Electronic Devices

Lectures 1&2
Semiconductors

Dr. Roaa Mubarak

The Course Grades

➢The Total Course grades **150 Marks**

- Midterm (أعمال السنة) 30 Marks.
- Laboratory (عملي) 20 Marks
- Final Exam (الامتحان النهائي) 100 Marks

خطة الدراسة للفرقة الاولي ـ قسم هندسة الالكترونيات والاتصالات

الفصل الدراسي الأول

كود المقرر	اسم المقرر	عدد الساعات الأسبوعية				توزيع الدرجات			عدد ساعات الامتحان التحريري	مجموع درجات المقرر	الساعات المعتمدة
		محاضرة	تطبيقات		مجموع	أعمال سنة	عملي وشفوي	تحريري			
			تمرين	معمل							
إلك 1405	النبائط الإلكترونية	2	1	1	4	30	20	100	3	150	2

The course includes:

1. **Semiconductor Materials.**
2. **P-N Junction and Diodes.**
3. **Bipolar Junction Transistor (BJT).**
4. **Field Effect Transistor (FET).**
5. **Applications.**

Reference:

Micro Electronics by ‘Jacob Millman’

Semiconductors Materials

Electronics

- It is the science and Technology of the motion of charges in gas, vacuum, or **Semiconductors**.

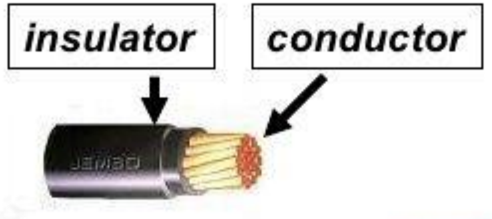
Materials:

The materials can be classified into:

- Conductors.
- Insulators.
- Semiconductors.

Conductor –

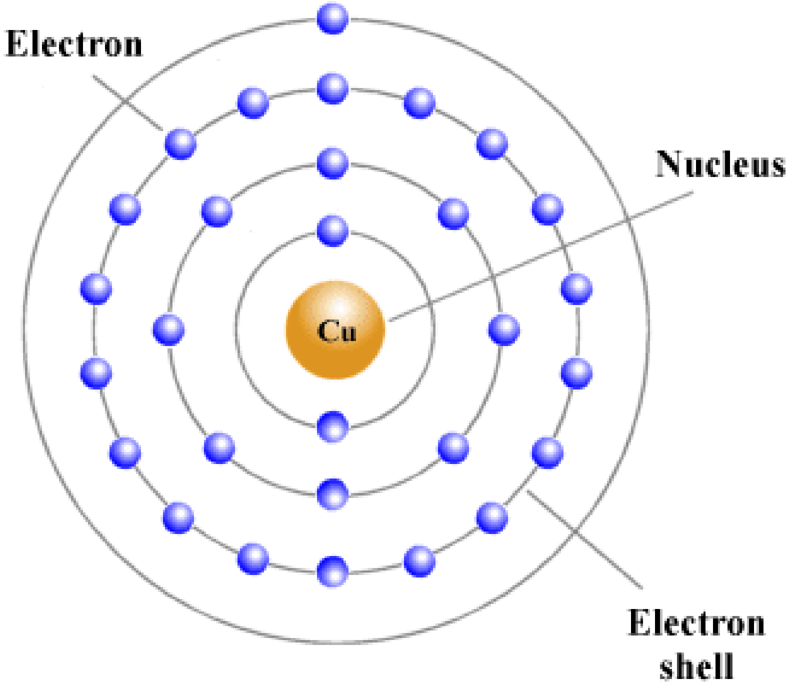
Any material that allows electric current to pass through it



- copper
- aluminum

- steel

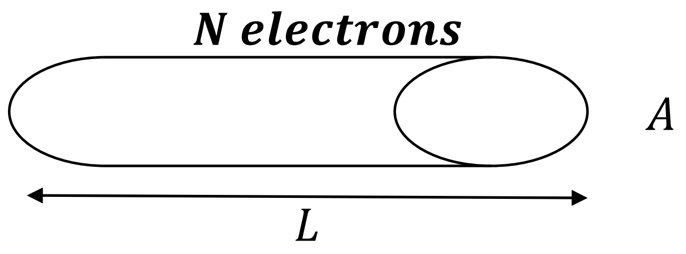
- any metal



Conductors:

- Conductors are the materials that support a flow of free charges (Free electrons) when voltage source is applied across its terminal ex: Copper, Aluminum, Silver, and Gold.
- Electron is the principle negatively charged particle whose charge, or quantity of electricity, has been determined as $1.6\ x10^{-19}$coulombs
- The No. of electrons per coulomb is the reciprocal of electronic charge or approximately $6\ x10^{18}$.
- Since Current of 1 ampere is 1 col/sec, a current of 1 Pico-ampere represents the motion of about 6 million electrons.
- Carriers: Electrons.

Current in Conductors



$I = \frac{N\,q}{T}$ & $vd = \frac{L}{T}$ drift velocity

$I = \frac{N\,q\,vd}{L}$ q = 1.6 $x10^{-19}$C. T: Time in sec.

Current Density $J = \frac{I}{A} = \frac{N\,q\,vd}{L\,A} = n\,q\,vd$ $n = \frac{N}{L\,A}$ electron concentration

$vd = \mu\,\mathcal{E}$ μ: electron mobility , Ɛ: Electric field

$$J = n\,q\,vd = n\,q\,\mu\,\mathcal{E} = \sigma\,\mathcal{E}$$

$\sigma(material\ conductivity) = n\,q\,\mu = \frac{1}{\rho}$ $(Electric\ field)\mathcal{E} = \frac{V}{L}$

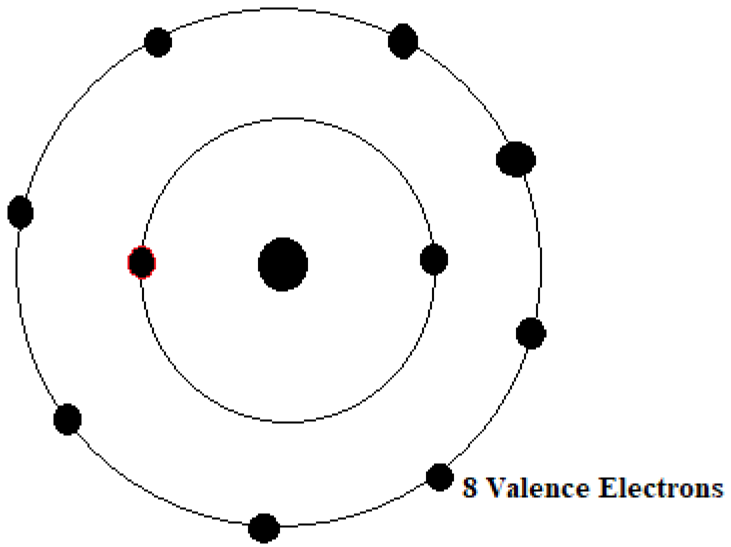
$$I = J\,A = \sigma\,\mathcal{E}\,A = \sigma\,\mathcal{E}\,A\,\frac{L}{L} = \frac{\sigma\,A}{L}V = \frac{V}{R}$$

$R = \frac{L}{\sigma\,A}$ σ: material ~~resistivity~~ conductivity

Insulators:

- They are materials that offer a very low level of conductivity when voltage is applied.

Ex: Glass – Plastic - Ceramic



Semiconductors:

- They are the materials that have a conductivity level some where between the extremes of an insulator and conductor.

Ex: Carbon ‘C’ – Silicon ‘Si’ – Germanium ‘Ge’

Carriers: Electrons & Holes.

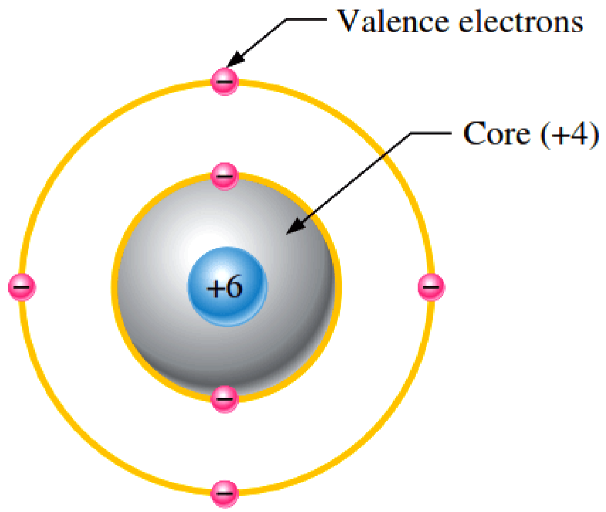
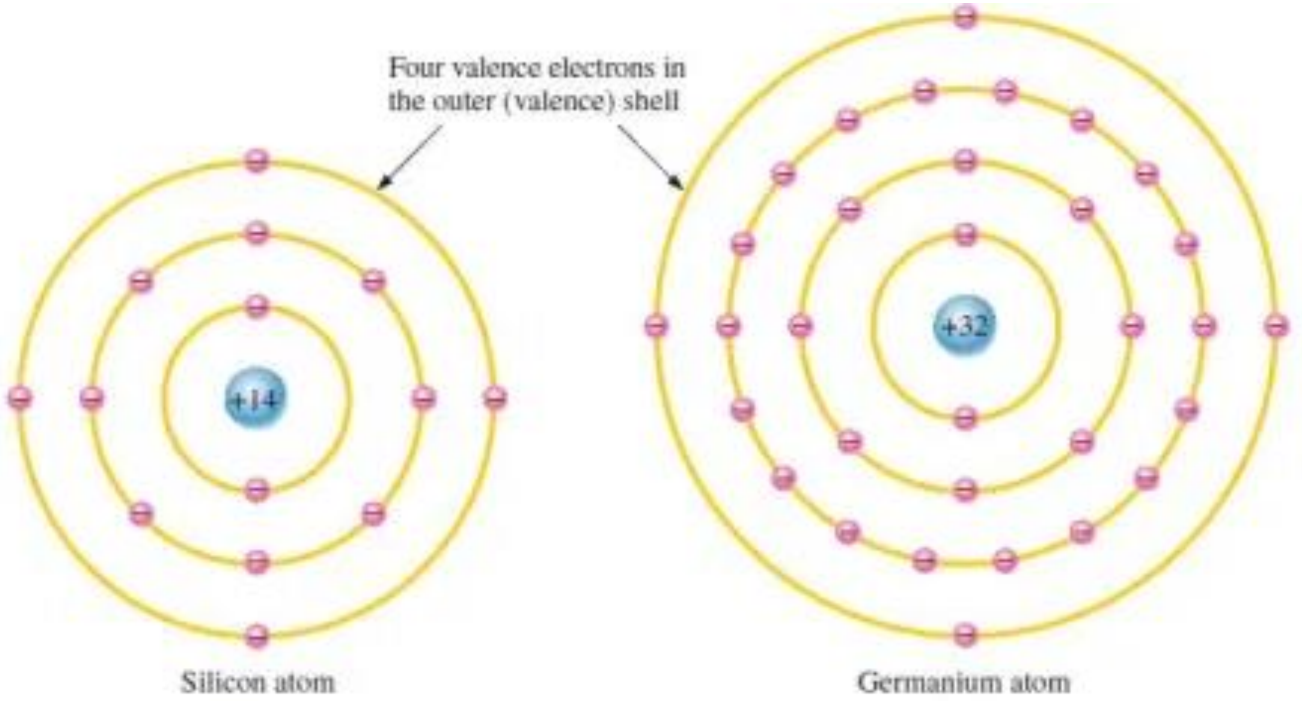
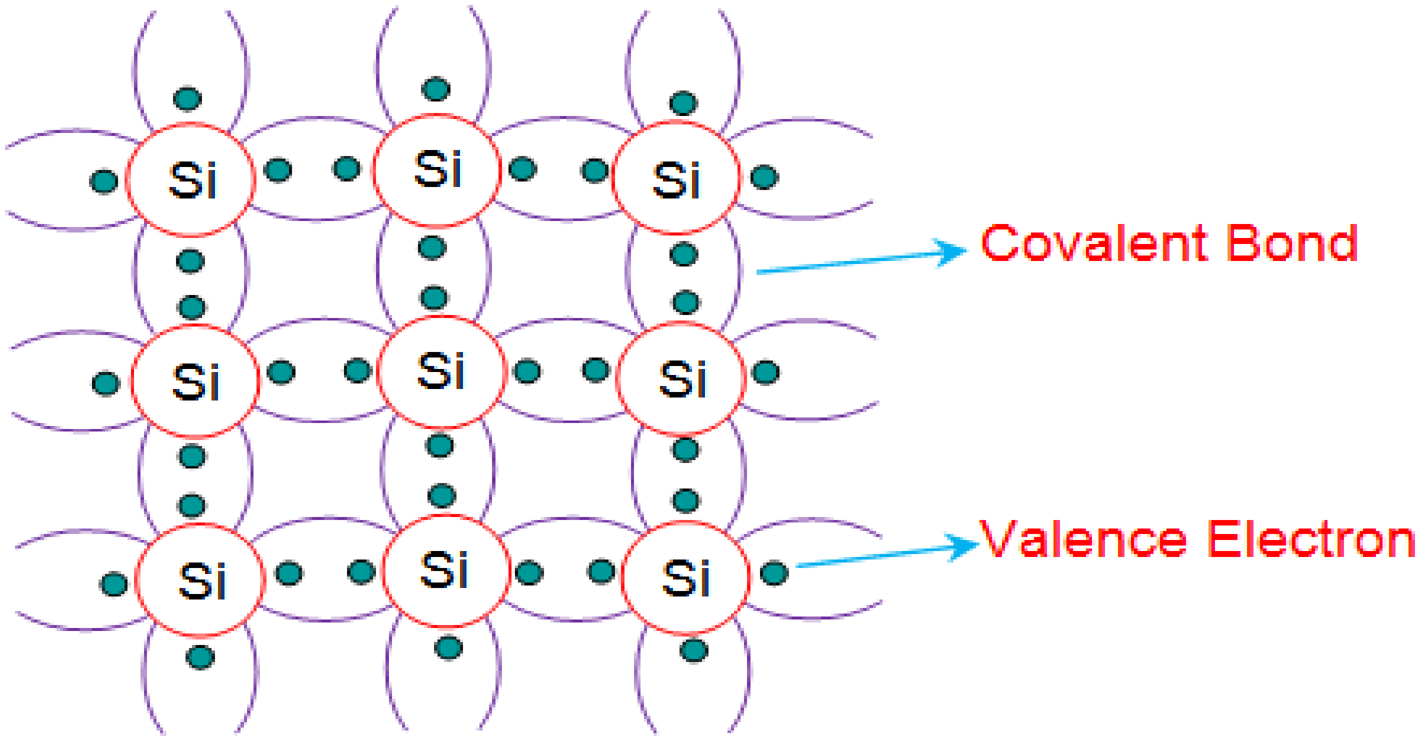


Diagram of a carbon atom



Semiconductors:

- Atoms link together with one another sharing their outer electrons to form physical structure called a crystal lattice, these links are called covalent bonds.



2-D Crystal Lattice of Silicon

Semiconductors:

Semiconductors classified into:

- Pure Semiconductors (Intrinsic Semiconductors).
- Impure Semiconductors (Extrinsic Semiconductors).

Intrinsic Semiconductors:

- Intrinsic Semiconductors is made of pure Silicon or Germanium.
- Free Electrons due to natural causes (Temperature- Energy- Light Energy) can be results.
- An increase in temperature of semiconductor results in increase in No. of free electrons.

$$n = p = ni$$

n : electron concentration,
p : hole concentration,
ni : intrinsic concentration.

Mass Action law:

$n * p = ni^2$.

$ni^2 = Ao\, T^3 e^{-Ego/KT}$.

Ao: constant related to the semiconductor.
T: Temperature in Kelvin.
K: Boltzman constant = $8.62\ x10^{-6}\ ev/\ K$
Ego: Band gap energy (ev)

Extrinsic Semiconductors:

- They are obtained by adding (doping) impurity atoms to intrinsic semiconductor.
- Adding one impure atom to one million of Si. These impurities can totally change the electrical properties of semiconductors.
- These materials are doped to create excess or luck of electrons.
- Extrinsic semiconductors made computer chips both for CPU and memory, and doped Semiconductors make it possible to **miniaturize** electronic component such as diodes and transistors.
- **Miniaturize** means (less space, faster and require less energy).

Impurities:

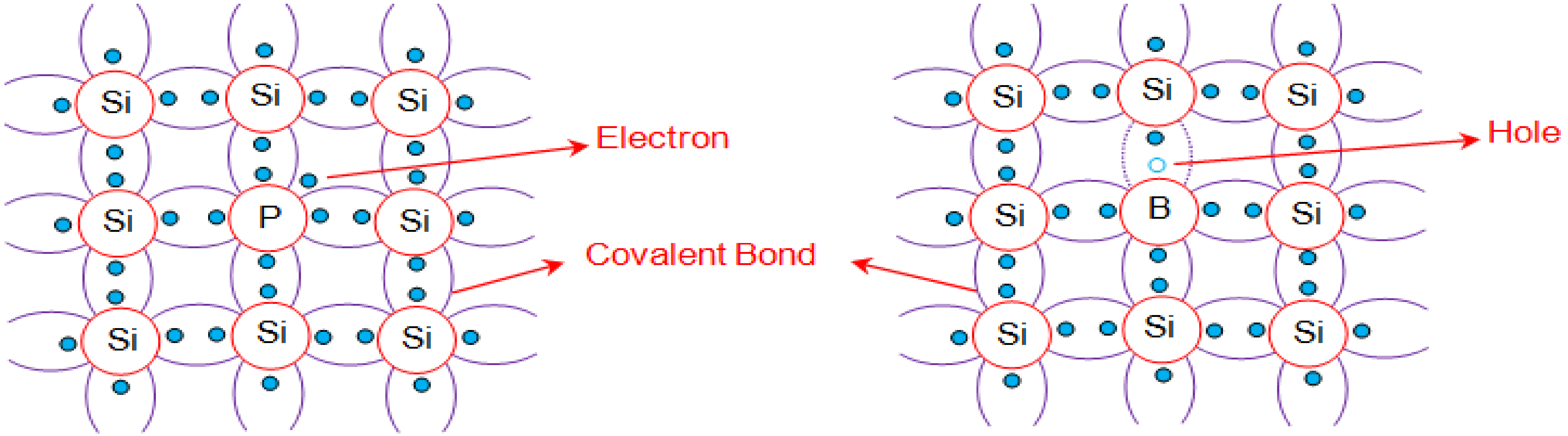
- **Trivalent materials (acceptors):**

Boron – Gallium – Indium ------- produce **P-type** semiconductors.

- **Pentavalent Materials (Donor):**

Phosphors – Arsenic – Antimony ------produce **n-type** semiconductors.

Extrinsic Semiconductors:



2-D Crystal Lattice of Silicon Doped with (a) Phosphorous (b) Boron

N-type

P-type

Extrinsic Semiconductors:

N-Type Semiconductor	P-type Semiconductor
Donor Atoms = ND	Acceptor Atoms = NA
Majority Carriers : Electrons	Majority Carriers: Holes
Minority Carriers : Holes	Minority Carriers : Electrons
$n = p + ND$ n >>>>>p n ≈ ND For mass action law $\mathrm{ND} * p = ni^2$ $Pn = ni^2/ND$	$p = n + NA$ P >>>>> n P ≈ NA For mass action law $\mathrm{n} * NA = ni^2$ $np = ni^2/NA$

Conductivity in Semiconductors

- **Metal's Current:**

The current comes from the movement of free electrons.

- **Semiconductor's Current:**

The current comes from both Electrons and Holes.

Currents in semiconductors:

- **Drift Current** due to applied electric field.
- **Diffusion current** due to non-uniform concentration.

Drift Current:

- Drift current density for **Conductors** $J = \frac{I}{A} = n\, q\, \mu\, \mathcal{E}$

- Drift current density for **Semiconductors** $J = \frac{I}{A} = n\, q\, \mu n\, \mathcal{E} + p\, q\, \mu p\, \mathcal{E}$

$$J = q(\, n\, \mu n\ + p\, \mu p\,)\mathcal{E} = \ \sigma\, \mathcal{E}$$

$$\sigma = q(\, n\, \mu n\ + p\, \mu p\,) = \frac{1}{\rho}$$

μn: Mobility of Electrons

μp: Mobility of holes

Diffusion Current

- In semiconductors, the flow of carriers from one region of higher concentration to lower concentration results in a " Diffusion Current".
- Diffusion of Electrons:

$$Jn = q\ Dn\ \frac{dn}{dx}$$

Dn: Electrons diffusion coefficient.

- Diffusion of Holes:

$$Jp = -q\ Dp\ \frac{dp}{dx}$$

Dp: Holes diffusion coefficient.

- Einstein Relation: $\frac{Dn}{\mu n} = \frac{Dp}{\mu p} = \frac{K\ T}{q} \approx 0.026\ \text{V} = \text{VT}$

Semiconductor's Currents:

- Total Current for Semiconductors = Drift currents + Diffusion Currents.

- Drift Current= $Jdrift = n\ q\ \mu n\ \mathcal{E} + p\ q\ \mu p\ \mathcal{E}$

- Diffusion Current = $Jdiff = q\ Dn\ \frac{dn}{dx} - q\ Dp\ \frac{dp}{dx}$

$$Jtotal = Jdrift + Jdiff$$

Properties of Silicon and Germanium

Properties of Silicon and Germanium

Property	*Silicon*	*Germanium*
Atomic number	14	32
Atomic weight	28.1	72.6
Density	2,330 kg/m^3	5,320 kg/m^3
Dielectric constant	12	16
Atoms/m^3	5.0×10^{28}	4.4×10^{28}
E_{G0} at 0 K	1.21 *e*V	0.785 *e*V
E_G at 300 K	1.12 *e*V	0.72 *e*V
Intrinsic concentration n_i at 300 K	$1.5 \times 10^{16}/m^3$	$2.5 \times 10^{19}/m^3$
Intrinsic resistivity ρ_i at 300 K	2,300 Ω-m	0.45 Ω-m
Electron mobility, μ_e	0.13 m^2/ V-s	0.38 m^2/ V-s
Hole mobility, μ_h	0.05 m^2/V-s	0.18 m^2/V-s
Diffusion constant, D_e	0.0034 m^2/s	0.0099 m^2/s
Diffusion constant, D_h	0.0013 m^2/s	0.0047 m^2/s