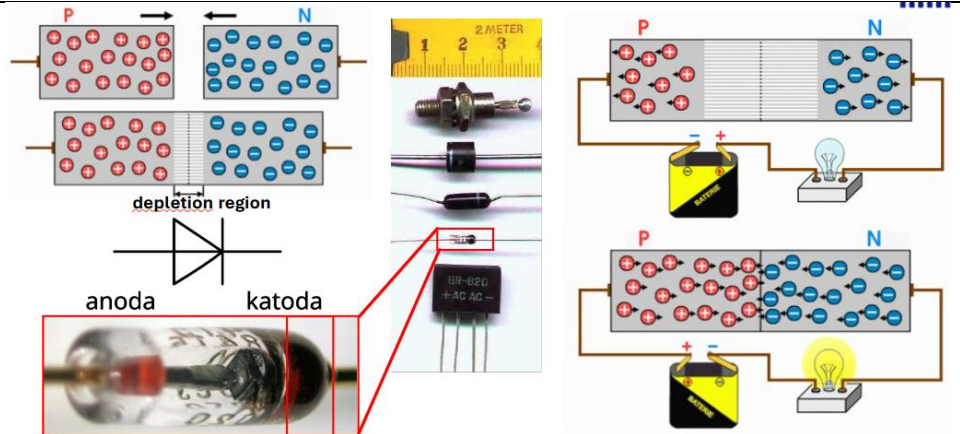
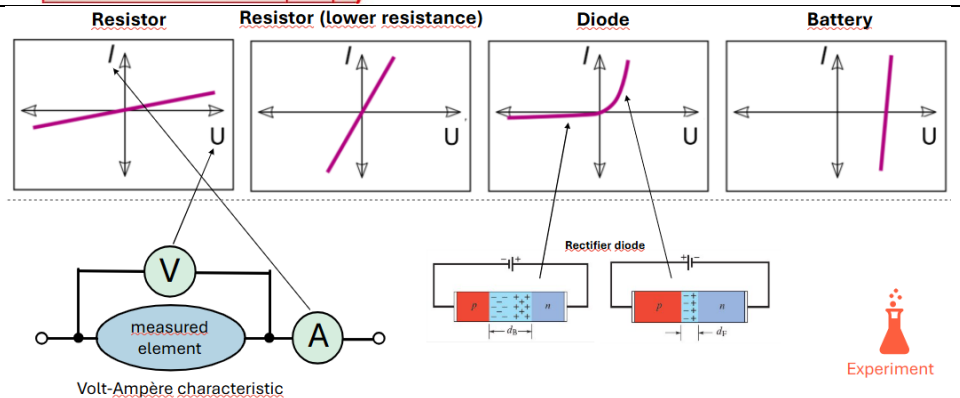
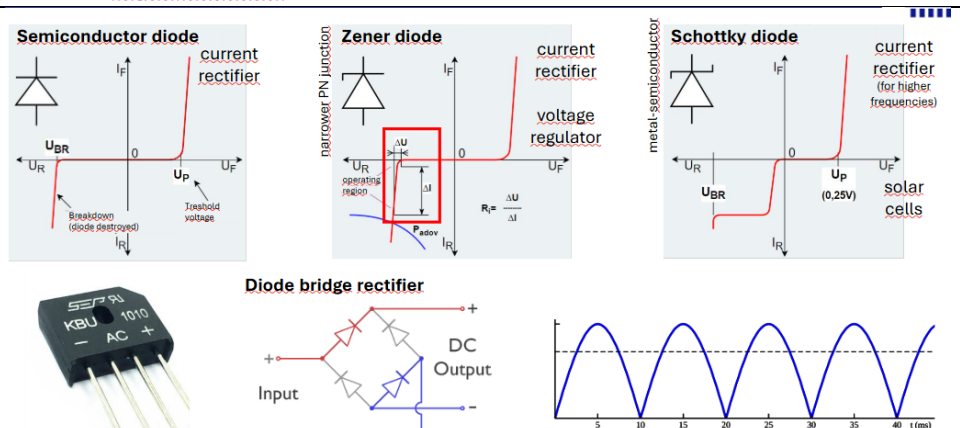
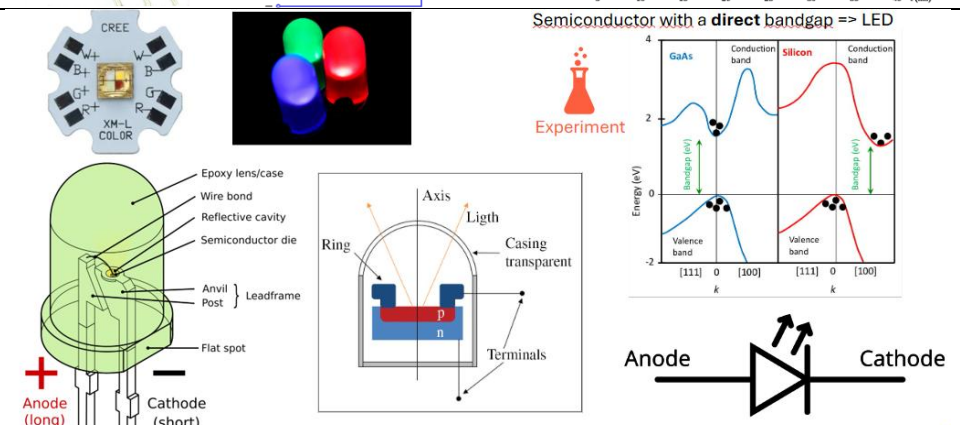
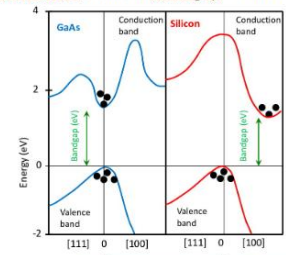
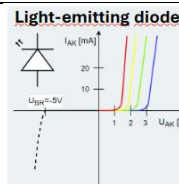


9.	Qu'est-ce qu'un semi-conducteur ?
Groupe cible	Élèves, enseignants en option
Âge des élèves	16–18
Durée	1,5–2 heures
Qu'est-ce qu'un semi-conducteur	intrinsic Pure Silicon extrinsic P-Type Aluminum => p-type acceptor (accepts electrons) Boron atom Void (Hole) N-Type Phosphorus => n-type donor (donates electrons) Antimony atom Fifth valence electron
Résumé de l'introduction	metal (conductor) zero band gap semiconductor band gap: $5 \text{ eV} > E_g > 0.5 \text{ eV}$ dielectric (non-conductor) band gap: $E_g > 5 \text{ eV}$ Extrinsic semiconductors: Phosphorus => p-type donor Aluminum => p-type acceptor Electrical resistance (Ω) Experiment CHIPS of Europe – Creating Higher-Education Industry Programmes for the Semiconductor Industry of Europe www.chips4europe.eu
Vidéo : métaux et isolants	METALS AND INSULATORS In quantum physics, an atom in a box displays discontinuous energy levels.

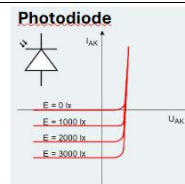
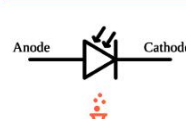
Applications :
 jonction PN → Diode

Caractéristique VA
 (éléments linéaires
 vs. non linéaires)

Caractéristique VA
 (avancée)

**Diode → LED (diode
 électroluminescente)**


**Diode → LED →
 Laser à semi-
 conducteur**

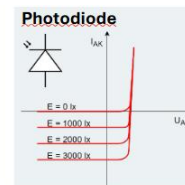
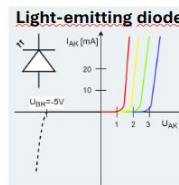
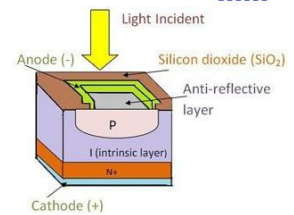
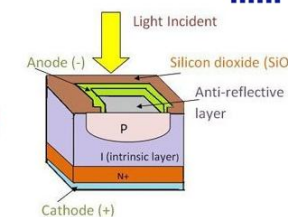
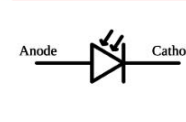
Color	Wavelength (nm)	Voltage (V)	Semiconductor material
Infrared	$\lambda > 780$	$0.5V \sim 1.9$	Gallium arsenide (GaAs) Aluminum gallium arsenide (AlGaAs)
Red	$610 < \lambda < 760$	$1.93 \sim 2.03$	Aluminum gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	$2.03 \sim 2.10$	Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	$570 < \lambda < 590$	$2.10 \sim 2.18$	Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	$500 < \lambda < 570$	$1.9^{III} \sim 2.5V < 4.0$	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminum gallium indium phosphide (AlGaInP) Aluminum gallium phosphide (AlGaP)
Blue	$450 < \lambda < 500$	$2.48 \sim 2.7$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	$400 < \lambda < 450$	$2.76 \sim 2.8$	Indium gallium nitride (InGaN)
Purple	multiple types	$2.48 \sim 3.7$	Dual InGaIn LEDs, blue with red phosphor, or white with purple phosphor
Ultraviolet	$\lambda < 400$	$3.1 \sim 4.4$	Diamond (235 nm) ^[1] Boron nitride (215 nm) ^{[1][2]} Aluminum nitride (AlN) (210 nm) ^[1] Aluminum gallium nitride (AlGaN) Aluminum gallium indium nitride (AlGaInN) — (down to 210 nm) ^[1]
White	Broad spectrum	$2.7 \sim 3.5$	Blue diode with yellow phosphor or violet/UV diode with multi color phosphor

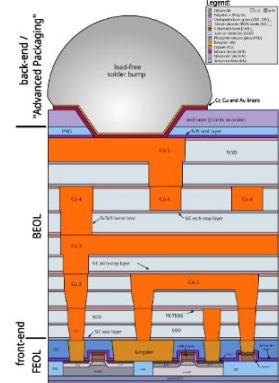
Semiconductor with a direct bandgap => LED

**Diode → LED →
 Photodiode**


Experiment


**speaker vs. microphone
 LED vs. photodiode**


Experiment

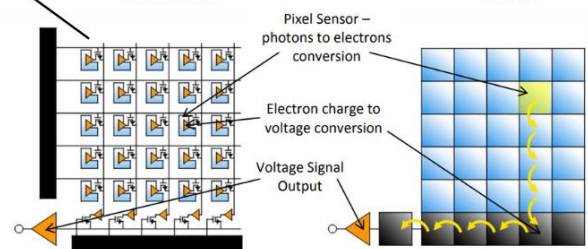

**speaker vs. microphone
 LED vs. photodiode**

Digital camera chip

**Diode → LED →
 Photodiode (CCD,
 CMOS)**
Integrated circuit


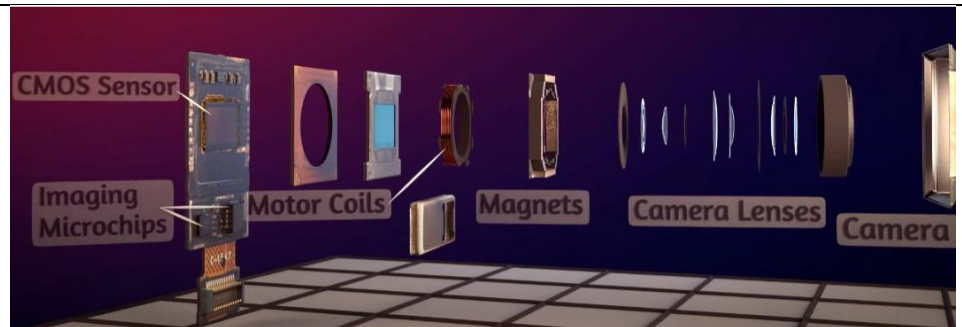
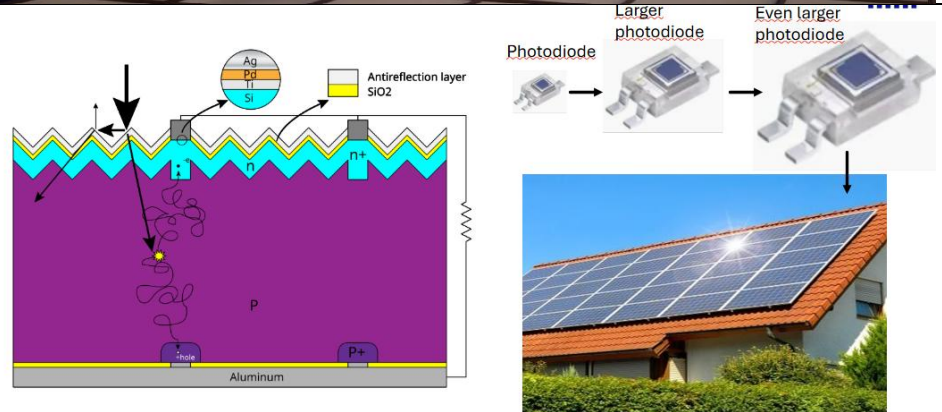
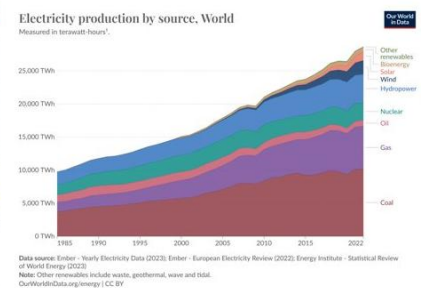
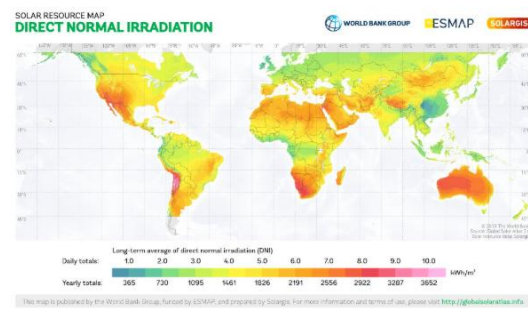
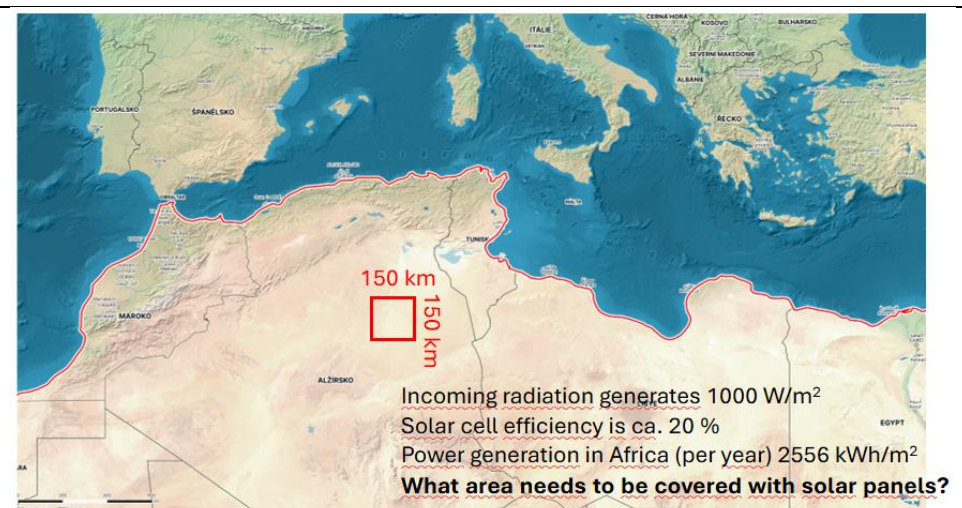
CMOS



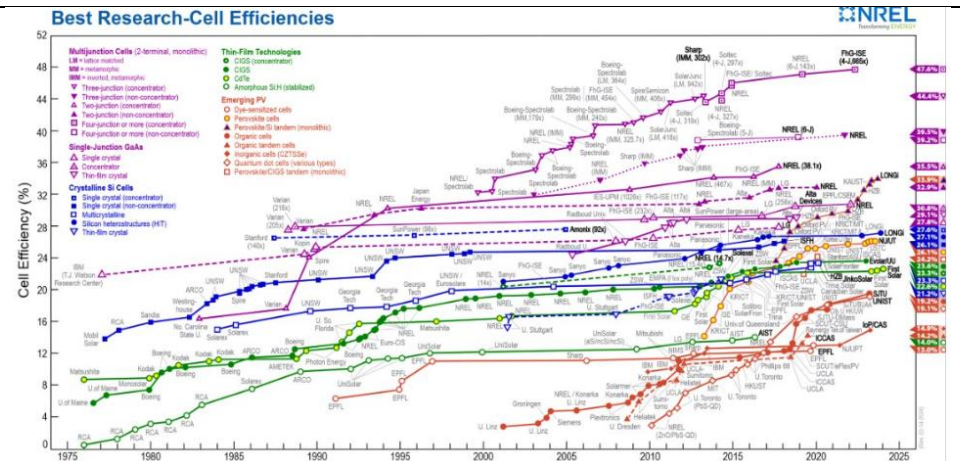
CCD



Appareil photo de téléphone

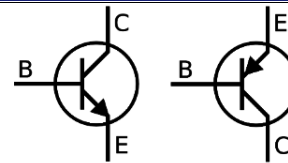
Diode → LED →
Photodiode →
Cellule solaireRayonnement solaire
vs. consommation
d'énergieCellules solaires
(pourquoi, combien,
comment... ?)

Cellules solaires : rendement

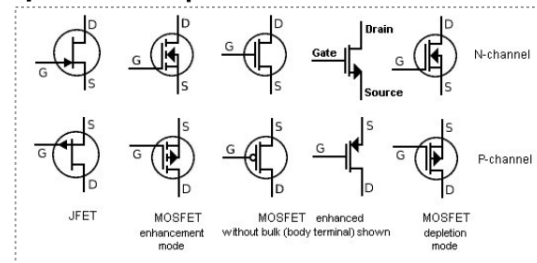


Transistor

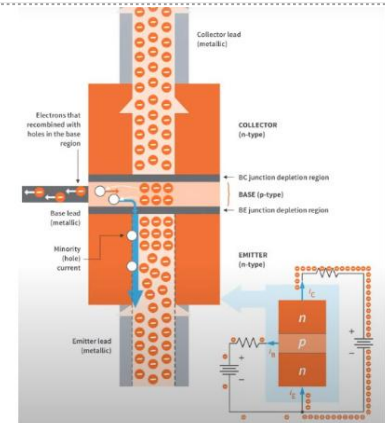
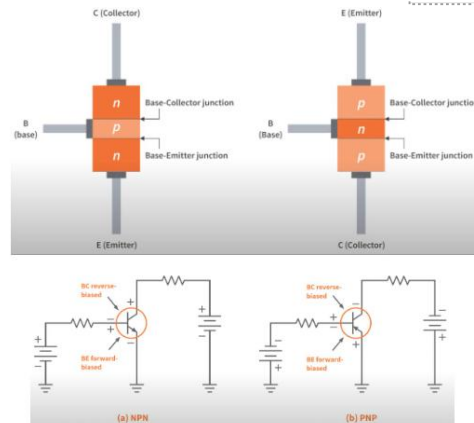
Bipolar junction transistor (BJT)



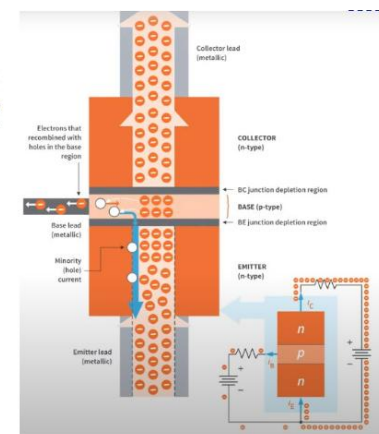
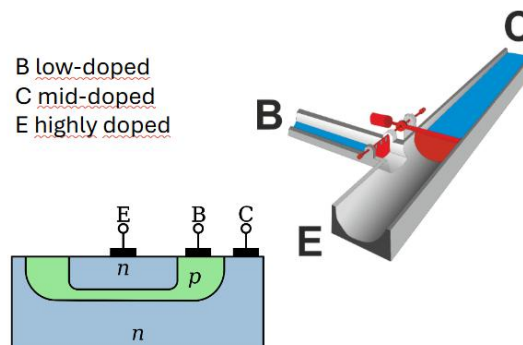
Unipolar transistor (FET)



Transistor bipolaire à jonction (BJT)

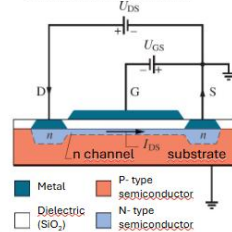
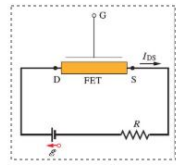


B low-doped
C mid-doped
E highly doped



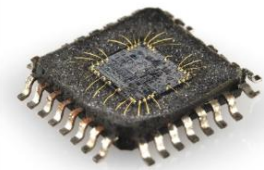
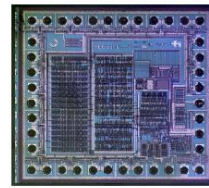
Transistor à effet de champ métal-oxyde-semi-conducteur (MOSFET)

Field effect transistor(FET)



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

Integrated circuit



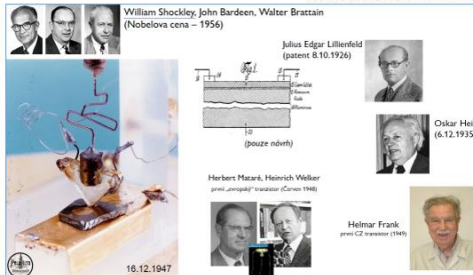
Microprocessor in cross-section



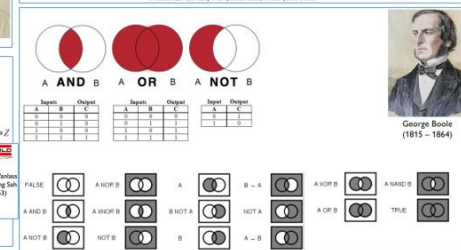
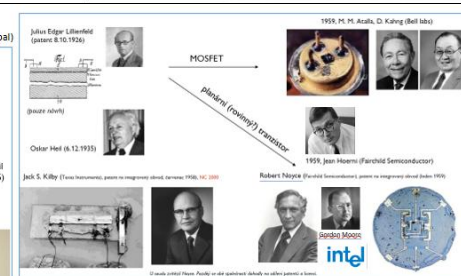
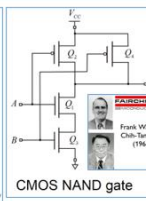
Technologie exponentielle : l'histoire du transistor

Exponential technology: The transistor tale

(with kind permission of prof. M. Kolibal)



Chcete založit novou firmu a hledat investory. Toho má po 35 schůzkách. Firma Fairchild se rozhodla investovat a stali se tak soudržní korporátní firmy Fairchild company, kde vznikla nová polovodičová Fairchild semiconductor.

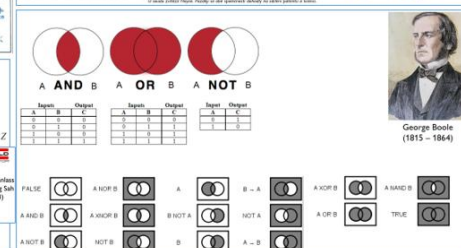
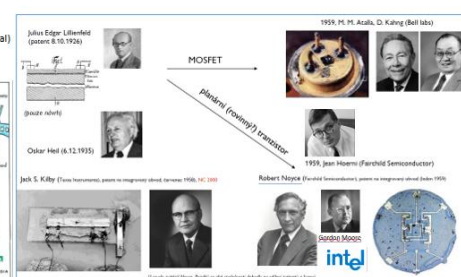
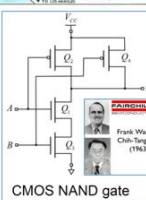


Exponential technology: The transistor tale

(with kind permission of prof. M. Kolibal)

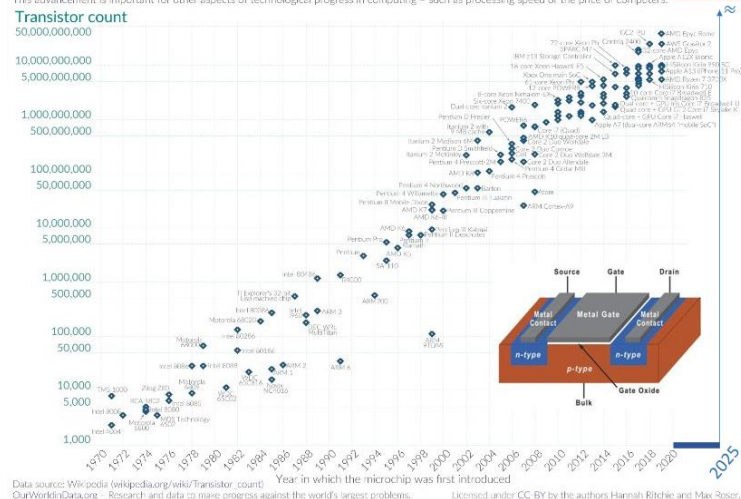


Chcete založit novou firmu a hledat investory. Toho má po 35 schůzkách. Firma Fairchild se rozhodla investovat a stali se tak soudržní korporátní firmy Fairchild company, kde vznikla nová polovodičová Fairchild semiconductor.



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.

Our World
in Data



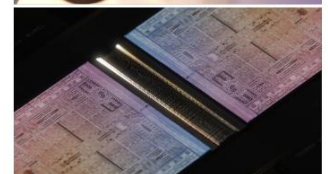
Semiconductor
device
fabrication



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 ^[106]	2023	Apple	3 nm	?	?
Apple M3 Pro (decade-core 64-bit ARMv8 SoC, SIMD, caches)	37,000,000,000 ^[106]	2023	Apple	3 nm	?	?
Apple M3 Max (hexadeca-core 64-bit ARMv8 SoC, SIMD, caches)	92,000,000,000 ^[106]	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) ^[108]	44,000,000,000–48,000,000,000 ^[108]	2023	Intel	10 nm ESDP (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 ^[109]	2023	Apple	5 nm	?	?
Apple M2 Max (12-core 64-bit ARMv8 SoC, SIMD, caches)	67,000,000,000 ^[109]	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/57X4 series) 9-chip module (up to 128 cores and 256 MB (L3) + 128 MB (L2) cache)	82,000,000,000 ^[101]	2023	AMD	5 nm (CCD) 6 nm (IOD)	?	?
AMD Instinct MI300A (multi-chip module, 24 cores, 128 GB GPU memory + 256 MB (LLC3) cache)	146,000,000,000 ^{[102][103]}	2023	AMD	5 nm (CCD, CCD) 6 nm (IOD)	1,017 mm ²	144,000,000



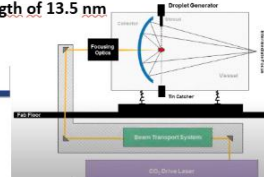
Graphics processing unit (GPU)

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	606.4 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 CONA3	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	?	?

Optical lithography using light with wavelength of 13.5 nm



ASML
CYMER



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



Thanks to nanotechnology!

Transistor à effet de champ métal-oxyde- semi-conducteur (MOSFET)

