ASICS are typically 3 to 20V power supply, mixed analogue and digital content - typically <20k gates of logic, clock speed 10Mhz, ultra-low standby power suitable for battery powered applications.
- Dynex Semiconductor. World class power semiconductors. In 2008, 75% of Dynex Power shares were acquired by Chinese manufacturer Zhuzhou CSR Times Electric Co., Ltd.,





A UK perspective of semiconductors

- House of Commons: report "The semiconductor industry in the UK" calls on the Government to establish semiconductors as critical infrastructure.
- Government: Dept of Science, Innovation & Technology identifies semiconductors as one of five critical technologies
- UK investing £0.1 billion in semiconductors (Levelling Up)
  - "replicate silicon valley"
  - 2023 Budget: £2.5 billion for quantum; £0.9billion for AI; **£0 for semiconductors?**

	Semiconductor investment ($Bn)	GDP ($Tn)	Semiconductor investment / %GDP
UK	0.15	3.2	0.005
USA	52	25.04	0.208
EU	45	16.6	0.271
China	200	18.32	1.092
S Korea	450	1.7	26.471
Japan	6.8	4.3	0.158
Taiwan	1.3	0.83	0.157
UK	**5**	**3.2**	**0.156**

Concerns for a UK semiconductor industry

1. Global free trade relies on global political stability..
    - Global political instability has led to today's semiconductor shortages
    - Future instability threats:
      China → Taiwan (TSMC); North Korea → South Korea (Samsung)
    - The UK spends 70 billion/year on defence for security

2. Historically, semiconductor industry is volatile
    - Microchip sales (~£1bn) − wafer fab (~£1bn) > £0 ↔ profit
    - Market crash in DRAM (late 1990s) → Siemens, Fujitsu etc closed in UK;
    - UK became nervous to re-invest in semiconductors

3. "We don't have the skilled people"
    - We need to raise awareness of our strengths
    - Many skilled people reluctantly leave UK (fabs closed, no semiconductor jobs, pay)
    - UK is 4th most popular choice for people wanting to move to another country
        - 2017 Gallup poll 600k people from 156 nations
        - 0.5M more people in UK now than a year ago
    - Skilled people will join a global business in UK

A future UK semiconductor industry

- UK needs a semiconductor industry for security and economic reasons
- We have some world class power semiconductor manufacturing, design and compound semiconductors.
  This is necessary but not sufficient for UK
- **We need: < 100nm CMOS foundry & mixed technology packaging** for more than Moore, 5G, automotive and Internet of Things (IoT) devices that rely on devices like analog, power management and display driver integrated circuits (ICs), MOSFETs, microcontroller units (MCUs) and sensors.
- A 200mm fab with 50,000 wafers/month can cost as much as $1 billion, including construction and equipment.
- Getting a state-of-the-art >300mm fab is possible in ~10 years, but with fab cost $10-20 billion.
- UK investing at least $5 billion would be consistent with comparators, based on investment as % of GDP
- Mindset: maximise our gains, not minimise our losses

- ***UK can have a semiconductor industry but needs: realistic investment of £billions + commercial incentives***