EEE6040: High Speed Electronic Devices

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Room F164b

Content

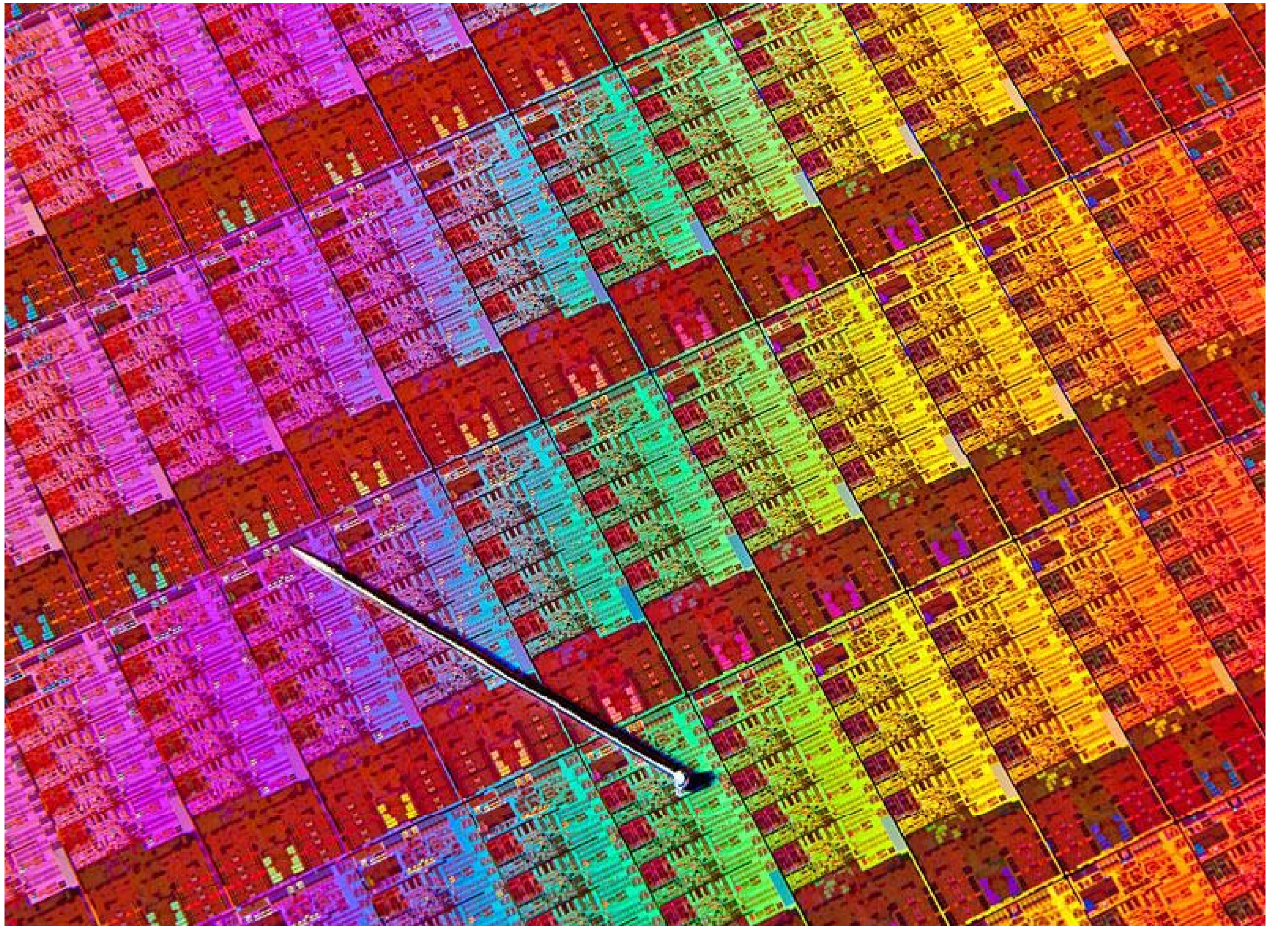
20 Lectures

2 Tutorials

1 Assignment

Additional materials

10 Credits



Intel 4th generation Core processors -'Haswell' Architecture - 2013

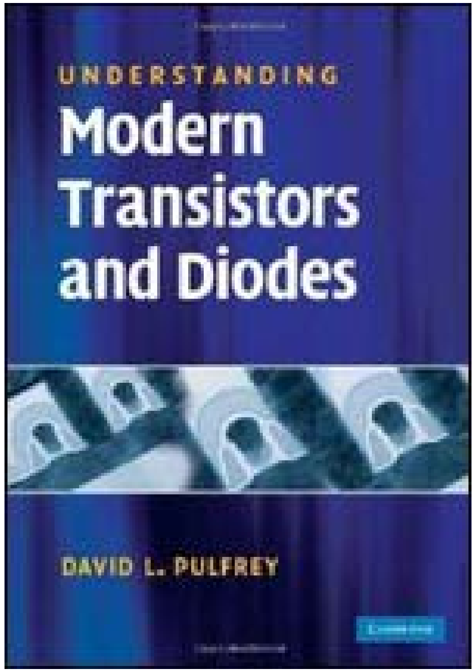
The course aims to:

- Establish the need for high speed/high performance solid state electronic devices
- Introduce the main classes of electronic devices today and outline the physical effects which control their operation
- Describe the benefits and limitations of integrated circuits and device miniaturisation
- Discuss the limitations on device performance due to physical effects
- Describe the present state-of-the-art in electronic devices and discuss their evolution and future functional improvements
- Explore the upper limitations on frequency and power performance of electronic devices and discuss future strategies.

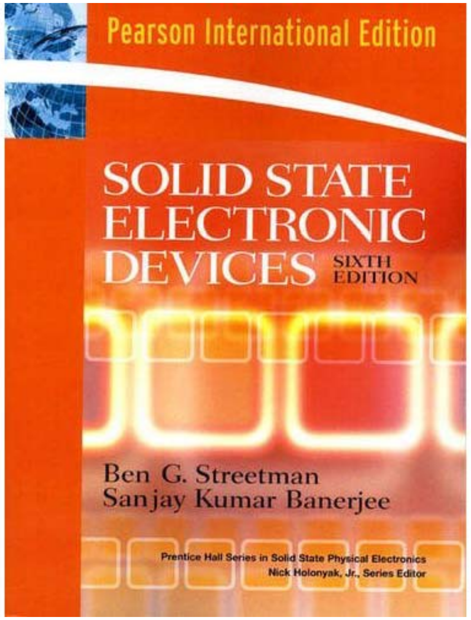
The objective is to provide an understanding of:

- The different types of solid-state device, the technological approach used and their basic device characteristics.
- The physical phenomena which control device performance and the methods used to enhance performance
- An understanding of integrated circuit technology and how discrete devices translate into integrated circuits
- The development of CMOS technology and its future perspectives
- What device approaches might be available in the future to further advance performance.

Recommended Books

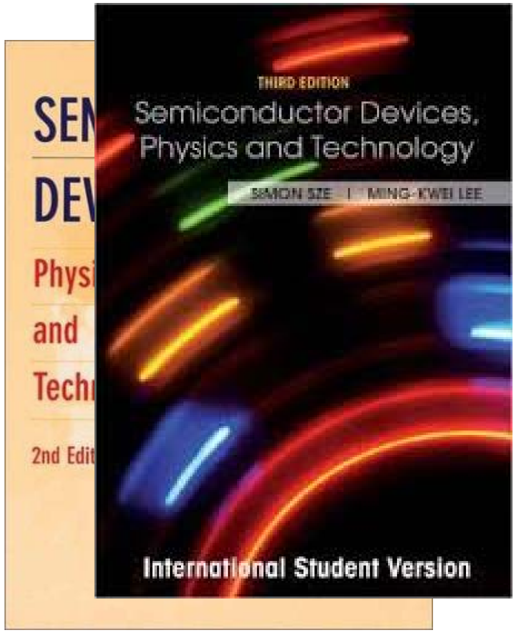


Understanding Modern Transistors and Diodes by David Pulfrey



Solid State Electronic Devices (Paperback) by Ben Streetman and Sanjay Banerjee

Semiconductor devices: Physics and Technolology. S.M.Sze and M-K.Lee



Semiconductor Devices: Physics and Technology (Hardcover) by Simon M. Sze

Part 1: Introduction

What do we mean by high speed Electronic devices?

What materials and structures are used?

What are the application areas?

How does this field look at an industrial level and how is it developing?

So what do we mean by high speed electronic devices?

These are solid-state electronic devices in which excess electrons and holes are engineered to provide conduction under certain voltage conditions

By virtue of their design and small size they can perform switching and amplification roles at very high speed (up to 100GHz in some cases)

Many of these materials are also able to absorb (detect) and emit light and can also perform these roles at high speed for optical communications

So where do you find these devices?

In almost every modern consumer and industrial application!

EEE6040 High Speed Electronic Devices

Solid-state electronics

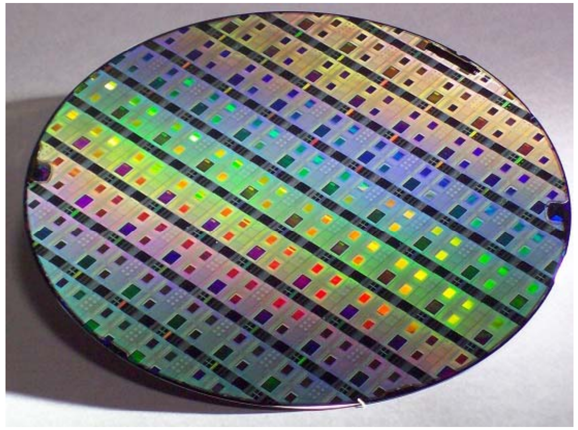
The materials we use are all solid elements or compounds with semi-metallic or semi-conductor behaviour. They all tend to come from the same region of the periodic table and therefore have similar electronic properties.

II	III	IV	V	VI
	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00
	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07
30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96
48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6
80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)

Other properties include:

- The formation of ordered crystalline structures.
- Electrical conductivity that can be modified over several orders of magnitude
- The presence of a energy gap (band gap) within which no electron states can exist.
- An interaction with light (photons) of energy above the band gap

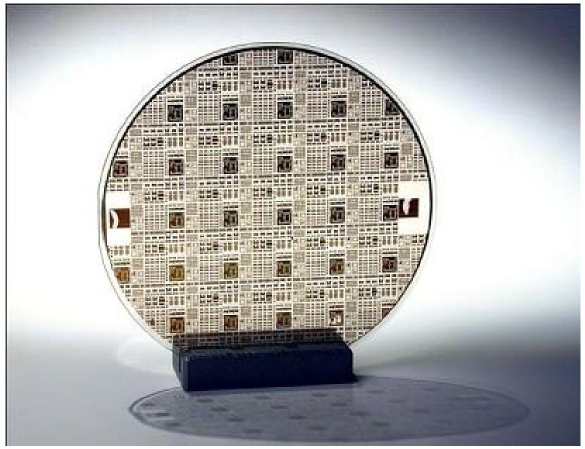
Semiconductor Materials



Elemental semiconductors: Si, Ge, C, Sn

Silicon is dominant in the electronics industry and has a major role in photonics (detectors, image sensors, optical systems)

Compound Semiconductors: GaAs, GaN, SiGe, InP, SiC, InGaAs, AlGaN, AlGaInP, InGaAsP..

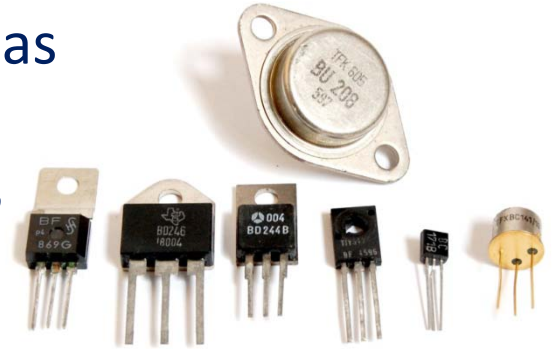


Represent about 10% of the market share. Play an important role in high speed electronics & power electronics and a key role in photonics (lasers, LEDs, detectors, photovoltaics etc)

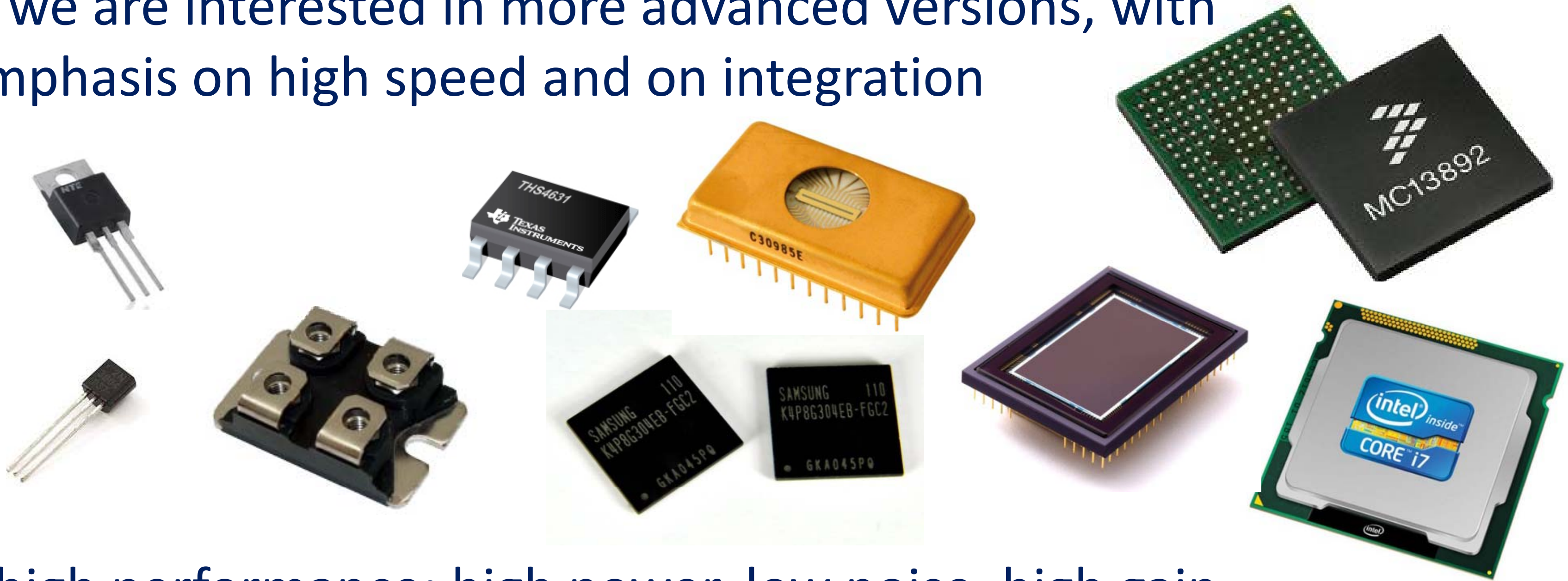
Types of device and function

The focus of this course is not so much on the basic function of semiconductor devices, such as transistors, diodes, FETs etc.

(this should be well covered by previous courses, though we will do some revision)



Here we are interested in more advanced versions, with an emphasis on high speed and on integration



Also high performance: high power, low noise, high gain

The need for high-speed devices

All aspects of our lives are now dominated by Information and Communications Technology (ICT)

We desire to access, transmit, process and store data at ever greater speed.

Wouldn't we all want ultrafast internet everywhere, the ability to share large files instantaneously, to read every book, watch ever film and see every picture?

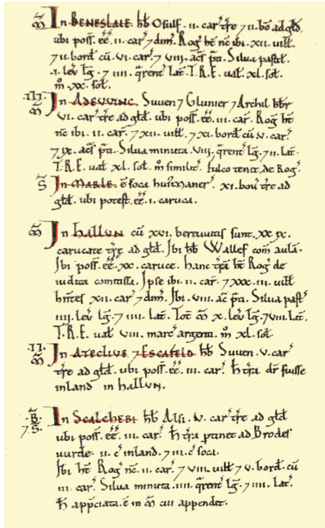
To use all this technology to help us with our work, entertain us at play and help manage our lives?

The ICT revolution

Written information through the ages

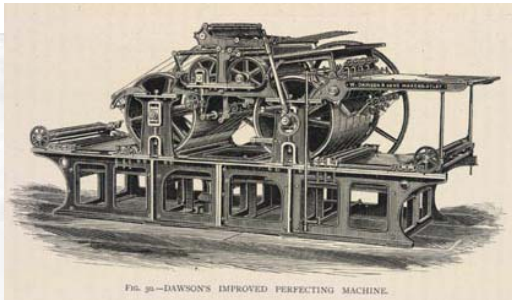
Mesopotamian Stone Tablet c3000B.C,

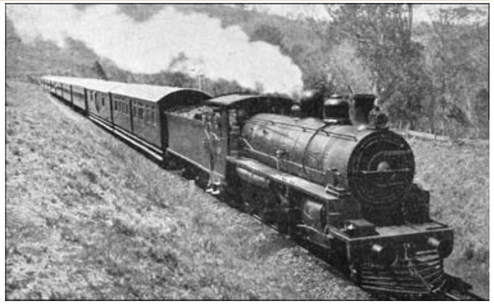
Chinese Court Paper Scroll c300A.D



Doomsday Book c 1086

Gutenberg printing press c1440





Mass produced Newspapers c1780

The ICT revolution

Development of the internet, digital media rendering, consumer computing devices c 1980

Digitisation & electronic storage/transfer of all forms of media

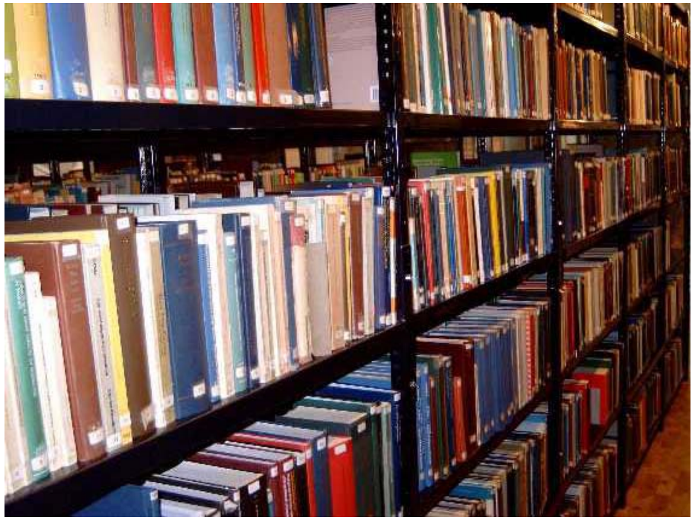
The ICT revolution

Sum of all human ‘pre-digital’ information (books, papers, photographs, analogue recordings) ~10 exabytes

(1 excabyte= 10^{18} bytes or 1 billion gigabytes)

In 2010 the World digital content was around 500 Exabytes

Estimates for 2020 are in the range of 5,000 Exabytes



20^{th} century information store

21^{st} century information store

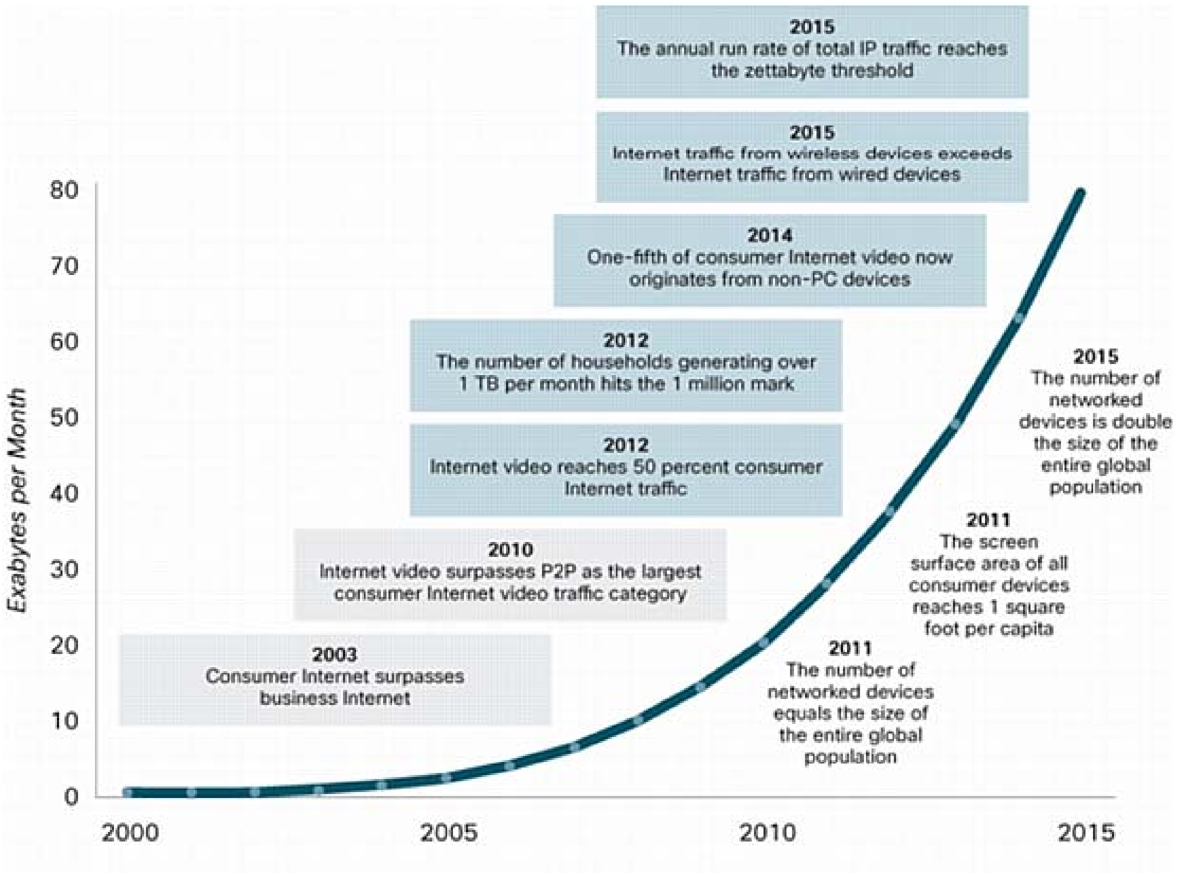
The ICT revolution

Current global internet traffic ~ 50 exabytes per month

Doubling every 2-3 years. Will soon reach a zetabyte per annum

Already passed one network device per head of population

Figure 1. Five Traffic Milestones and Three Traffic Generator Milestones by 2015

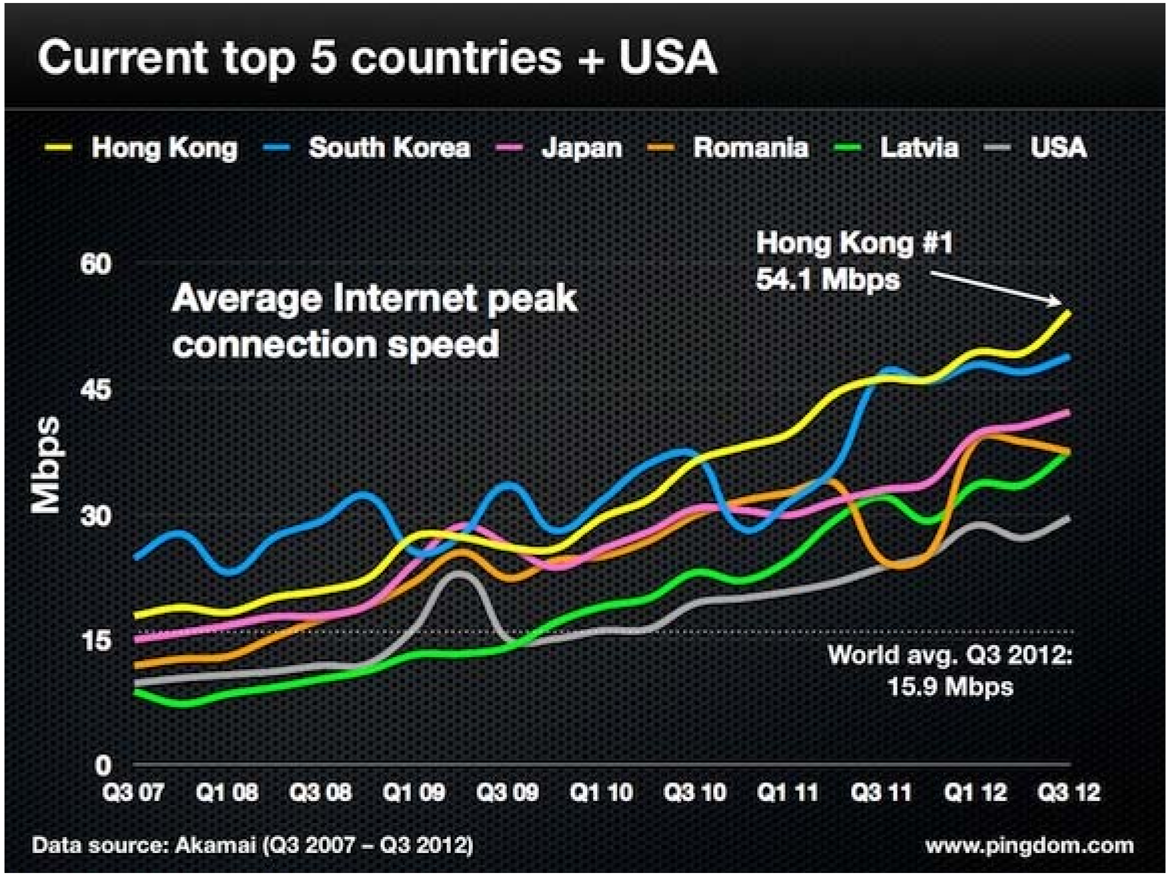


Source: Cisco VNI, 2011

The ICT revolution

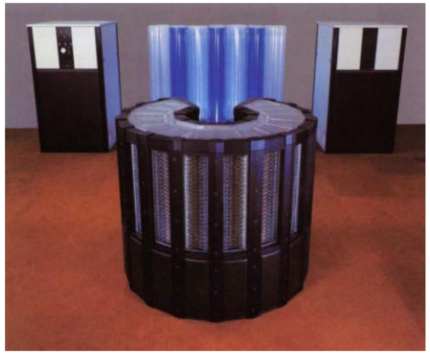
World average peak interconnection speed ~ 16Mbps (UK average ~ 9Mbps)

Doubling every 3-4 years, though not for every user (new fibre broadband installations capable of 100Mbps)



If you want the best internet- go to Hong Kong or South Korea!

High performance applications



Computing

Fastest computers (Cray, Riken, IBM) are running at a few Petaflops (10^{15} **FL**oating point **O**perations **P**er **S**econd)

Fastest general purpose PC running about 80Gflops. Typical PC ~ 10 Gflops

Flops/$ and Flops/watt are very important. We are now down to about 10M$/Petaflop and 10MW/Petaflop

Estimates suggest the human brain can process about 40 Petaflops and uses only ~ 20Watts!

High performance applications

Data Transfer

Mobile

Frequencies: 900, 1800, 2600MHz. Data rates: 3G up to 22Mbits/s, 4G up to 1Gbits/s (4G)

WiFi: Frequencies: 2-6GHz. Data rates: up to 54Mbits/s (802.11g)

Digital TV

Frequencies(DVB-T): 474-850MHz (DVB-T), 10-12GHz (Satellite). Data rates: 1-3Mbit/s per channel

Fixed line Internet

Data rates. ADSL (copper wire) up to 8Mbits/s,Cable: up to 50Mbits/s, BT optical fiber 2.5Gbits/s. Internet fiber backbone (level 3) 40Gbits/s

High performance applications

Data Storage

Magnetic hard disk

PC hard disk- typical 70-100 Mbit/s, 500Gbytes

Server hard disk up to 3Gbit/s, up to 10Tbytes per drive

Solid state memory

DRAM typically 50-90Mb/s. High end embedded DRAM up to 1.6Gb/s.

Largest chip = 4Gbytes

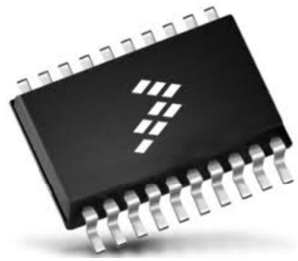
Flash (solid state hard drive, memory cards etc): 4-200Mb/s

NB: Data transfer-USB 2.0 480Mb/s, USB 3.0 (up to 4.8Gb/s)

High Speed Electronic Devices

Digital circuits required for high speed digital processing, internet infrastructure, servers, storage and test equipment. Driven by the growth of the internet.

Dominant technology: Si CMOS

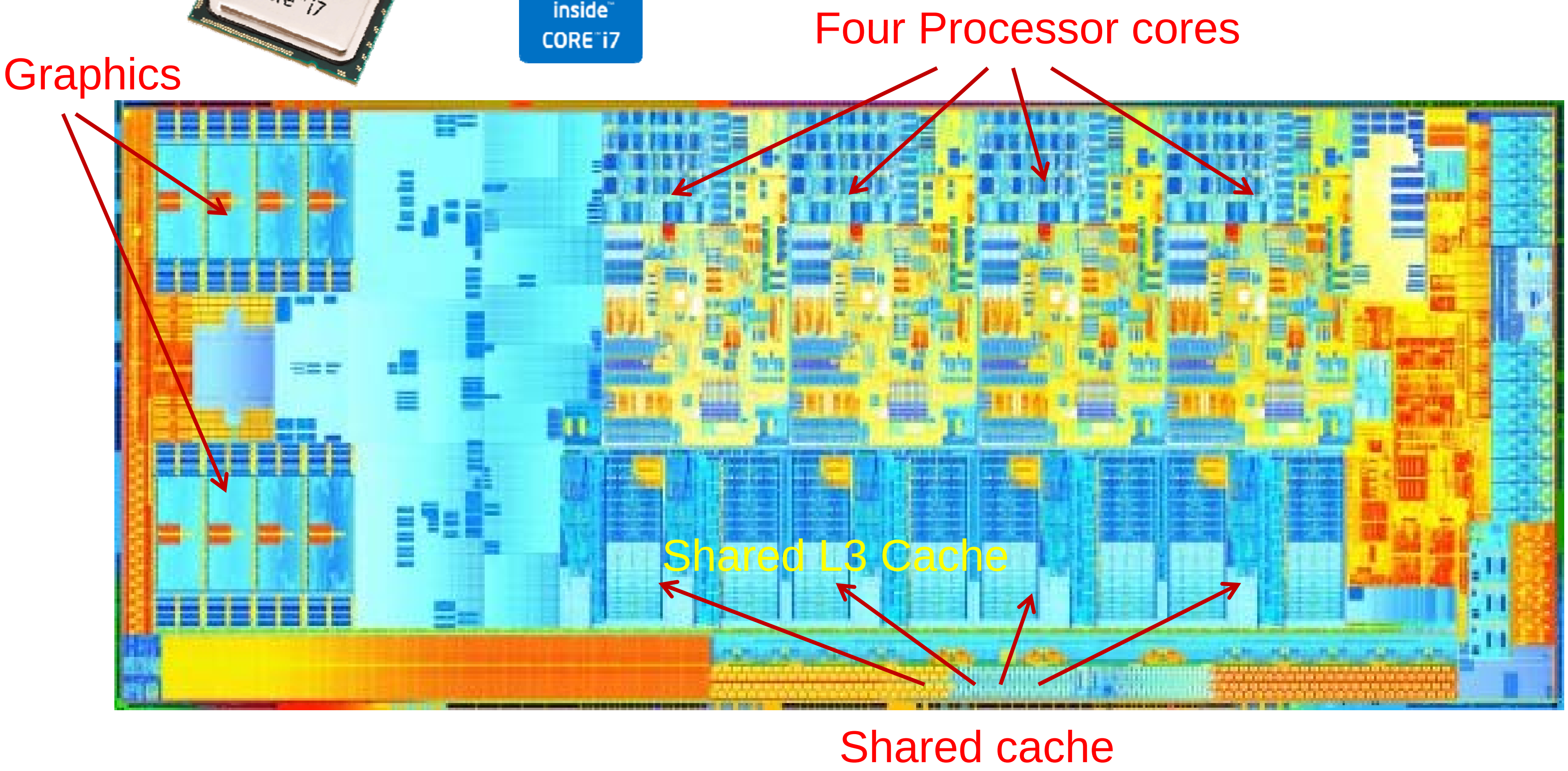


Analogue circuits required for real time signal processing, ADC, mod/demod, mux/demux at microwave frequencies. Driven by demands from mobile phone, satellite& other high frequency communications and RADAR.

Mixed technologies (Si, GaAs, InP MMIC)

At the forefront- CMOS processor technology

Intel Core i7- 4th Gen (Quad)
1.6billion transistors per core, 3.5GHz,
22nm tri-gate CMOS process



Global semiconductor market

The total market for semiconductor devices is now about 350 billion US$ p.a (increasing at 6-9% p.a)

This feeds an electronic equipment market of value of about 1.2 trillion US$ p.a

The total economic ‘added value’ of this equipment is estimated to be in the region of 40 trillion US$

Semiconductors are one of the worlds largest industries

<u>Important segments</u>

Integrated circuits: Computing 110B$, Smartphones 105B$, Memory 35B$, ASIC 30$

Discrete semicondcutors: Power devices 16B$, LED 12B$, Lasers 3B$, detectors/sensors 2B$

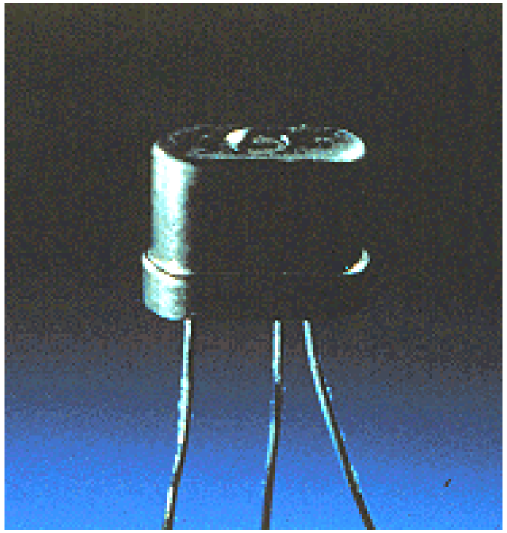
Global electronic device market

Company	Origins	Country	Main products	Sales (B$)
Intel	Gordon Moore & Robert Noyce from Fairchild	USA	Microprocessors, motherboard chipsets, Network interface controllers, flash memory, graphic chips, embedded processors.	49
Samsung	Cheil Woolen Fabrics	Korea	DRAM, flash memory, embedded processors	28
TSMC	Taiwan Semi. Mfg. Co. 1987	Taiwan	Microprocessors, mixed-signal, analog cicuits	17
Texas Inst.	Geophysical Service Inc. 1930	USA	Embedded processors, digital signal processors,, power management, analog circuits, wireless chipsets	11
Toshiba	Tokyo Denki - Electric Lamps 1890's	Japan	DRAM, flash memory, embedded processors	10.6
Renesas	Nippon Electric Co. (telephones) 1898. Demerged 2010	Japan	Embedded processors, digital signal processors,, power management,	9.1
SK Hynix	Hyundai construction 1947. Demerged 2012.	Korea	DRAM, flash memory,	9
ST Microelectronics	Società Generale Semiconduttori & Thomson. Merger1987	Italy/France	Embedded processors, digital signal processors,,	8.4

Some large 'fabless' comanies such as Qualcomm, Nvidea and AMD do not appear on this list. These companies design and specify the production of ICs, but have them made under contract elsewhere

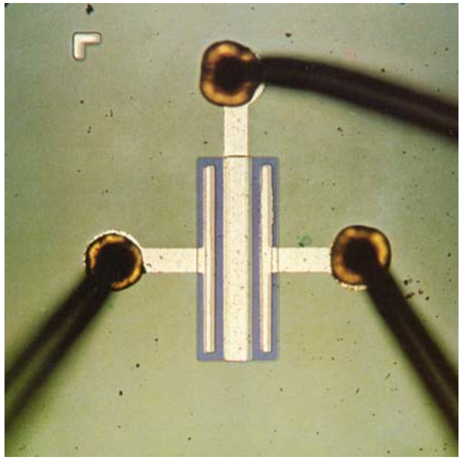
Development of Solid-state Electronics

First transistor (Ge) developed by John Bardeen, Walter Brattain and William Shockley at Bell Labs in 1949

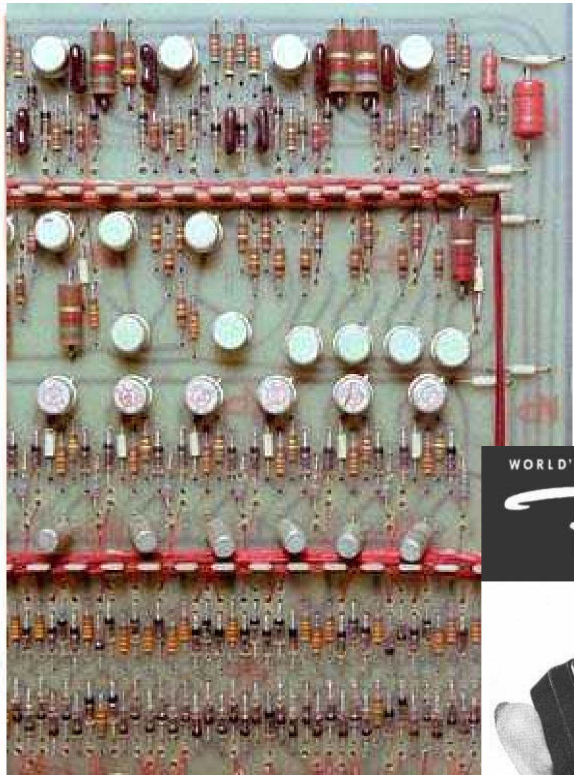


First Commercial bipolar transistor by Texas Instruments in 1954

Early MOSFET (Fairchild ,1961), following on from John Atalla and Dawon Kahng's first demonstration at Bell Labs in 1959



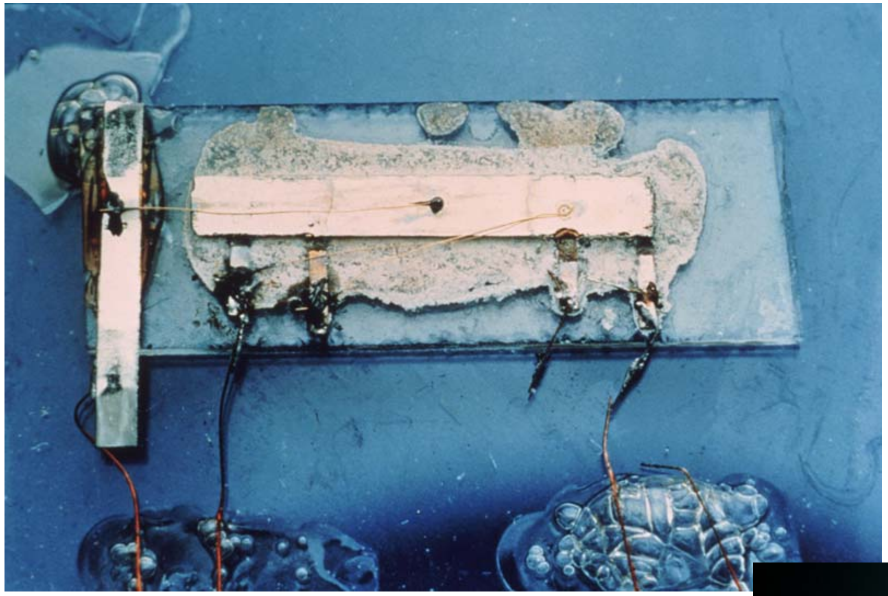
Development of Solid-state Electronics



Typical circuit boards from the 1950’s and 1960’s showing the assembly of discrete transistors, diodes, resistors, capacitors

Advert for the first mass-produced transistor consumer device; the Regency radio developed by Texas Instruments in 1954

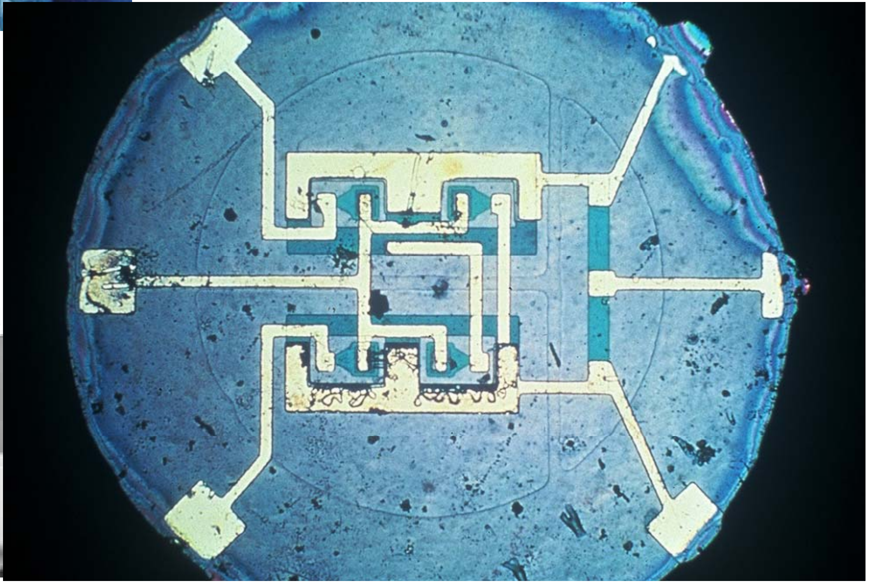
Development of Solid-state Electronics



In 1958, Jack Kilby (Texas Instruments) realised the first integrated circuit. The major step was to make all the components out of silicon (both active and passive)

In 1961 Robert Noyce (Fairchild) realised the first commercial IC.

This took the Kilby idea further through the deposition and etching of metal to provide interconnects

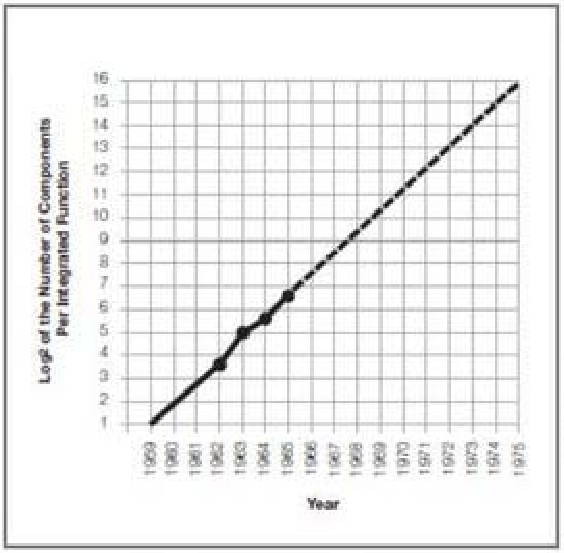


Development of Solid state Electronics

One of the characteristics of solid-state electronics is that there has always been the demand for greater future performance for the same (or lower cost)

Gordon Moore, one of the founders of Intel (with Noyce) wrote in 1965 about how integrated electronics could deliver on this ambition.

He suggested an economic trend which has become known as Moore's law.



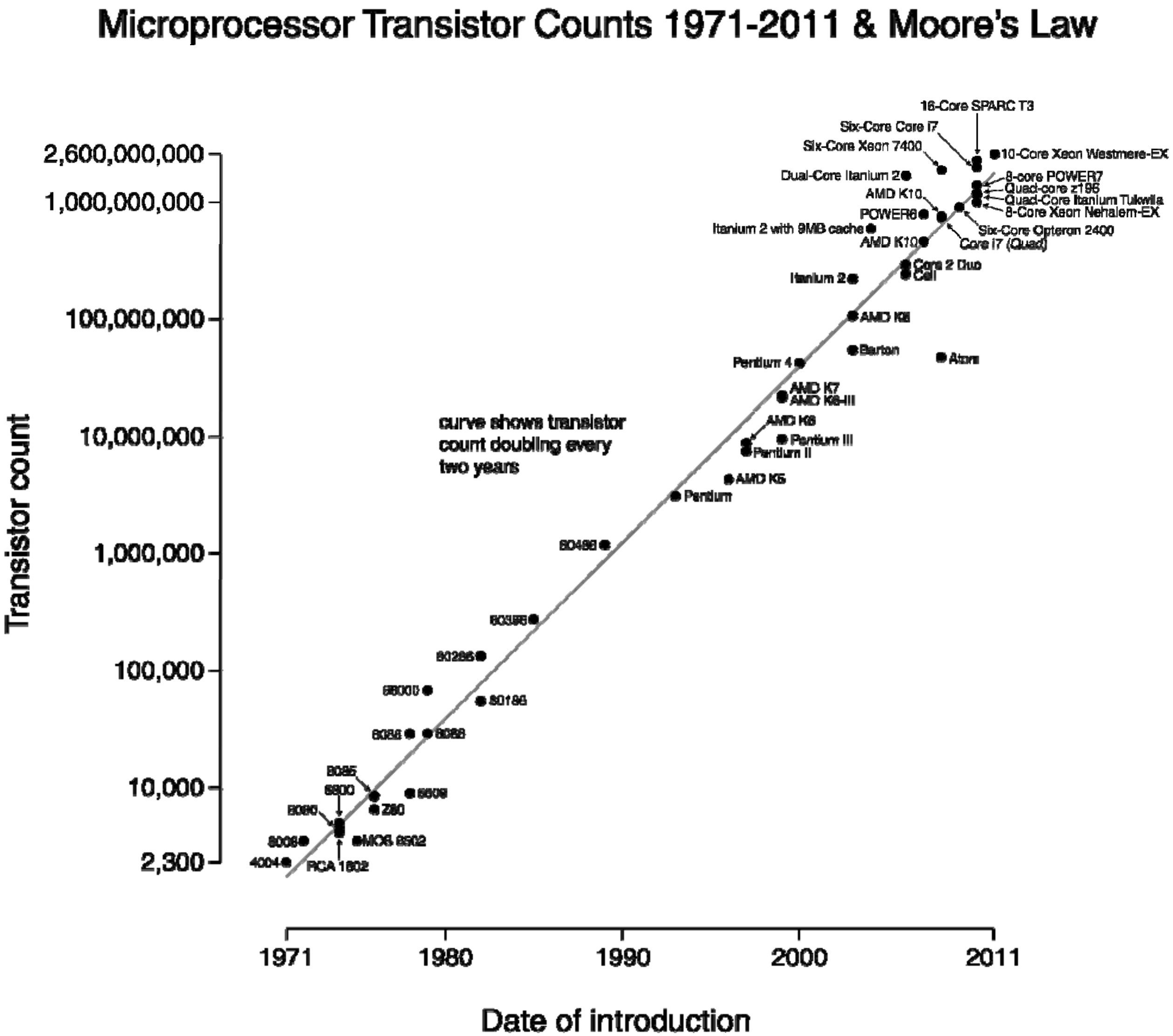
"**Reduced cost** is one of the big attractions of integrated electronics, and the cost advantage continues to increase as the technology evolves toward the production of larger and larger circuit functions on a single semiconductor substrate."
Electronics, Volume 38, Number 8, April 19, 1965

Development of Solid-state Electronics

Moore realised that the size of transistors could be continuously scaled down, resulting in a higher number per IC (for about the same price)

Moore's law is an empirical observation that the number of transistors on an 'affordable' IC doubles every two years.

The reasons for the doubling are quite complex and partly economic



Development of Solid-state Electronics

Moore's law equivalents

Transistors per IC.

Cost per transistor

Memory cost per storage unit

Computing performance per unit cost.

Processing Speed per IC

Power consumption per transistor

Pixels per unit area

Moore's law has held up remarkably well for over 40 years

It is still largely based on the scaling down of silicon electronics

There have always been times when the law looked like it might be breached

Technological issues: Defects, lithography, metallurgy, material limitations, leakage, physical fundamentals

Economic Issues: Oil crisis of 1973, banking crisis 2007, company revues, cost of technology steps

Development of Solid-state Electronics

So will Moore's law continue?

No Moore

Science and technology

No Moore?

The Collapse of Moore's Law: Physicist Says It's Already Happening

Moore's Law Is Dead: The Future Of Computing

We can no longer guarantee that computer chips will keep growing smaller and more powerful. In fact, we're getting close to capacity. What does this mean for the future of computing?

The Moore's Law blowout sale is ending, Broadcom's CTO says

Moore's Law bending, ready to break

Intel's former chief architect: Moore's law will be dead within a decade

More Moore

Intel reveals 14nm PC, declares Moore's Law 'alive and well'

But is Chipzilla whistling in the dark?

By Rik Myslewski, 10th September 2013

15 Moore's Years: 3D chip stacking will take Moore's Law past 2020

Intel's 22nm 3D Transistors Will Keep Moore's Law Alive

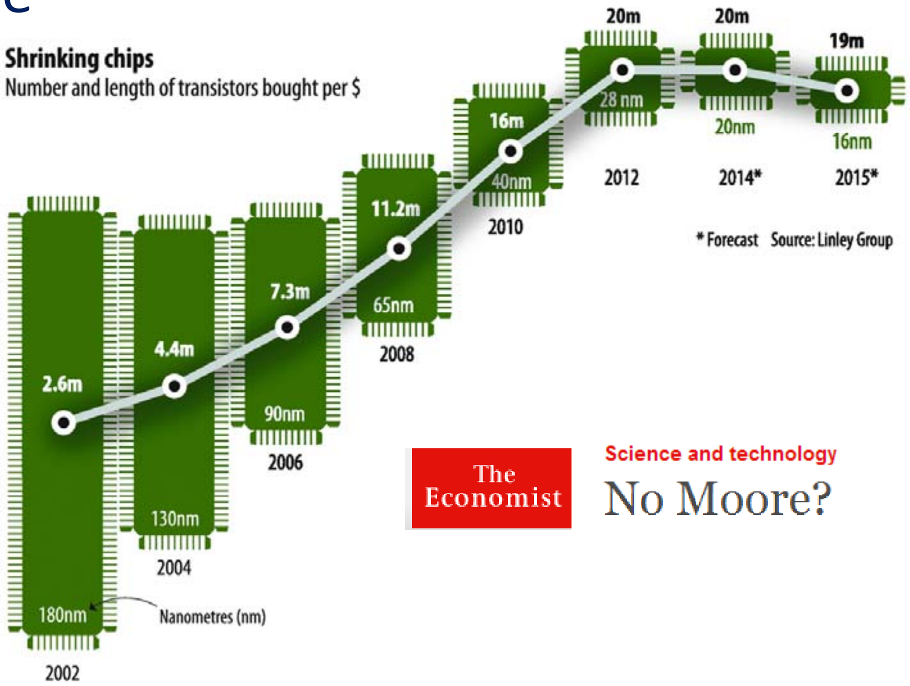
Nanowire Transistors Could Keep Moore's Law Alive

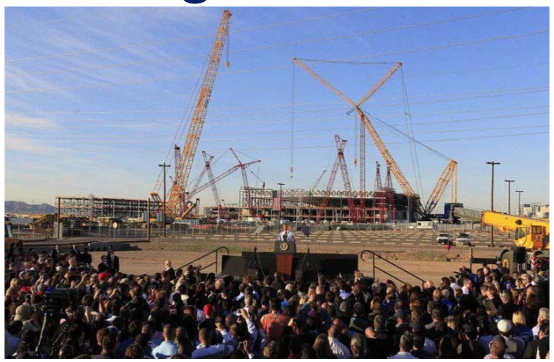
Moore's Law to roll on for another decade

Development of Solid-state Electronics

The main issue is not necessarily technological progress, though there are some barriers on the horizon, but the cost of implementing it. Each step in the scaling progress has become progressively much more expensive

As we scale down further the cost per transistor is beginning to saturate and maybe even increasing





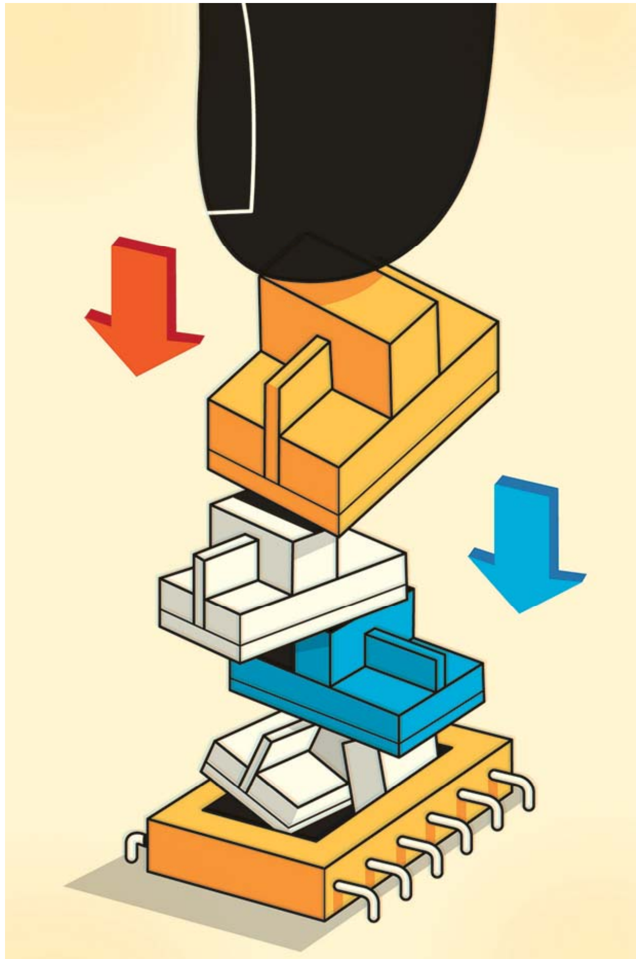
In 2014, Intel mothballed a new 5B$ fab in Arizona designed for next generation of 14nm processors

For those who are interested, read

IEEE spectrum

“The end of the shrink”

“Moore’s law is not over, but things are getting really difficult”



Development of Solid-state Electronics

It may be that a host of new technologies can rescue Moore's law and that new applications can supply the revenues to achieve this

New technologies: new materials (eg: III-V CMOS, graphine), new structures (nanowire, quantum dot), or perhaps entirely new approaches (eg: quantum computing, optical processing)

New applications: 5G wireless, wearable devices, 4K TV, electronic paper, smart homes and offices, self driving vehicles

We will discuss some of these issues later