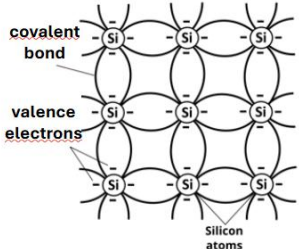
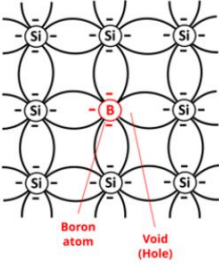
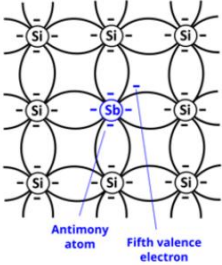
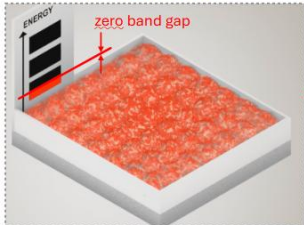
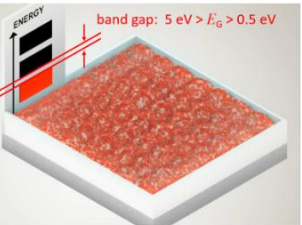
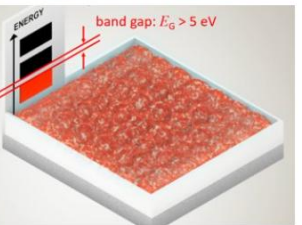
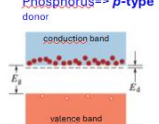
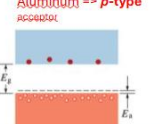
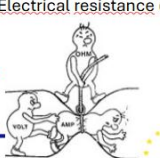
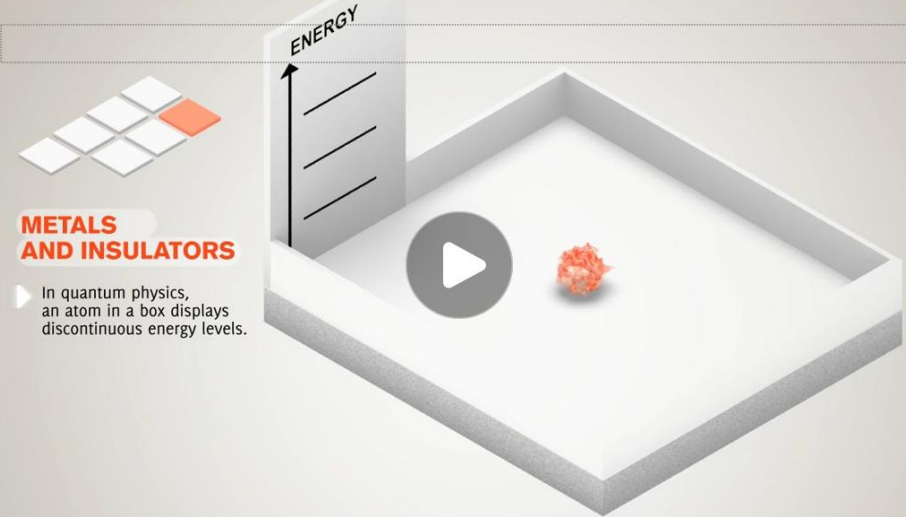
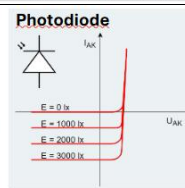


9.	Was ist ein Halbleiter?
Zielgruppe	Schüler, optional Lehrkräfte
Alter der Schüler	16–18
Dauer	1,5-2 Stunden
Was ist ein Halbleiter	intrinsic Pure Silicon  covalent bond valence electrons Silicon atoms Aluminium ==> p-type acceptor (accepts electrons) P-Type  Boron atom Void (Hole) Phosphorus ==> n-type donor (donates electrons) N-Type  Antimony atom Fifth valence electron
Zusammenfassung der Einführung	metal (conductor)  zero band gap semiconductor  band gap: 5 eV > E_g > 0.5 eV dielectric (non-conductor)  band gap: E_g > 5 eV Phosphorus ==> p-type donor  conduction band valence band Aluminium ==> p-type acceptor  conduction band valence band Electrical resistance (Ω)  Experiment Extrinsic semiconductors: CHIPS of Europe – Creating Higher-Education Industry Programmes for the Semiconductor Industry of Europe www.chipsforeurope.eu 8
Video: Metalle und Isolatoren	METALS AND INSULATORS ▶ In quantum physics, an atom in a box displays discontinuous energy levels. 

Anwendungen: PN-Übergang → Diode	
Strom-Spannungs-Kennlinie (lineare vs. nichtlineare Bauelemente)	Resistor Resistor (lower resistance) Diode Battery Volt-Ampere characteristic Experiment
Strom-Spannungs-Kennlinie (vertiefend)	Semiconductor diode current rectifier Zener diode current rectifier voltage regulator Schottky diode current rectifier (for higher frequencies) solar cells Diode bridge rectifier
Diode → LED (Leuchtdiode)	Semiconductor with a direct bandgap => LED Experiment

Semiconductor with a **direct** bandgap => LED

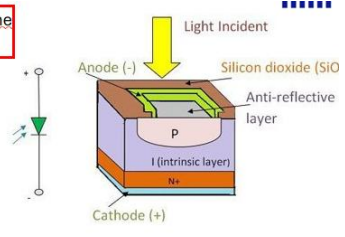
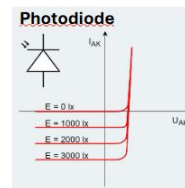
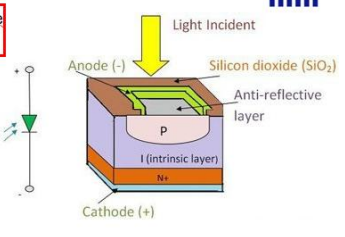
Diode → LED → Fotodiode



Anode  Cathode



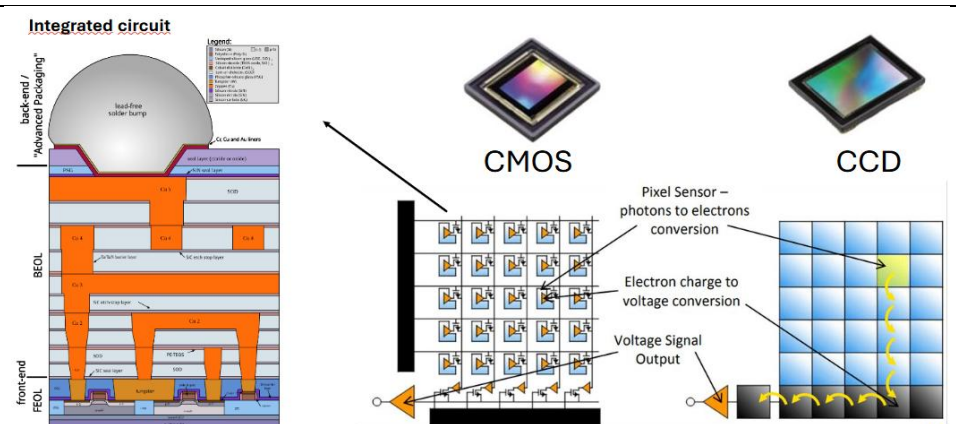
Experiment



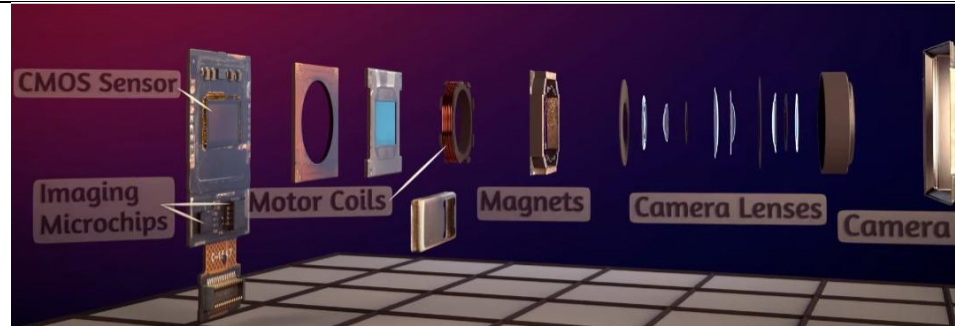
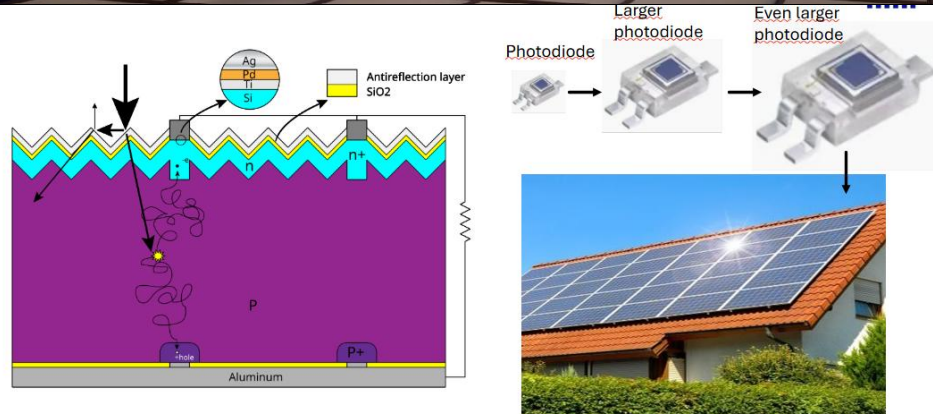
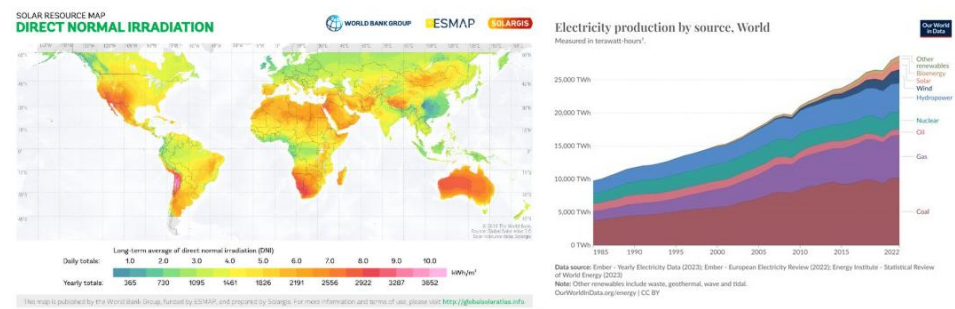
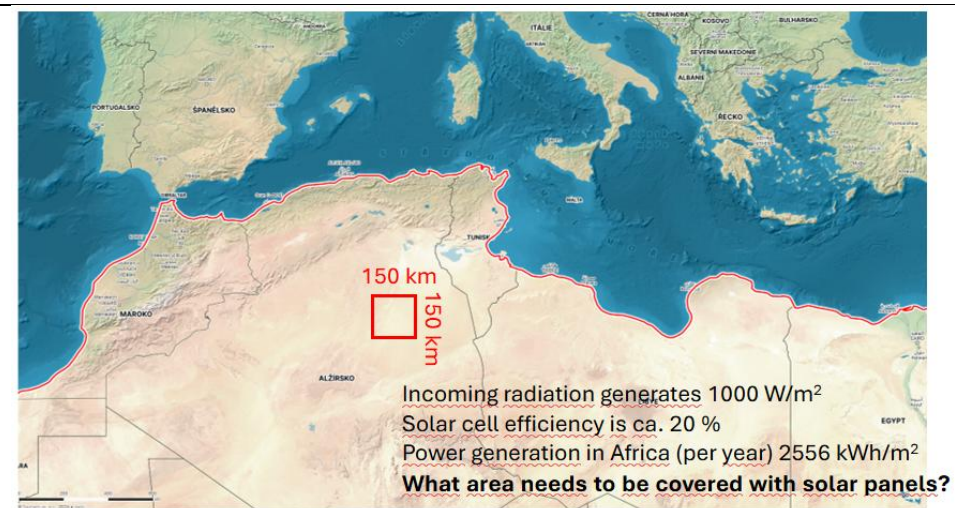
Digital camera chip



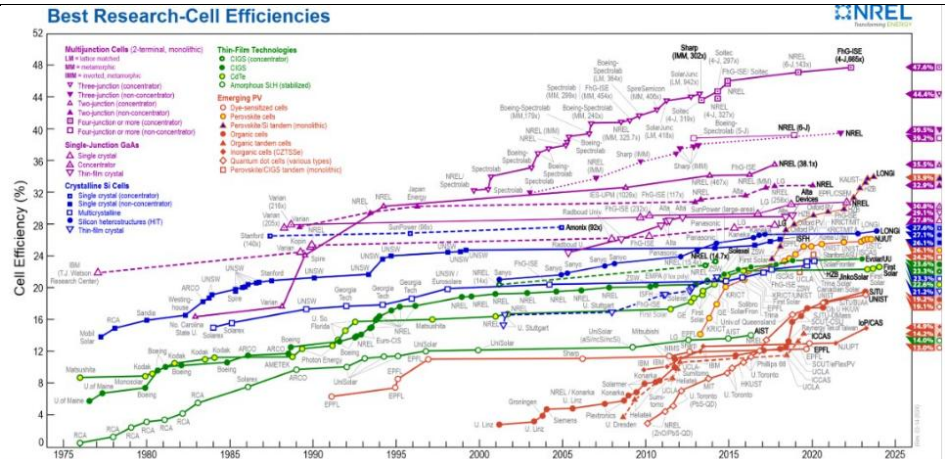
**Diode → LED →
Fotodiode (CCD,
CMOS)**



Handykamera

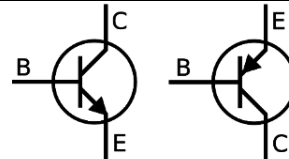
Diode → LED →
Fotodiode →
SolarzelleSolareinstrahlung
vs.
EnergieverbrauchSolarzellen
(warum, wie viele,
wie..?)

Solarzellen: Wirkungsgrad

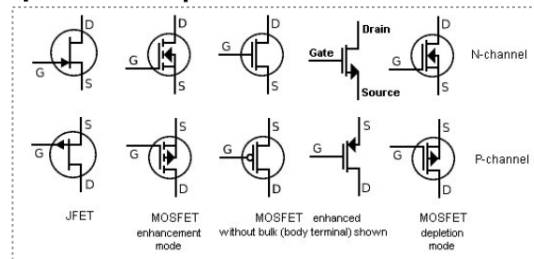


Transistor

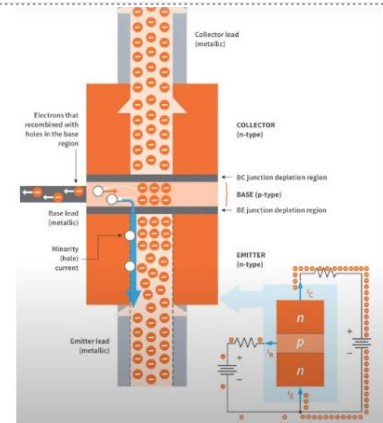
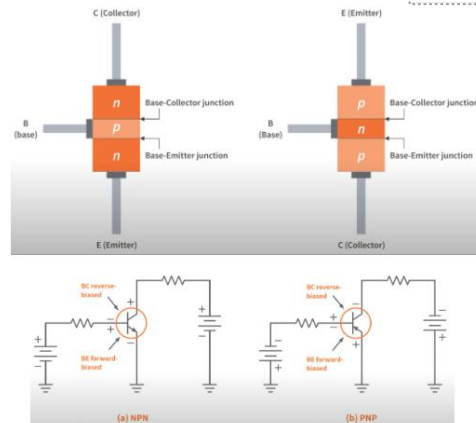
Bipolar junction transistor (BJT)



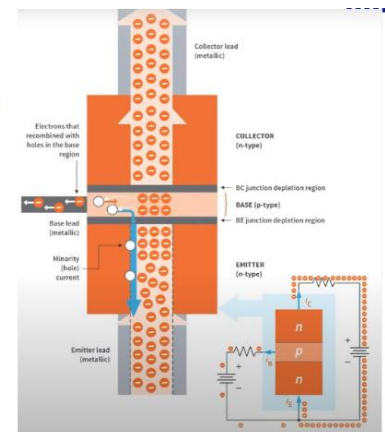
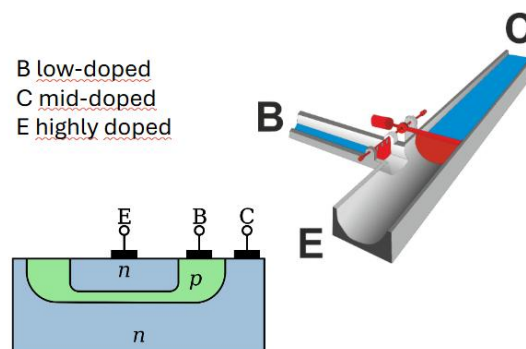
Unipolar transistor (FET)



Bipolartransistor (BJT)

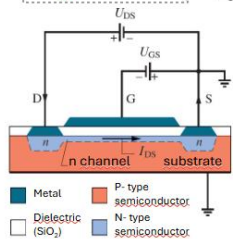
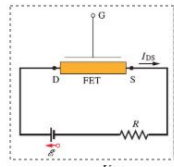


B low-doped
C mid-doped
E highly doped



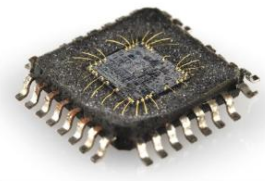
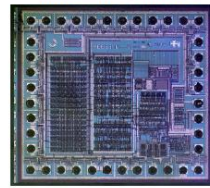
Metall-Oxid-Halbleiter-Feldeffekttransistor (MOSFET)

Field effect transistor(FET)

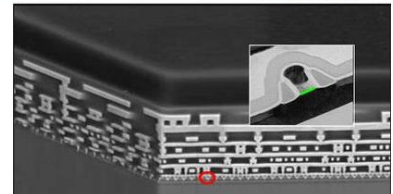


S-D current flows = 1
S-D current does not flow = 0
Very fast switching (~1 ps)

Integrated circuit



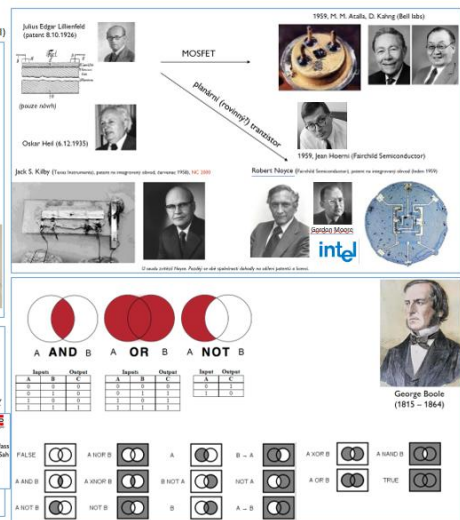
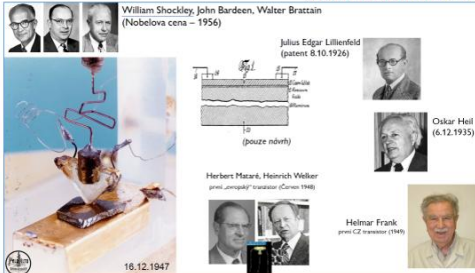
Microprocessor in cross-section



Exponentielle Technologie: Die Geschichte des Transistors

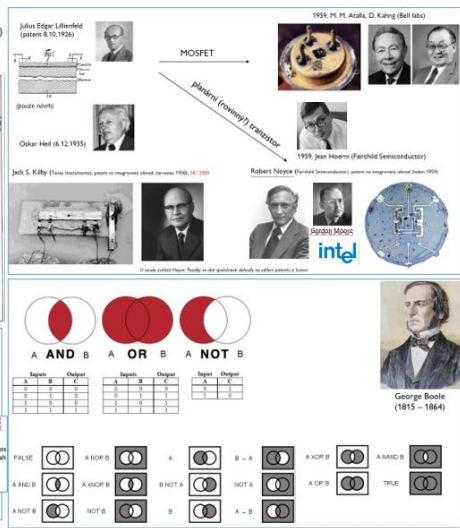
Exponential technology: The transistor tale

(with kind permission of prof. M. Kolbat)



Exponential technology: The transistor tale

(with kind permission of prof. M. Kolbat)

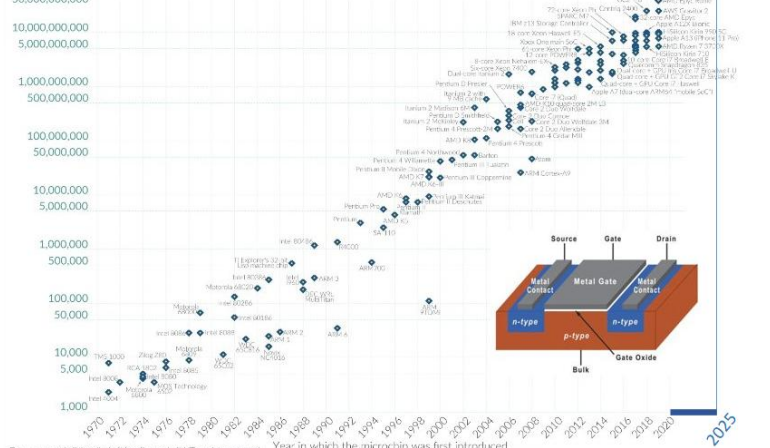


Moore's Law: The number of transistors on microchips doubles every two years

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

Transistor count

50,000,000,000



Data sources: Wikipedia (wikipedia.org/wiki/Transistor count)
OurWorldInData.org – Research and data to make progress against the world's largest problems.

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Our World in Data

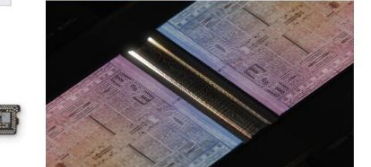
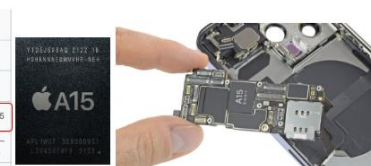
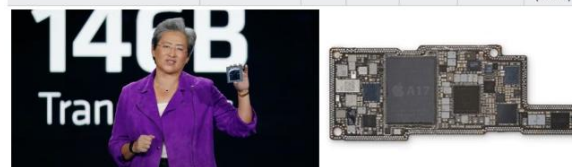
~ 10¹¹

Semiconductor device fabrication

MOSFET scaling (process nodes)

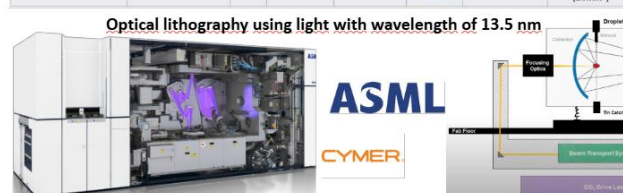
- 20 µm – 1968
- 10 µm – 1971
- 6 µm – 1974
- 3 µm – 1977
- 1.5 µm – 1981
- 1 µm – 1984
- 800 nm – 1987
- 600 nm – 1990
- 350 nm – 1993
- 250 nm – 1996
- 180 nm – 1999
- 130 nm – 2001
- 90 nm – 2003
- 65 nm – 2005
- 45 nm – 2007
- 32 nm – 2009
- 28 nm – 2010
- 22 nm – 2012
- 14 nm – 2014
- 10 nm – 2016
- 7 nm – 2018
- 5 nm – 2020
- 3 nm – 2022
- Future
- 2 nm – 2025
- 1 nm – 2027

Apple M3 (octa-core 64-bit ARMv8 SoC, SIMD, caches)	25,000,000,000 ^[108]	2023	Apple	3 nm	?	?
Apple M3 Pro (octa-core 64-bit ARMv8 SoC, SIMD, caches)	37,000,000,000 ^[108]	2023	Apple	3 nm	?	?
Apple M3 Max (hexadeca-core 64-bit ARMv8 SoC, SIMD, caches)	92,000,000,000 ^[108]	2023	Apple	3 nm	?	?
Apple A17	19,000,000,000 ^[107]	2023	Apple	3 nm	103.8 mm ²	183,044,315
Sapphire Rapids quad-chip module (up to 60 cores and 112.5 MB of cache) ^[109]	44,000,000,000–48,000,000,000 ^[109]	2023	Intel	10 nm ESF (Intel 7)	1,600 mm ²	27,500,000–30,000,000
Apple M2 Pro (12-core 64-bit ARMv8 SoC, SIMD, caches)	40,000,000,000 ^[108]	2023	Apple	5 nm	?	?
Apple M2 Max (12-core 64-bit ARMv8 SoC, SIMD, caches)	67,000,000,000 ^[108]	2023	Apple	5 nm	?	?
Apple M2 Ultra (two M2 Max dies)	134,000,000,000 ^[7]	2023	Apple	5 nm	?	?
AMD Epyc Bergamo (4th gen/97X4 series) S-chip module (up to 128 cores and 256 MB (L3) + 128 MB (L2) cache)	82,000,000,000 ^[109]	2023	AMD	5 nm (CCD) 6 nm (IOD)	?	?
AMD Instinct M300A (multi-chip module, 24 cores, 128 GB GPU memory + 256 MB (LLC/L3) cache)	146,000,000,000 ^[109]	2023	AMD	5 nm (CCD) 6 nm (IOD)	1,017 mm ²	144,000,000



Graphics processing unit (GPU)

GH100 Hopper	80,000,000,000	2022	Nvidia	TSMC	4 nm	814 mm ²	98,280,000
AD102 Ada Lovelace	76,300,000,000	2022	Nvidia	TSMC	4 nm	608.4 mm ²	125,411,000
AD103 Ada Lovelace	45,900,000,000	2022	Nvidia	TSMC	4 nm	378.6 mm ²	121,240,000
AD104 Ada Lovelace	35,800,000,000	2022	Nvidia	TSMC	4 nm	294.5 mm ²	121,560,000
AD106 Ada Lovelace	?	2023	Nvidia	TSMC	4 nm	190 mm ²	?
AD107 Ada Lovelace	?	2023	Nvidia	TSMC	4 nm	146 mm ²	?
Navi 31 RDNA3	57,700,000,000 (MCM) 45,400,000,000 (GCD) 6+2,050,000,000 (MCD)	2022	AMD	TSMC	5 nm (GCD) 6 nm (MCD)	531 mm ² (MCM) 306 mm ² (GCD) 6+37.5 mm ² (MCD)	109,200,000 (MCM) 132,400,000 (GCD) 54,640,000 (MCD)
Navi 32 RDNA3	28,100,000,000 (MCM)	2023	AMD	TSMC	5 nm (GCD) 6 nm (MCD)	350 mm ² (MCM) 200 mm ² (GCD) 4+37.5 mm ² (MCD)	80,200,000 (MCM)
Navi 33 RDNA3	13,300,000,000	2023	AMD	TSMC	6 nm	204 mm ²	65,200,000
Aqua Vanjaram CDNA3	153,000,000,000 (MCM)	2023	AMD	TSMC	5 nm (GCD) 6 nm (MCD)	?	?
GB200 Grace Blackwell	208,000,000,000	2024	Nvidia	TSMC	4 nm	?	?



Taiwan Semiconductor Manufacturing Company Limited
(TSMC, sometimes only Taiwan Semiconductor)



Thanks to nanotechnology!

Metall-Oxid-Halbleiter-Feldeffekttransistor (MOSFET)

