

# Φυσική και Τεχνολογία Υλικών και Διατάξεων Στερεάς Κατάστασης

**Δρ Χρήστος Τσάμης**

Ινστιτούτο Νανοεπιστήμης και Νανοτεχνολογίας

ΕΚΕΦΕ «Δημόκριτος»

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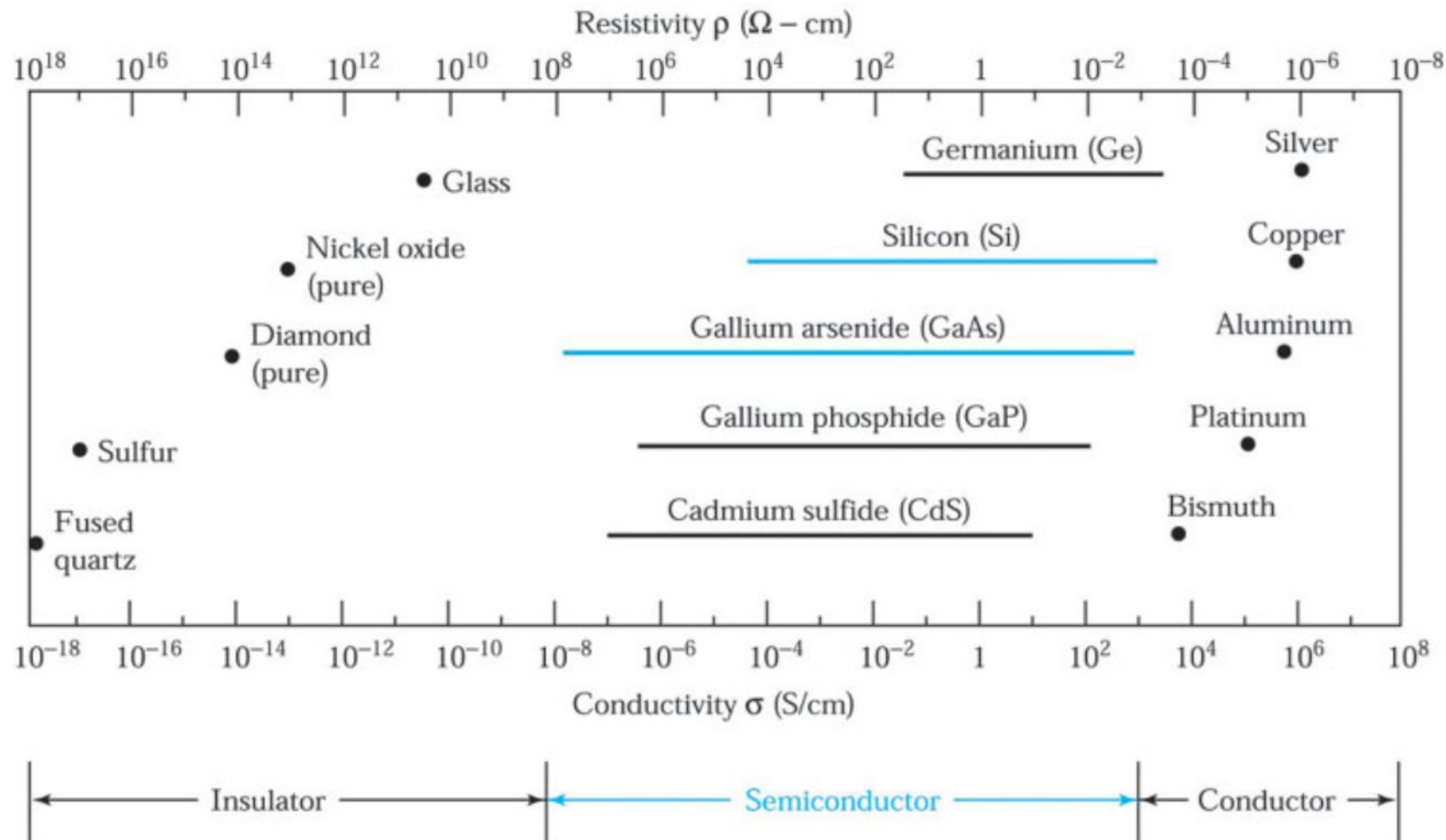
Πάτρα, 2026

## Περιεχόμενα διαλέξεων

- Εισαγωγή στους ημιαγωγούς
- Στατιστική φορέων στους ημιαγωγούς
- Φαινόμενα μεταφοράς στους ημιαγωγούς
- Βασικές εξισώσεις ημιαγωγών
- Γέννηση και επανασύνδεση φορέων στους ημιαγωγούς

## ΕΝΟΤΗΤΑ Ι: Τι είναι οι ημιαγωγοί

- Οι ημιαγωγοί είναι μια κατηγορία στερεών υλικών των οποίων η ηλεκτρική αγωγιμότητα κυμαίνεται μεταξύ της αγωγιμότητας των μεταλλικών αγωγών και των μονωτών.
- Η μοναδικότητά τους έγκειται στην ικανότητά τους να μεταβάλλουν την αγωγιμότητά τους μέσω εξωτερικών ερεθισμάτων, όπως η θερμοκρασία, το φως ή η προσθήκη προσμίξεων.



# ΕΝΟΤΗΤΑ Ι: Που βρίσκονται οι ημιαγωγοί (Μερικά παραδείγματα)

## Ηλεκτρονικά



## Μεταφορές



## Υποδομές



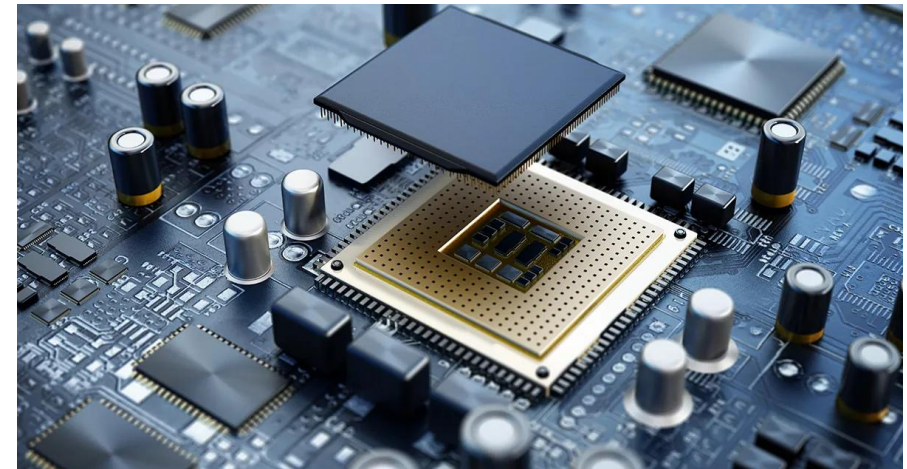
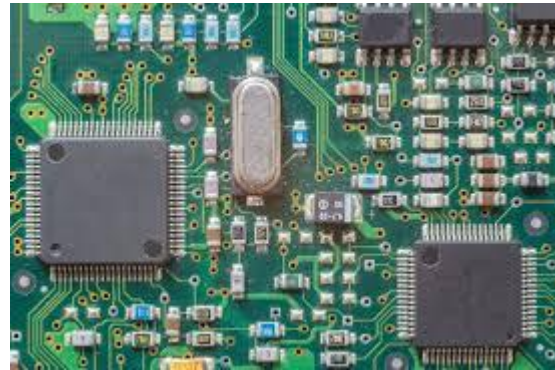
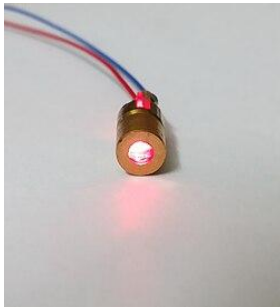
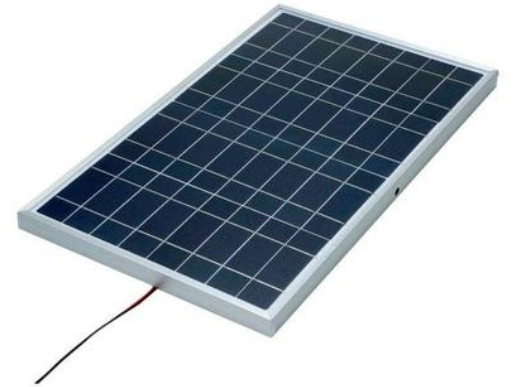
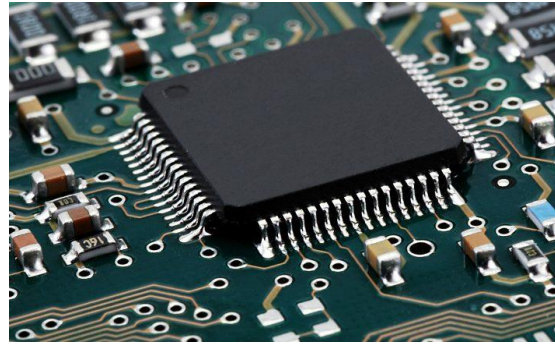
## Οικιακές συσκευές

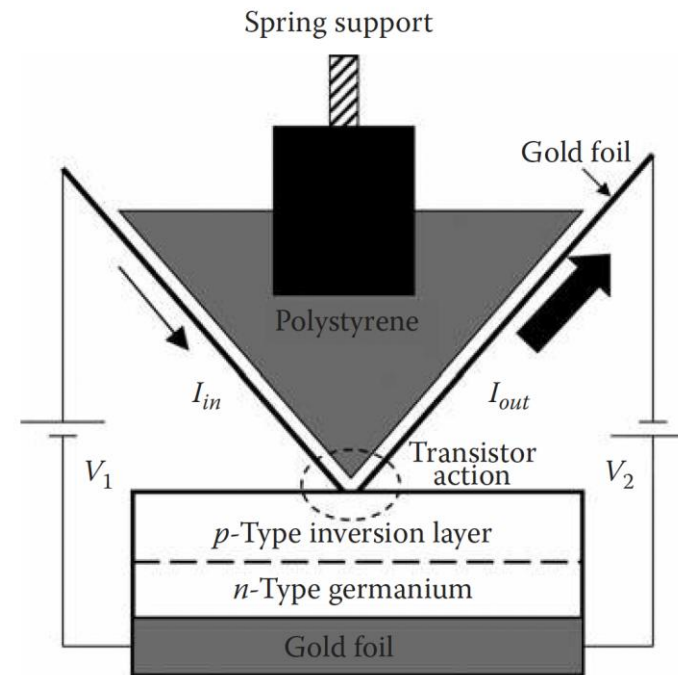
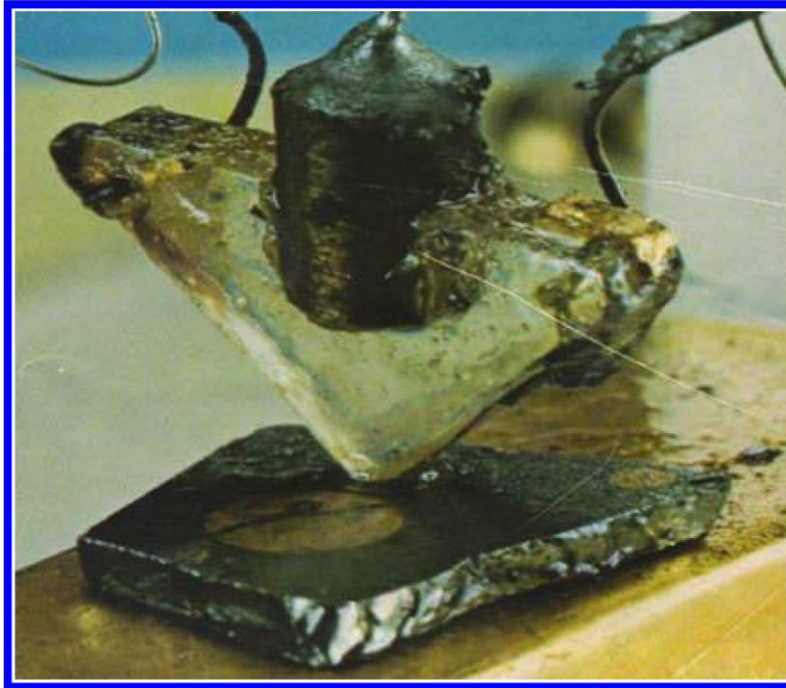


.. Και πολύ περισσότερα



# ΕΝΟΤΗΤΑ Ι: Που βρίσκονται οι ημιαγωγοί





**1947:** The famous point-contact transistor, the first solid-state amplifying device, invented in 1947 by John Bardeen and Walter Brattain at Bell Laboratories in the United States. Bardeen and Brattain discovered that by placing two gold contacts close together on the surface of a crystal of germanium through that an electric current was flowing a device that acted as an electrical amplifier was produced. (Photograph courtesy of Alcatel-Lucent.) A schematic diagram of the device is shown on the right.



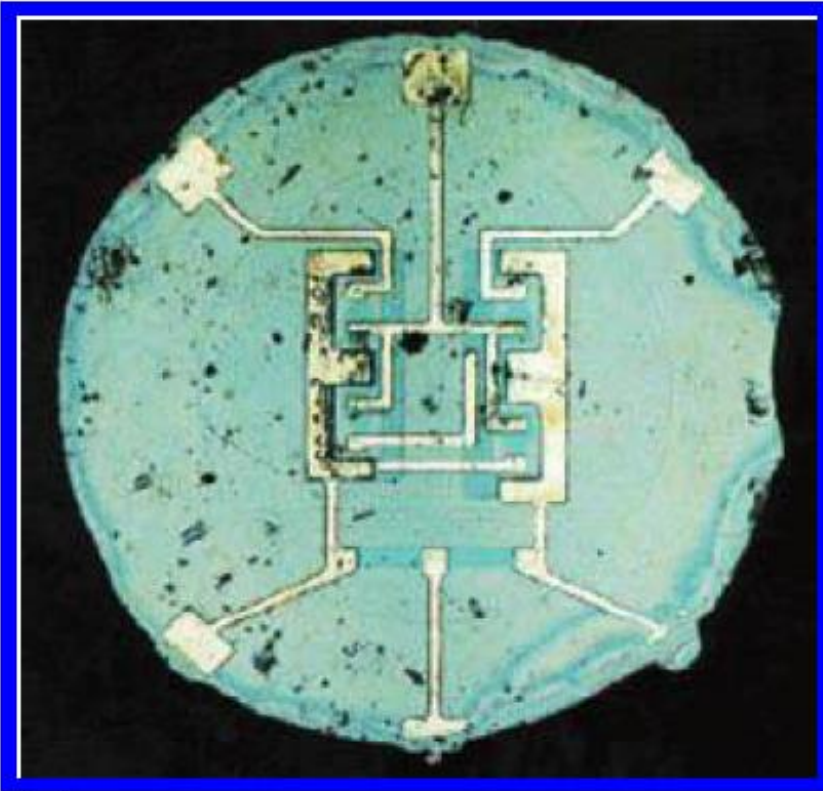
(a)

**1951:** The first Bipolar Junction Transistor (BJT)  
(Photograph courtesy of Alcatel-Lucent.)

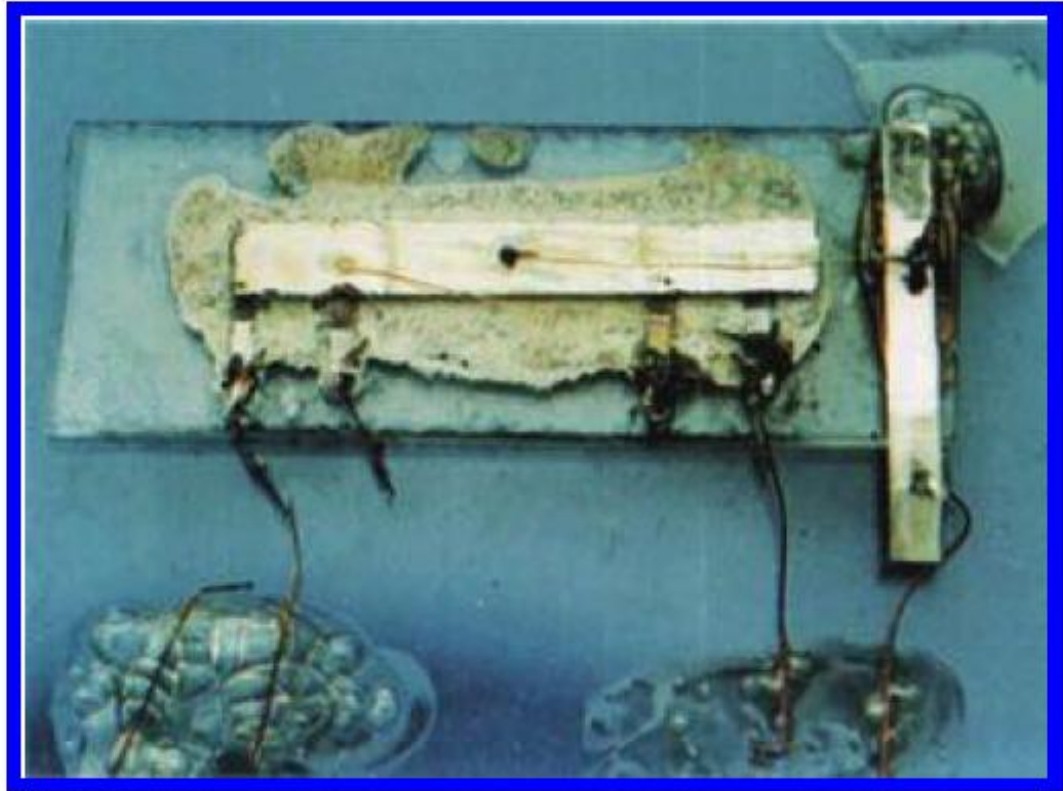


(b)

**1959:** The first MOSFET  
(Photograph courtesy of Alcatel-Lucent.)



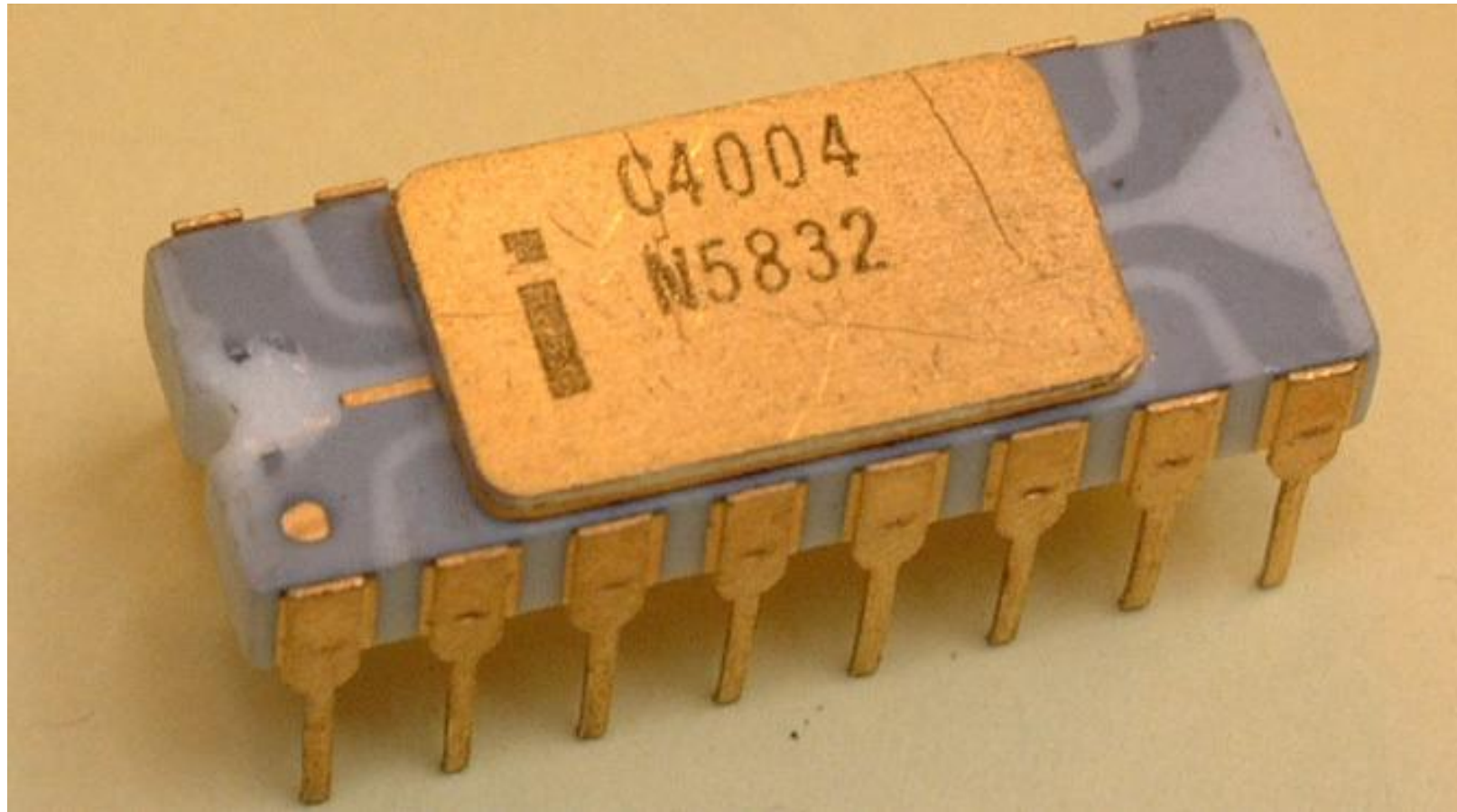
(a)



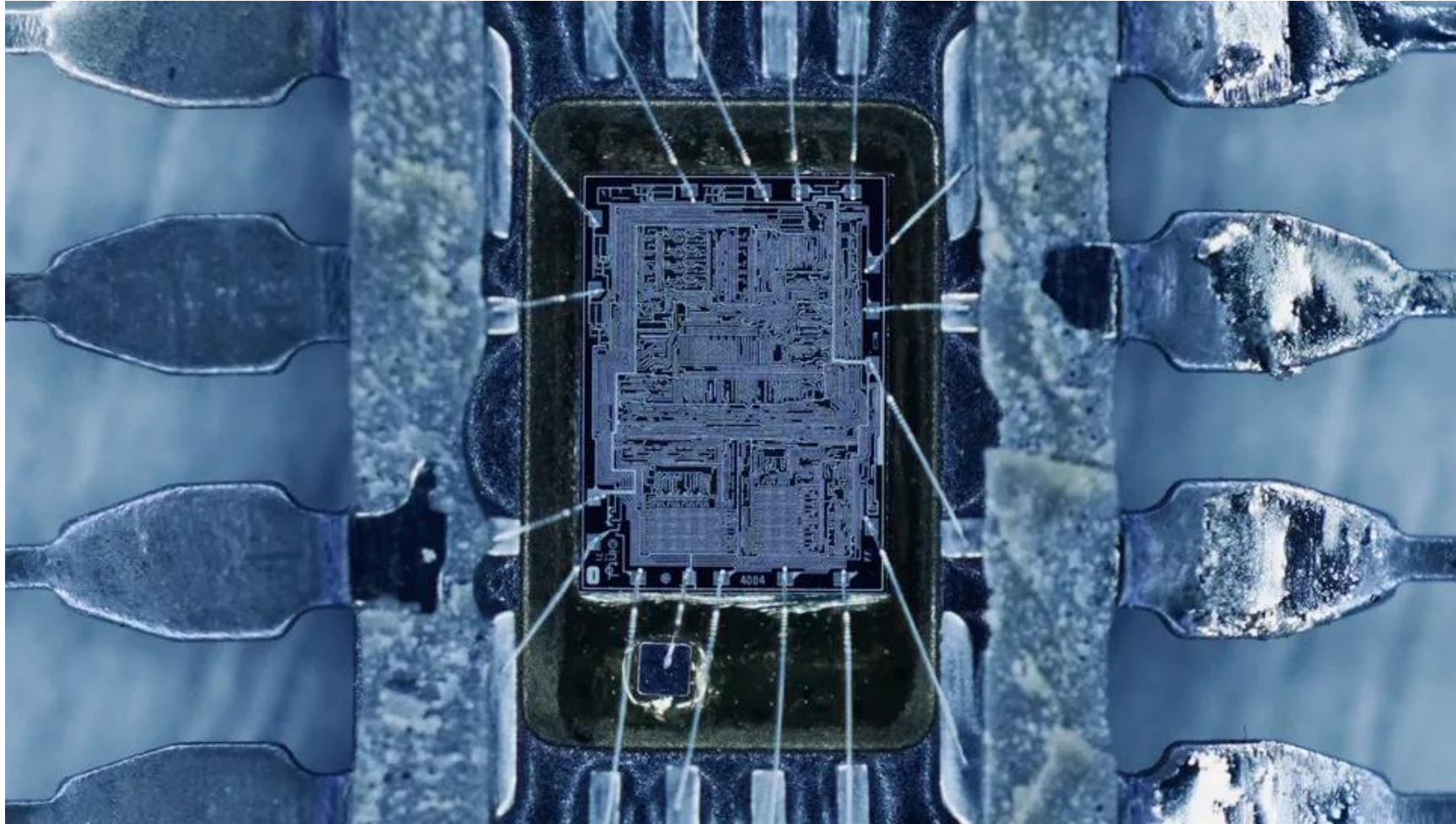
(b)

1960: The first planar integrated circuits. (a) Noyce and Moore's IC. (b) Kilby's IC. (Photograph courtesy of Texas Instruments, Dallas, TX, and Fairchild, San Jose, CA.)

**Planar technology --→ Miniaturization**

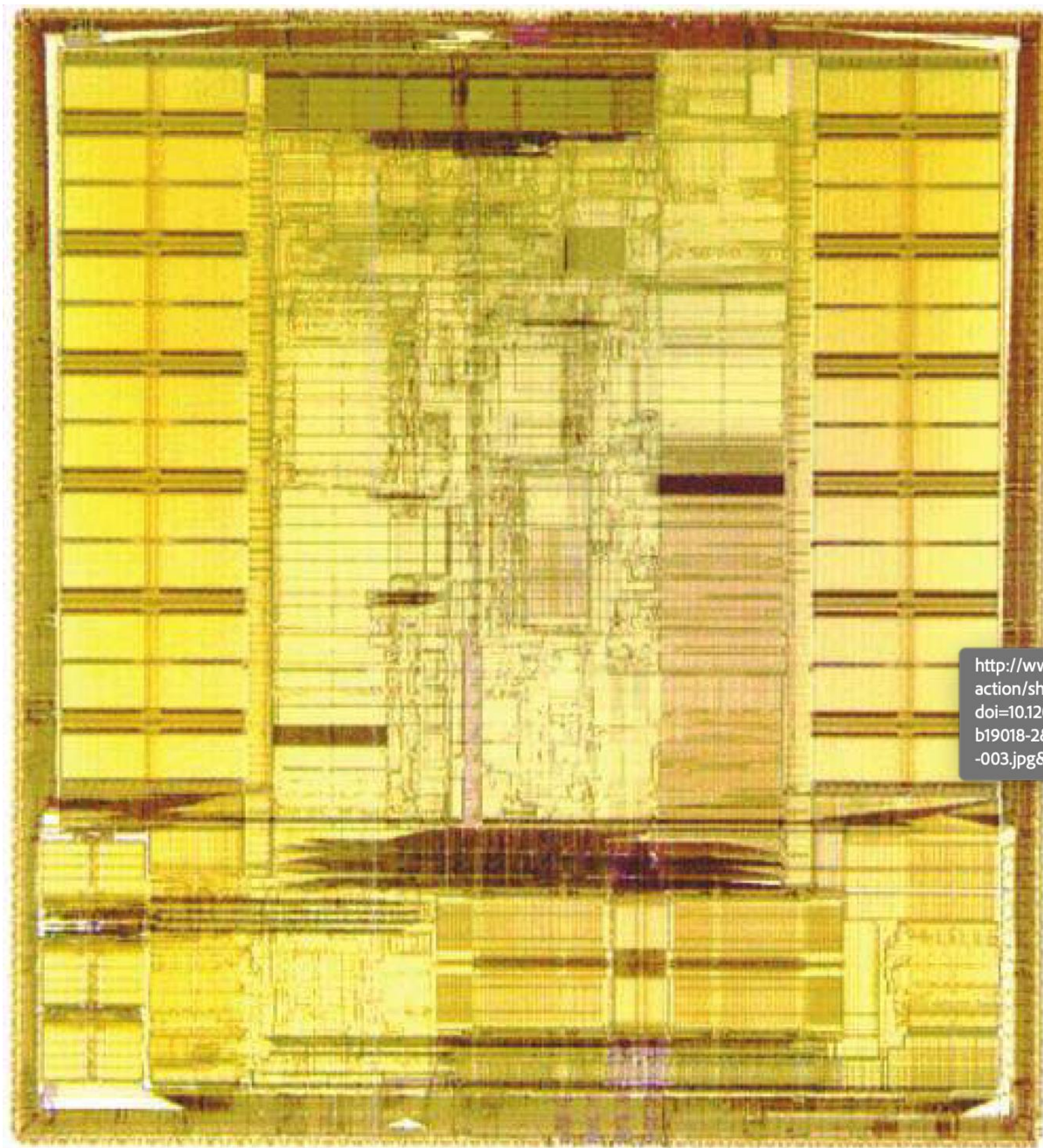


**1971:** The first microprocessor, the Intel 4004. (Courtesy of Intel Corporation, Santa Clara, CA.)



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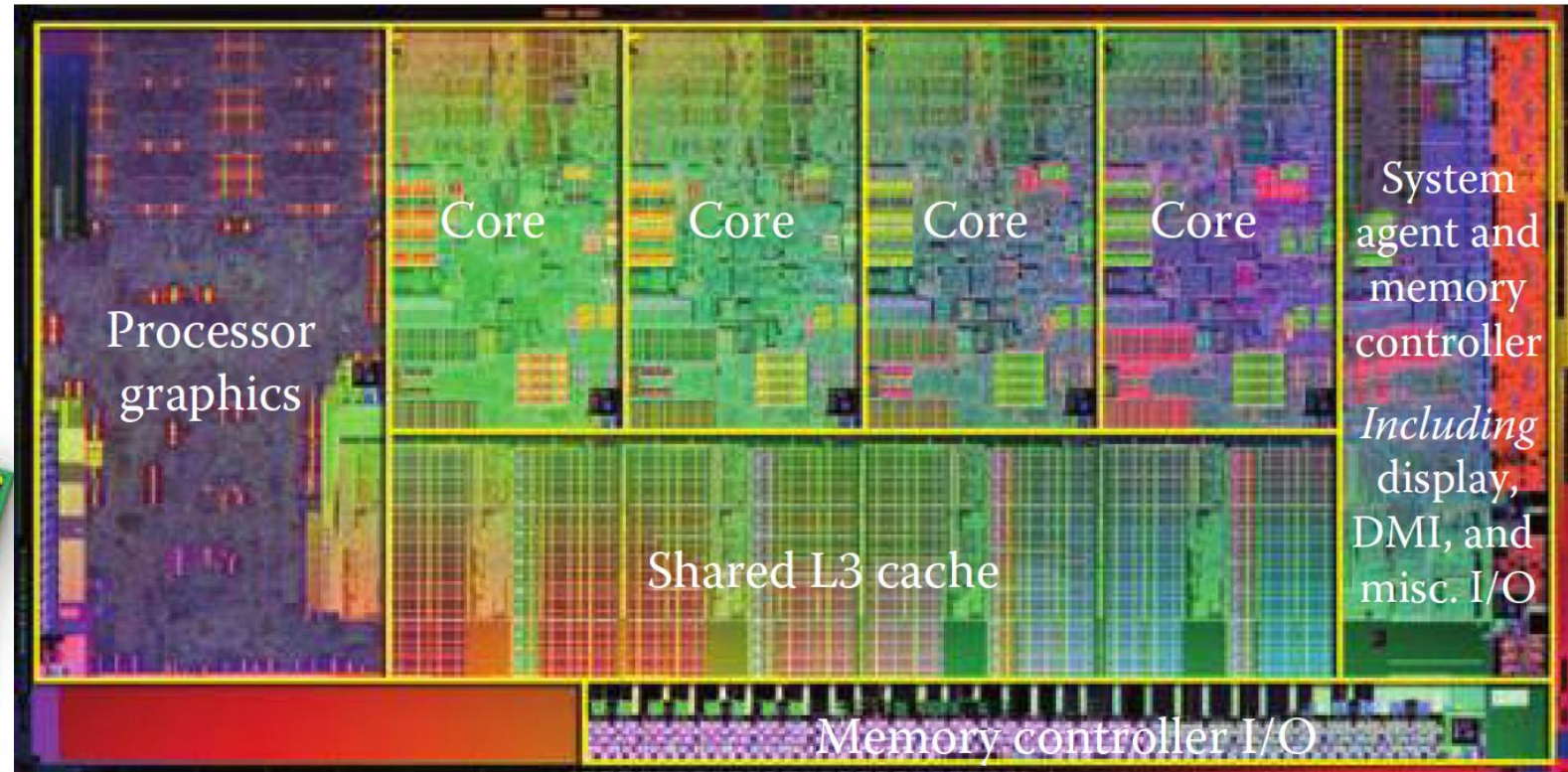
**2,300**-transistor (10,000nm)



<http://www.action/showaction/showaction/doi=10.1201/b19018-2&img=19018-2-003.jpg&v>

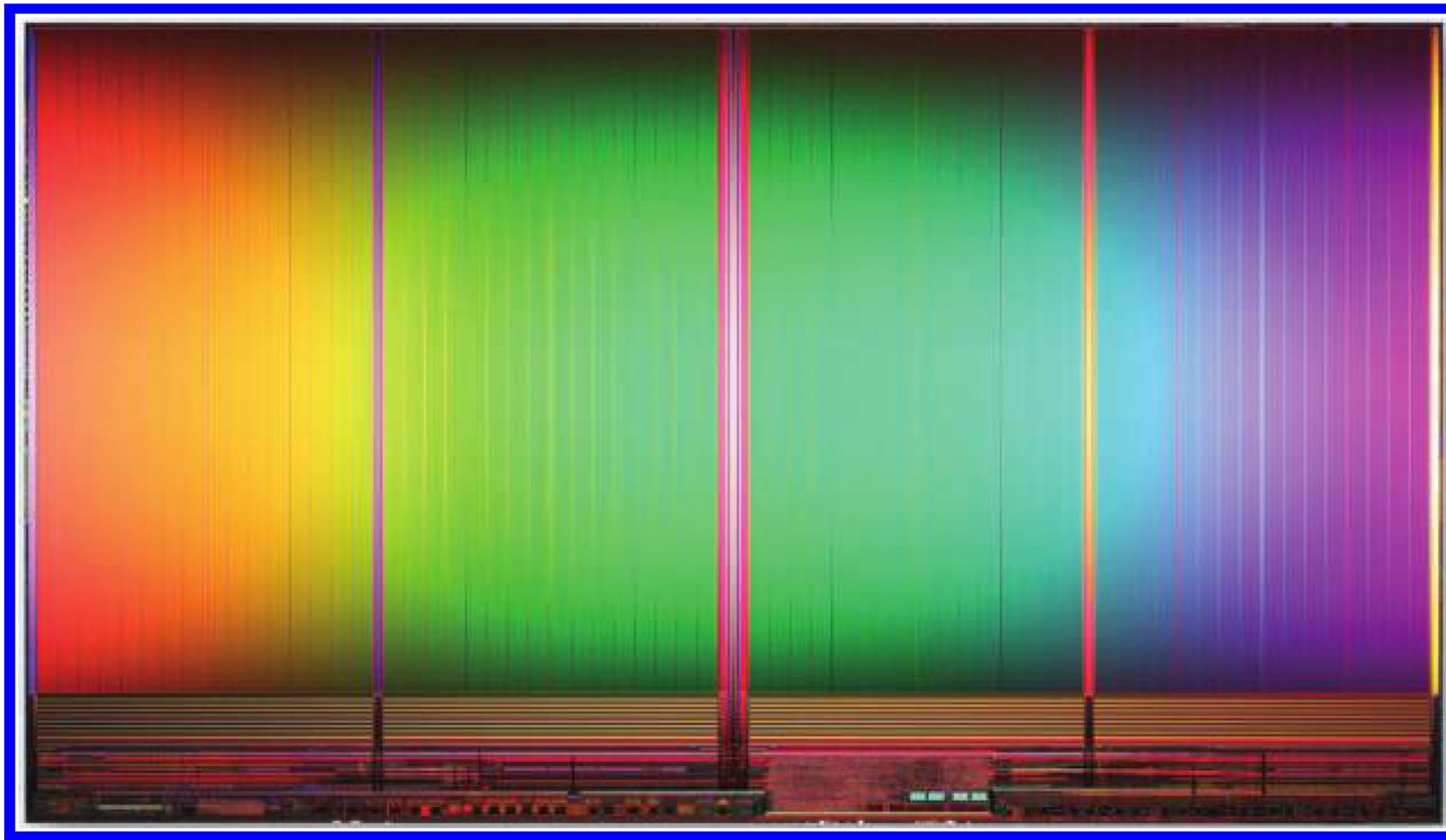
**1997:** The DEC ALPHA 21164 , the first billion-instructions-per-second (BIPS) microprocessor. This microprocessor contains over **9,300,000 transistors** and is roughly 1.0 cm on a side in size. (Courtesy of Digital Equipment Corporation, Maynard, MA.)

The CORE i7 microprocessor. (Courtesy of Intel Corporation, Santa Clara, CA.)

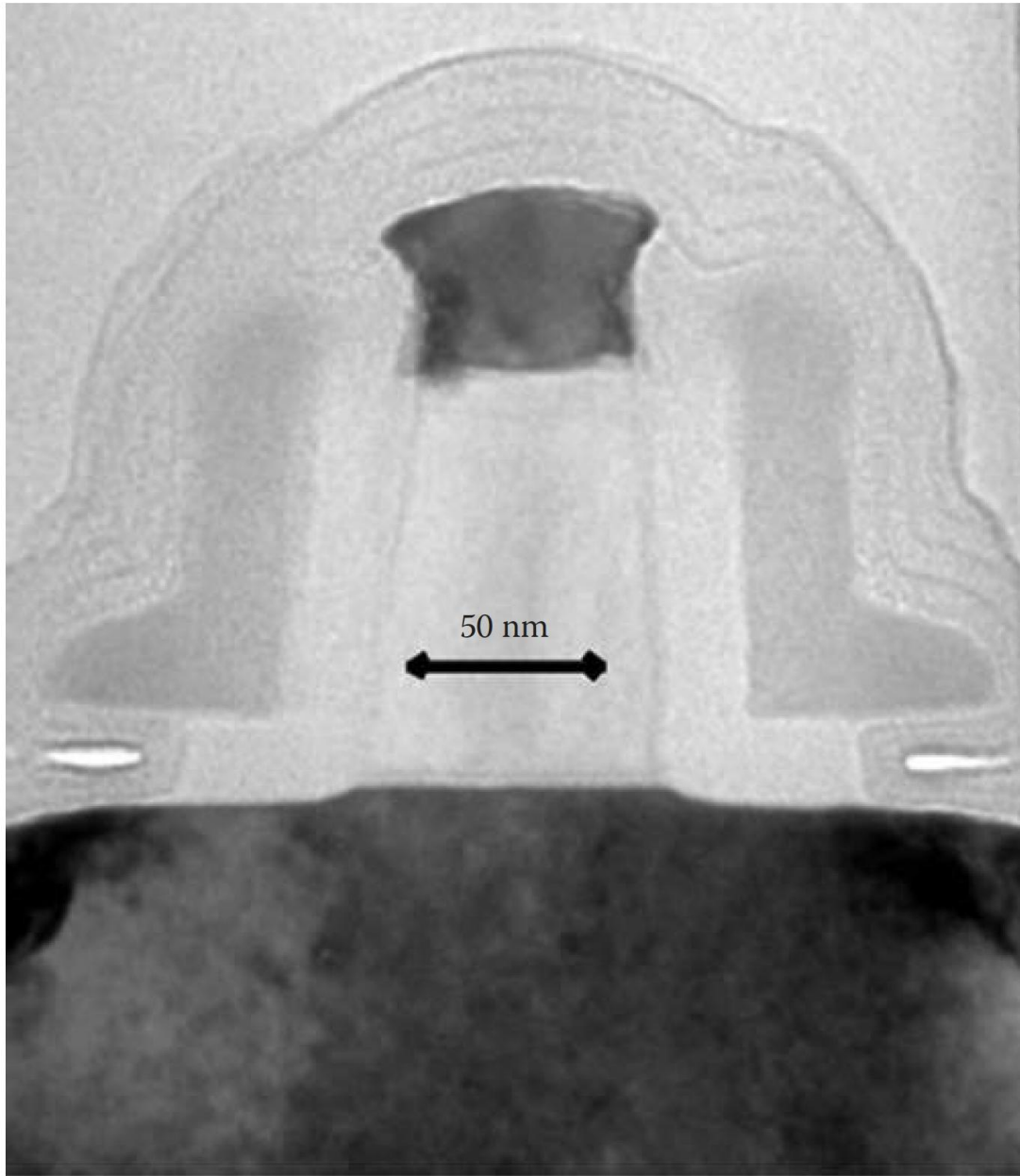


**2008** (First Gen): ~731 Million (Quad-core)

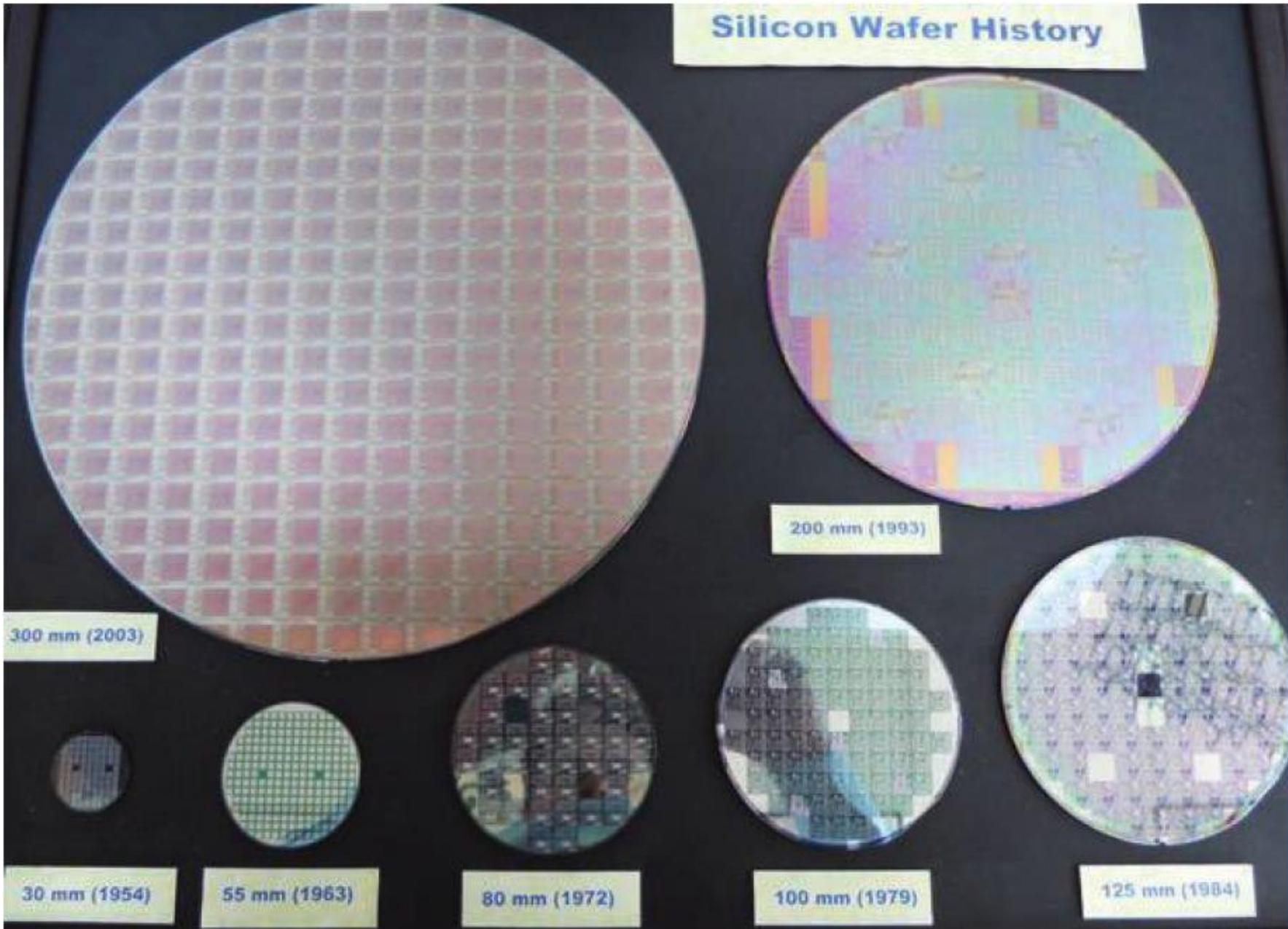
**2021+** (12th Gen/Recent): >9 Billion (e.g., Core i7-12700K)

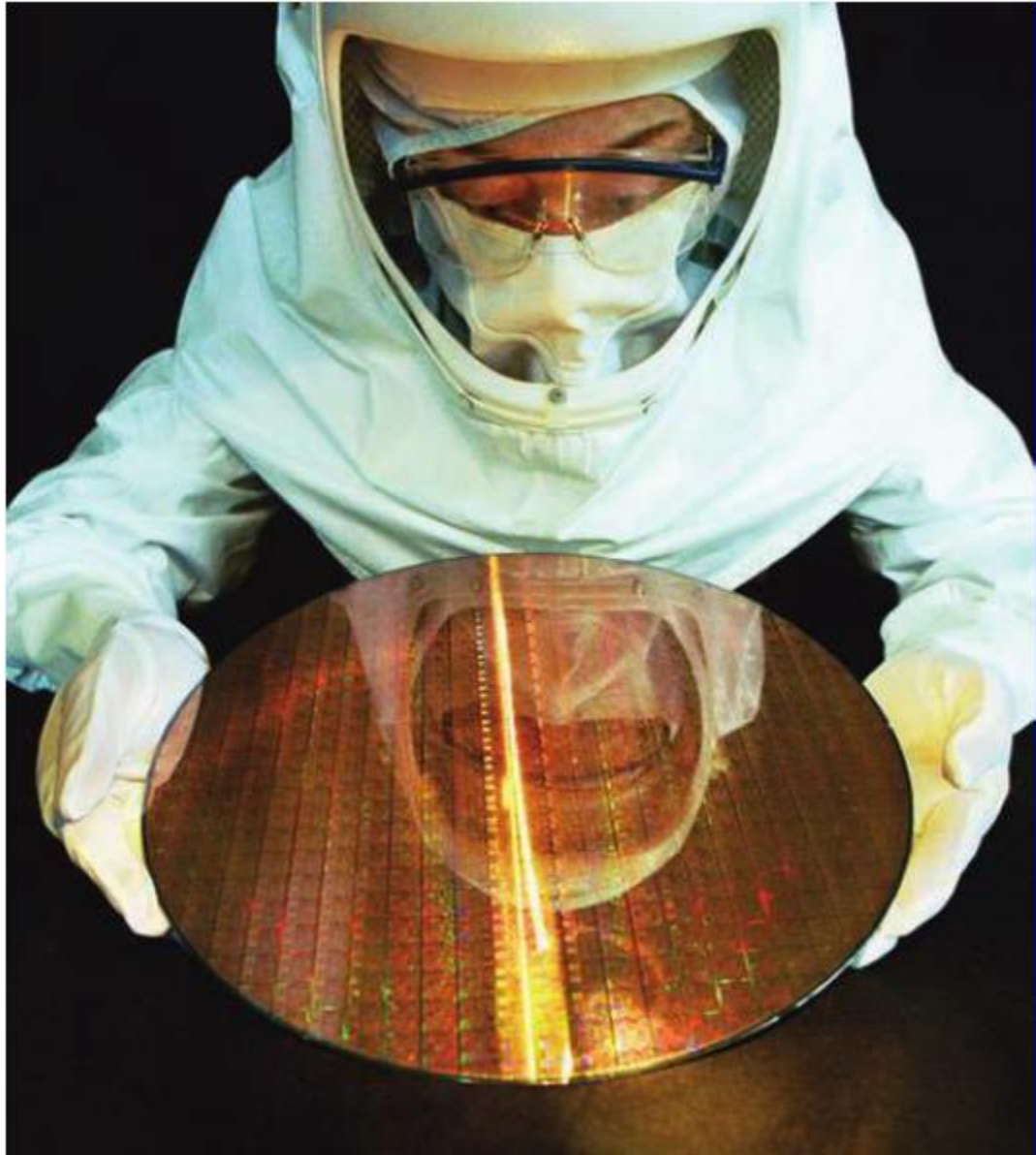


A bird's-eye view of a **64 GB** (billion byte) FLASH memory chip. This integrated circuit contains over **64,000,000,000 transistors** and is roughly **1.0 cm on the y-axis** in size. (Courtesy of Samsung Corporation, Seoul, Korea.)



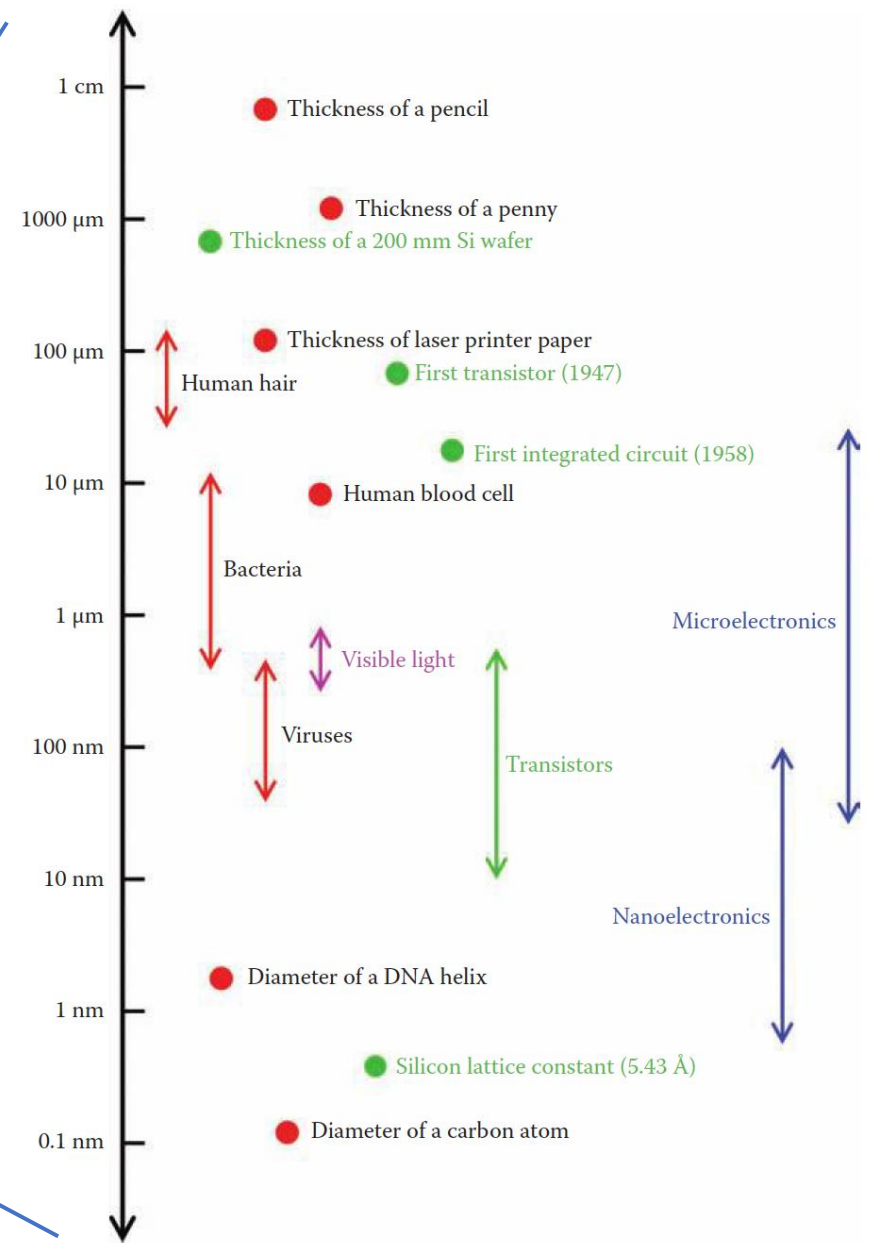
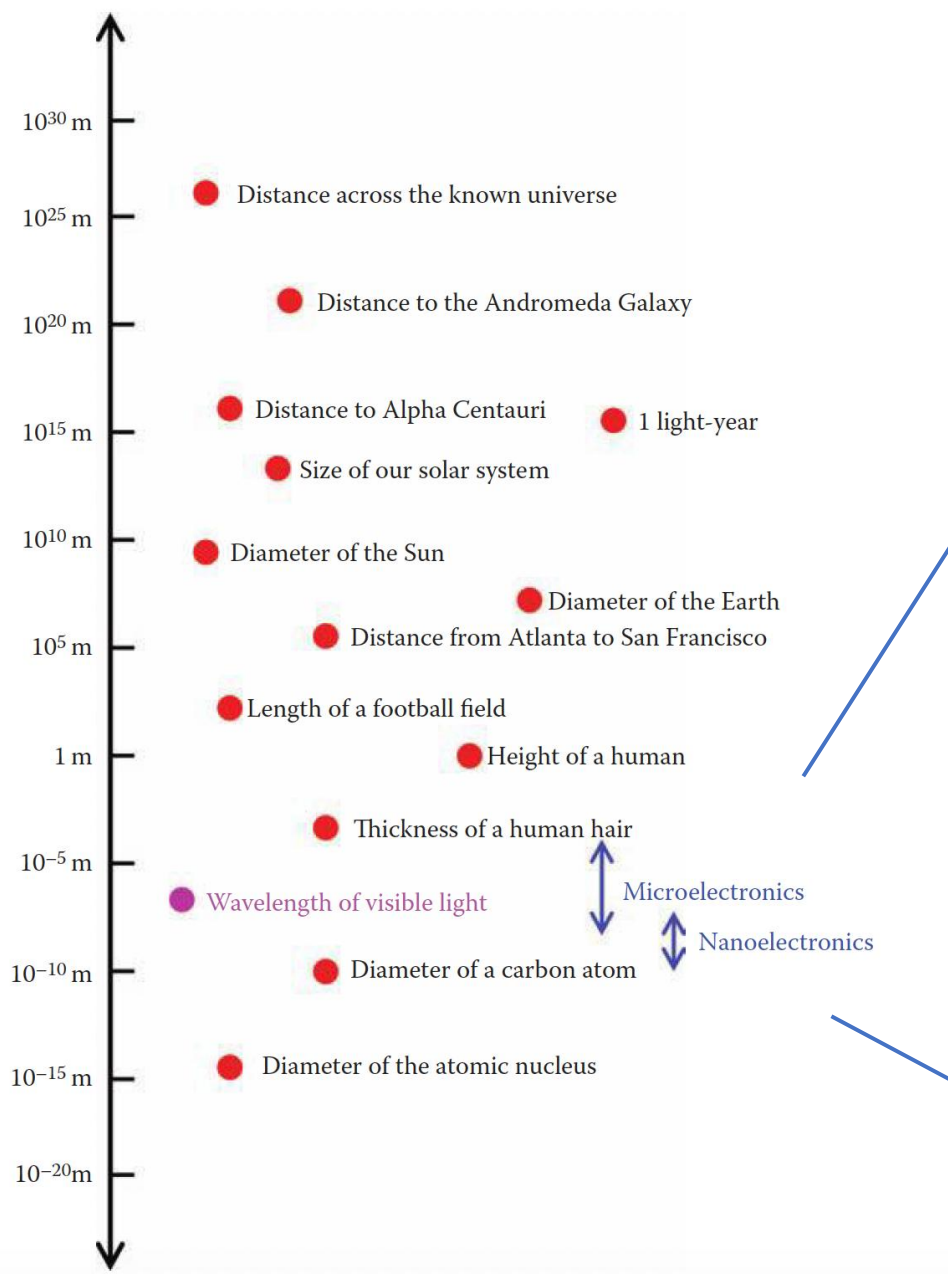
A cross-sectional view of a nanoscale CMOS transistor. The active transistor region is 50 nm, 50 billionths of a meter. (Courtesy of Intel Corporation, Santa Clara, CA.)





A 300 mm wafer. (Courtesy of Intel Corporation, Santa Clara, CA.)

# ΕΝΟΤΗΤΑ Ι: Κλίμακες μεγεθών



## Elemental

Group

II

III

IV

V

VI

Si  
Ge

Silicon  
Germanium

	5 B boron	6 C carbon	7 N nitrogen	8 O oxygen
	13 Al aluminum	14 Si silicon	15 P phosphorus	16 S sulfur
30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium
48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium
80 Hg mercury		82 Pb lead		

Group	II	III	IV	V	VI
		5 B boron	6 C carbon	7 N nitrogen	8 O oxygen
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30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	
48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	
80 Hg mercury		82 Pb lead			

## Elemental

Si  
Ge

Silicon  
Germanium

## Compound

IV-IV  
III-V

SiC

Silicon carbide

GaAs

Gallium arsenide

GaN

Gallium nitride

GaP

Gallium phosphide

GaSb

Gallium antimonide

InP

Indium phosphide

InAs

Indium arsenide

InSb

Indium antimonide

II-VI

ZnO

Zinc oxide

ZnS

Zinc sulfide

ZdTe

Cadmium telluride

IV-VI

PbS

Lead sulfide

PbSe

Lead selenide

..

Group	II	III	IV	V	VI
		5 B boron	6 C carbon	7 N nitrogen	8 O oxygen
		13 Al aluminum	14 Si silicon	15 P phosphorus	16 S sulfur
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48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	
80 Hg mercury		82 Pb lead			

## Elemental

Si  
Ge  
Silicon  
Germanium

## Compound

IV-IV  
III-V  
SiC  
GaAs  
GaN  
GaP  
GaSb  
InP  
InAs  
InSb  
Silicon carbide  
Gallium arsenide  
Gallium nitride  
Gallium phosphide  
Gallium antimonide  
Indium phosphide  
Indium arsenide  
Indium antimonide

II-VI  
ZnO  
ZnS  
ZdTe  
Zinc oxide  
Zinc sulfide  
Cadmium telluride

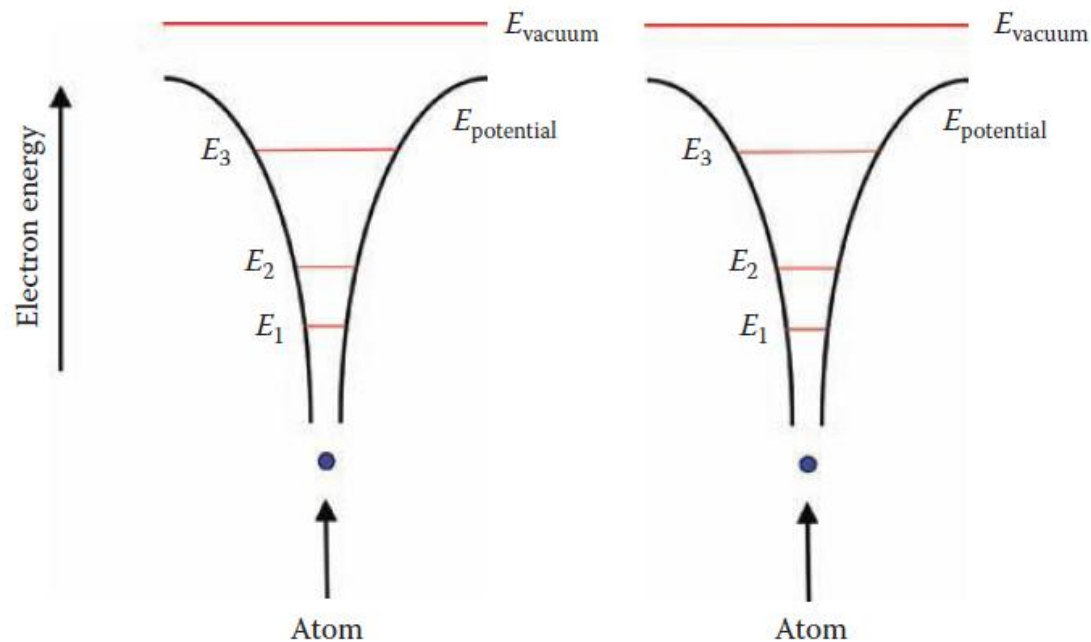
IV-VI  
PbS  
PbSe  
Lead sulfide  
Lead selenide

## Alloys

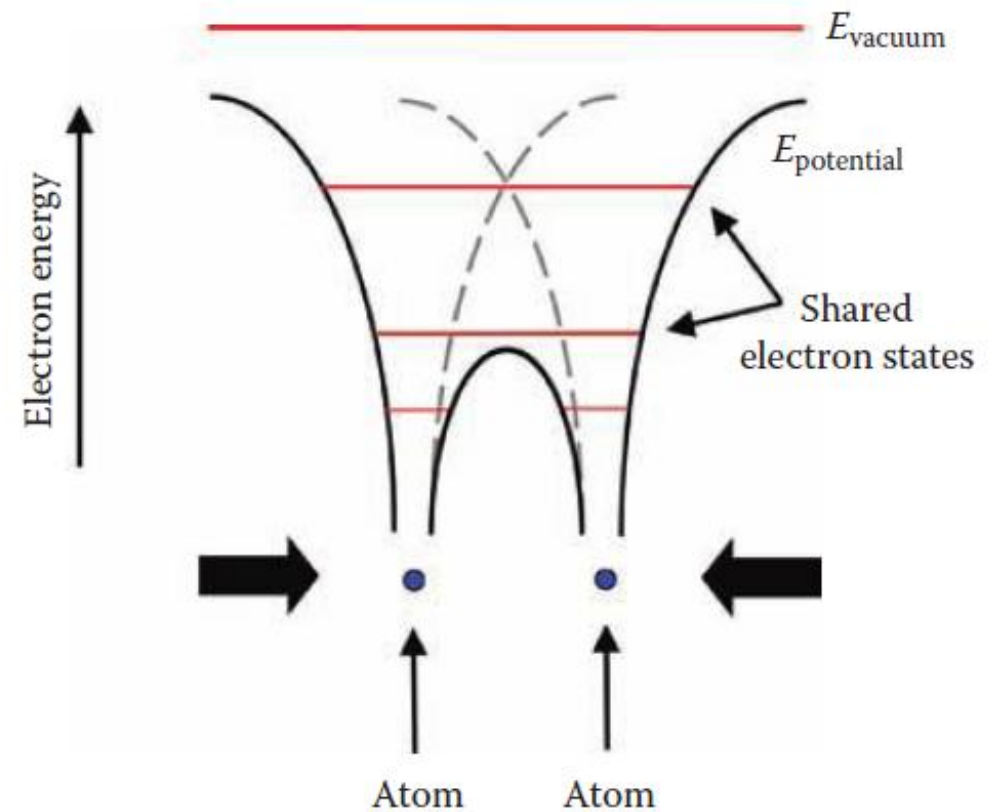
binary  
 $Si_xGe_{1-x}$   
Silicon germanium

ternary  
 $Al_xGa_{1-x}As$  "al-gas"  
 $In_xGa_{1-x}P$  "in-gap"  
 $Hg_{1-x}Cd_xTe$  "mer-cat"

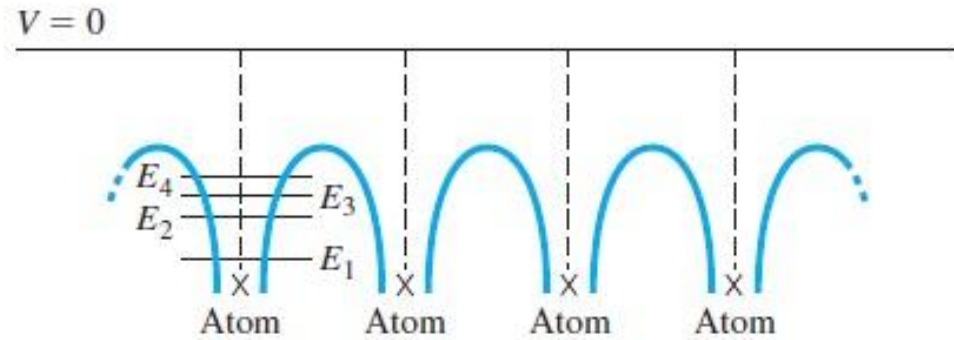
quarternary  
 $Al_xGa_{1-x}As_{1-y}Py$



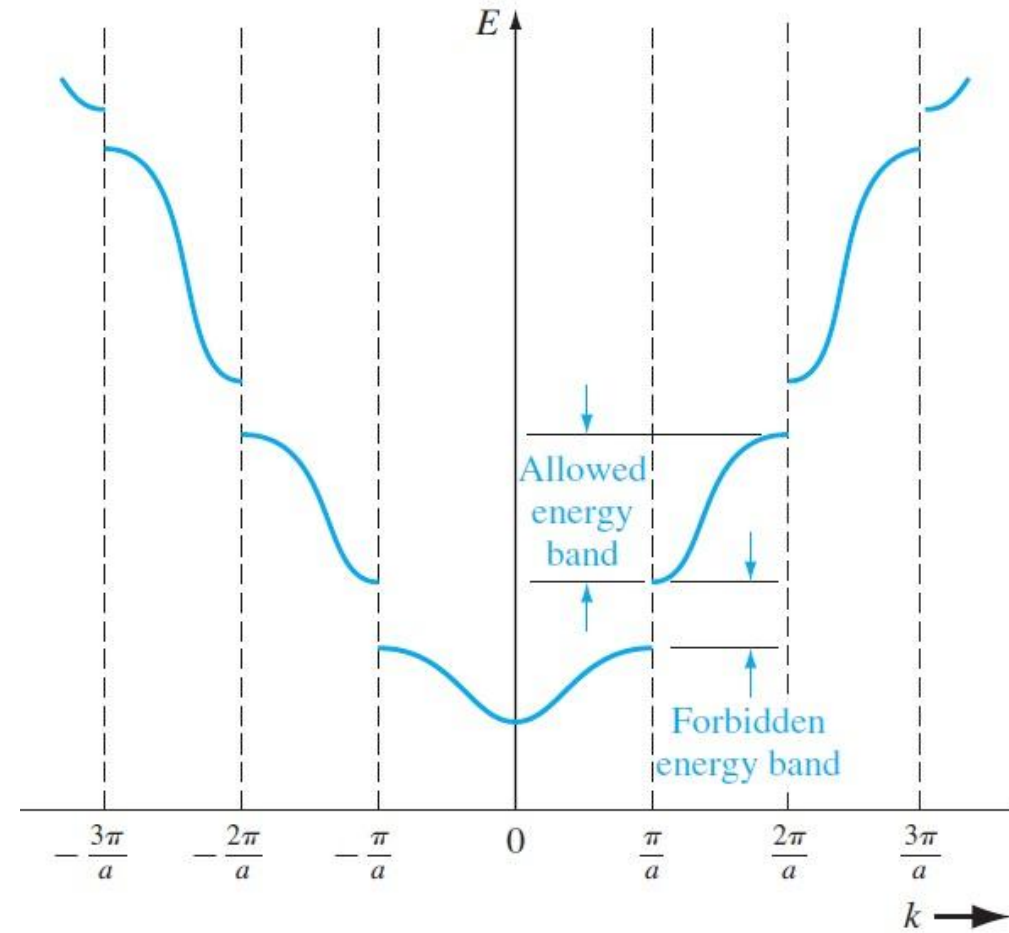
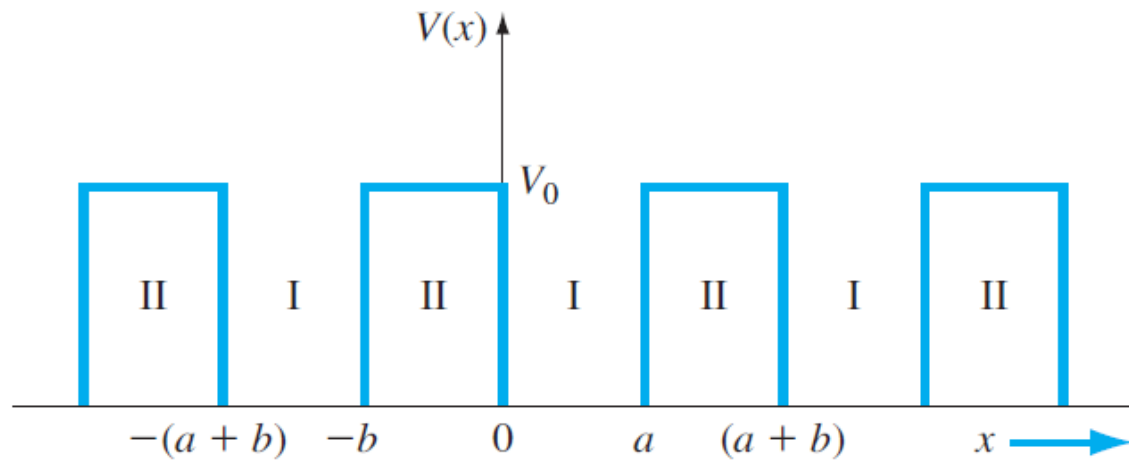
Conceptual view of the electron energy as a function of position for two isolated silicon atoms, each with discrete electron energy states.



Conceptual view of the electron energy as a function of position for two silicon atoms brought into close proximity, now with shared discrete electron energy states.



Kronig-Penney model



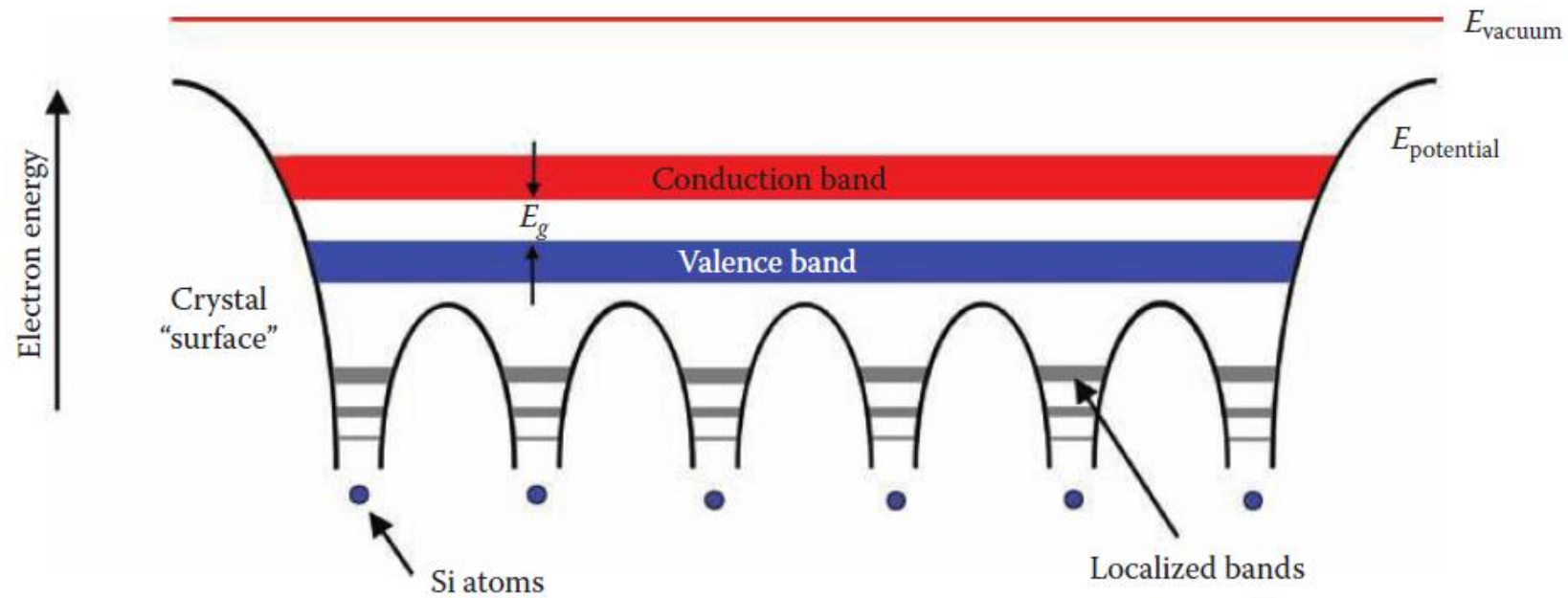
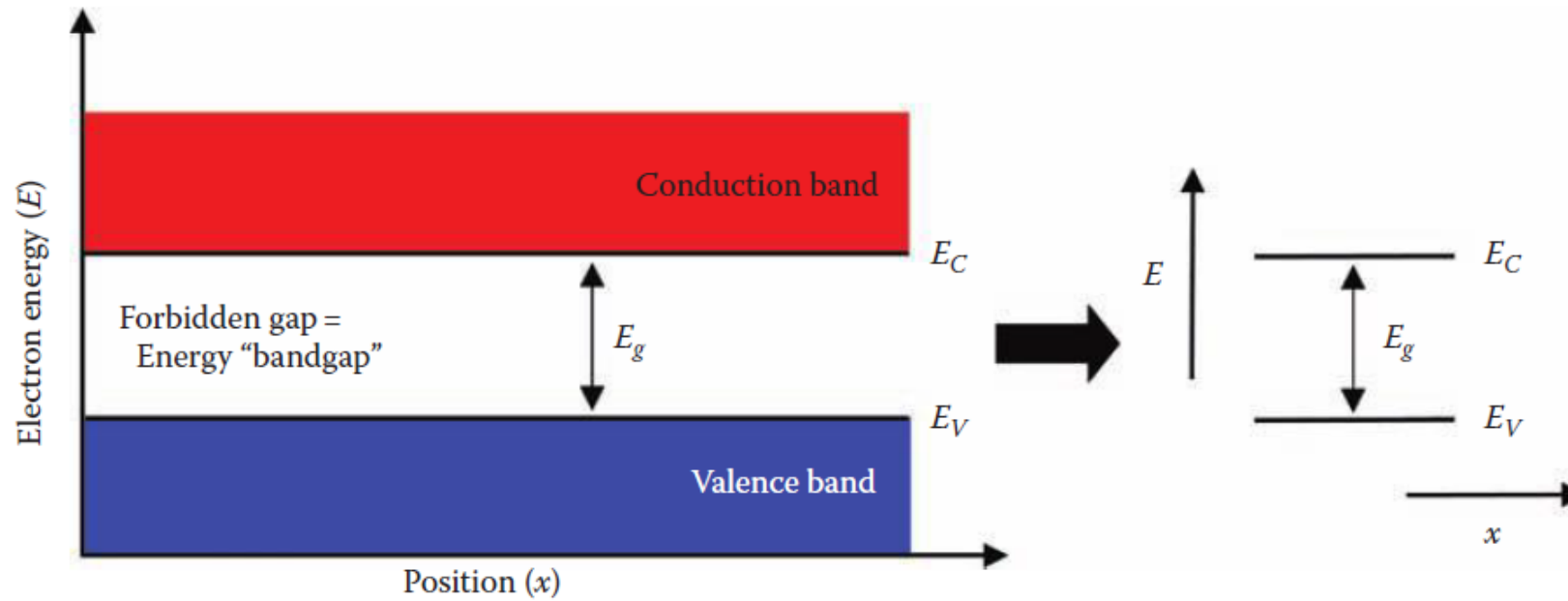


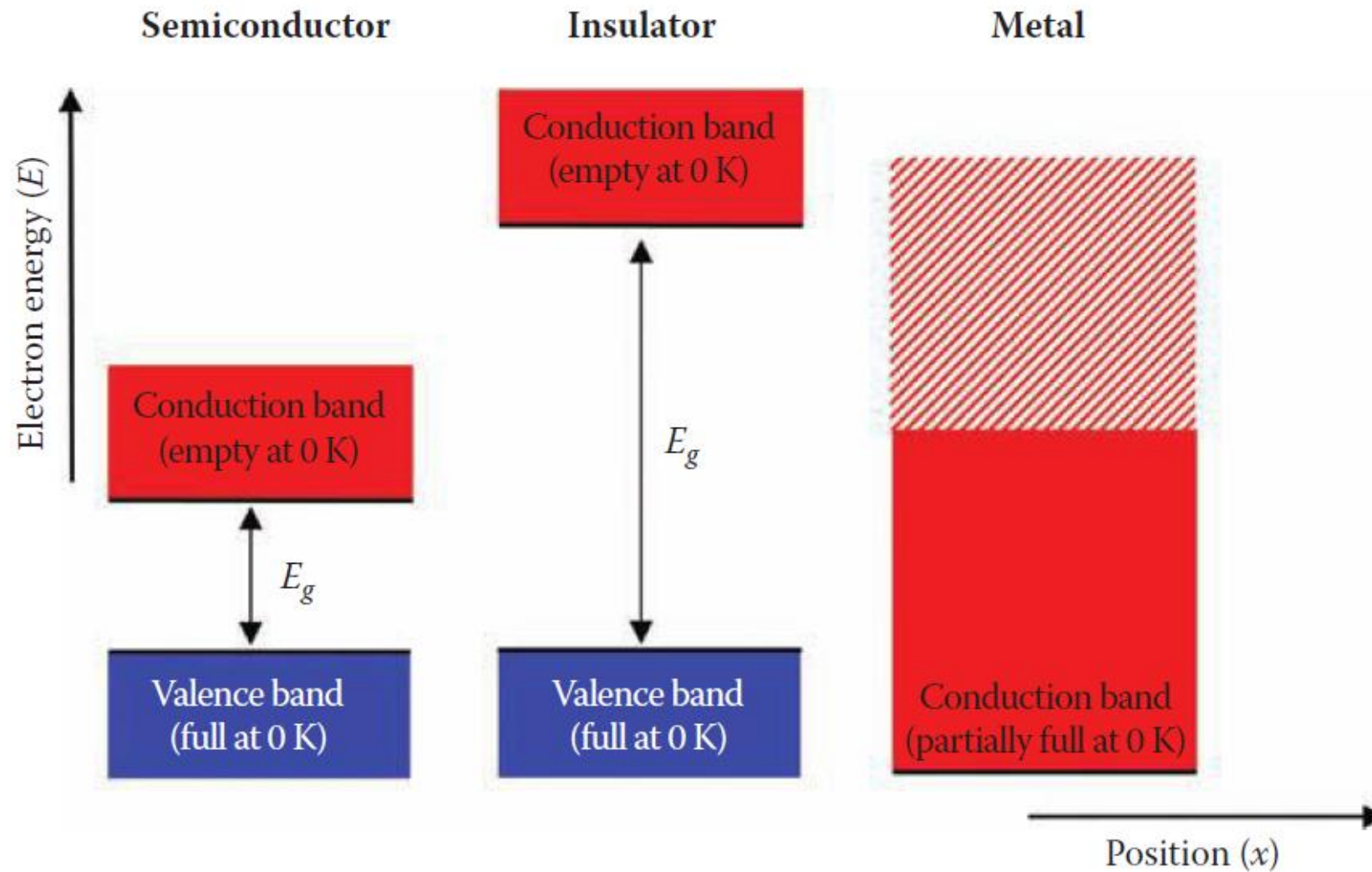
FIGURE 5.11

Conceptual view of the electron energy as a function of position for a semi-infinite 1D lattice of silicon atoms, now with both localized electron energy bands and, importantly, extended valence and conduction bands.



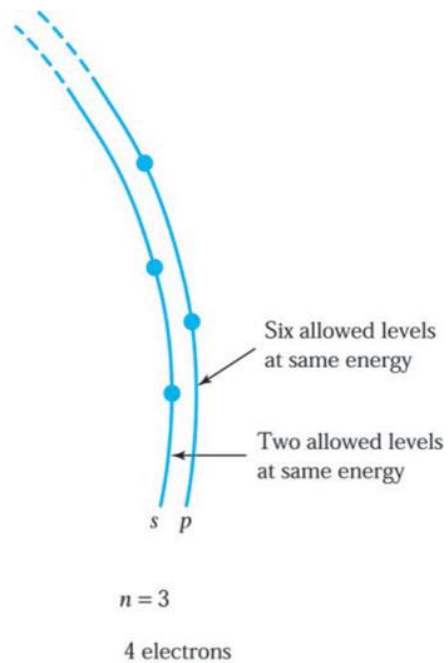
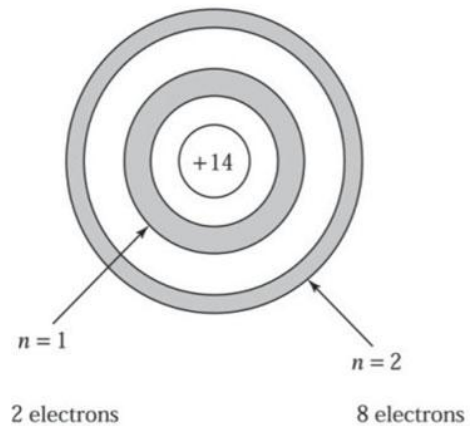
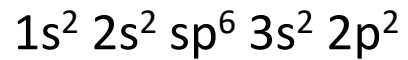
The energy band diagram: electron energy as a function of position as we move through the crystal.

Διάκριση των υλικών με βάση τις ενεργειακές ζώνες



## Ατομική δομή του Πυριτίου (Si)

Ατομικός αριθμός  $Z=14$



## Ενεργειακές ζώνες σε κρυσταλλική δομή πυριτίου

