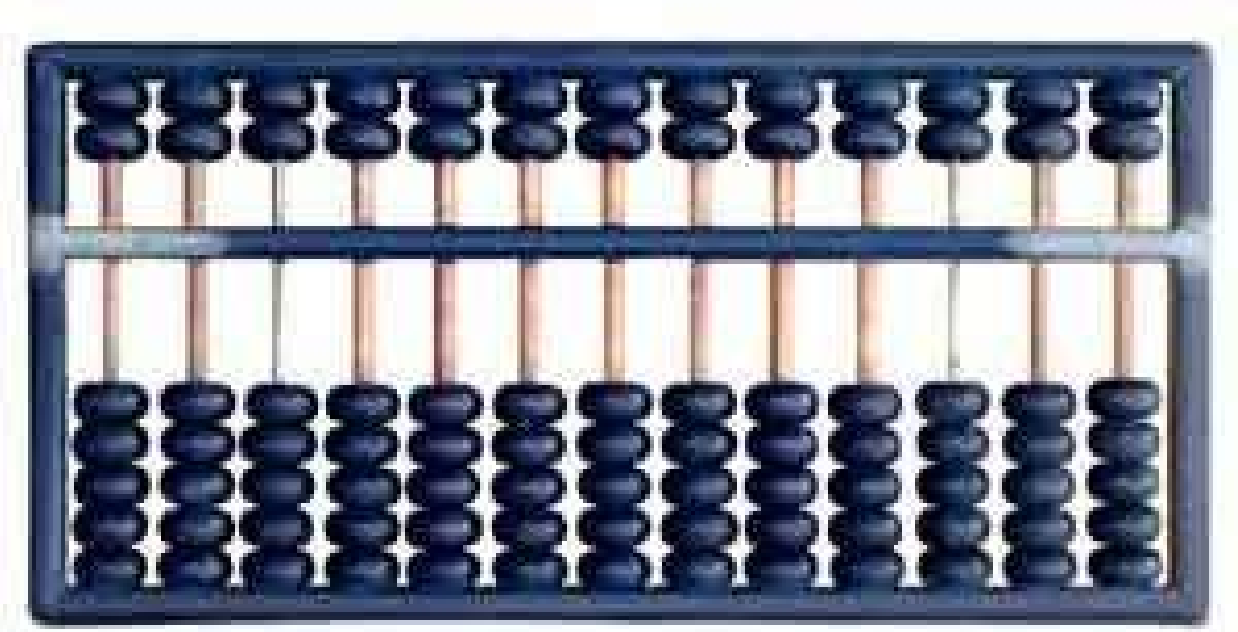
Review: History of computers: mechanical calculator

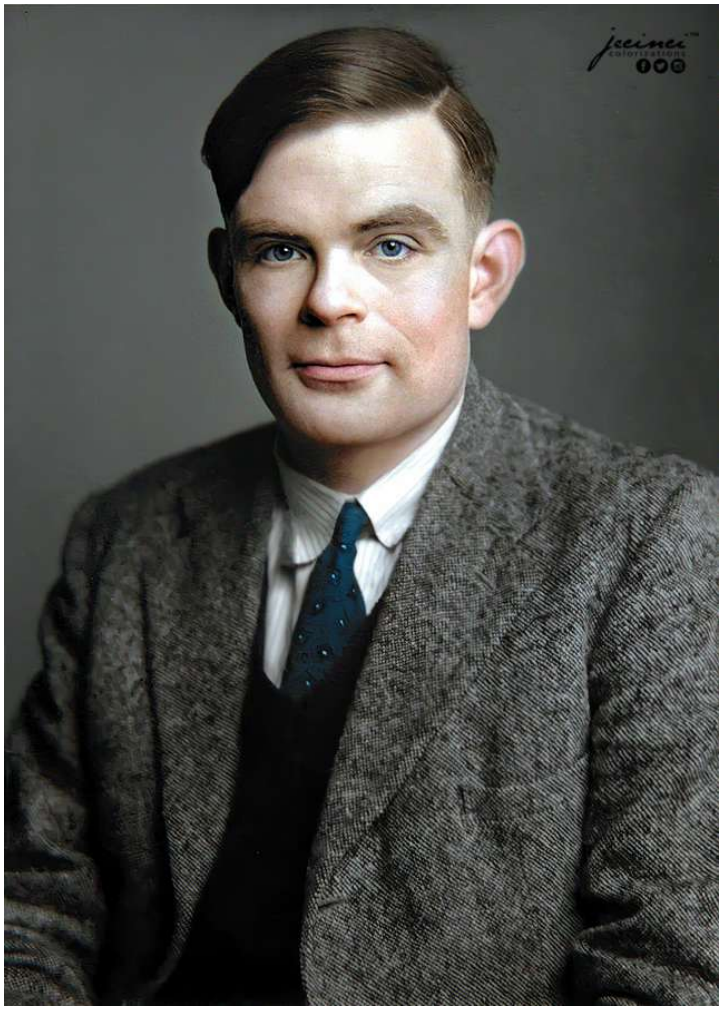
- Abacus, used in Babylon, China, etc., thousands years ago
- Move the bead up and down to add and subtract
- Could not do multiplication or division directly



https://www.omnicalculator.com/physics/trajectory-projectile-motion

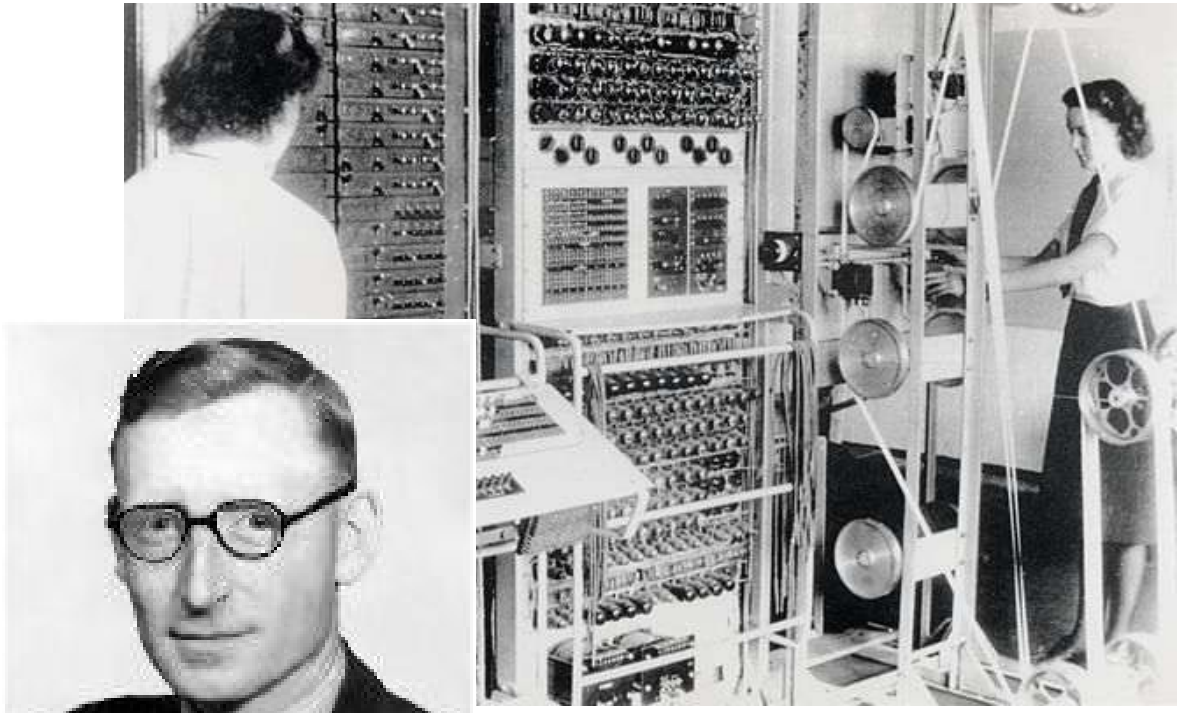
Review: History of computers

- **Alan Turing '*On Computable Numbers*'** in 1936
- The paper proved that a machine capable of processing a stream of 1s and 0s (binary) would be capable of solving any problem.
- Father of theoretical computer science



Review: History of computers: electronic calculator

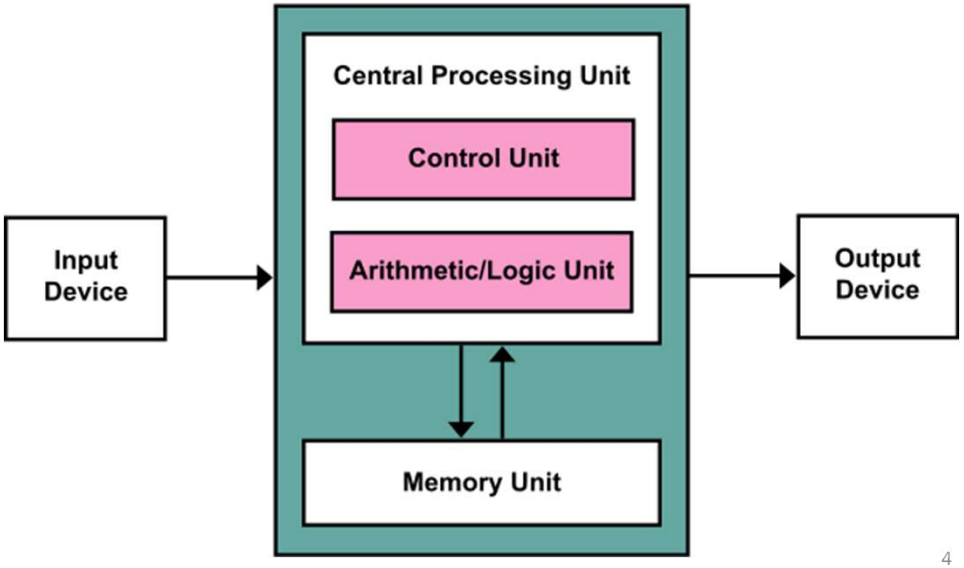
- **Colossus**
- Designed by **Tommy Flowers** and his colleagues in 1943-1945
- First programmable, **electronic**, digital computer
- It was used to crack the German's Enigma code
- Calculation it was able to solve in two hours, would take humans eight weeks to finish



https://en.wikipedia.org/wiki/Colossus_computer

Review: History of computers

- von Neumann architecture
- 1945, developed by von Neumann, based on discussions with John Presper Eckert and John Mauchly
- Adopted by most modern computers



Review: History of computers

First generation are those made with vacuum tubes.

Computer	Date	Units	Notes
IBM 604	1948	5,600	First all-electronic calculator for use with unit record equipment. Could multiply and divide data from punched cards. Had 1,250 tubes.
IBM CPC	1949	700	Combined an IBM 604 with other unit record machines to carry out a sequence of calculations defined by instructions on a deck of punched cards.
Ferranti Mark 1	1951	9	First commercially available stored program computer, based on Manchester Mark 1.
UNIVAC I	1951	46	First mass-produced stored-program computer. Used delay-line memory.
LEO I	1951	1	First computer for commercial applications. Built and used by J. Lyons and Co., a restaurant and bakery chain. Based on EDSAC design.

Review: History of computers: 4th generation

- Very Large Scale Integrated (VLSI) circuits, VLSI circuits contained about 5000 transistors on a very compact chip: Microprocessor
- Microprocessor-based **fourth generation of computers**
- Data processing logic and control is included on a single integrated circuit (IC), or a small number of ICs.
- Microprocessors enables significant reduction of computer sizes

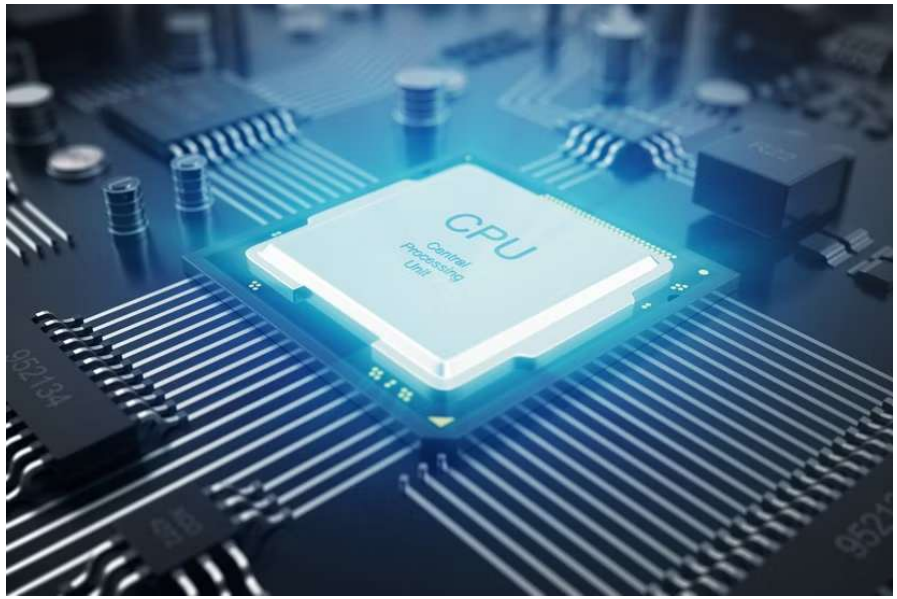
Review: Super computers

- **High performance computer systems**
  - primarily for scientific and engineering work requiring exceedingly high-speed computations.
  - Applications including weather forecasting, nuclear weapons, earthquake simulations
- **Significant progress was made in the first decade of the 21st century.**

https://www.britannica.com/technology/supercomputer

Review: Development of Processor

- The processor is the “brain” of the computer
- A higher transistor density in a CPU generally means more processing power and functionality
- The processor is an essential component of a computer system, as it determines the speed and performance of the system.



Review: INTEL DUAL CORE

- Introduced in 2006.
- It is 32-bit or 64-bit μP.
- It has two cores.
- Clock speed of 1.3 GHz to 3.4 GHz

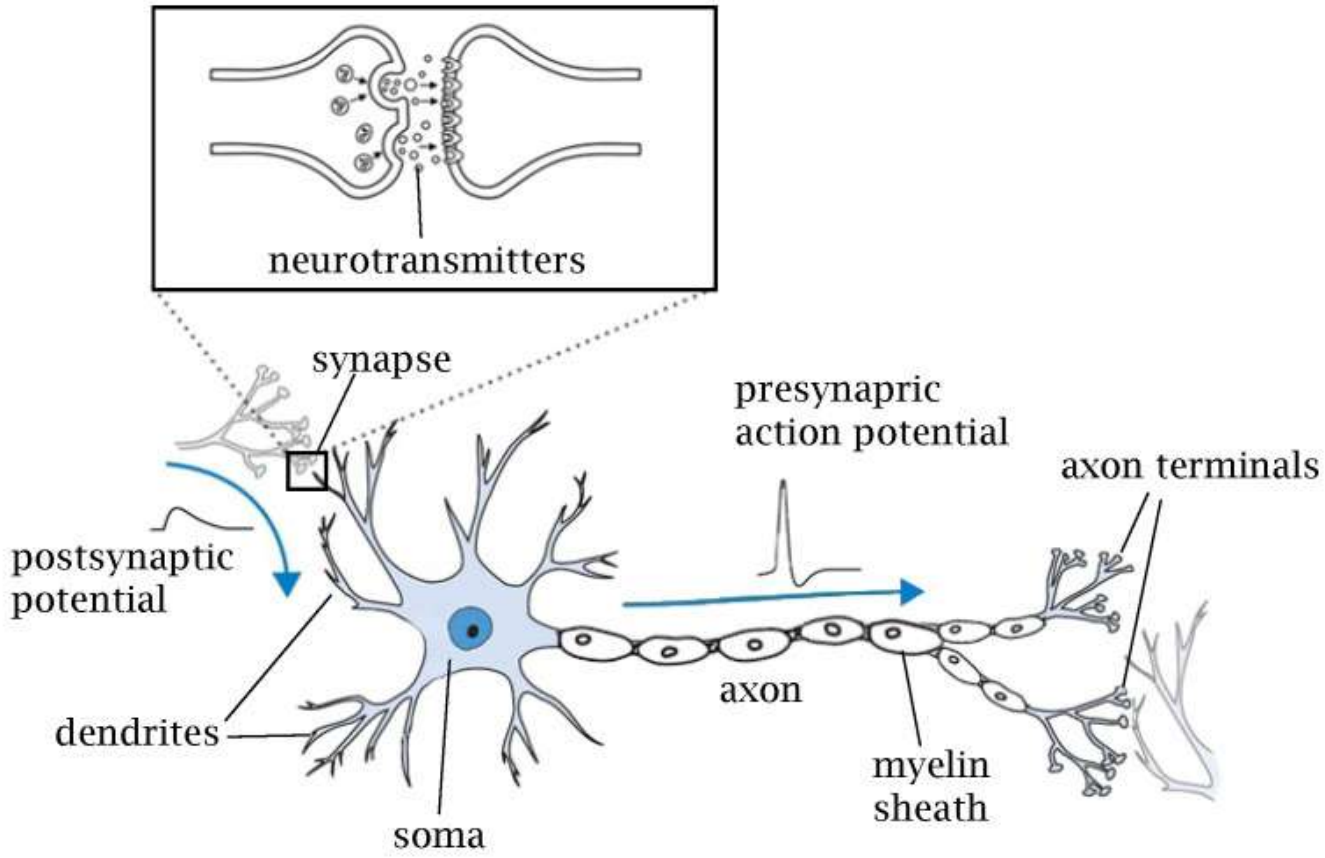
Review: Quantum computers

Classical computing vs. quantum computing

Classical computing	Quantum computing
Used by large-scale, multipurpose computers and devices.	Used by high-speed, quantum mechanics-based computers.
Information is stored in bits.	Information is stored in quantum bits.
There is a discrete number of possible states: 0 or 1.	There is an infinite, continuous number of possible states.
Calculations are deterministic, meaning repeating the same input results in the same output.	Calculations are probabilistic, meaning there are multiple possible outputs to the same input.
Data processing is carried out by logic and in sequential order.	Data processing is carried out by quantum logic at parallel instances.
Operations are defined by Boolean algebra.	Operations are defined by linear algebra over Hilbert space.
Circuit behavior is defined by classical physics.	Circuit behavior is defined by quantum mechanics.

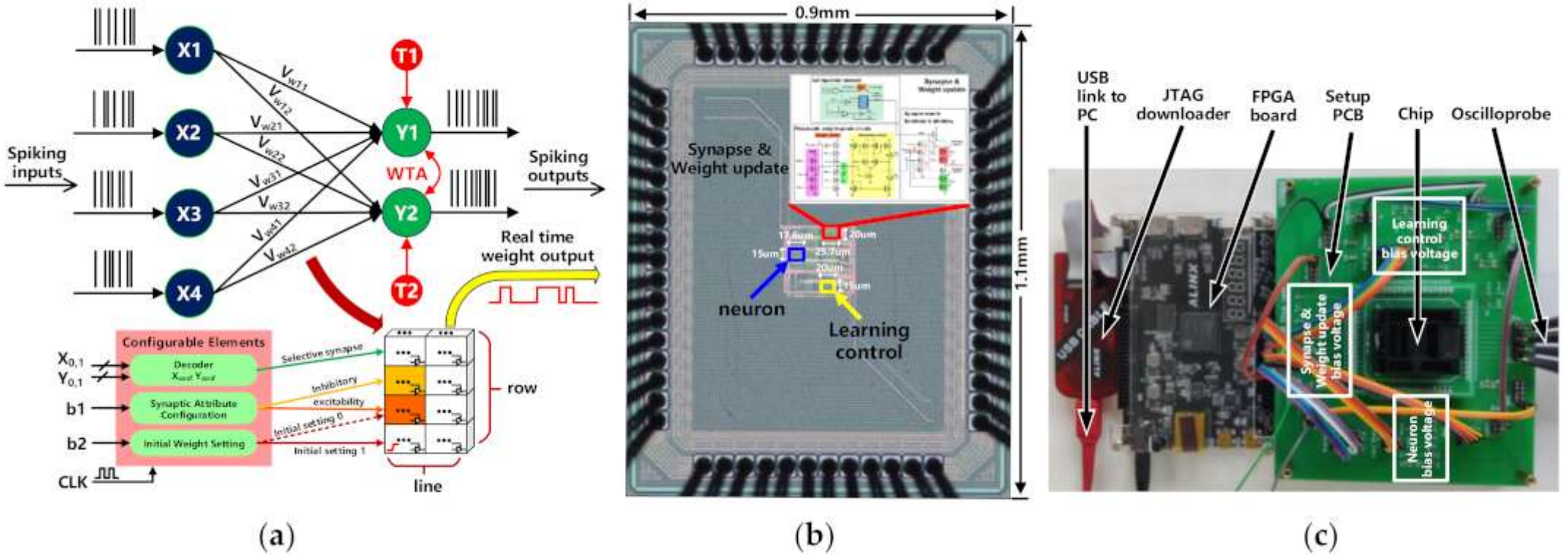
https://www.techtarget.com/searchdatacenter/tip/Classical-vs-quantum-computing-What-are-the-differences

Review: Spiking Neural Networks



https://pmc.ncbi.nlm.nih.gov/articles/PMC9313413/

Review: Neuromorphic computing



Reconfigurable SNN implementation. (**a**) Proposed SNN chip structure diagram. (**b**) Chip micrograph. (**c**) Prototype measurement system.

https://www.mdpi.com/2079-9292/12/19/4147

Trade war between U.S. and China

Go find another 'sucker': Trump threatens 100% tariff on BRICS countries over Dollar alternatives

ET Online • Last Updated: Dec 01, 2024, 10:37:00 AM IST

Synopsis

President-elect Donald Trump threatens 100% tariffs on BRICS exports if they try to replace the U.S. dollar in global trade. This warning follows the BRICS summit where strategies to boost non-dollar transactions were discussed. Russian President Putin indicated limited progress on creating a unified BRICS currency or an alternative to SWIFT.

In a rather stern warning to the BRICS

Chip war between U.S. and China

Introduction to Function Hub For Sustainable Future

Lecture 11： Chip Production

Qichun Yang

2024-12-02

香港科技大学(广州)
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

Vocabulary of this lecture

- **Transistor:** 晶体管
- **Miniaturization:** 小型化
- **Semiconductor:** 半导体
- **Voltage:** 电压
- **Electron:** 电子
- **Germanium:** 锗
- **Conductor:** 导体
- **Insulator:** 绝缘体
- **Logical operation:** 逻辑运算
- **Boolean value:** 布尔值 （T or F）
- **Silicon:** 硅
- **Integrated Circuit:** 集成电路
- **Silicon ingot:** 硅锭
- **Wafer:** 晶圆
- **Photolithography:** 光刻
- **Yield rate:** 良品率
- **Extreme Ultraviolet: EUV,** 极紫外
- **Photoresist:** 光刻胶
- **Heat dissipation:** 散热

Outline

- Transistors
- Integrated Circuit
- Chip production
- Future directions

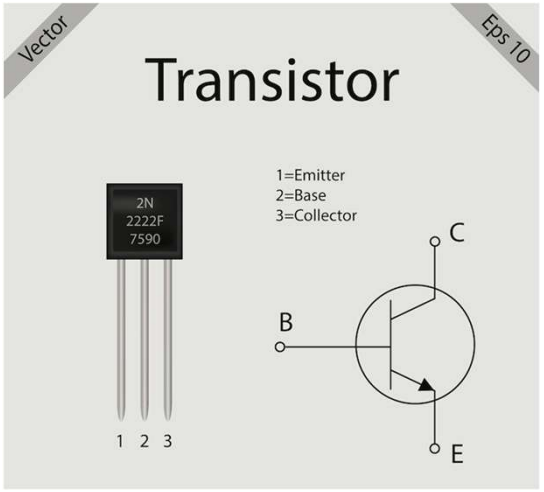
Outline

- **Transistors**
- **Integrated Circuit**
- **Chip production**
- **Future directions**

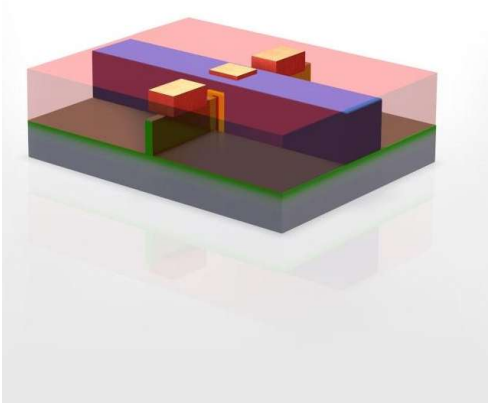
- What is most manufactured piece of equipment in history?

Transistor

Early transistors,
in mm



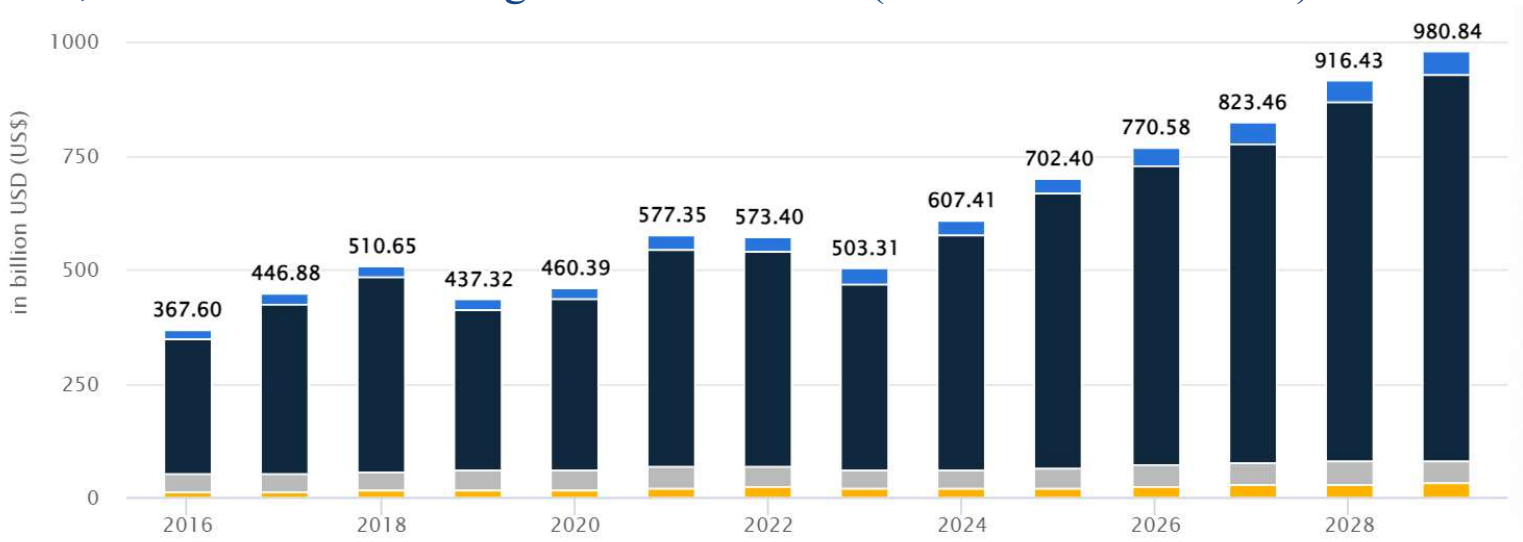
Transistors in chips
in nm



Iphone 16 Pro contains
17.3~18.0billion

Transistor

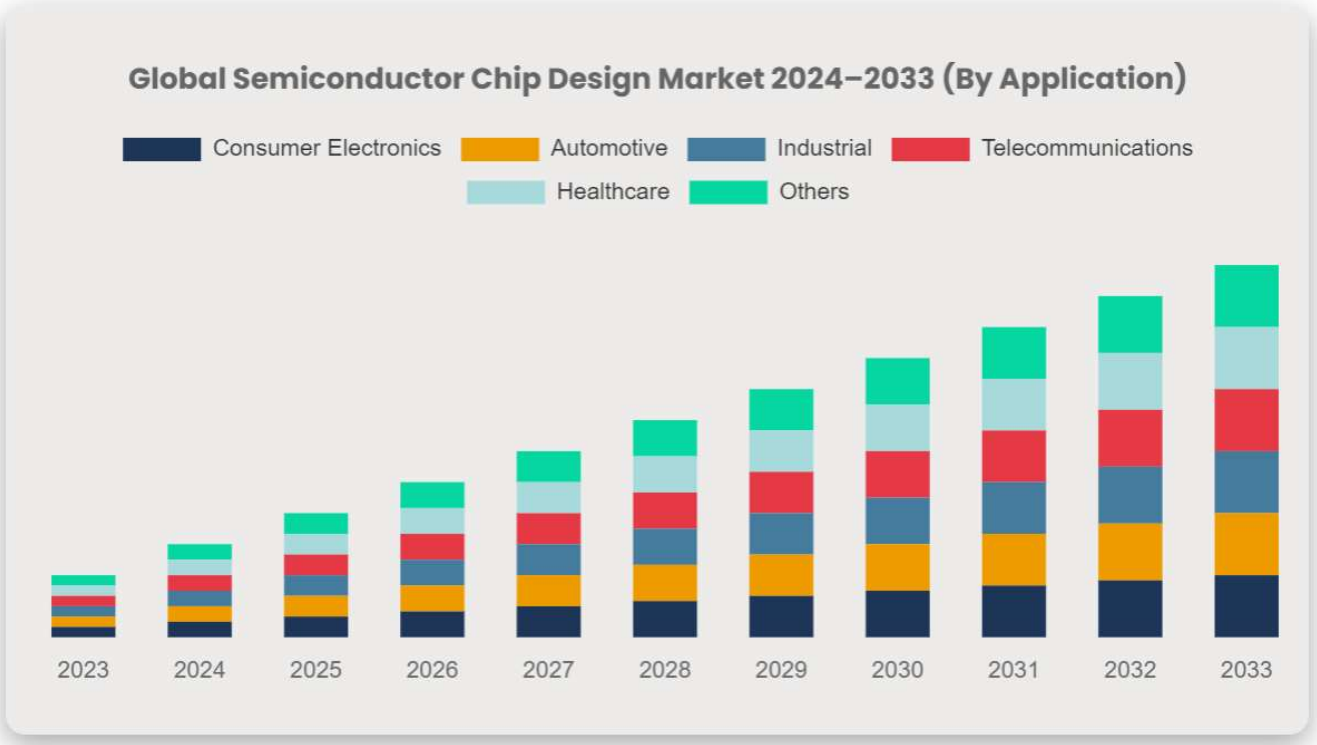
- Revenue in the Semiconductors market is reach US$607.40bn in 2024.
- Integrated Circuits dominates the market with a market volume of US$515.00bn in 2024.
- Revenue is expected to show an annual growth rate (CAGR 2024-2029) of 10.06%, resulting in a market volume of US$980.80bn by 2029.
- In global comparison, most revenue will be generated in China (US$177.80bn in 2024).



https://www.statista.com/outlook/tmo/semiconductors/worldwide#revenue

Transistor

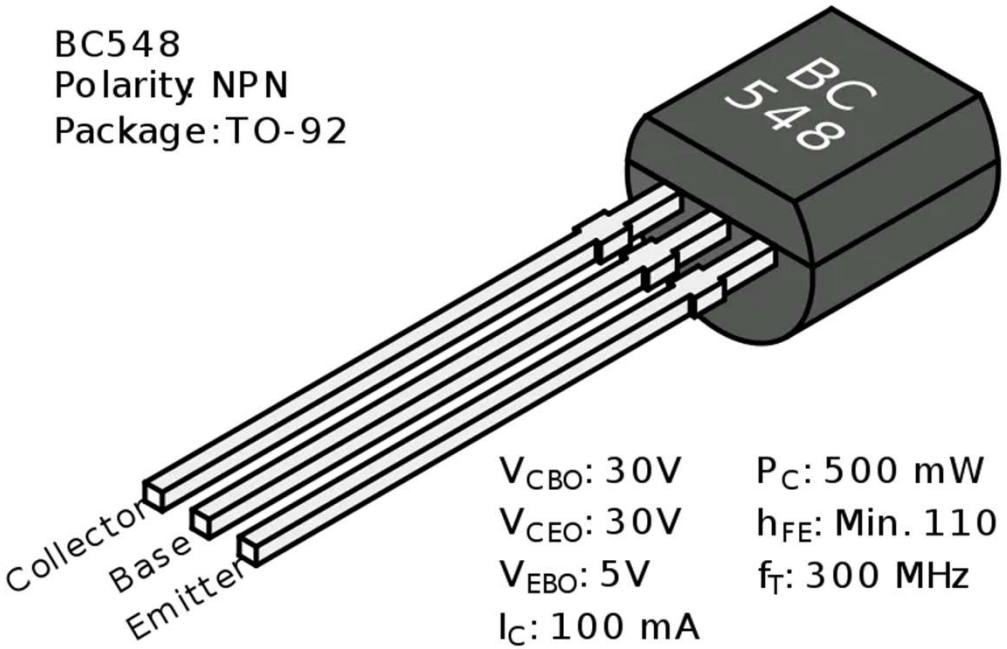
- Increasing Demand for Consumer Electronics
- Expansion of 5G Technology
- Rise of Artificial Intelligence and Machine Learning
- Automotive Industry Advancements
- Internet of Things (IoT) Growth
- Data Center Expansion
- Technological Miniaturization
- Increased R&D Investments



https://www.custommarketinsights.com/report/semiconductor-chip-design-market/

Transistor

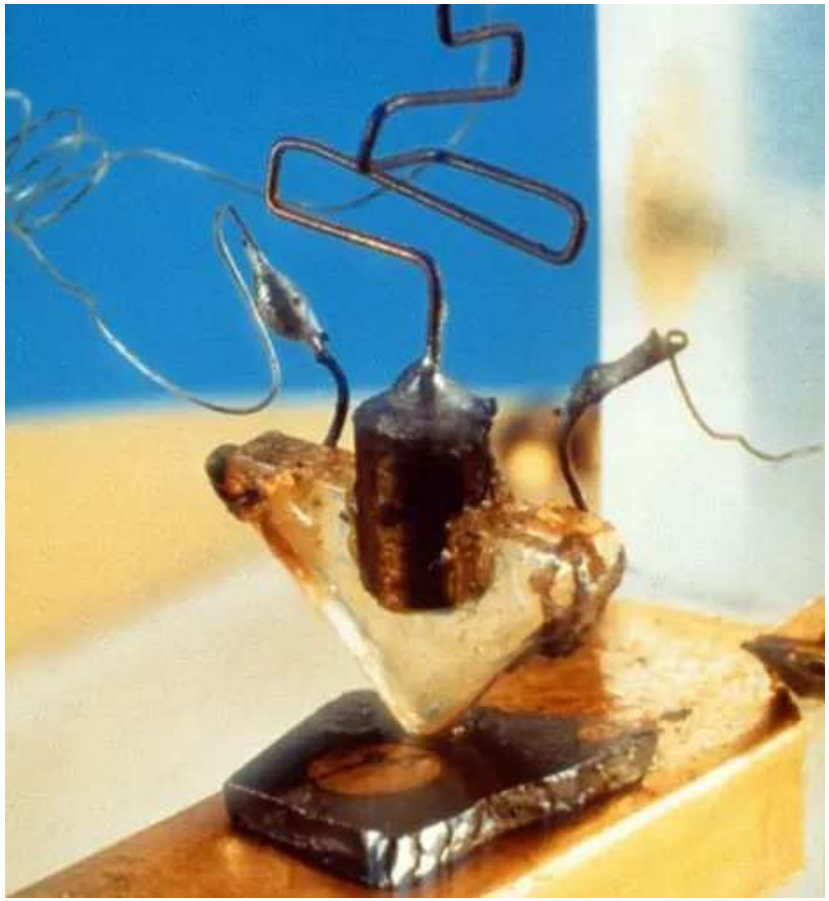
- Transistor is a three-terminal electronic device
- Transistor is used as switch and amplifier with various electronic devices.



https://medium.com/swlh/transistors-the-greatest-invention-of-the-20th-century-31dbf9c2871b

Transistor

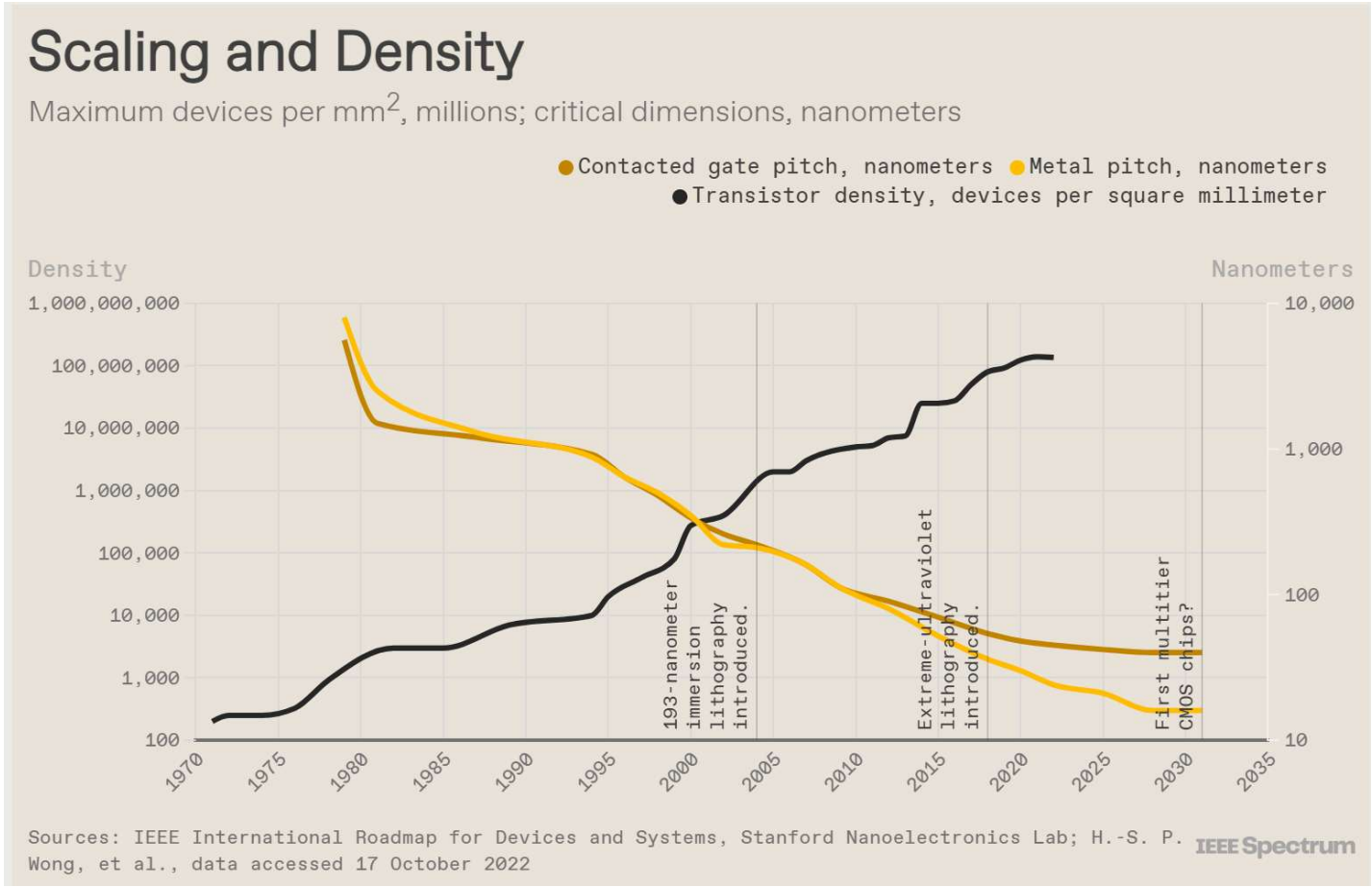
- The first transistor was invented in 1947
- Transistors consume less power hence they have great efficiency than vacuum tubes
- The introduction of the transistor is often considered one of the most important inventions in 20th century.



https://www.lindahall.org/about/news/scientist-of-the-day/the-transistor/

Transistor

- Size decreases with advances in design, materials, and manufacturing.
- Transistors become smaller, faster, cheaper, flatter, and more flexible



https://spectrum.ieee.org/transistor-density

Transistor: structure

- A transistor consists of three terminals:
  - **Base:** controls the base current flow from the emitter to the collector
  - **Emitter (NPN):** supplying electrons
  - **Collector (NPN):** collecting electrons

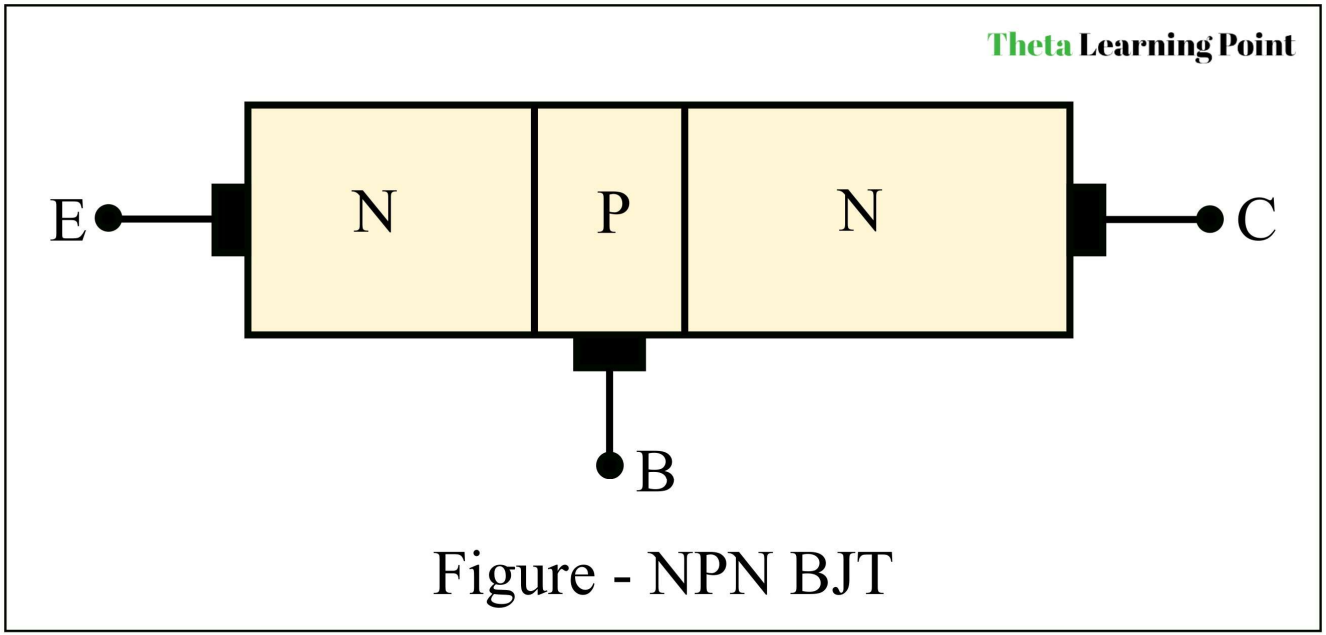
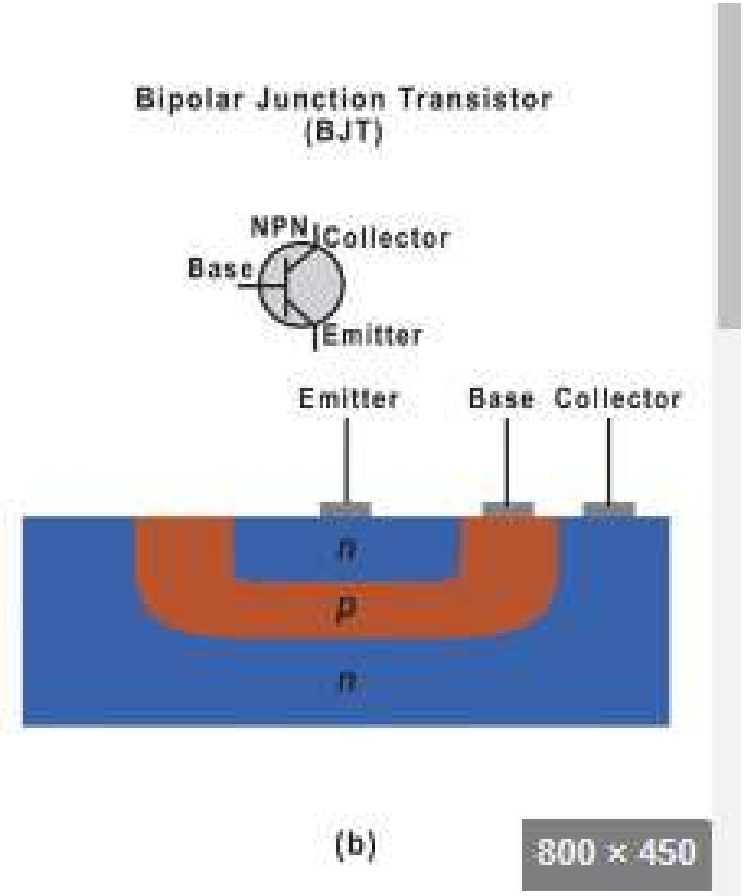


Figure - NPN BJT

https://www.thetalearningpoint.com/2023/06/what-is-bipolar-junction-transistor-bjt.html

Transistor: 3 terminals

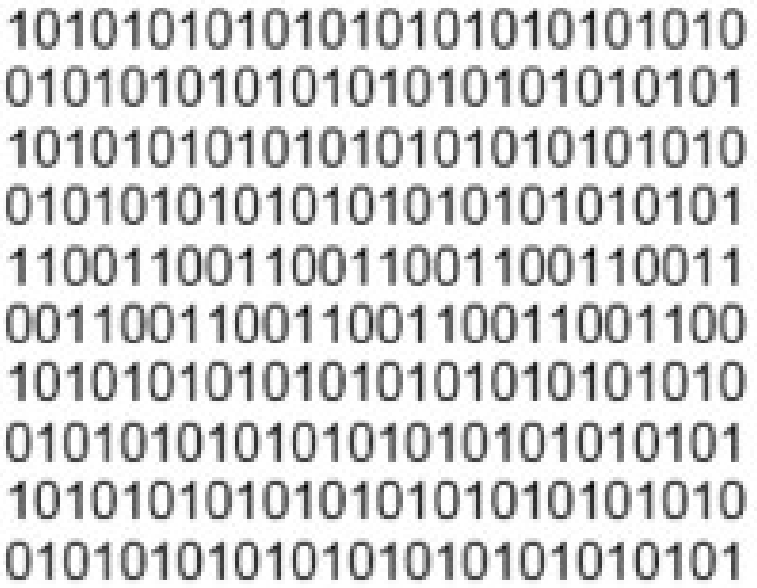
- The Bipolar Junction Transistor (BJT) is the simplest type of transistor
- A transistor is a semiconductor device
  - **Conductor: when** applying a positive voltage to the base. Can be treated as '**1**'.
  - **Insulator**: **when** no voltage is applied to the base. Can be treated as '**0**'.



https://medium.com/swlh/transistors-the-greatest-invention-of-the-20th-century-31dbf9c2871b

Transistor: application in processing binary data

- In computer science, information is coded to binary data
- Computers work with binary information directly
- Transistors can be used to represent these binary information



http://justsolve.archiveteam.org/wiki/Binary_Data

Transistor: application in processing binary data

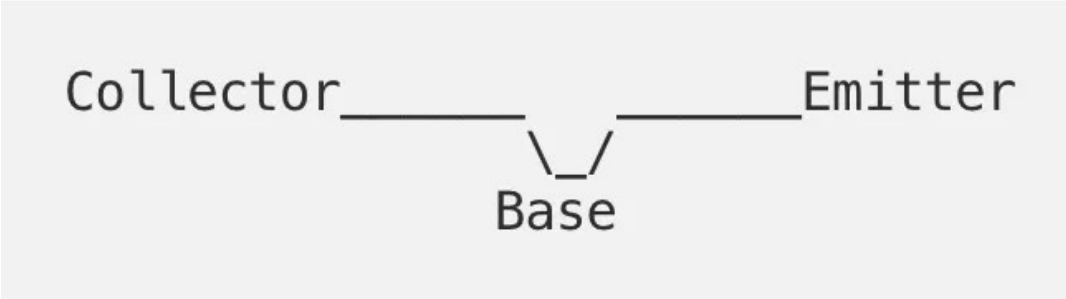
- Logical operations (NOT, AND, OR) are fundamental in the processing of binary information

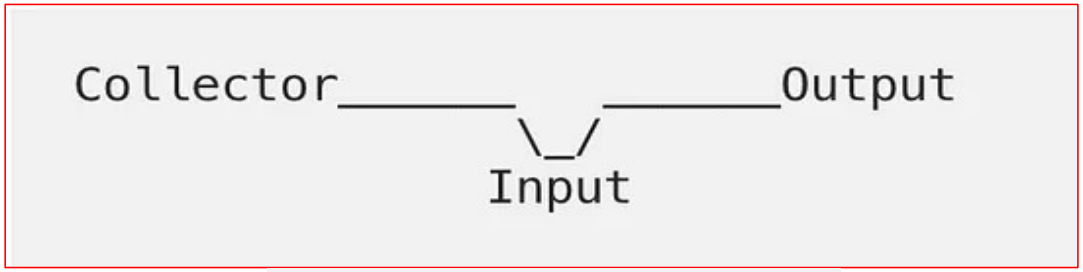
x	y	x AND y	x OR y	NOT x	NOT y
0	0	0	0	1	1
0	1	0	1	1	0
1	0	0	1	0	1
1	1	1	1	0	0

https://semiconvn.com/home/hoc-thiet-ke-vi-mach/bai-hc-vi-mch/13318-booleanalgebraandlogiccircuits.html

Transistor: transistors for logical operations

- Input/output of transistors



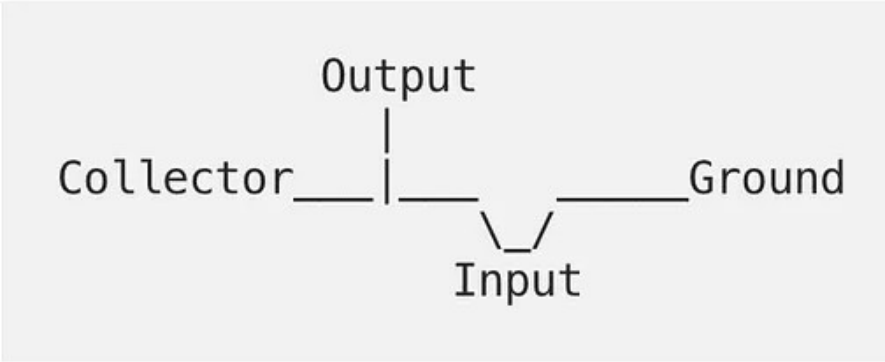


IN	OUT
0	0
1	1

https://semiconvn.com/home/hoc-thiet-ke-vi-mach/bai-hc-vi-mch/13318-booleanalgebraandlogiccircuits.html

Transistor: transistors for logical operations

- NOT operation

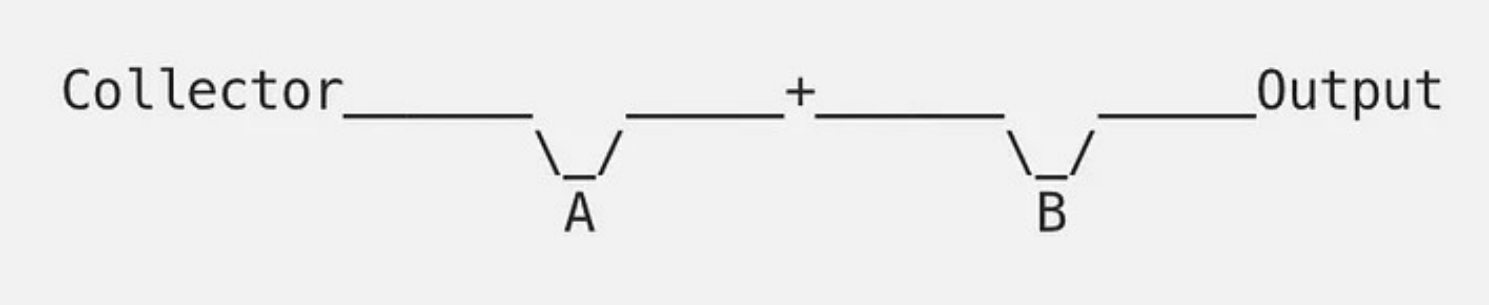


IN	OUT
0	1
1	0

https://semiconvn.com/home/hoc-thiet-ke-vi-mach/bai-hc-vi-mch/13318-booleanalgebraandlogiccircuits.html

Transistor: transistors for logical operations

- AND operation



A	B	OUT
0	0	0
0	1	0
1	0	0
1	1	1

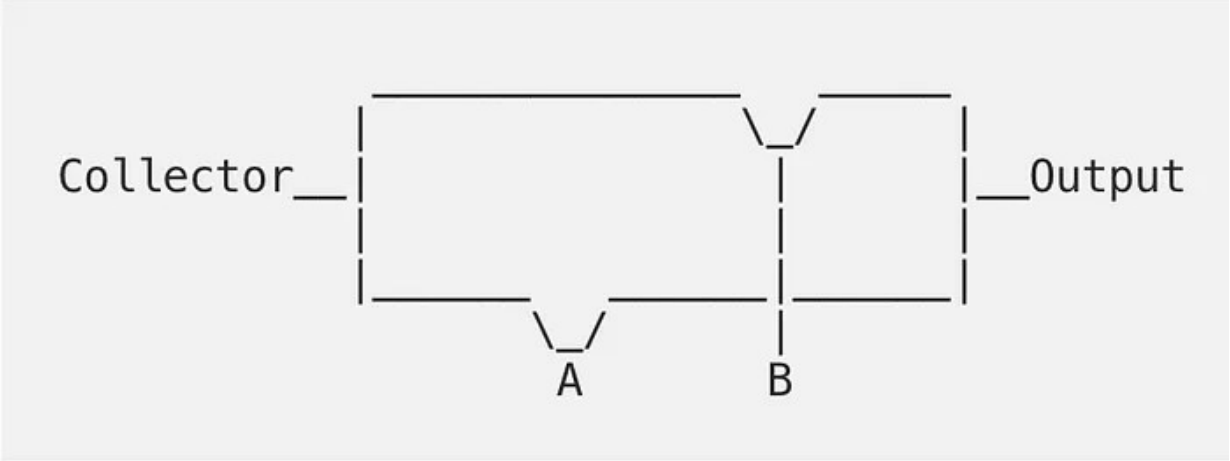
https://semiconvn.com/home/hoc-thiet-ke-vi-mach/bai-hc-vi-mch/13318-booleanalgebraandlogiccircuits.html

Transistor: transistors for logical operations

- OR operation

  and other operations

(NAND, Adder etc.)



A	B	OR
0	0	0
0	1	1
1	0	1
1	1	1

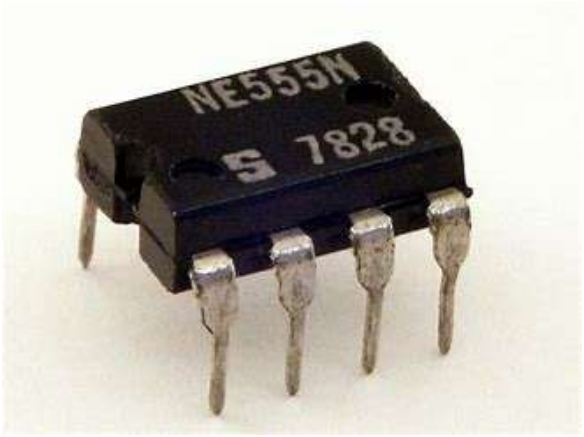
https://semiconvn.com/home/hoc-thiet-ke-vi-mach/bai-hc-vi-mch/13318-booleanalgebraandlogiccircuits.html

Outline

- Transistors
- **Integrated Circuit**
- Chip production
- Future directions

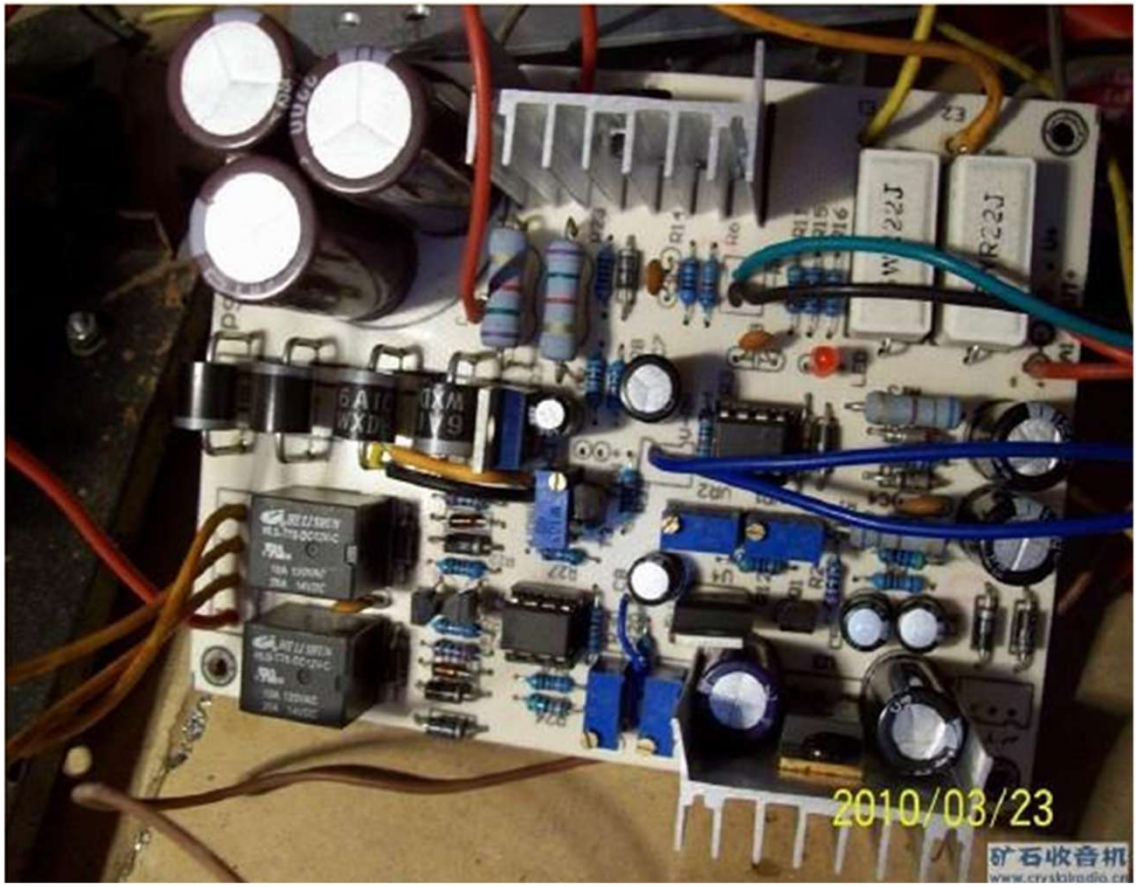
Integrated Circuit（IC）

- IC: semiconductor wafers with millions of tiny resistors, capacitors, and other components
- Also known as **Silicon chip** or **Computer chip** or **Micro chip**



Integrated Circuit（IC）

- Although replacing vacuum tubes with transistor reduce sizes of devices, but they are still bulky
- Hard to repair when large amounts of transistors are installed together



Integrated Circuit（IC）

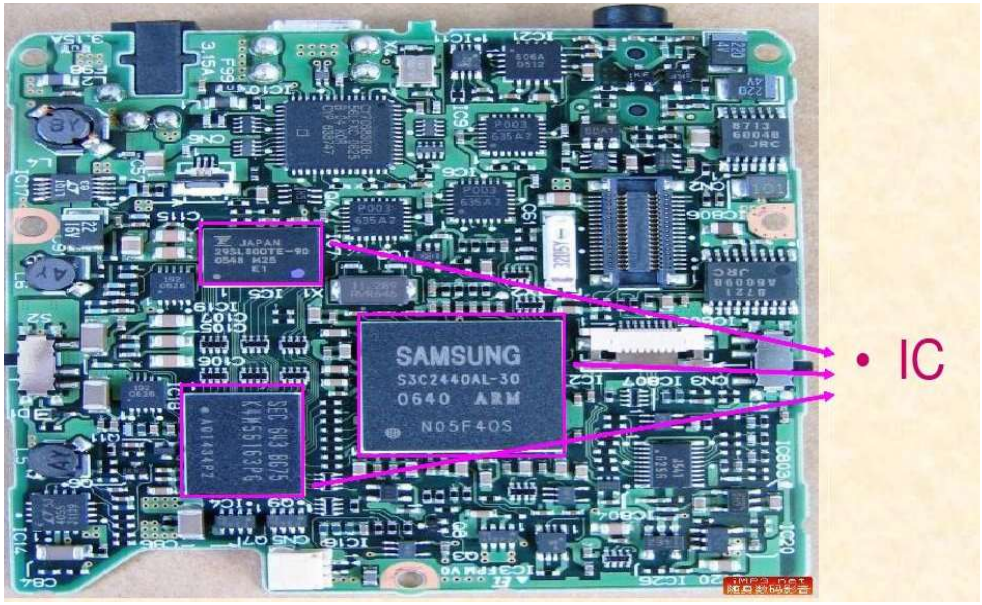
- Jack Kilby, the scientist at the Texas Instruments,1958.

"why shouldn't we make all the components(not only the transistors), but also the capacitors , resistors out of the ***Silicon(Si).*** *If this could be done than the entire circuit can made out of the single* ***Silicon(Si) crystal*** *"*

- And this can make the circuit smaller(much smaller) and even easier to produce.

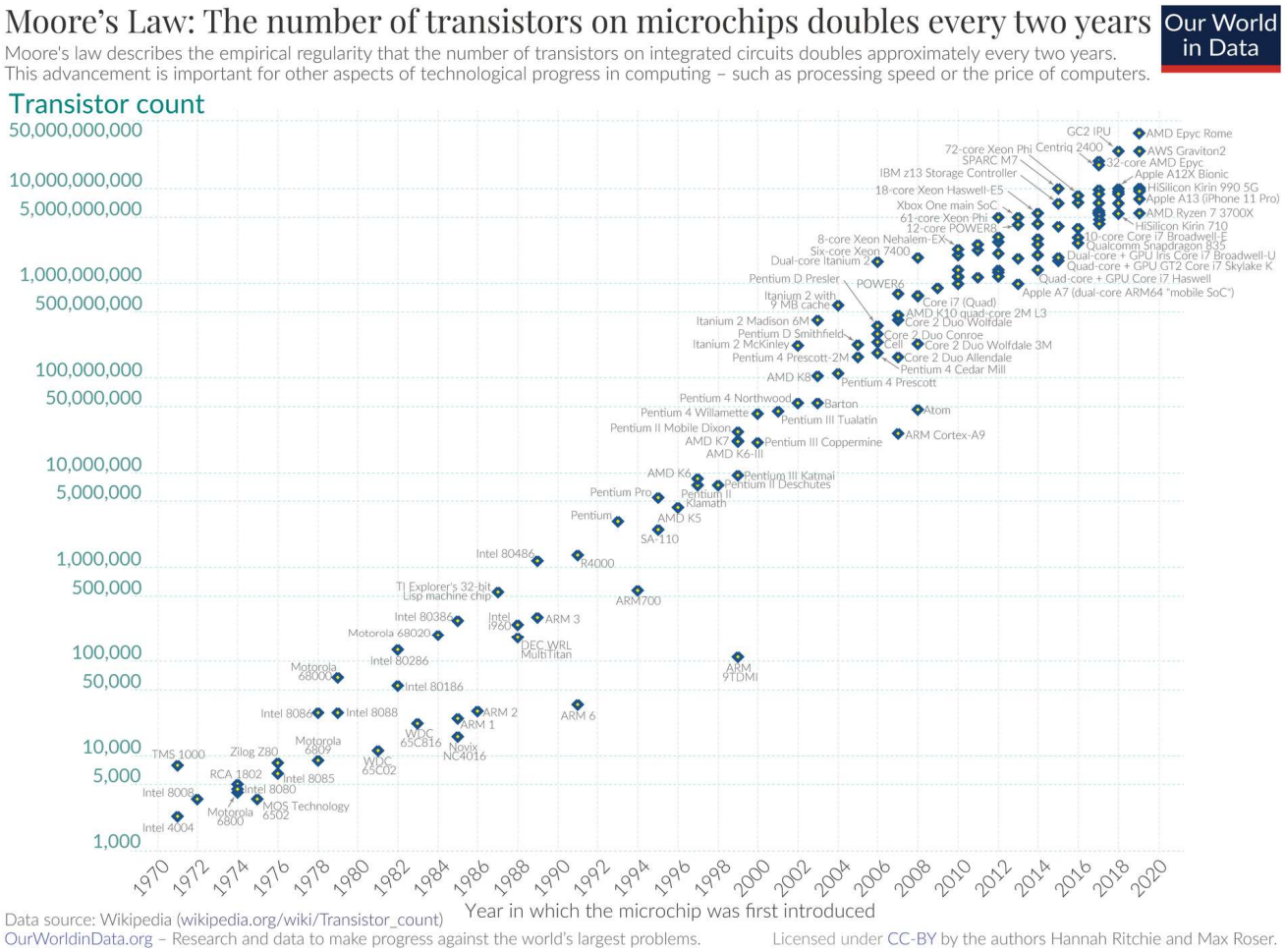
Integrated Circuit（IC）

- Depending upon the number of components these IC's can be classified as follows:
  - **SSI** – Small-Scale Integration ($0\text{-}10^2$)
  - **MSI** – Medium-Scale Integration ($10^2\text{-}10^3$)
  - **LSI** – Large-Scale Integration ($10^3\text{-}10^5$)
  - **VLSI** – Very Large-Scale Integration ($10^5\text{-}10^7$)
  - **ULSI** – Ultra Large-Scale Integration ($>=10^7$)



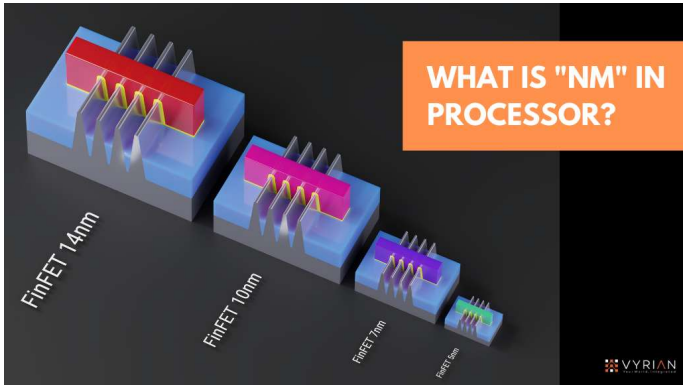
Integrated Circuit（IC）: Moore’s law

- **1965, Gordon E. Moore, the co-founder of Intel, made an observation that eventually became known as Moore's Law.**
- **“Number of transistors on a microchip doubles about every two years with a minimal cost increase”**



Integrated Circuit（IC）

- Sizes of transistors decreased quickly
- Different companies have different definitions of transistor sizes



Peak Quoted Transistor Densities (MTr/mm2)				
AnandTech	IBM	TSMC	Intel	Samsung
22nm			16.50	
16nm/14nm		28.88	44.67	33.32
10nm		52.51	100.76	51.82
7nm		91.20	237.18*	95.08
5nm		171.30		
3nm		292.21*		
2nm	333.33			

Data from Wikichip, Different Fabs may have different counting methodologies
* Estimated Logic Density

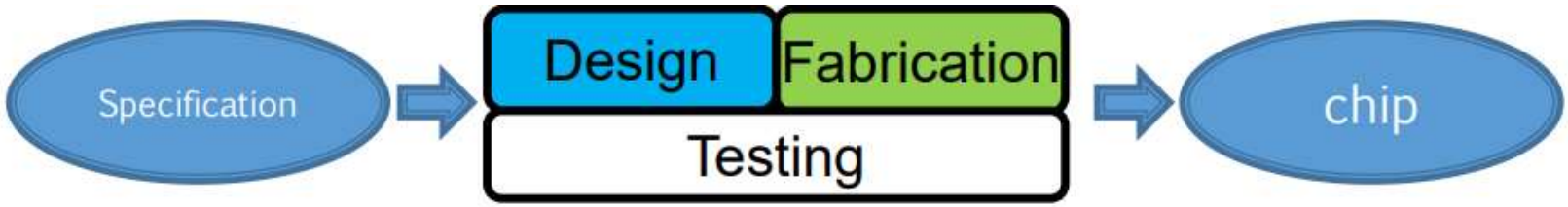
Credit to Prof. Renjing Xu

Outline

- Transistors
- Integrated Circuit
- **Chip production**
- Future directions

Chip production

- The process of converting sand into powerful semiconductors
- Including key steps such as design, fabrication, and testing



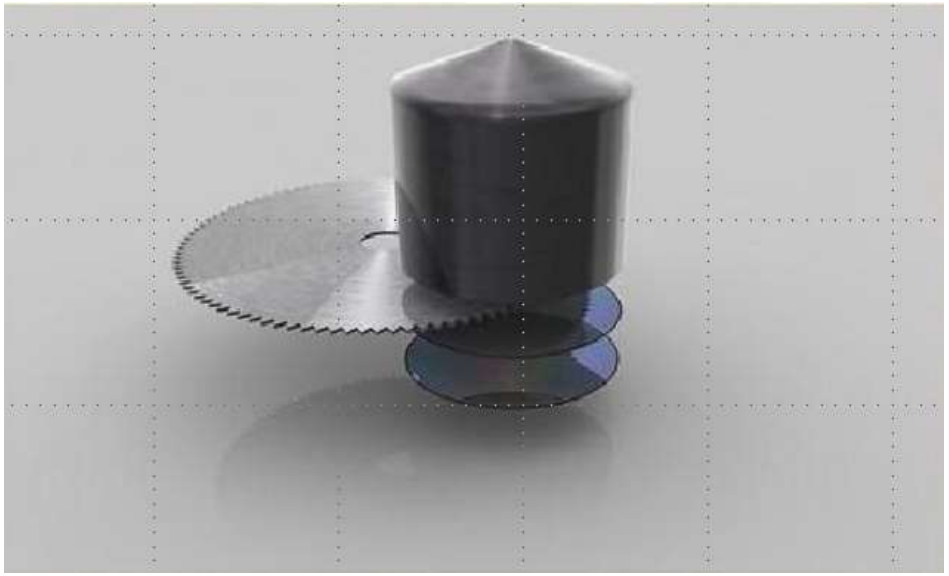
Credit to Prof. Jiang Xu

Chip fabrication

- Takes hundreds of steps in total
- From sand (SiO_2) to pure Silicon

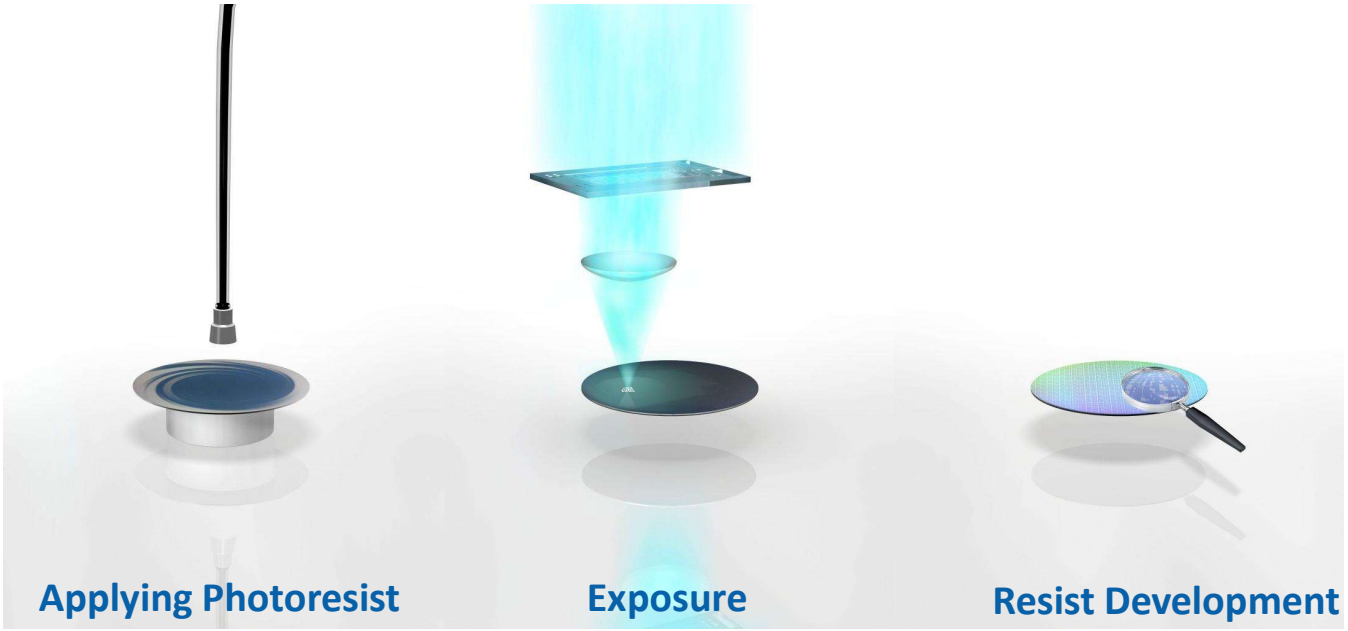
Chip production

- **From silicon ingot to wafer**



Chip production

- **Photolithography**

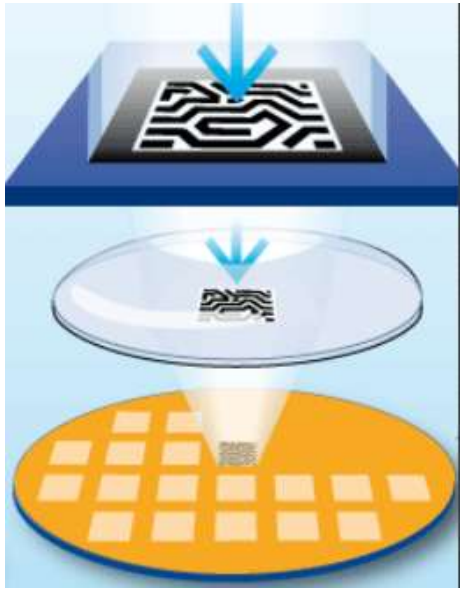


Intel Corporation, 2012

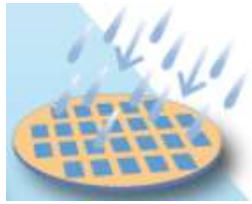
Photolithography

Create a Designed pattern on a transparent substrate (Mask)

Put photoresist on wafers



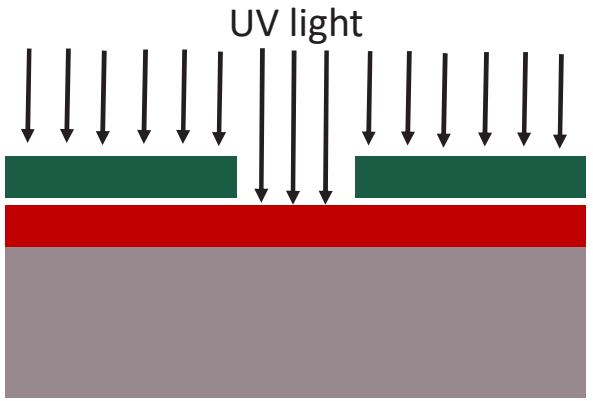
Shine a light to change the photoresist



The pattern replicated in photoresist after developer wash

(Cartoons taken from ASML presentation slides)

Positive photoresist and negative photoresist



Mask blocks UV light at some areas

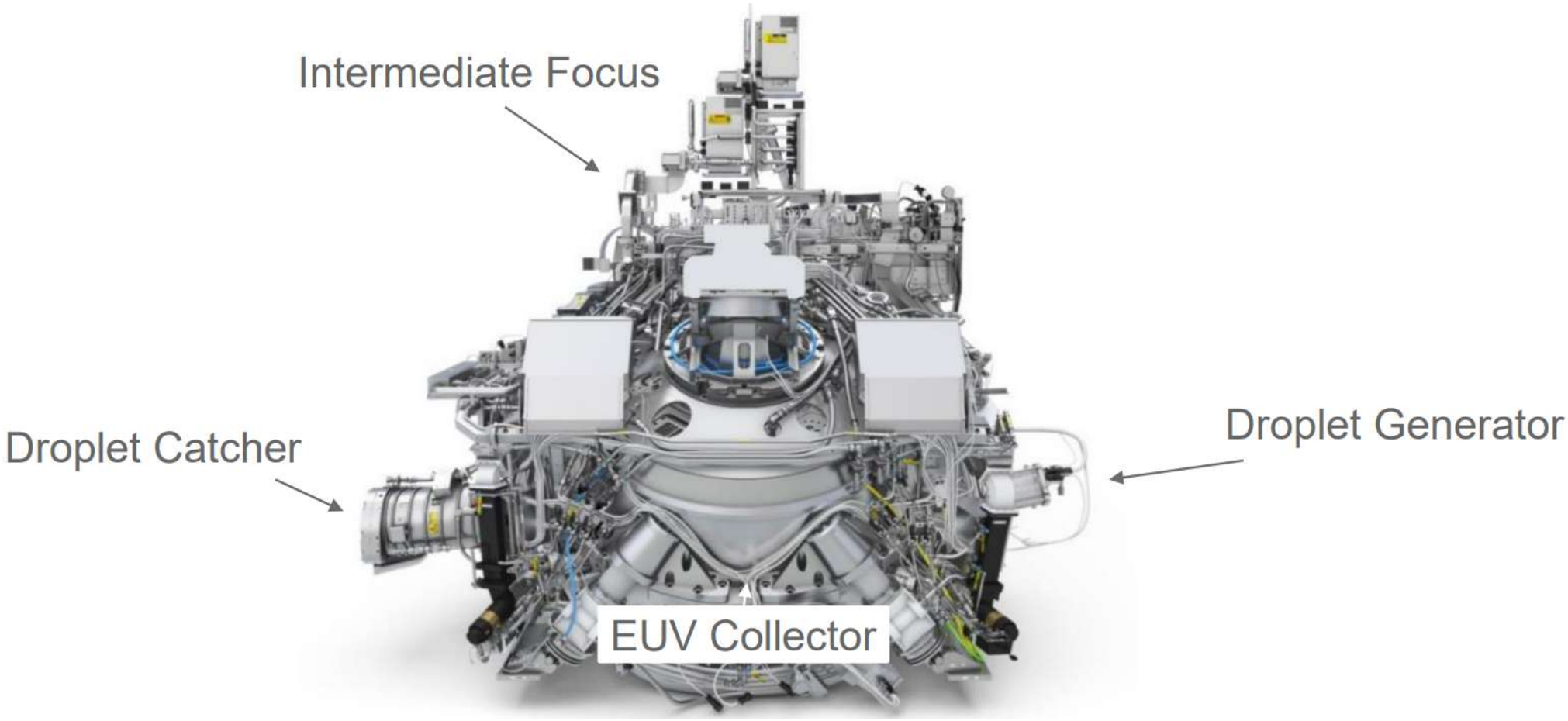
Photoresist only exposed where UV passes

Substrate

Light increases solubility in positive resist

Light decreases solubility in negative resist

ASML


Intermediate Focus
Droplet Catcher
Droplet Generator
EUV Collector

Chip production

➢ Ion Implantation

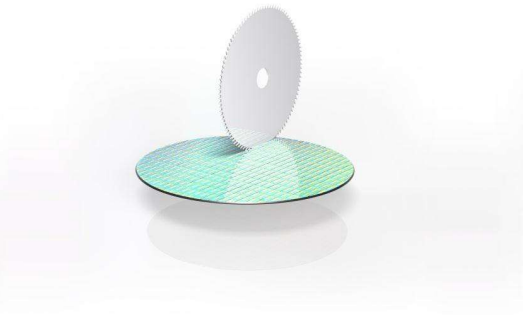
Ion Implantation | Removing Photoresist | Begin Transistor Formation

Intel Corporation, 2012

Chip production

➢ Wafer Sort / Singulation

Wafer Sort



Wafer Slicing

Selecting Die for Packaging

Intel Corporation, 2012

How chips are made

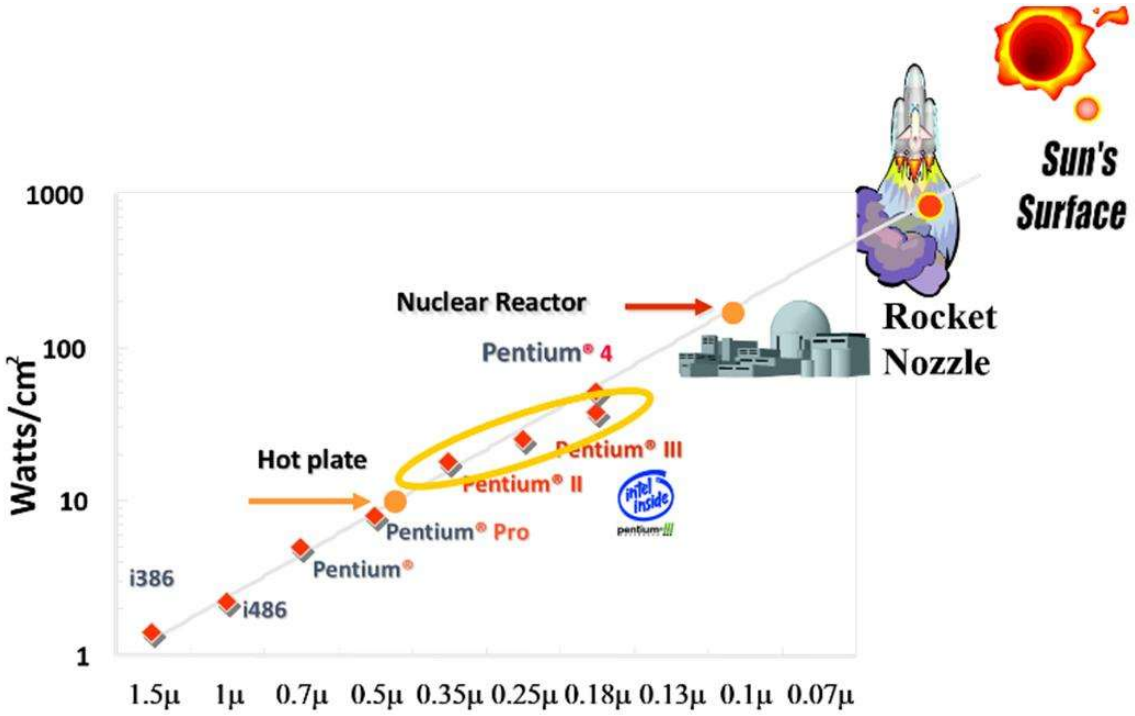
Credit to Prof. Renjing Xu

Outline

- Transistors
- Integrated Circuit
- Chip production
- **Future directions**

Challenges in producing smaller transistors

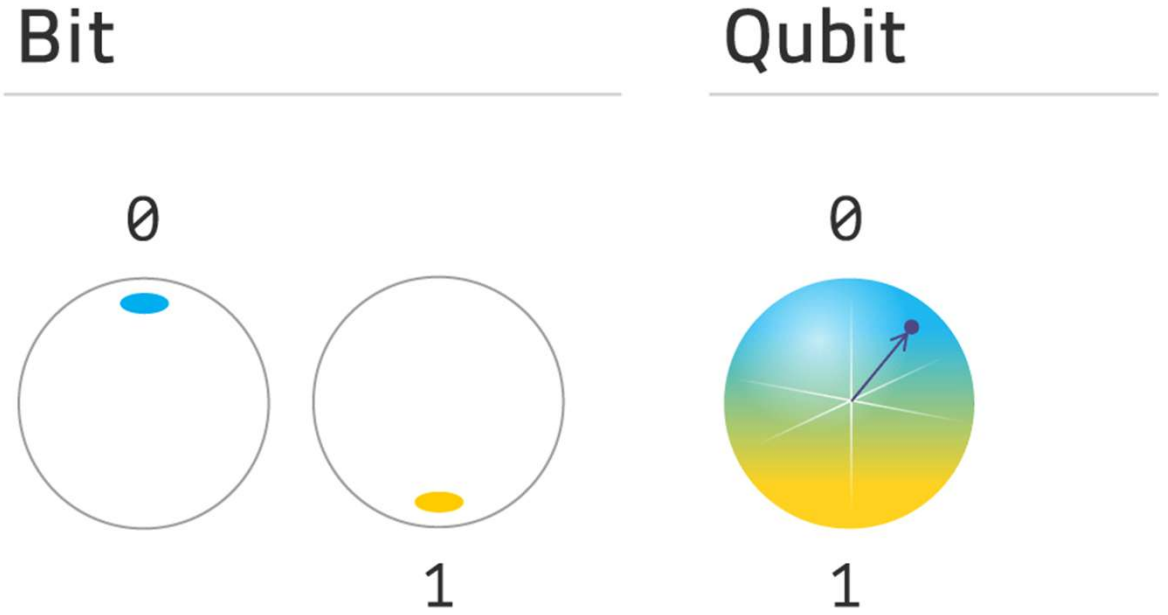
- **Heat dissipation:** chips generate more heat with decreasing size of transistors
- **Quantum effects:** quantum mechanical disrupt transistor operation



Etiemble 2018. 45-year CPU evolution: one law and two equations

Future of IC: Quantum circuits

- **Quantum Circuits:** qubits that can exist in multiple states at the same time, allowing for complex calculations faster than classical computers.



https://1qbit.com/blog/quantum-computing/a-bit-or-two-about-qubits/

Future of IC: AI feature and 3D IC

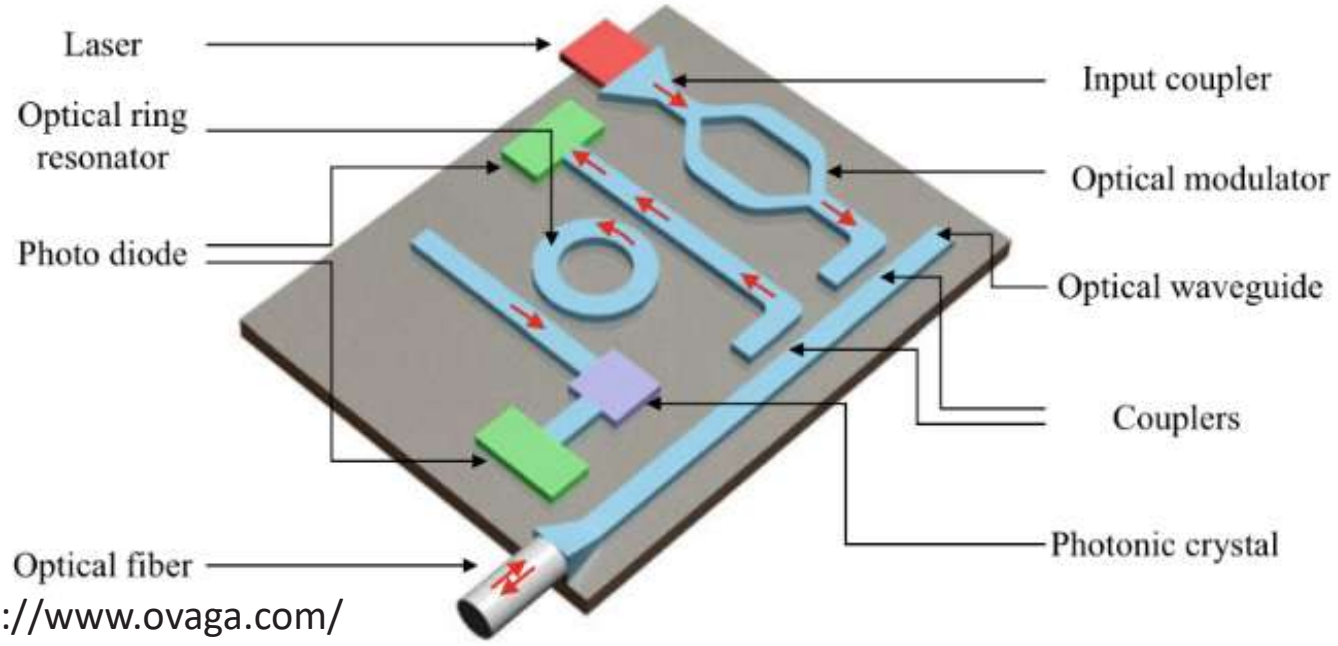
- **Artificial intelligence:** ICs specifically designed for machine learning, enabling faster and more energy-efficient computing.

- **3D IC:** Multiple layers of transistor stacking together could improve efficiency and performance, enabling the integration of different functions, paving the way for more powerful and versatile electronic systems.

https://blog.win-source.net/

Future of IC: photonic integrated circuits

- **Photonic integrated circuits (PICs)：** using light rather than electrical signals to transmit and process information. PICs are expected to incorporate photonics to delivering superior speed and energy efficiency compared to traditional electrical interconnects



https://blog.win-source.net/， https://www.ovaga.com/

Future of IC: Energy-saving design and low-power technology

- **Energy efficiency IC:** As transistors get smaller, energy efficiency becomes a top priority. Utilizing advanced materials and novel design methods is critical to extending the battery life of portable devices

https://blog.win-source.net/

MICS thrust

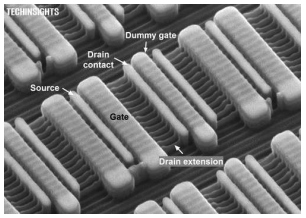
Credit to Prof. Renjing Xu

MICS thrust

Material

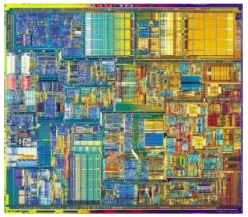
Materials Characterization and Preparation Facility

Fabrication



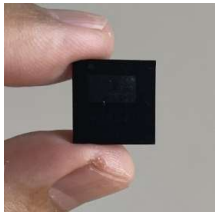
Nanosystem Fabrication Facility

IC



Novel IC Exploration Facility

Packaging



Center for Heterogeneous Integration of μ-systems and Packaging

Systems

Central Research and Education Software Tools

EDA Research Center

Supercomputing center

Credit to Prof. Renjing Xu