微纳光电子材料与器件工艺原理

Introduction

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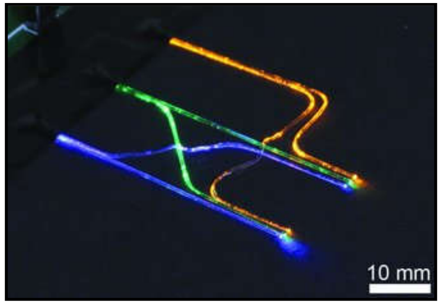
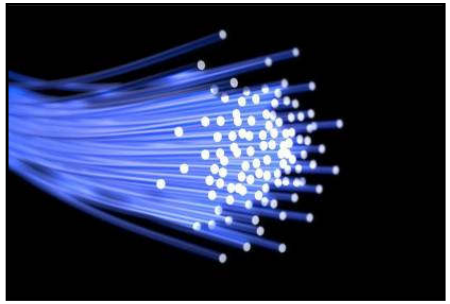
Optical and Electronic Devices

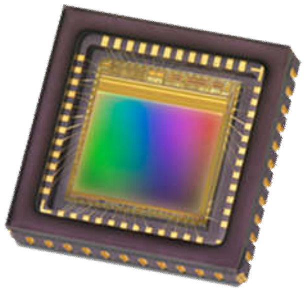

LEDs


lasers

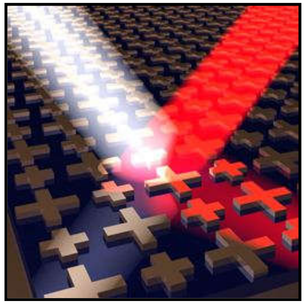


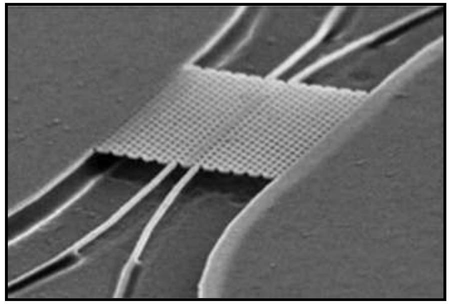
waveguides

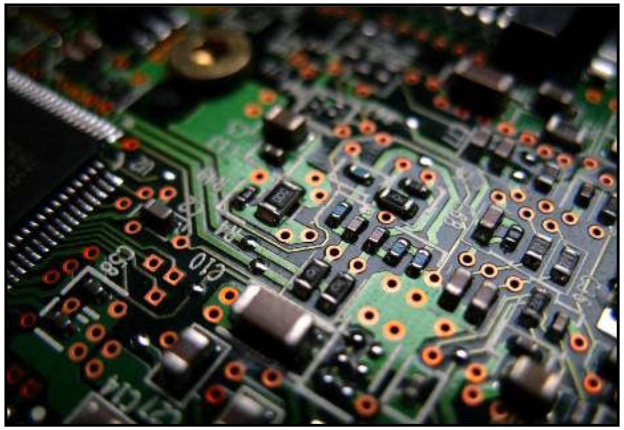

fibers

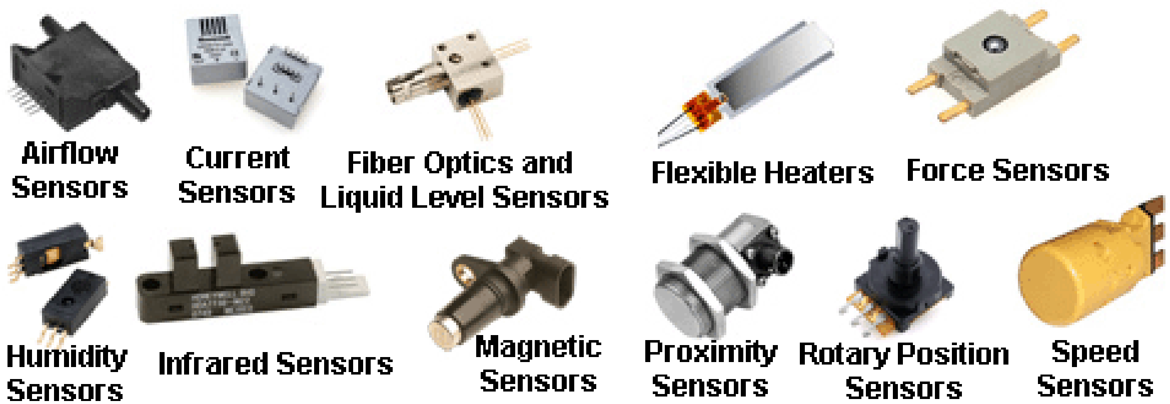

detectors


solar cells


metamaterials


photonic crystals


integrated circuits



Course Information

- Focus on the fabrication and processing methods to form electronic and optical devices at micro- and nano-scale

- Cover fundamental concepts to grow, pattern, deposit, etch and integrate various materials (silicon, III-V, etc) to form electronic and optical devices

- Emerging fabrication technologies such as nanofabrication and self-assembly will also be included

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
  - Integration circuits, Moore's law
  - Advanced optical and electronic devices
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- **Materials: Structures and Synthesis (Week 2)**
  - Crystal structures
  - Semiconductor wafer preparation
  - Optical fiber drawing
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
  - Cleanroom, foundry
  - Contamination and cleaning
  - Lab safety
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- **Photolithography (Week 4, 5)**
  - **optical principles, emerging technologies**
  - **photoresist process**
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- **Doping (Week 6)**
  - **p-type, n-type, pn junctions**
  - **diffusion doping, ion implantation, in situ doping**
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- **Materials Growth and Deposition (Week 7, 8, 9)**
  - Epitaxy, thermal oxidation
  - dry process: PVD, CVD, ...
  - wet process: electrodeposition, spin coating, ...
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- **Materials Etching (Week 10, 11)**
  - wet etch
  - dry etching
  - CMP, FIB, ...
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- **Integration and Packaging (Week 12)**
  - **wafer bonding, SOI, soldering, welding, transfer, ...**
- Emerging Technologies (Week 13, 14)
- Final Presentation (Week 15, 16)

Syllabus

- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- **Emerging Technologies (Week 13, 14)**
  - **nanoimprint, 3D printing, self-assembly, epi release, transfer printing, flexible, ...**
- Final Presentation (Week 15, 16)

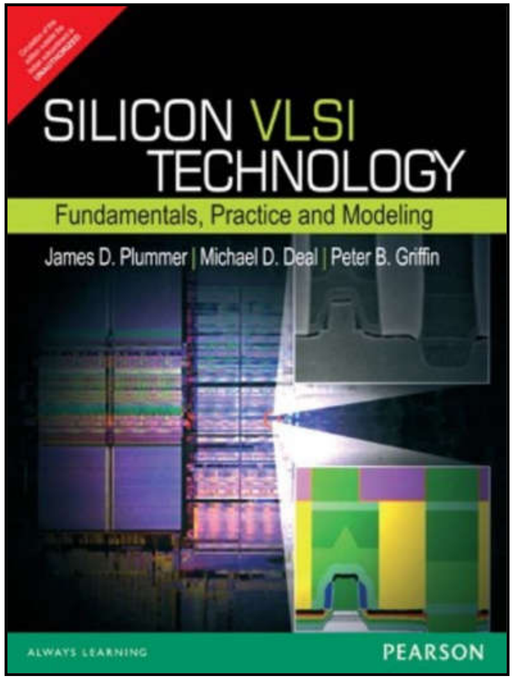
Syllabus

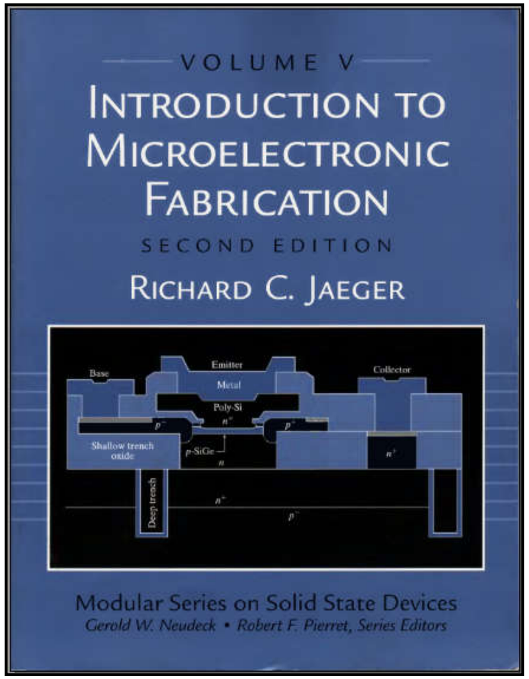
- Introduction (Week 1)
- Materials: Structures and Synthesis (Week 2)
- Cleanroom Environment (Week 3)
- Photolithography (Week 4, 5)
- Doping (Week 6)
- Materials Growth and Deposition (Week 7, 8, 9)
- Materials Etching (Week 10, 11)
- Integration and Packaging (Week 12)
- Emerging Technologies (Week 13, 14)
- **Final Presentation (Week 15, 16)**

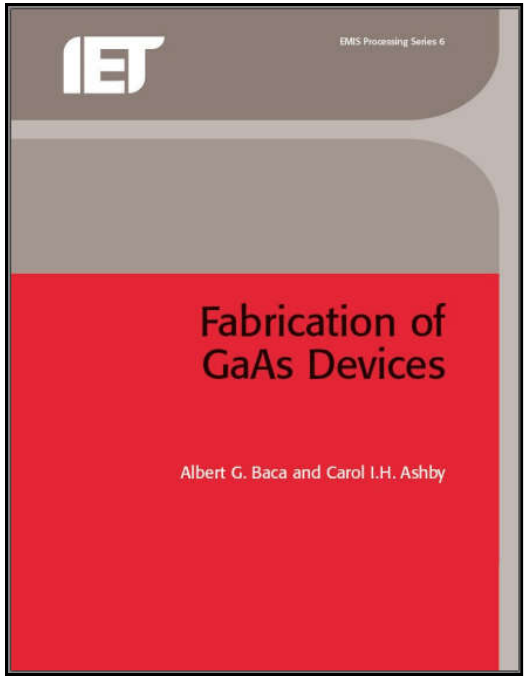
References

- 清华网络学堂

  http://learn.tsinghua.edu.cn







Nobel Prize in Physics

1956	Semiconductor transistors
1991	Liquid crystals
2000	Integrated circuits
2000	Semiconductor heterostructures
2009	CCD imaging sensors
2009	Optical fibers
2010	Graphene
2014	GaN based blue LEDs

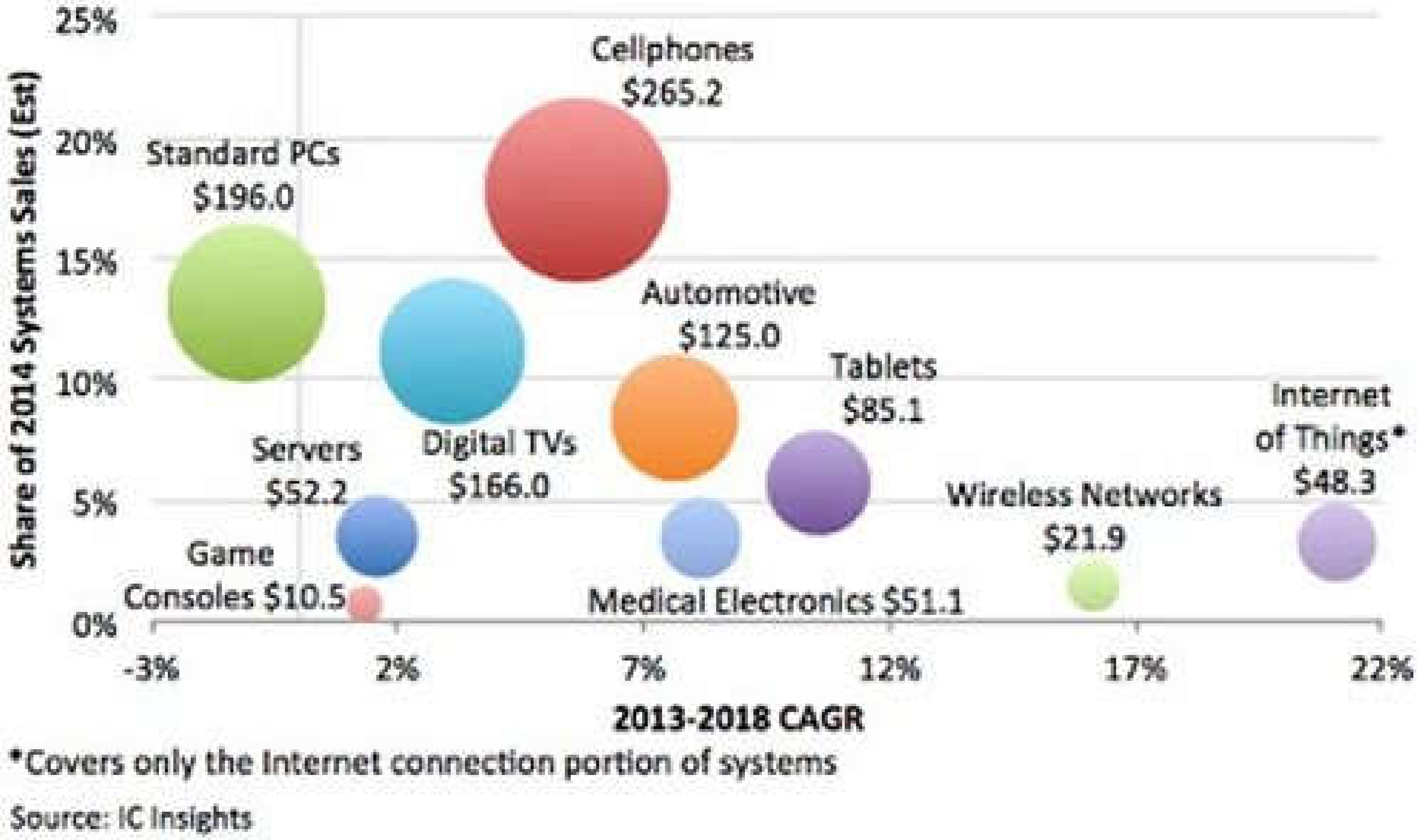
'Disruptive' Technologies

- 1956 Semiconductor transistors ← vacuum tubes
- 1991 Liquid crystals ← CRT displays
- 2000 Integrated circuits
- 2000 Semiconductor heterostructures
- 2009 CCD imaging sensors ← film cameras
- 2009 Optical fibers ← copper cables
- 2010 Graphene
- 2014 GaN based blue LEDs ← incandescent light bulbs

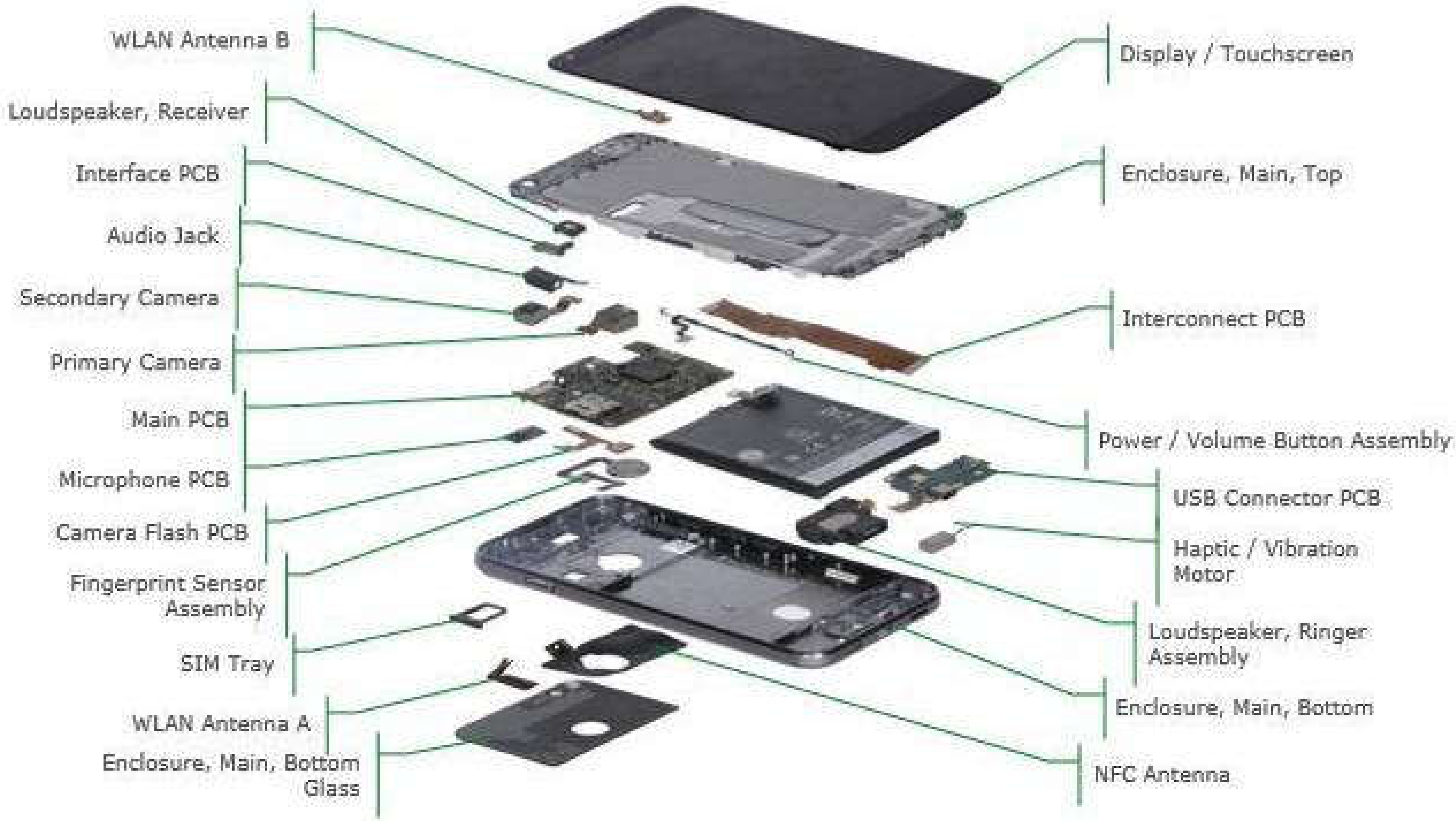
Semiconductor Market

current ~ 500 billion $$$

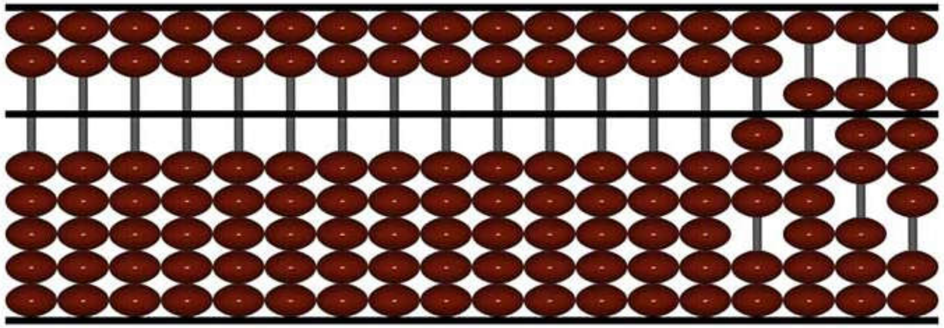
GDP of Thailand: 400 billion $$$



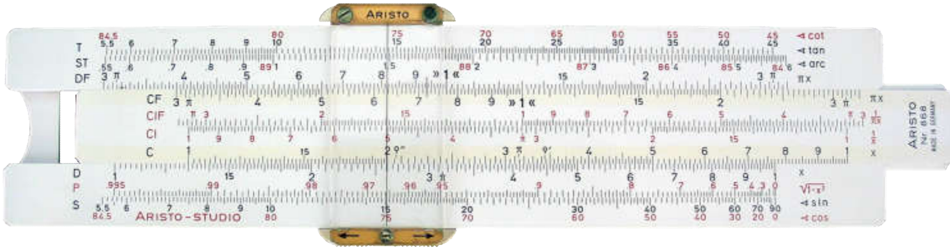
Devices in a Smartphone



Some 'Ancient' Computers

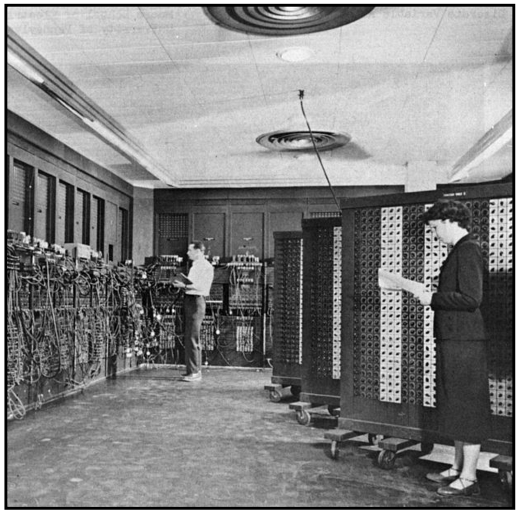


abacus



slide rule

- First 'electronic' computer
  - ENIAC, 1943
  - 30 tons, 200 kW
  - 18000 vacuum tubes
  - 5000 times/sec
  - cost $480,000



vacuum tube

First Semiconductor Transistor

Germanium
Bipolar Transistor

The first point contact transistor
William Shockley, John Bardeen, and Walter Brattain
Bell Laboratories, Murray Hill, New Jersey (1947)

Bardeen Brattain

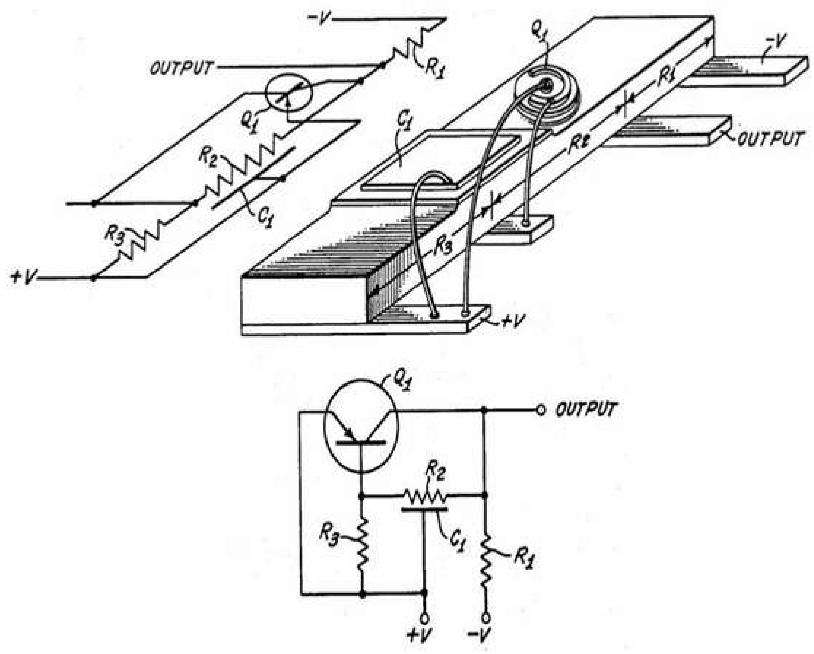
Shockley

1956 Nobel Prize in Physics

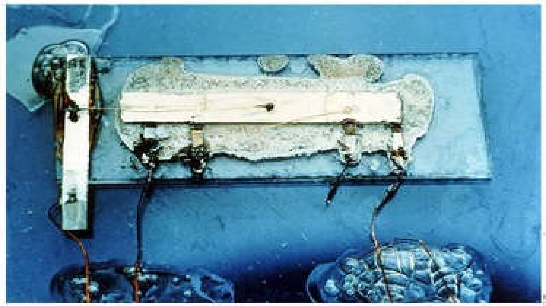
First Integrate Circuits

The First (2D) Integrated Circuit
Jack Kilby, Texas Instruments, 1958

- Transistor, Resistors and Capacitors on the same piece of semiconductor
- Interconnects between components not integrated
  → Low connectivity between components



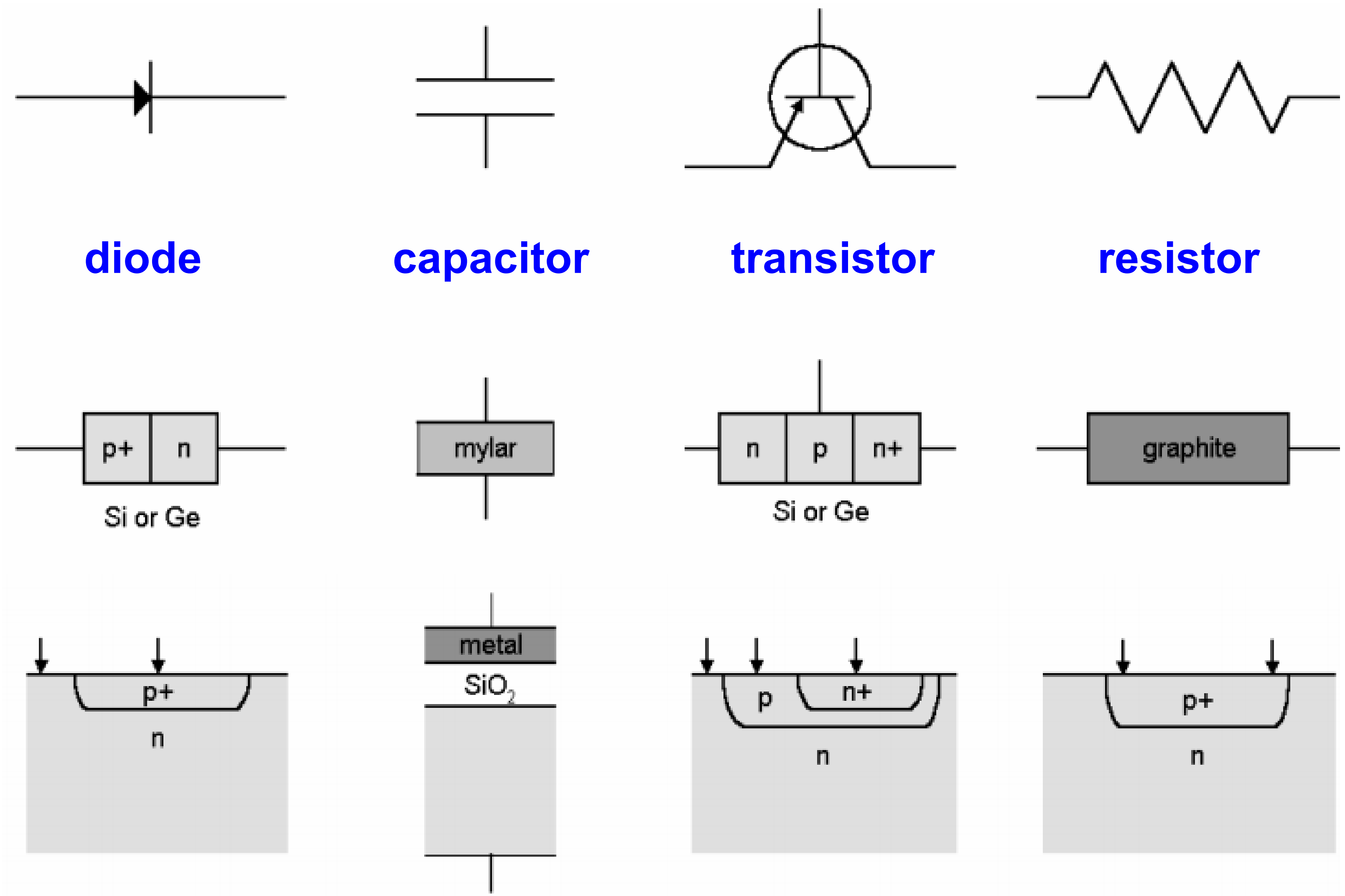
Germanium



J. Kilby
1923–2005

2000 Nobel Prize in Physics

First Integrate Circuits



All devices can be made in the same semiconductor!

First Integrate Circuits

"There is plenty room at the bottom", APS Meeting, 1959

MINIATURIZING THE COMPUTER

I don't know how to do this on a small scale in a practical way, but I do know that computing machines are very large; they fill rooms. Why can't we make them very small, make them of little wires, little elements—and by little, I mean *little*. For instance, the wires should be 10 or 100 atoms in diameter, and the circuits should be a few thousand angstroms across. Everybody who has analyzed the logical theory of computers has come to the conclusion that the possibilities of computers are very interesting—if they could be made to be more complicated by

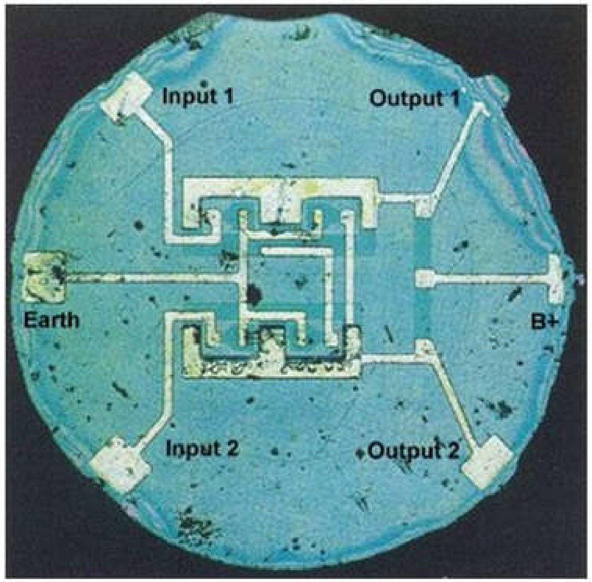
R. Feynman

First Integrate Circuits

The First *Monolithic* (2D) Integrated Circuit
Robert Noyce, Fairchild Semiconductor, 1961

- Transistor, Resistors and Capacitors on the same piece of semiconductor
- Interconnects between components integrated
  → High connectivity between components

4 transistors

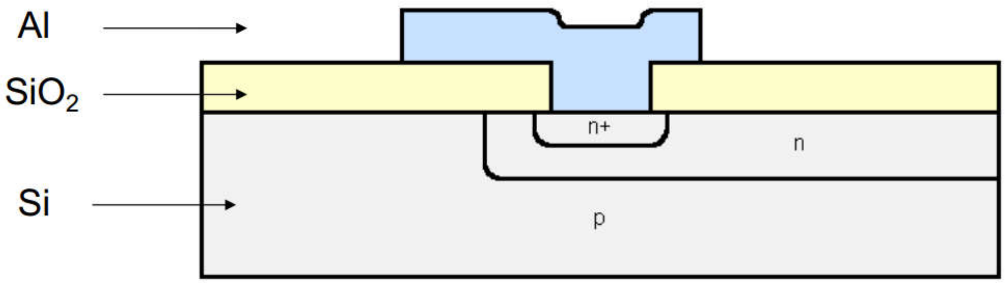


Silicon

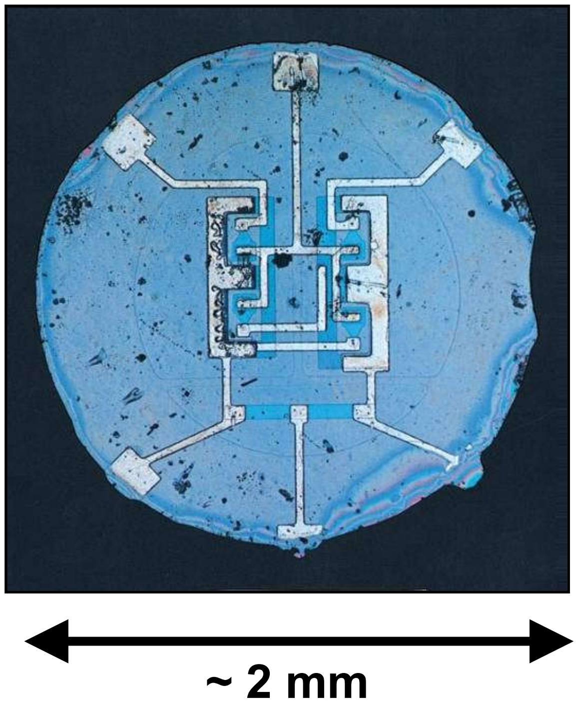
R. Noyce
1927–1990

First Integrate Circuits

- Thermal oxidation (SiO_2)
- Photolithography
- Etching
- Thermal diffusion (n-Si, p-Si)
- Metal deposition (Al)



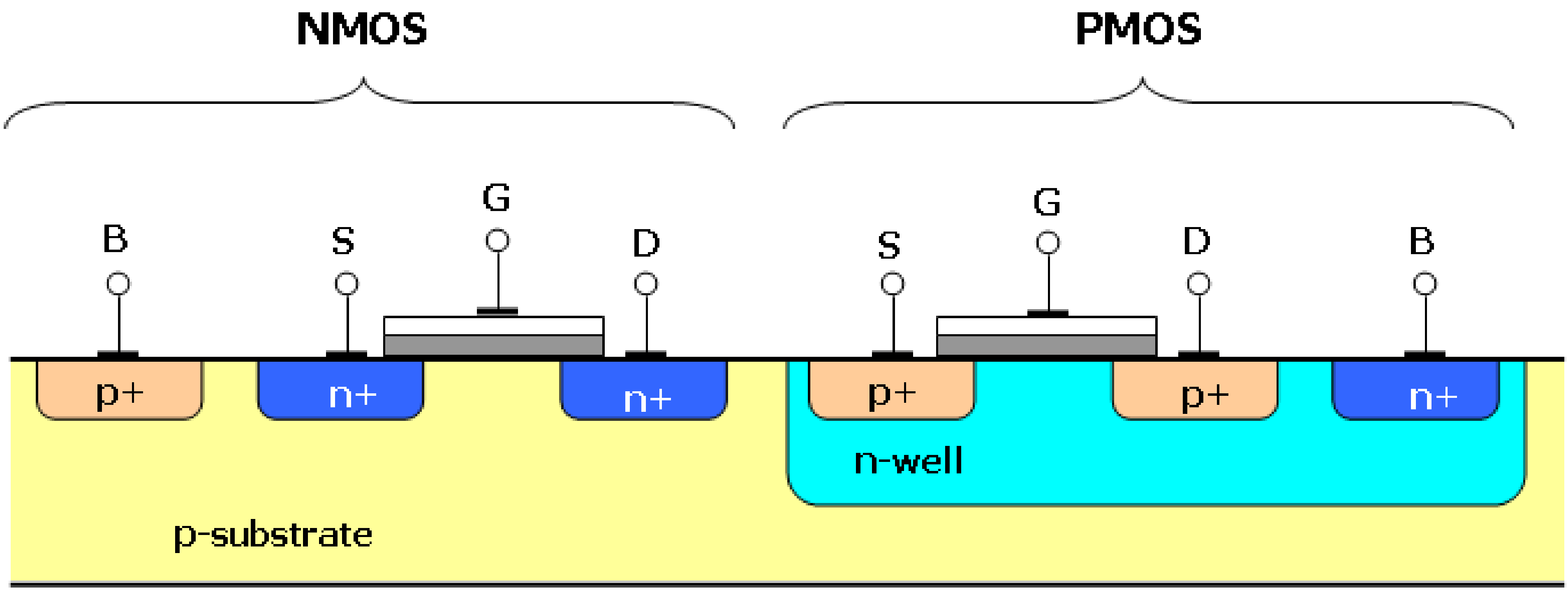
Explained on board



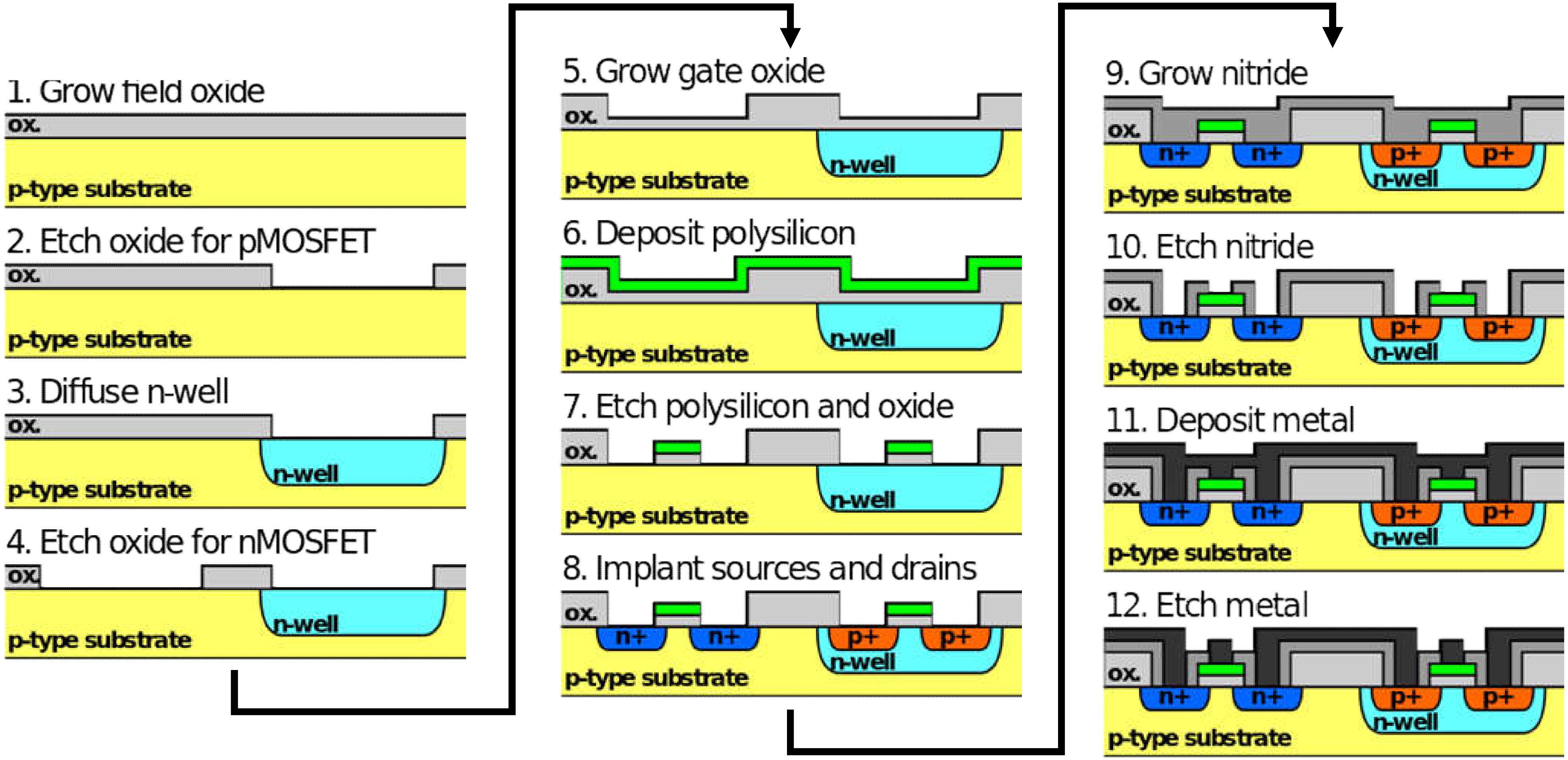
Very similar to today's process

CMOS

- **Complementary Metal-Oxide-Semiconductor**
  - **F. Wanlass, Fairchild, 1963**

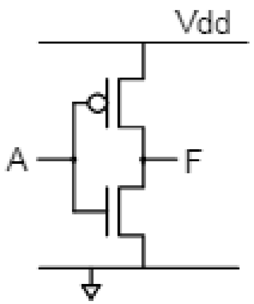


CMOS Process



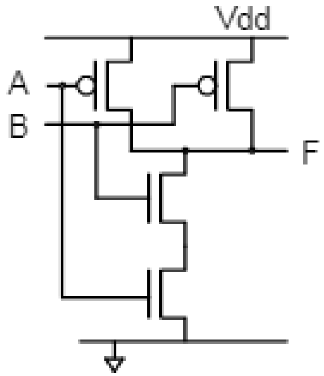
Video

CMOS Logic



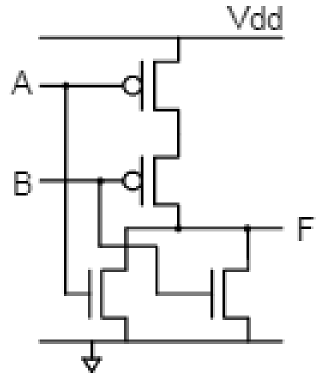
A	F
L	H
H	L

CMOS INVERTER



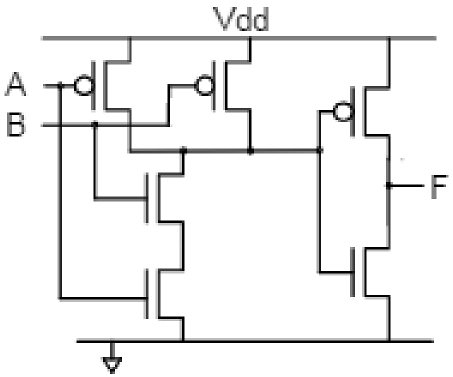
A	B	F
L	L	H
L	H	H
H	L	H
H	H	L

CMOS NAND



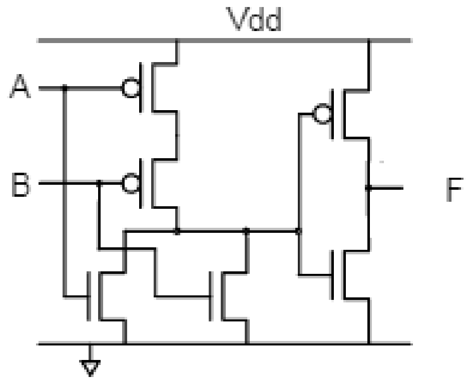
A	B	F
L	L	H
L	H	L
H	L	L
H	H	L

CMOS NOR



A	B	F
L	L	L
L	H	L
H	L	L
H	H	H

CMOS AND

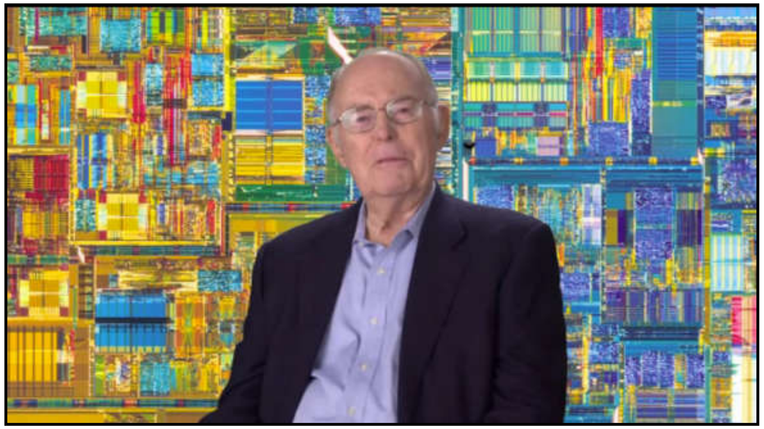


A	B	F
L	L	L
L	H	H
H	L	H
H	H	H

CMOS OR

Integrate Circuits

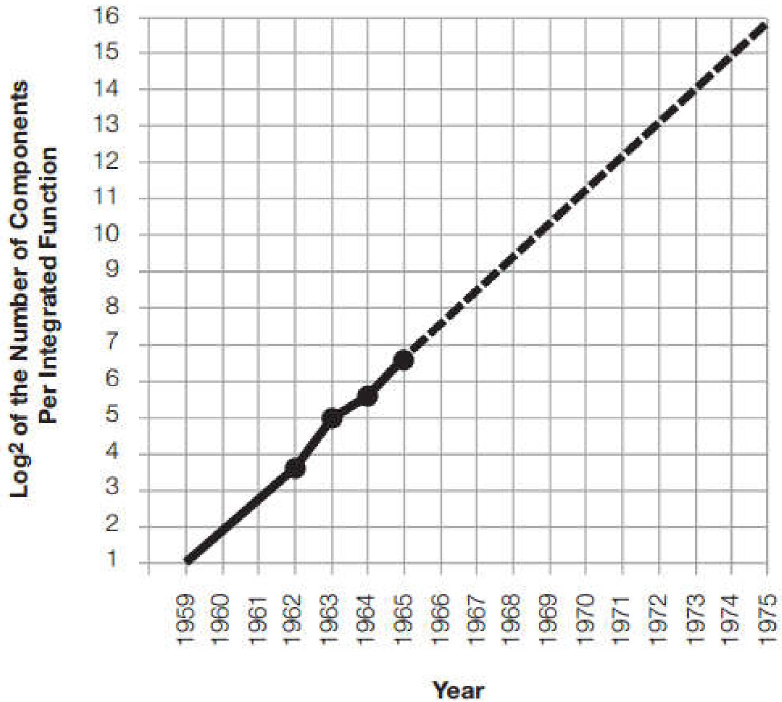
- **Moore's law, Fairchild, 1965**



G. Moore

The complexity for minimum component costs has increased at a rate of roughly a factor of two per year (see graph on next page). Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.

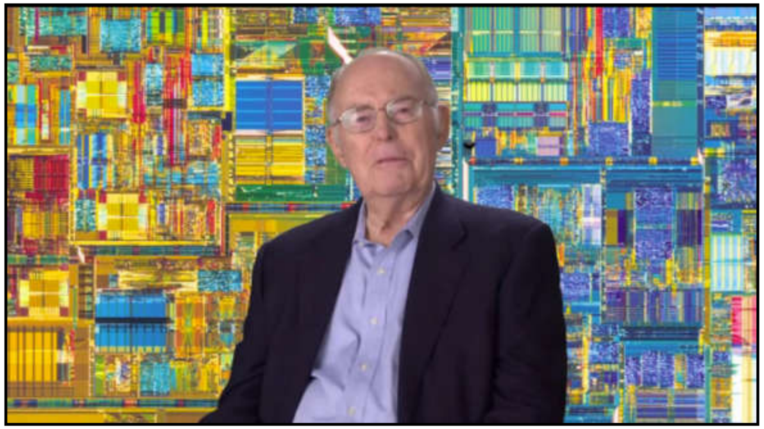
I believe that such a large circuit can be built on a single wafer.



G. E. Moore, *Electronics Mag.* **38,** (1965)

Integrate Circuits

- **Moore's law, Fairchild, 1965**

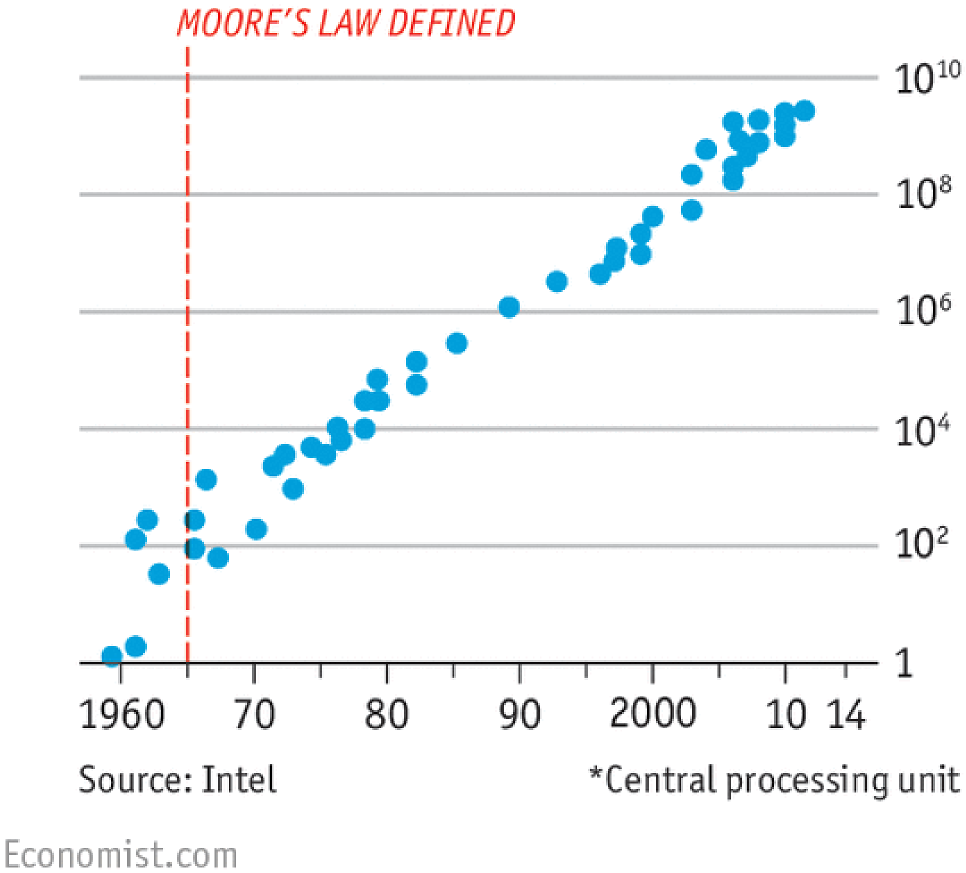


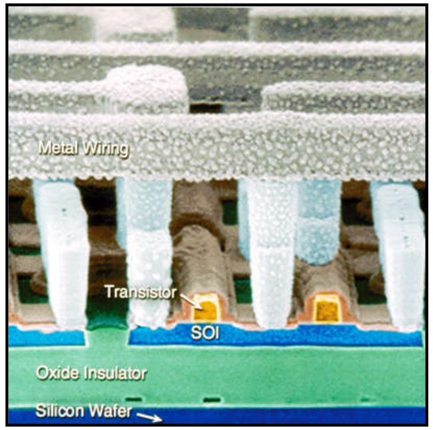
G. Moore

G. E. Moore, *Electronics Mag.* **38,** (1965)

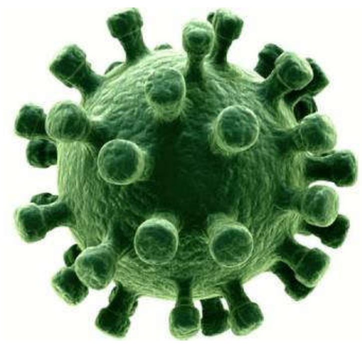
Integrate Circuits

- **Moore's law, Fairchild, 1965**

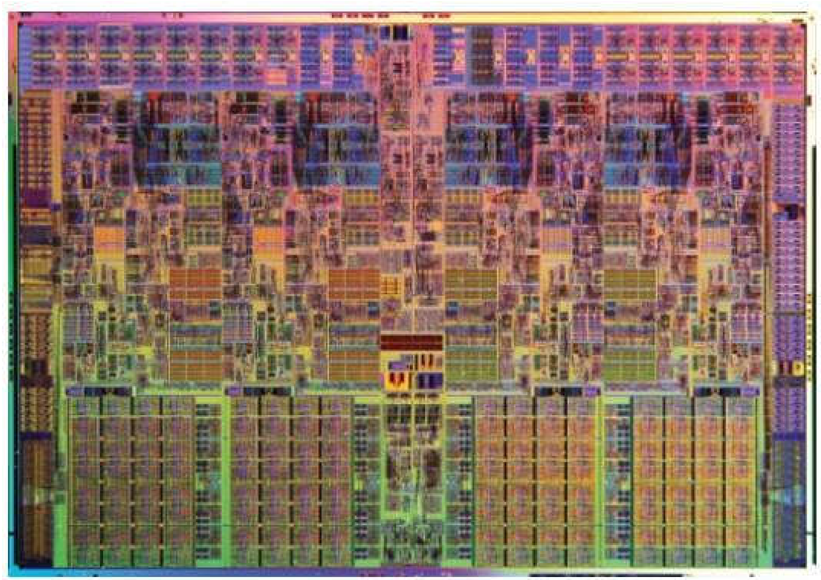




< 100 nm



virus



Intel i7 CPU, ~ 10^9 transistors

Modern Electronics is a real Nanotechnology

Integrate Circuits

1980s

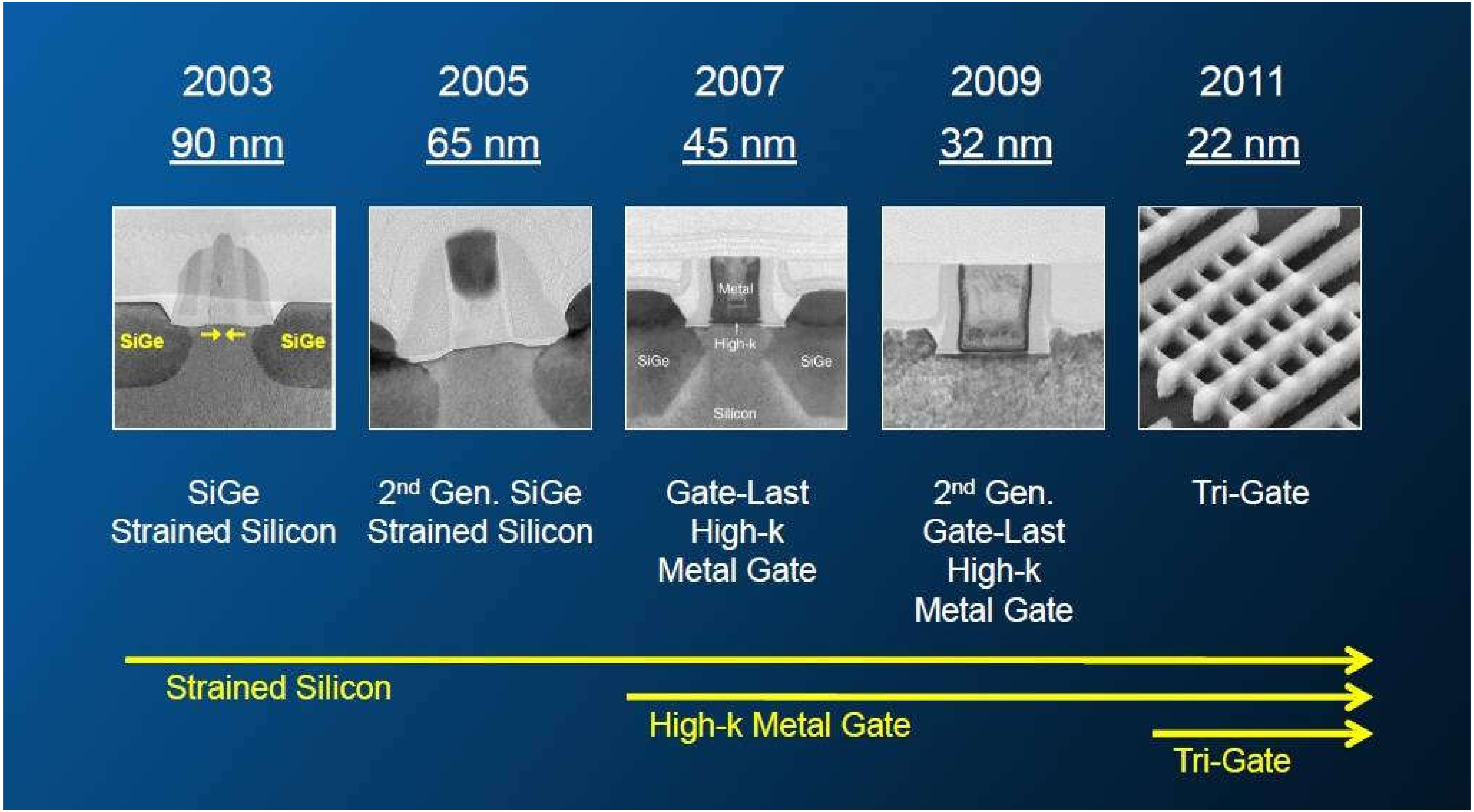
¥2549.00

英特尔（Intel）酷睿四核I7-7700k 盒装

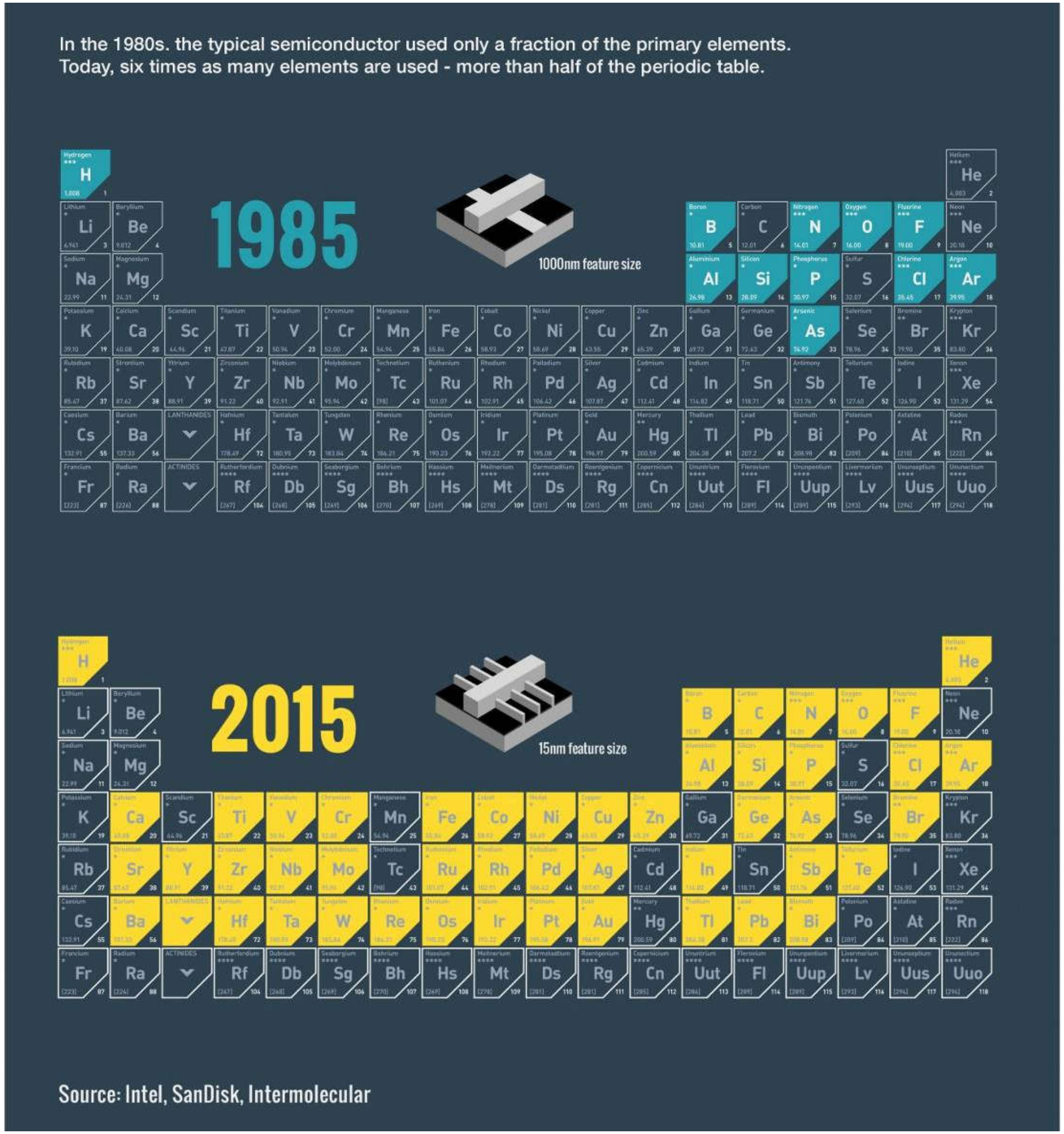
CPU处理器 采用Kabylake架构，LGA 1151

2017, price > gold

Transistor Evolution



Materials in IC

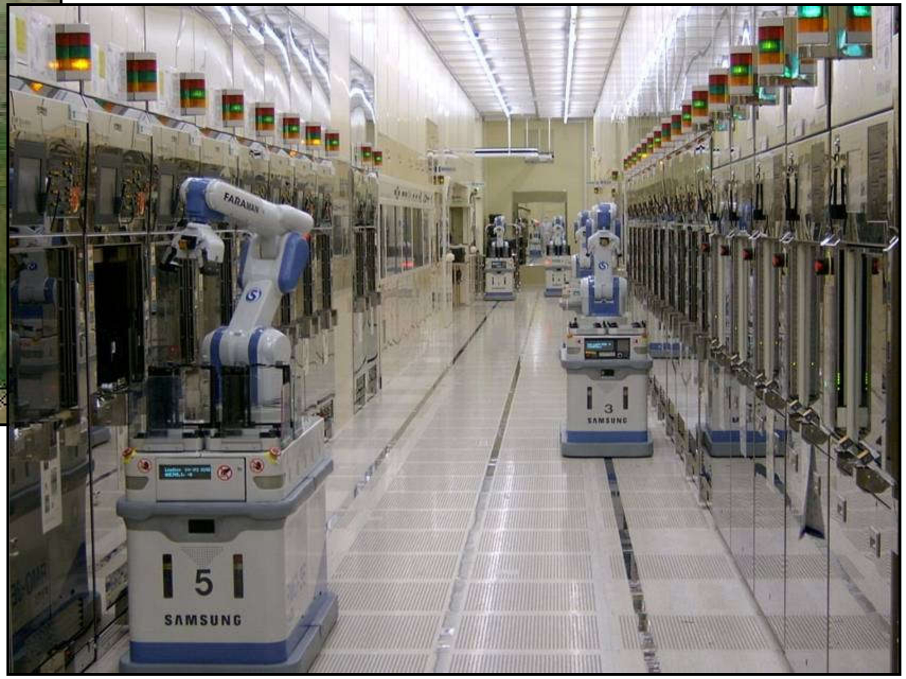


Modern IC foundry

Video 1

Video 2 Intel

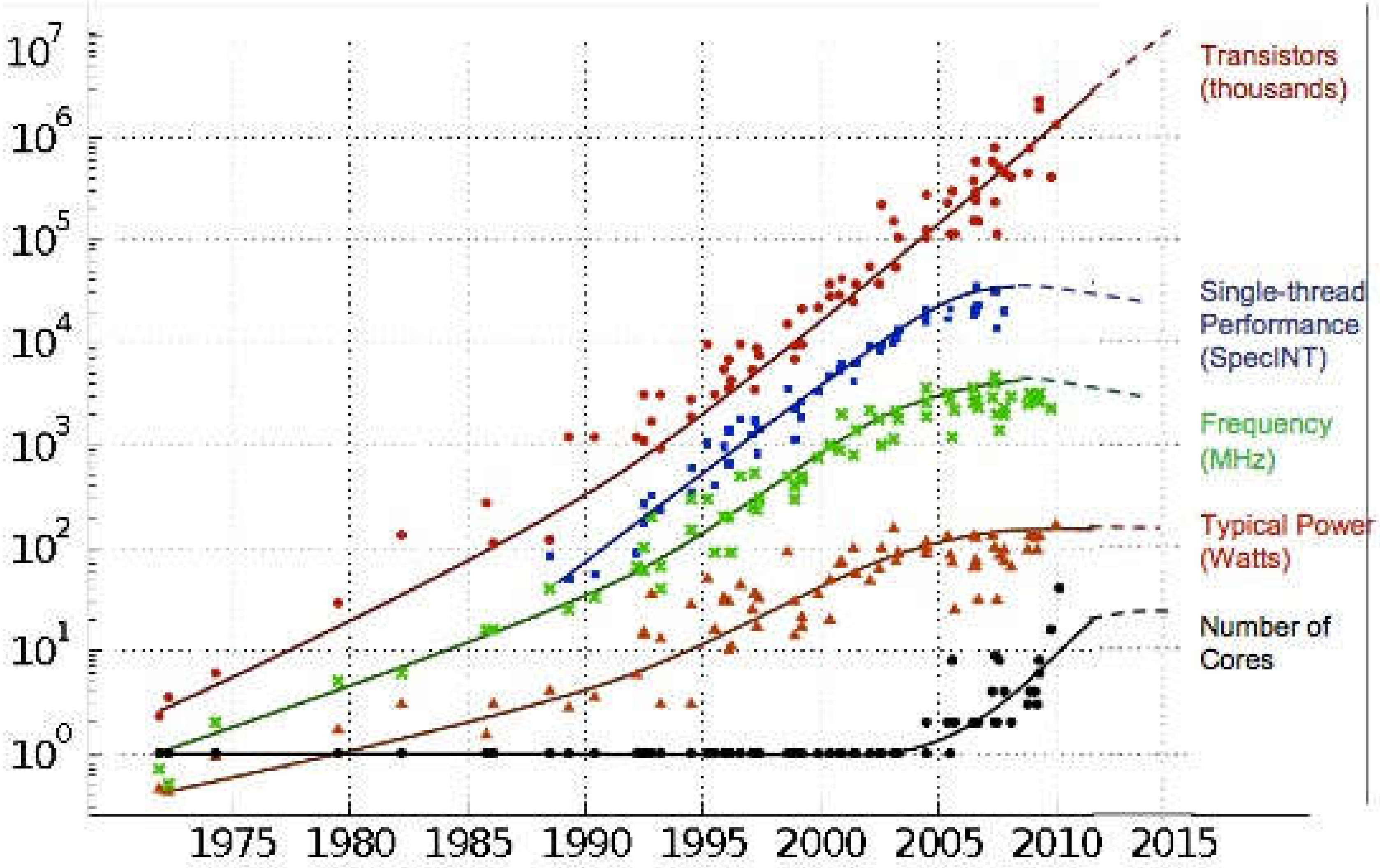
Global Foundries



Samsung

Cost > 10 billion $$$

All Good Things Come to an End



Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten
Dotted line extrapolations by C. Moore

All Good Things Come to an End

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FEATURE NEWS

THE SEMICONDUCTOR INDUSTRY WILL SOON ABANDON ITS PURSUIT OF MOORE'S LAW. NOW THINGS COULD GET A LOT MORE INTERESTING.

City. The Semiconductor Industry Association (SIA) in Washington DC, which represents all the major US firms, has already said that it will cease its participation in the road-mapping effort once the report is out, and will instead pursue its own research and development agenda.

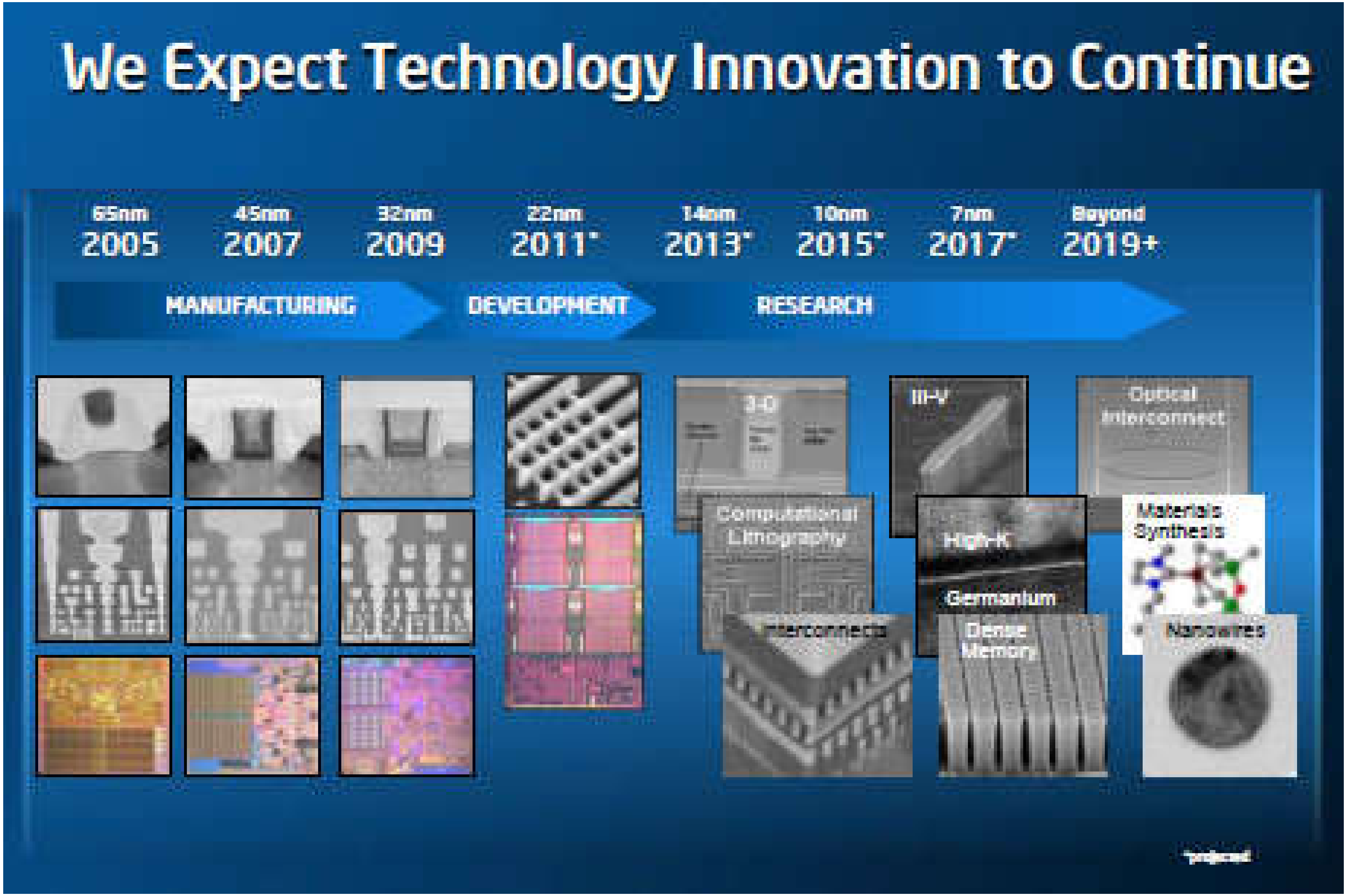
Everyone agrees that the twilight of Moore's law will not mean the end of progress. "Think about what happened to airplanes," says Reed. "A Boeing 787 doesn't go any faster than a 707 did in the 1950s — but they are very different airplanes", with innovations ranging from fully electronic controls to a carbon-fibre fuselage. That's what will happen with computers, he says: "Innovation will absolutely continue — but it will be more nuanced and complicated."

LAYING DOWN THE LAW

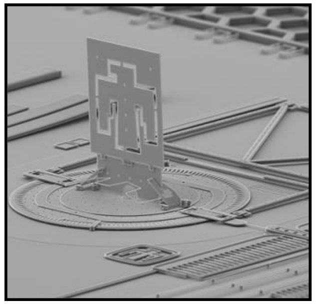
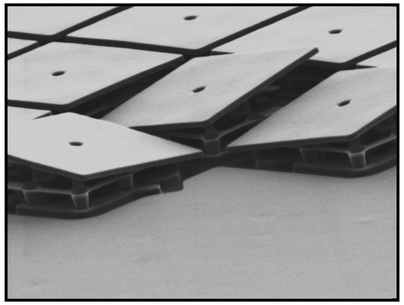
The 1965 essay[1] that would make Gordon Moore famous started with a meditation on what could be done with the still-new technology of integrated circuits. Moore, who was then research director of Fairchild

M. M. Waldrop, *Nature* **530,** 144 (2016)

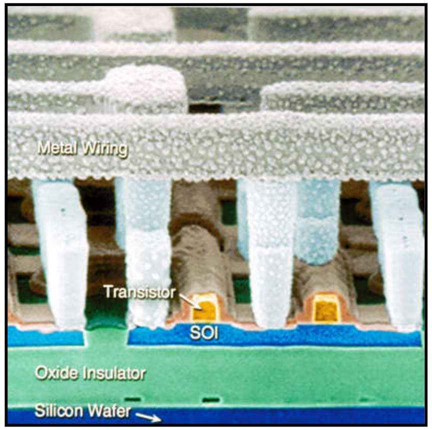
New Opportunities



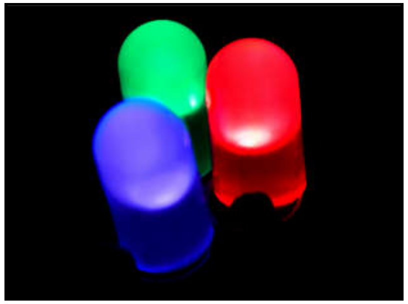
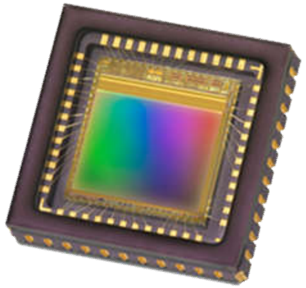
New Devices and Applications

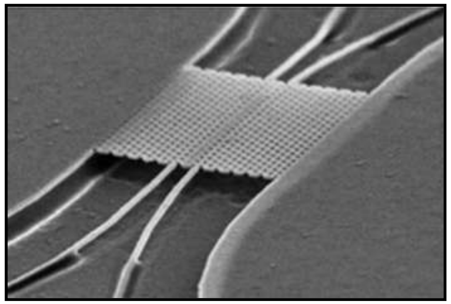
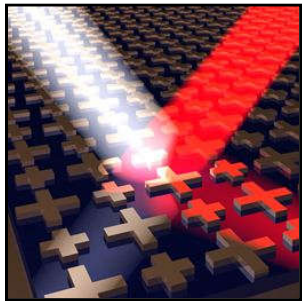
Microelectromechanical Systems (MEMS)



Microelectronics

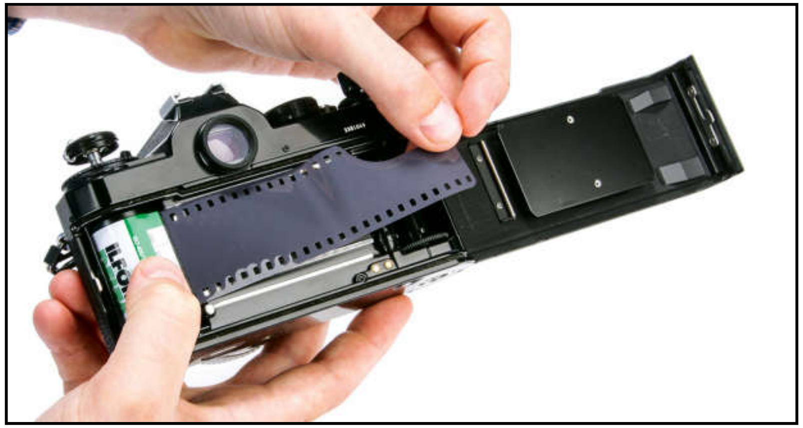




Optoelectronics

Micro and Nano Photonics

Image Sensors



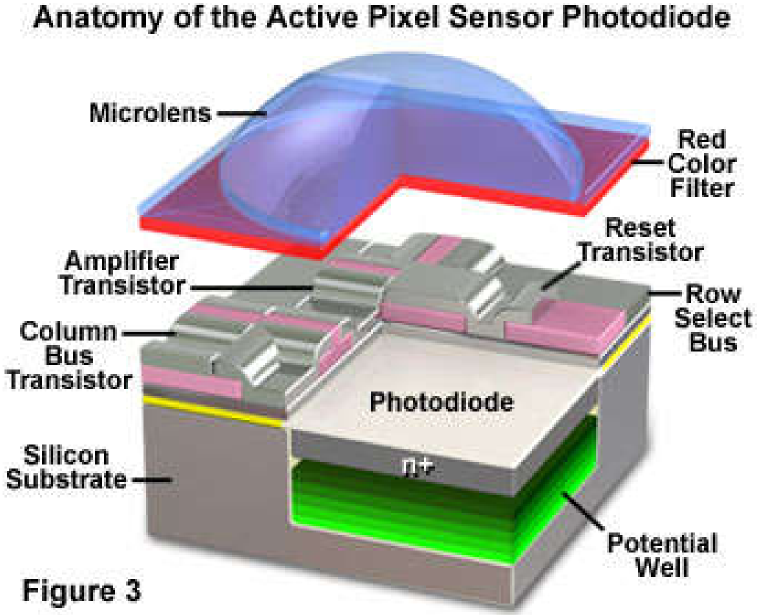
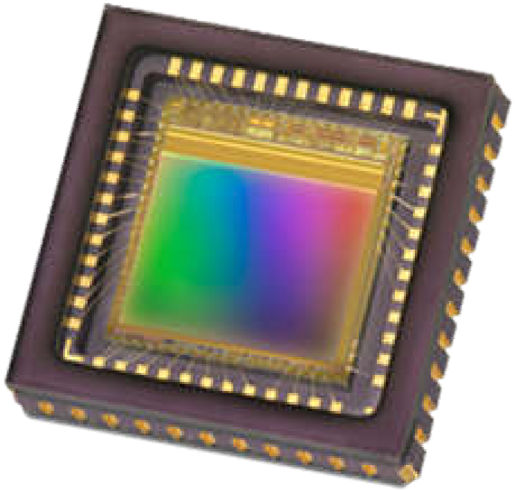


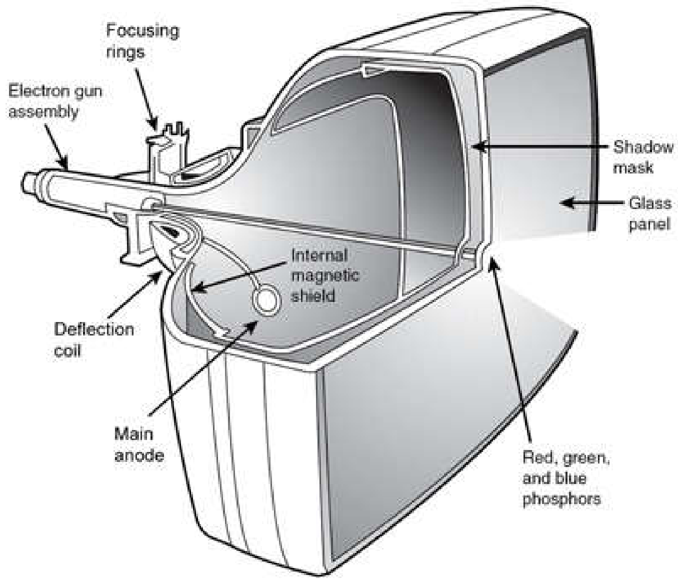
Figure 3

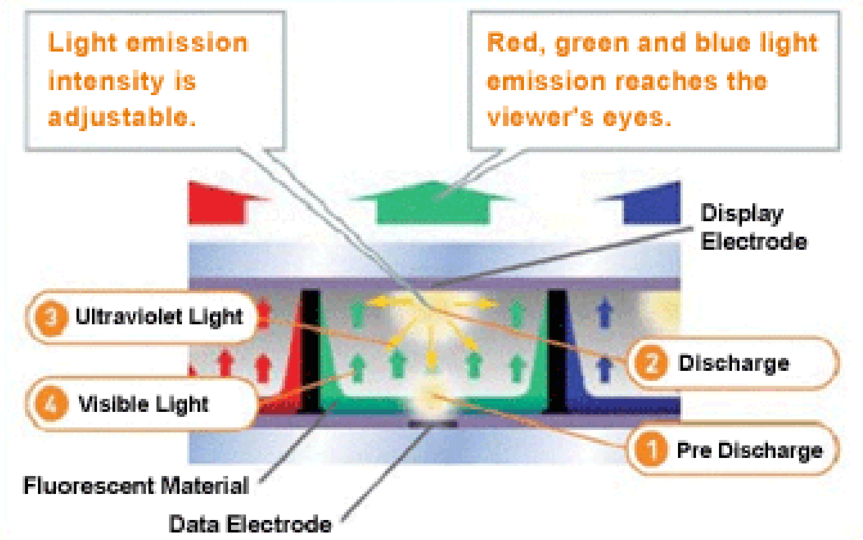


films

CMOS sensors

Displays



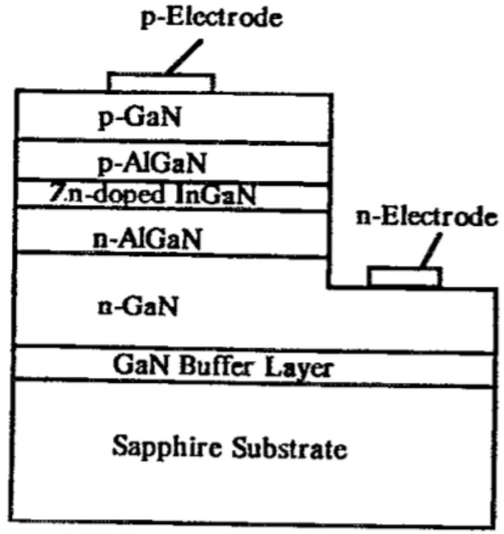


CRT

Flat panel

Light Sources

Incandescent bulb



S. Nakamura, *et al.*, Appl. Phys. Lett. **64,** 1687 (1994)

Fluorescent lamp

LEDs

Gallium Nitride (GaN) LED

- **GaN LED on sapphire**
  - 日本，Nichia
  - 2014 Nobel Prize in Physics


I. Akasaki

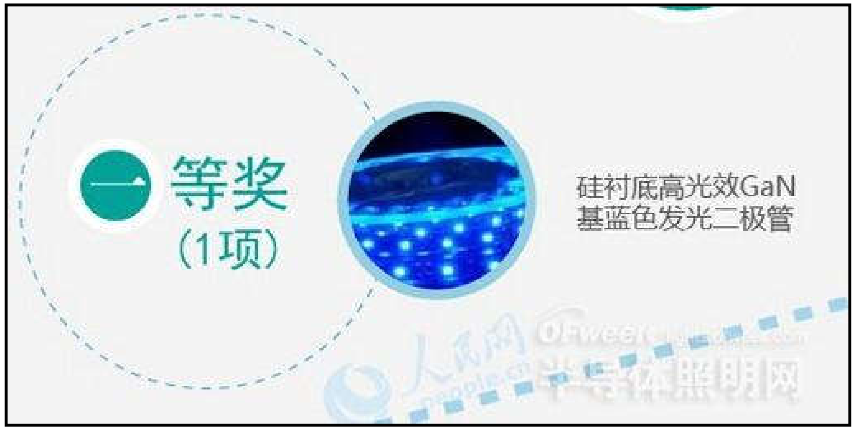

H. Amano


S. Nakamura

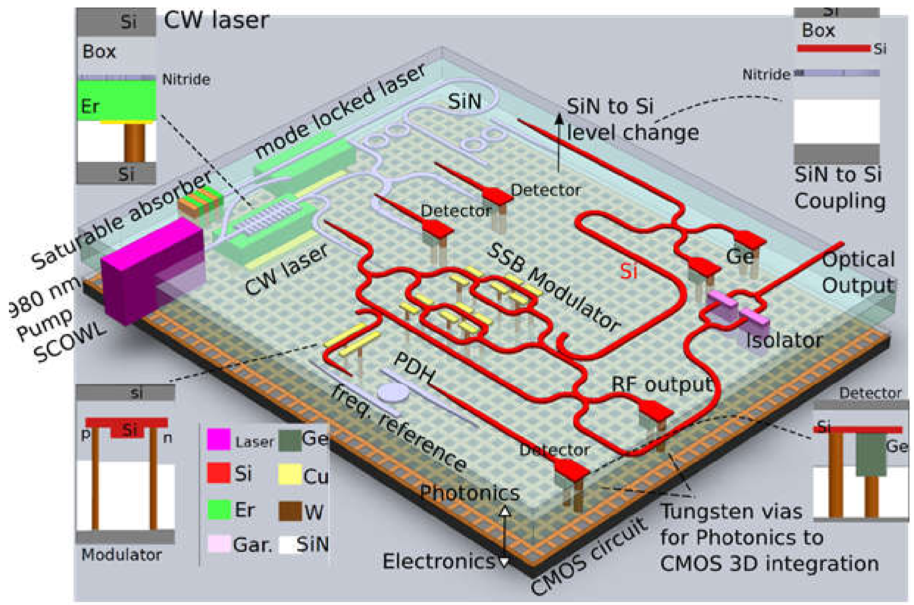
- **GaN LED on silicon carbide (SiC)**
  - USA, Cree

CREE™

- **GaN LED on silicon**
  - 中国，南昌大学
  - 2015年中国技术发明一等奖



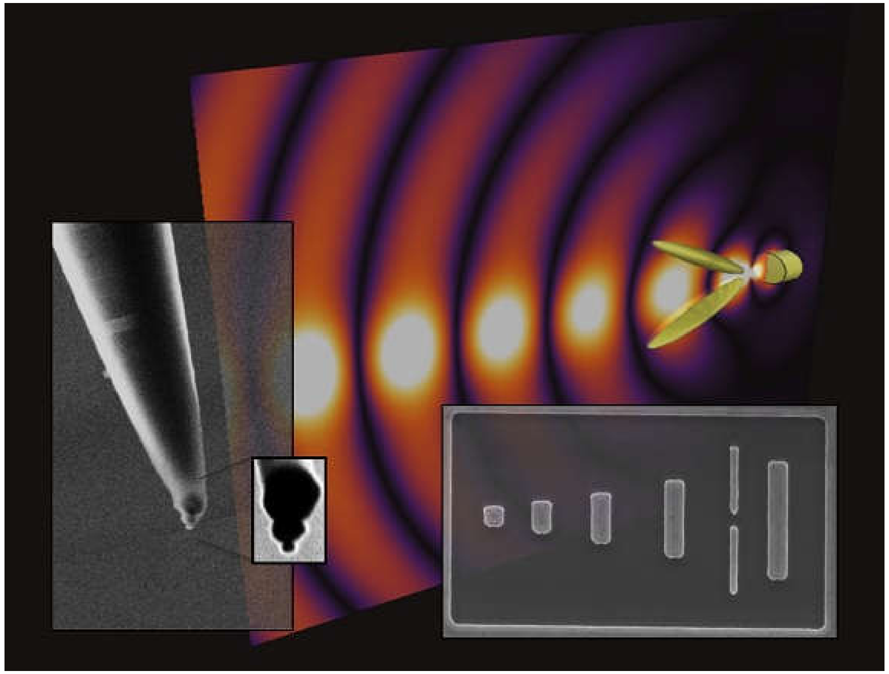
Integrated Photonic Circuits



Conventional optics

Integrated photonics

Integrated Photonic Circuits



Microwave Antenna

Optical Antenna

Thank you for your attention