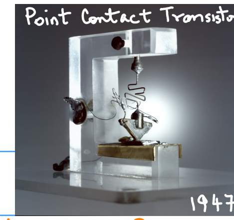
25.10.2023

Bipolar Junction Transistors (BJTs)

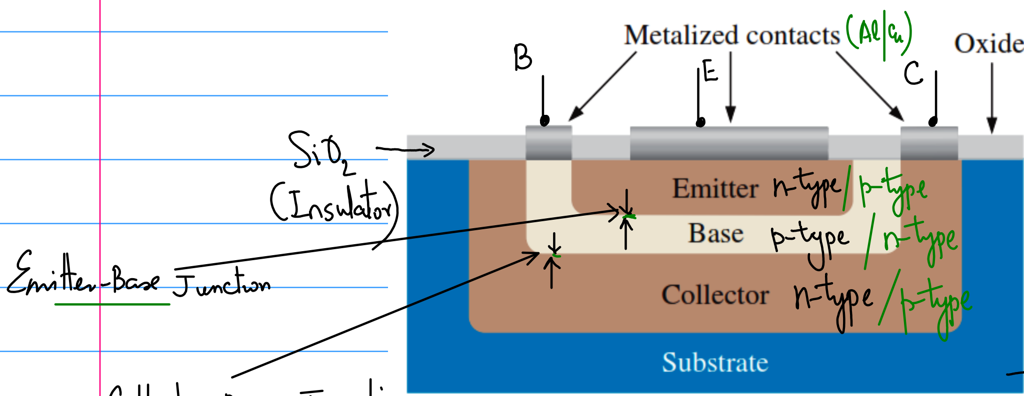


1956 Nobel Prize in Physics – William B. Shockley, John Bardeen & Walter H. Brattain

Bipolar : Both electrons & holes are participating in device operation.

Junction : p-n / n-p (Barrier potential associated with junction).

Transistor : Transfer of resistor (ie, transfer of current levels)



→ starting material

(a) Basic epitaxial planar structure

growth

MBE : Molecular beam epitaxy

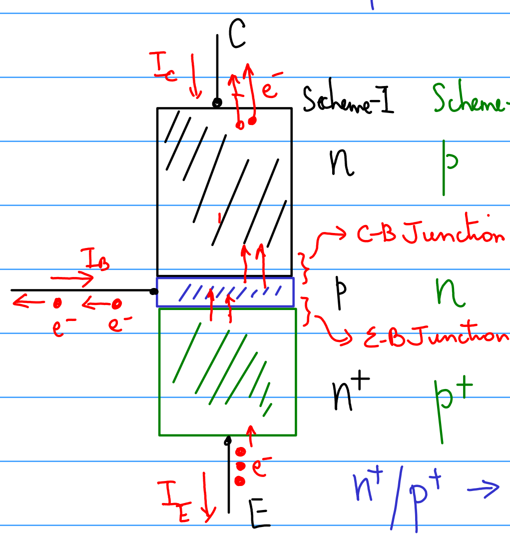
Fabrication of a BJTs.

Thickness :

C : Thickest layer

B : Thinnest layer

E : Moderate thickness



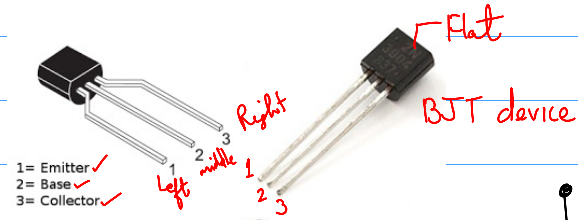
n^+/p^+ → Heavily doping

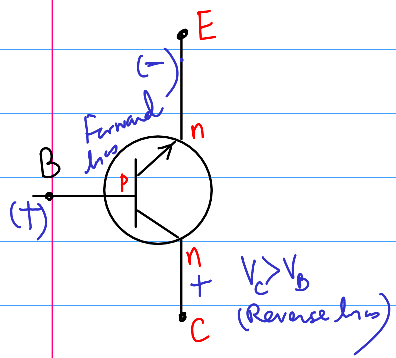
Doping levels :

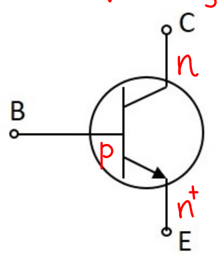
C : Moderately doped ($\sim 10^{14-15}\ cm^{-3}$) dopant

B : Lightly doped ($10^{12-13}\ cm^{-3}$)

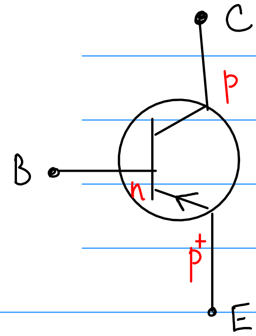
E : Heavily doped ($10^{16-18}\ cm^{-3}$)







n-p-n Transistor



p-n-p Transistor

Basic BJT operation:

(i) Emitter-Base Junction : Forward-Bias

(ii) Collector-Base Junction : Reverse-Bias

For Active mode of operation

$I_B \uparrow$ 2 times

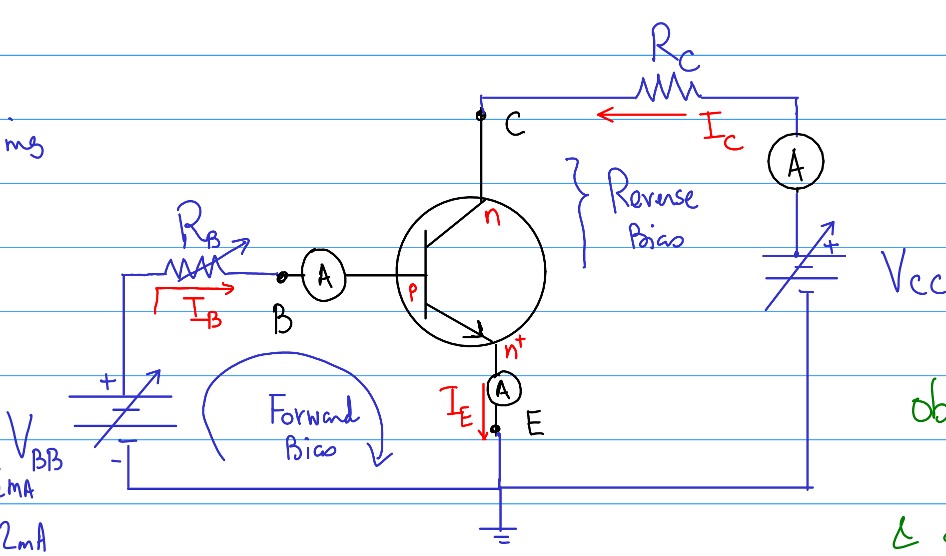
$I_{B_1} = 10\,\mu A$

$I_{B_2} = 20\,\mu A$

$I_C = \beta_{DC} I_B$

$I_{C_1} = 100 \cdot 10\,\mu A = 1\,mA$

$I_{C_2} = 100 \cdot 20\,\mu A = 2\,mA$



$\underbrace{V_C > V_B}$

We are trying to observe the current levels in the collector, Base & Emitter terminal.

– Any change in the Base-Emitter terminals, the change is directly appearing in the collector terminal.

$I_E = I_B + I_C$

$\boxed{I_E ;\ I_C \sim mA}$; $\boxed{I_B \sim \mu A}$

We define a parameter, $\beta_{DC} = \dfrac{I_C}{I_B} = \dfrac{\sim mA}{\sim \mu A} \simeq 100$ (typical)

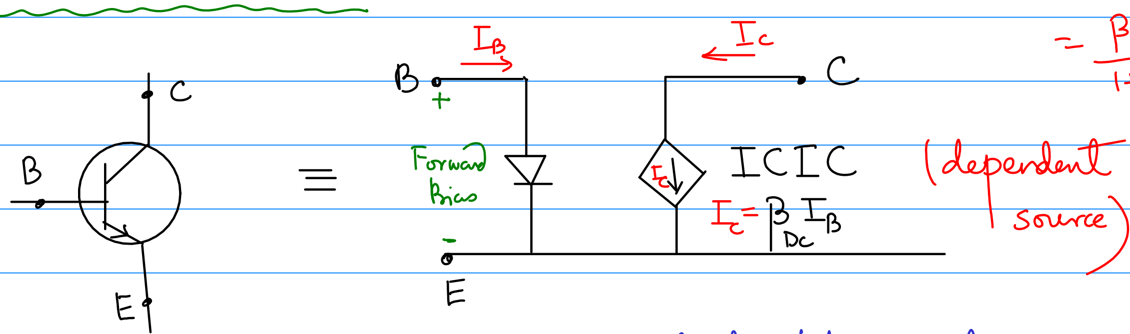
β_{DC} = typically varies b/w 50–300

$$\boxed{\alpha_{DC} = \frac{\beta_{DC}}{1+\beta_{DC}}}$$

- Common-Emitter Current Gain (β_{DC})
- Common-Base Current Gain (α_{DC}) $= \dfrac{I_C}{I_E} = \dfrac{I_C}{I_B + I_C}$

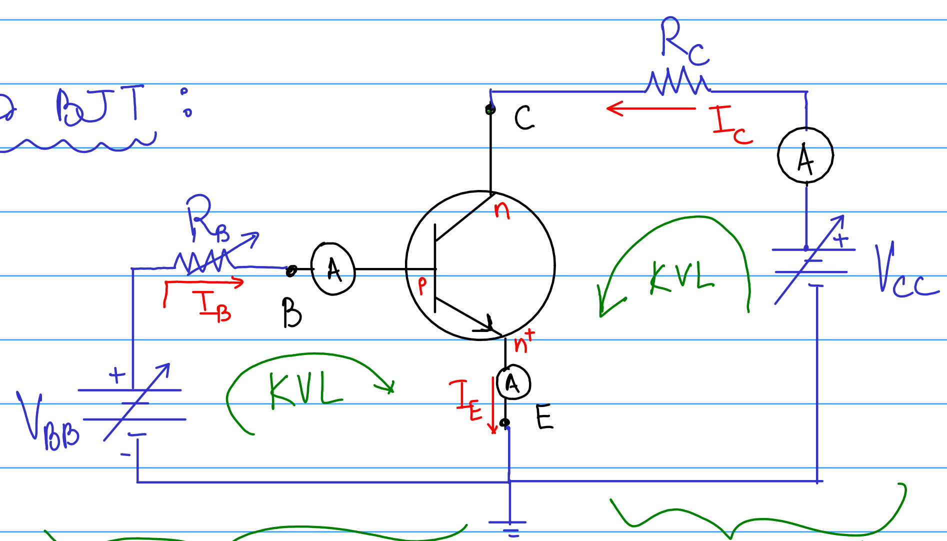
$$= \frac{I_C/I_B}{1 + I_C/I_B} = \frac{\beta_{DC}}{1+\beta_{DC}}$$

Transistor DC Model:



Equivalent ckt model.

Biased BJT:

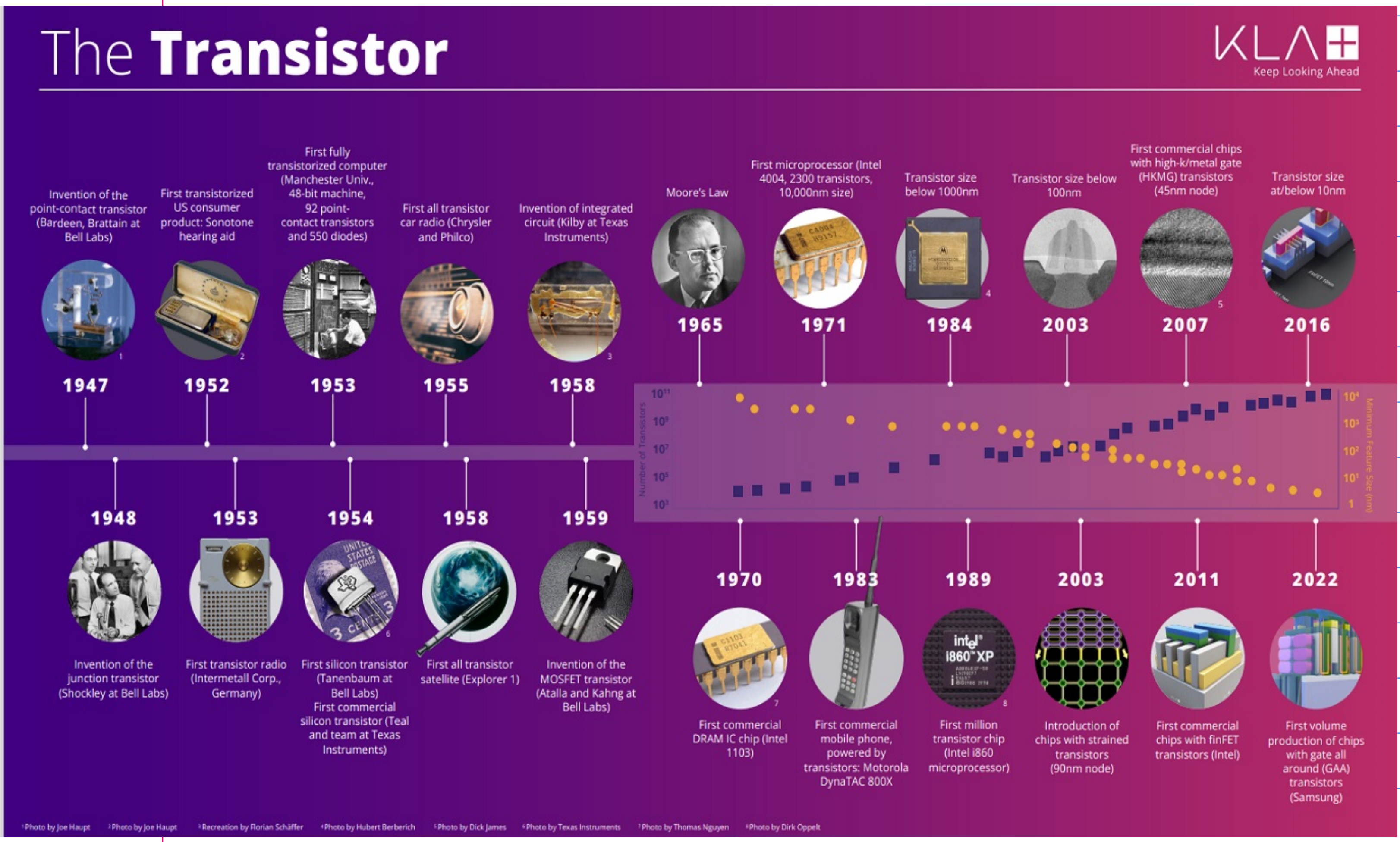


$V_{CC} = I_C R_C + V_{CE}$

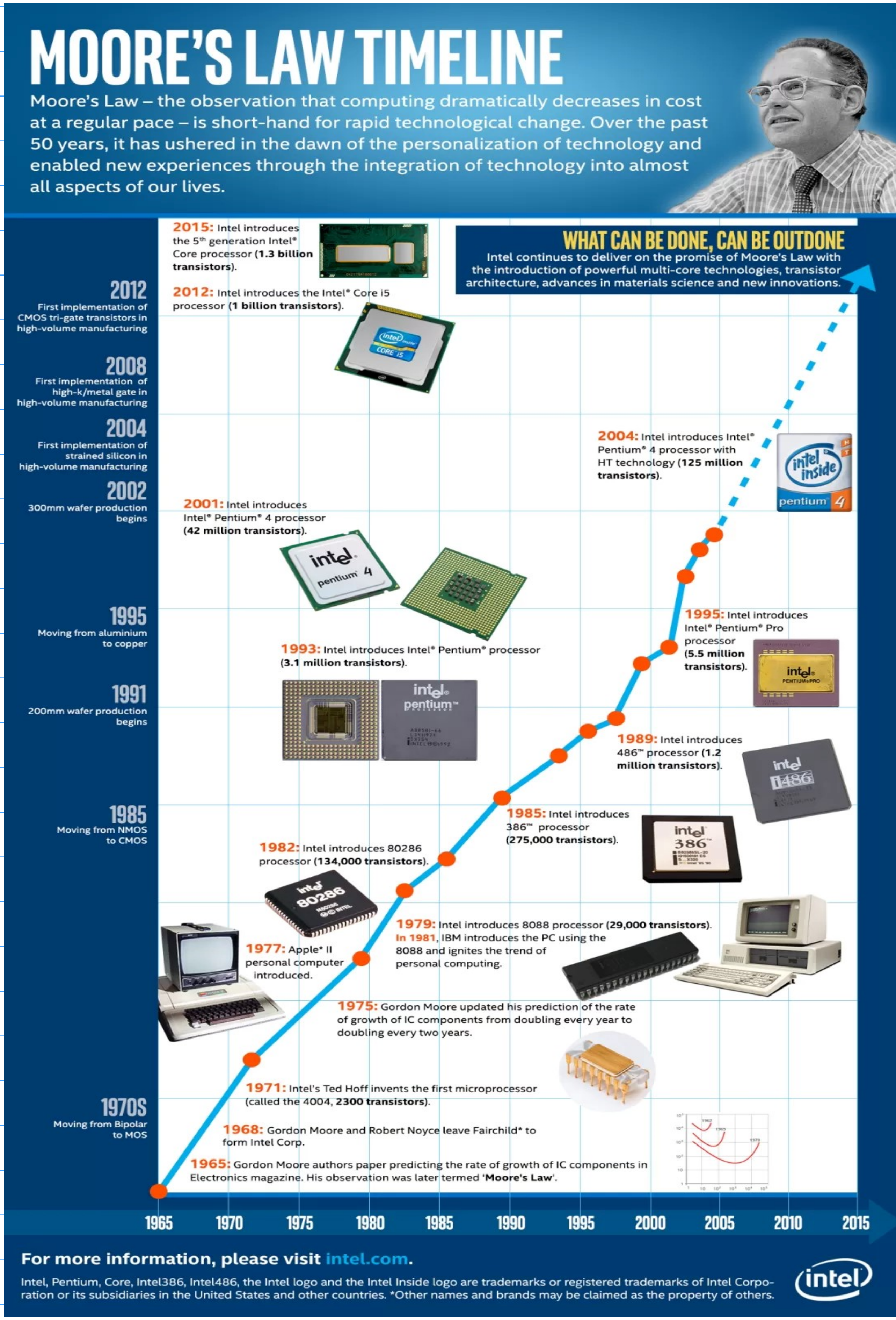
$\underset{\sim}{I_C} = \dfrac{V_{CC} - V_{CE}}{R_C}$

Input Output

$V_{BB} = I_B \cdot R_B + V_{BE} \Rightarrow \underset{\sim}{I_B} = \dfrac{V_{BB} - V_{BE}}{R_B}$



The Transistor
KLA
Keep Looking Ahead
1947
Invention of the point-contact transistor (Bardeen, Brattain at Bell Labs)
1952
First transistorized US consumer product: Sonotone hearing aid
1953
First fully transistorized computer (Manchester Univ., 48-bit machine, 92 point-contact transistors and 550 diodes)
1955
First all transistor car radio (Chrysler and Philco)
1958
Invention of integrated circuit (Kilby at Texas Instruments)
1948
Invention of the junction transistor (Shockley at Bell Labs)
1953
First transistor radio (Intermetall Corp., Germany)
1954
First silicon transistor (Tanenbaum at Bell Labs)
First commercial silicon transistor (Teal and team at Texas Instruments)
1958
First all transistor satellite (Explorer 1)
1959
Invention of the MOSFET transistor (Atalla and Kahng at Bell Labs)
1965
Moore's Law
1971
First microprocessor (Intel 4004, 2300 transistors, 10,000nm size)
1984
Transistor size below 1000nm
2003
Transistor size below 100nm
2007
First commercial chips with high-k/metal gate (HKMG) transistors (45nm node)
2016
Transistor size at/below 10nm
Number of Transistors
Minimum Feature Size (nm)
1970
First commercial DRAM IC chip (Intel 1103)
1983
First commercial mobile phone, powered by transistors: Motorola DynaTAC 800X
1989
First million transistor chip (Intel i860 microprocessor)
2003
Introduction of chips with strained transistors (90nm node)
2011
First commercial chips with finFET transistors (Intel)
2022
First volume production of chips with gate all around (GAA) transistors (Samsung)
1 Photo by Joe Haupt
2 Photo by Joe Haupt
3 Recreation by Florian Schäffer
4 Photo by Hubert Berberich
5 Photo by Dick James
6 Photo by Texas Instruments
7 Photo by Thomas Nguyen
8 Photo by Dirk Oppelt


MOORE'S LAW TIMELINE
Moore's Law – the observation that computing dramatically decreases in cost at a regular pace – is short-hand for rapid technological change. Over the past 50 years, it has ushered in the dawn of the personalization of technology and enabled new experiences through the integration of technology into almost all aspects of our lives.
WHAT CAN BE DONE, CAN BE OUTDONE
Intel continues to deliver on the promise of Moore's Law with the introduction of powerful multi-core technologies, transistor architecture, advances in materials science and new innovations.
2012
First implementation of CMOS tri-gate transistors in high-volume manufacturing
2008
First implementation of high-k/metal gate in high-volume manufacturing
2004
First implementation of strained silicon in high-volume manufacturing
2002
300mm wafer production begins
1995
Moving from aluminium to copper
1991
200mm wafer production begins
1985
Moving from NMOS to CMOS
1970S
Moving from Bipolar to MOS
2015: Intel introduces the 5th generation Intel® Core processor (1.3 billion transistors).
2012: Intel introduces the Intel® Core i5 processor (1 billion transistors).
2004: Intel introduces Intel® Pentium® 4 processor with HT technology (125 million transistors).
2001: Intel introduces Intel® Pentium® 4 processor (42 million transistors).
1995: Intel introduces Intel® Pentium® Pro processor (5.5 million transistors).
1993: Intel introduces Intel® Pentium® processor (3.1 million transistors).
1989: Intel introduces 486™ processor (1.2 million transistors).
1985: Intel introduces 386™ processor (275,000 transistors).
1982: Intel introduces 80286 processor (134,000 transistors).
1979: Intel introduces 8088 processor (29,000 transistors). In 1981, IBM introduces the PC using the 8088 and ignites the trend of personal computing.
1977: Apple* II personal computer introduced.
1975: Gordon Moore updated his prediction of the rate of growth of IC components from doubling every year to doubling every two years.
1971: Intel's Ted Hoff invents the first microprocessor (called the 4004, 2300 transistors).
1968: Gordon Moore and Robert Noyce leave Fairchild* to form Intel Corp.
1965: Gordon Moore authors paper predicting the rate of growth of IC components in Electronics magazine. His observation was later termed 'Moore's Law'.
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
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