BENHA UNIVERSITY
FACULTY OF ENGINEERING (SHOUBRA)
ELECTRONICS AND COMMUNICATIONS ENGINEERING

CCE 201
Solid State Electronic Devices

(2022 - 2023) term 231

Lecture 1: Semiconductor Physics.

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Outlines

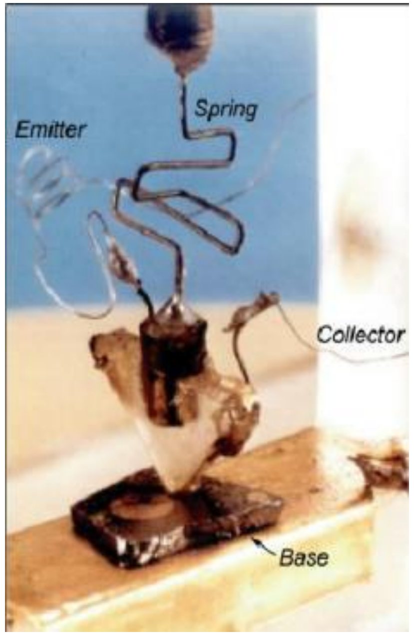
- Why semiconductors?
- Semiconductors and their structure.
- Band Diagram.
- Intrinsic Semiconductors.

Why semiconductors?

- **Semiconductor devices** are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide.
- **Semiconductor devices** have replaced thermionic devices (vacuum tubes) in most applications. They use electronic conduction in the solid state as opposed to the vacuum state or gaseous state.
- **Semiconductor devices** are available as discrete units (such as those sold in electronics stores) or can be integrated along with a large number — often millions — of similar devices onto a single chip, called an integrated circuit (IC).

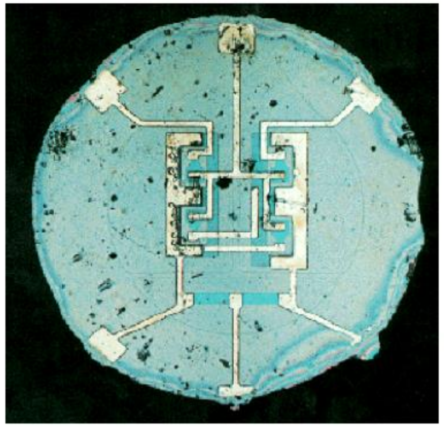
First BJT transistor 1947:

- The transistor was probably the most important invention of the 20th Century, and the story behind the invention is one of clashing egos and top secret research.
- Picture shows a point-contact transistor structure comprising the plate of n-type germanium and two line-contacts of gold supported on a plastic wedge.



Why semiconductors?

first monolithic integrated circuit

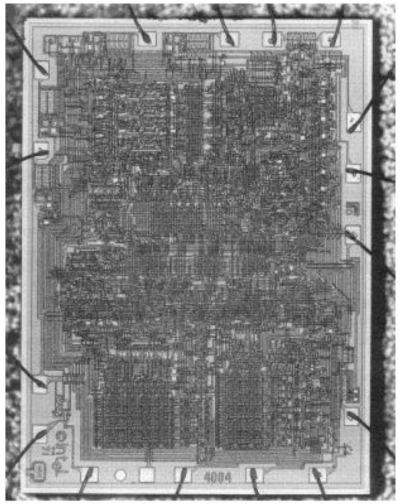


1961

Picture shows a flip-flop circuit containing 6 devices, produced in planar technology.

Source:
R. N. Neyce,
“Semiconductor device-and-lead structure”,
U.S.Patent 2,981,877

first microprocessor



1971

Picture shows a four-bit microprocessor *Intel 4004*.

- 10 μm technology
- 3 mm × 4 mm
- 2300 MOS-FETs
- 108 kHz clock frequency

Source:
Intel Corporation

Semiconductor devices are WIDELY used

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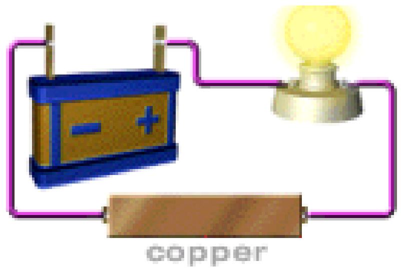
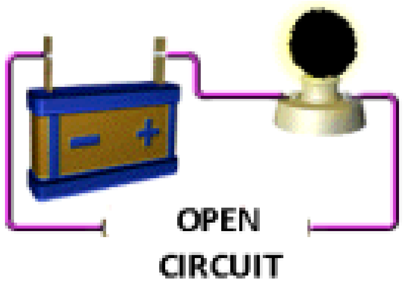
Solid Materials

- **Conductors**: Allow Electric current to flow through them.

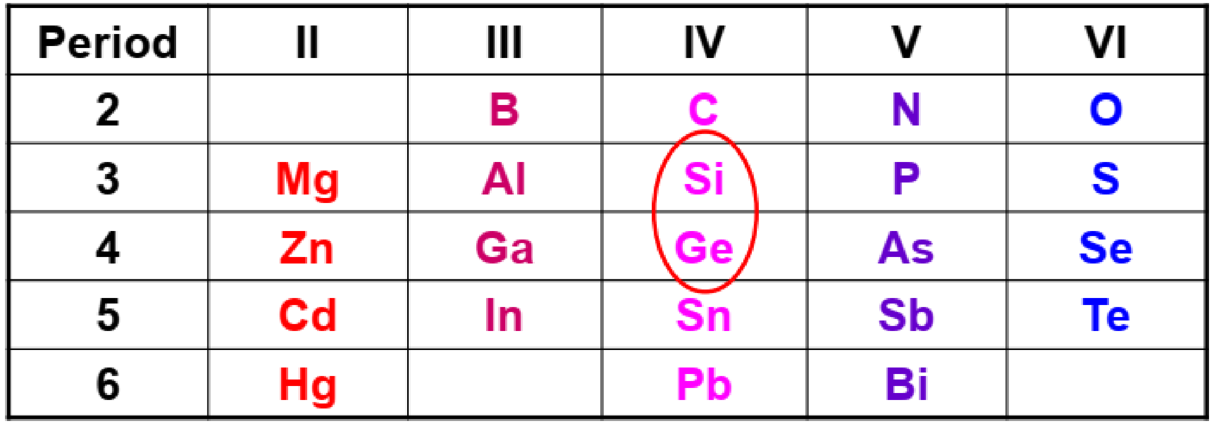


- **Insulators**: Do not Allow Electric current to flow through them.

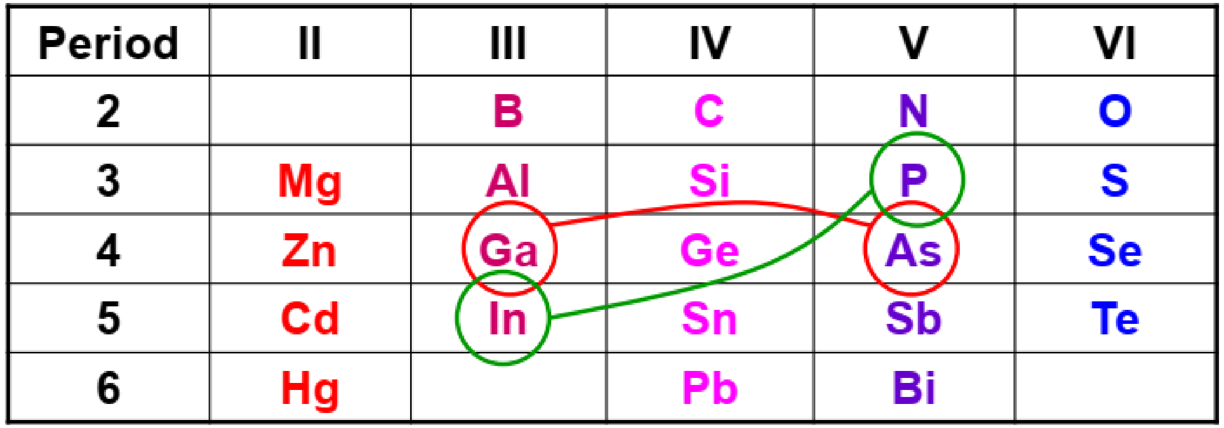


- **Semiconductors**: Materials whose conductivity lies in between that of Conductors (copper) and insulators (glass). They have conductivities in the range of 10-4 to 10+4 S/m.

semiconductors



Period	II	III	IV	V	VI
2		B	C	N	O
3	Mg	Al	Si	P	S
4	Zn	Ga	Ge	As	Se
5	Cd	In	Sn	Sb	Te
6	Hg		Pb	Bi	



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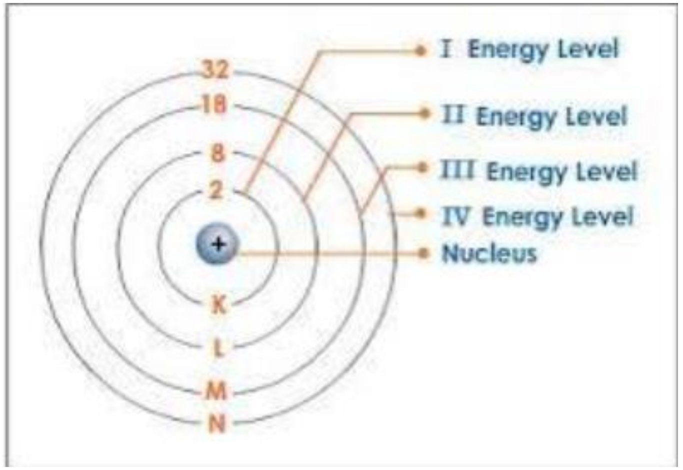
single-element: such as germanium and silicon (column IV of periodic table) –compose of single species of atoms

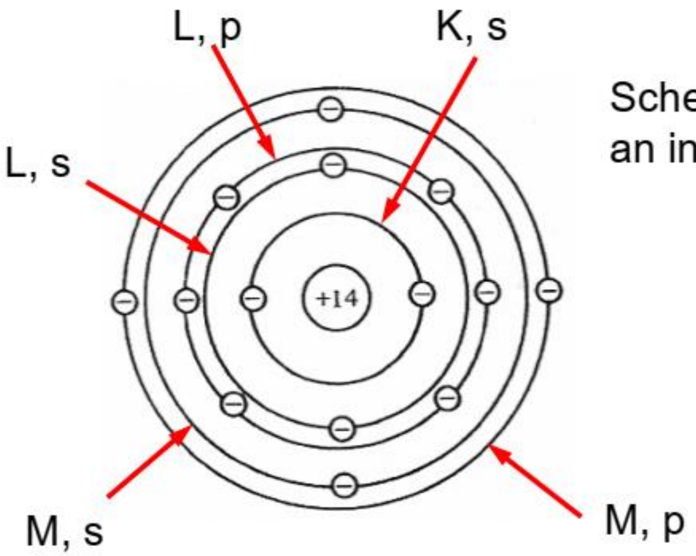
compound: such as gallium-arsenide. – combinations of atoms of column III and column V (combination of two atoms results in binary compounds).

semiconductors

electron shells and sub-shells

shell n	K 1	L 2		M 3			N 4			
sub-shell l	s 0	s 0	p 1	s 0	p 1	d 2	s 0	p 1	d 2	f 3
electron number	2	2	6	2	6	10	2	6	10	14
	2	8		18			32			



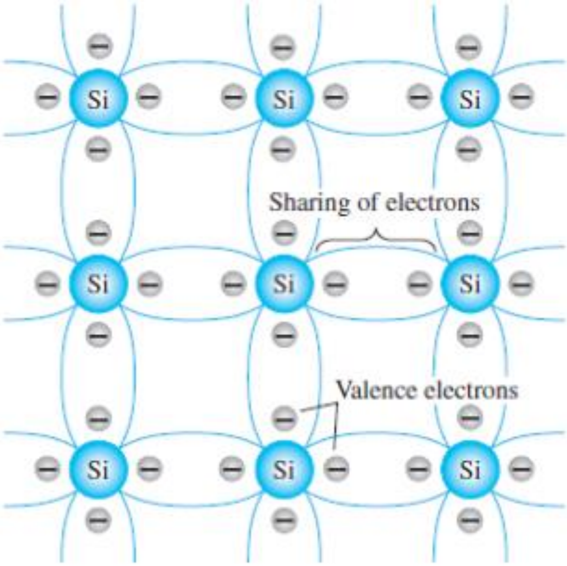


Schematic representation of an insulated silicon atom.

Silicon : It’s a Group 4 element (tetravalent elements) which means it has 4 electrons in outer shell. However, like all other elements it would prefer to have 8 electrons in its outer shell.

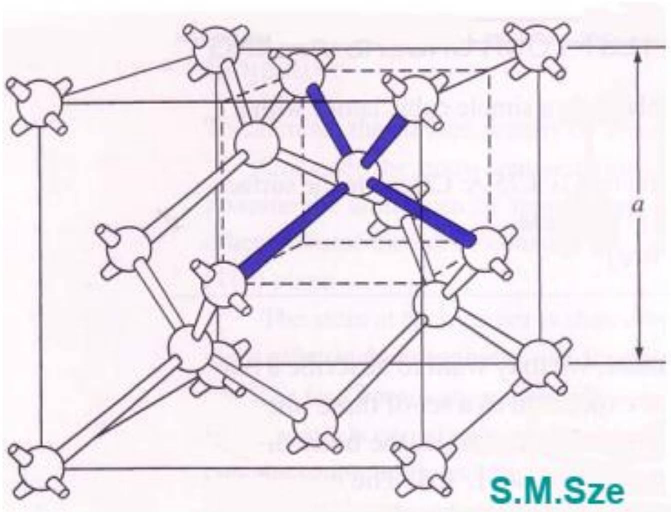
Atomic Crystal Structure

- **valence electron** – is an electron that participates in the formation of chemical bonds. It can exist only in the outermost electron shell.
- **covalent bond** – is a form of chemical bond in which two atoms share a pair of electrons.

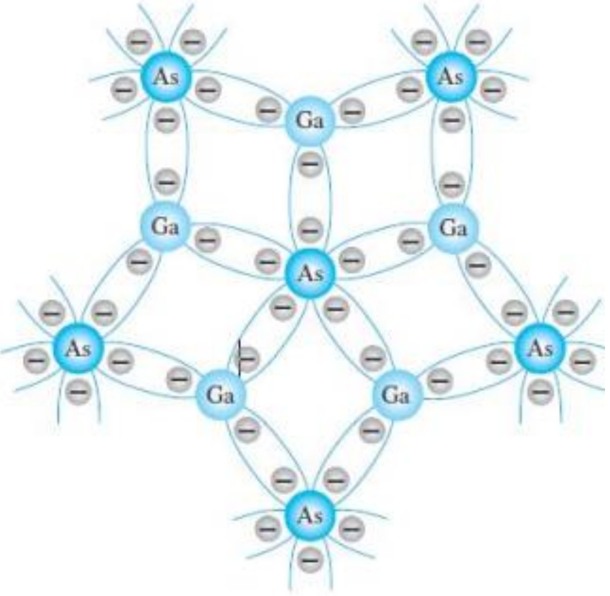


Covalent bonding of the silicon atom.

Si: diamond lattice



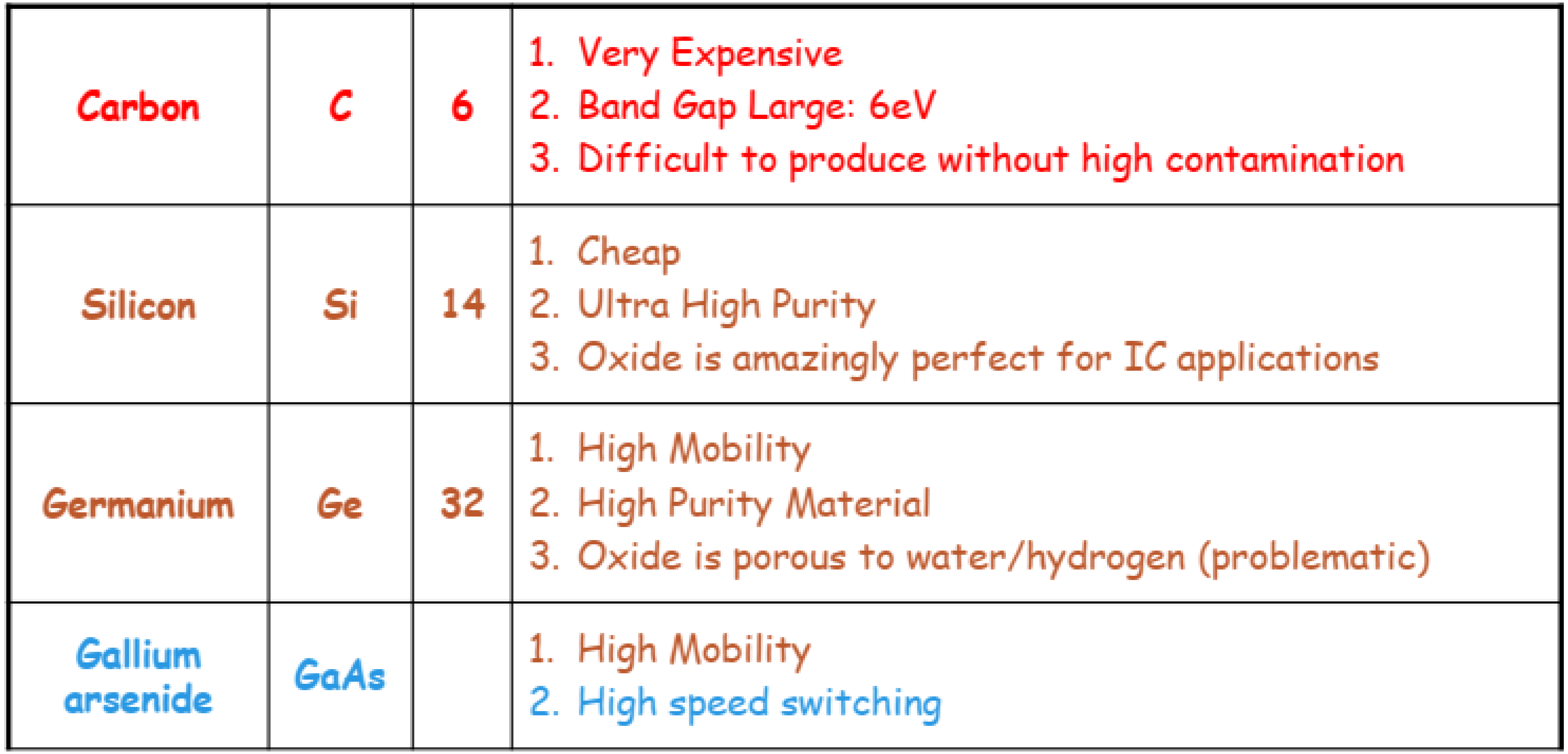
S.M.Sze



Covalent bonding of the GaAs crystal.

semiconductors

Possible Semiconductor Materials



Carbon	**C**	**6**	1. Very Expensive 2. Band Gap Large: 6eV 3. Difficult to produce without high contamination
Silicon	**Si**	**14**	1. Cheap 2. Ultra High Purity 3. Oxide is amazingly perfect for IC applications
Germanium	**Ge**	**32**	1. High Mobility 2. High Purity Material 3. Oxide is porous to water/hydrogen (problematic)
Gallium arsenide	**GaAs**		1. High Mobility 2. High speed switching

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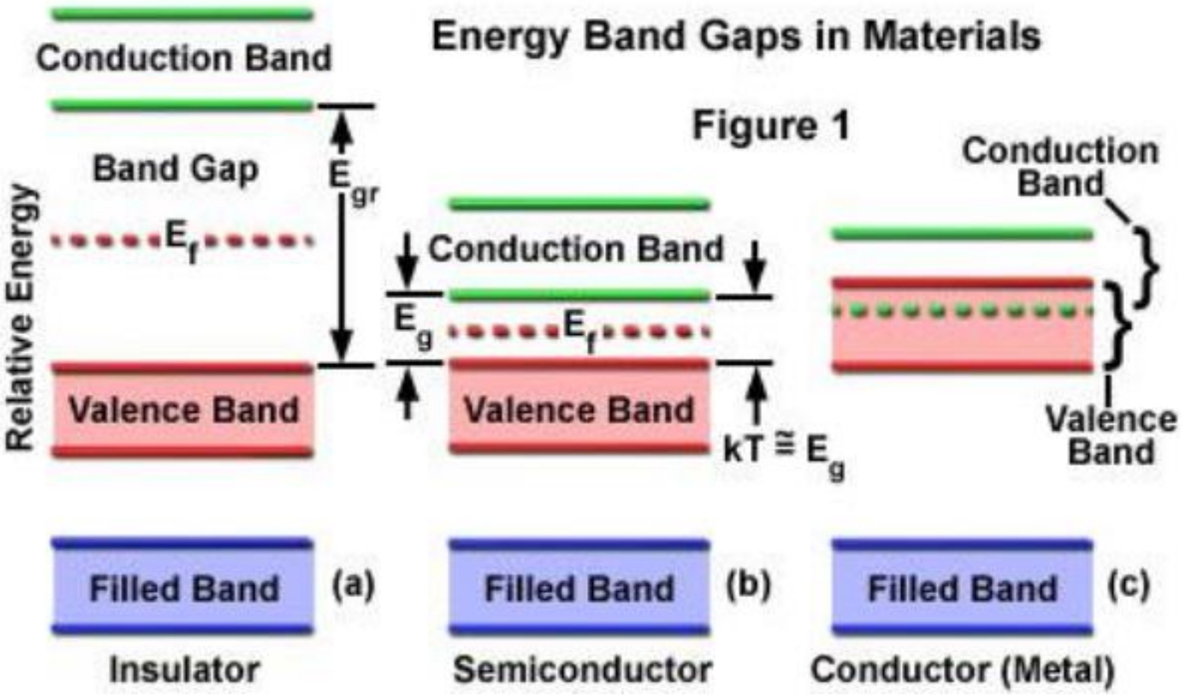
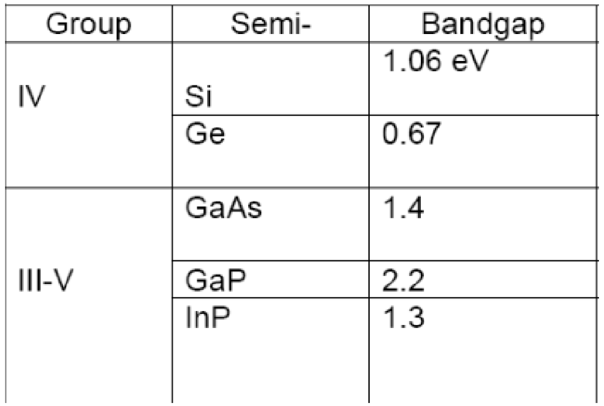
Band Diagram

- **Conductors**:
  - If we have used up all the electrons available and a band is still only half filled, the solid is said to be a good conductor. The half-filled band is known as the conduction band.
- **Insulators**:
  - When we have used up all the electrons the highest band is full and the next one is empty with a large gap between the two bands, the material is said to be a good insulator.
- **Semiconductors**:
  - Some materials have a filled valence band just like insulators but a small gap to the conduction band.
  - At zero Kelvin the material behave just like an insulator but at room temperature, it is possible for some electrons to acquire the energy to jump up to the conduction band. The electrons move easily through this conduction band under the application of an electric field. This is an **intrinsic semiconductor.**





Group	Semi-	Bandgap
IV	Si	1.06 eV
	Ge	0.67
III-V	GaAs	1.4
	GaP	2.2
	InP	1.3

Band Diagram

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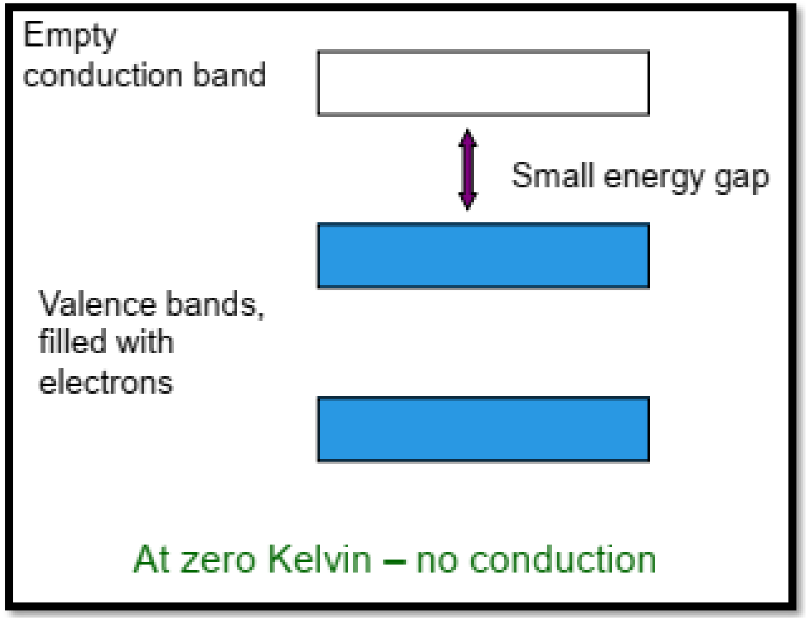

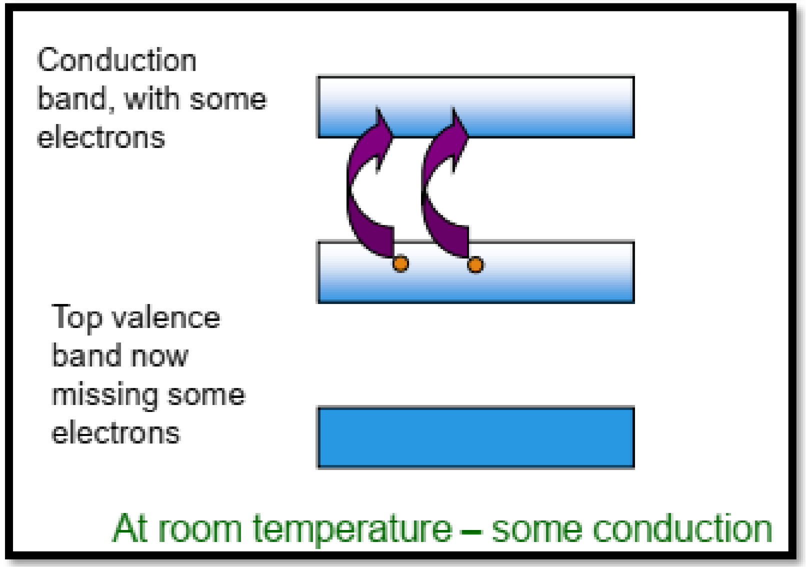

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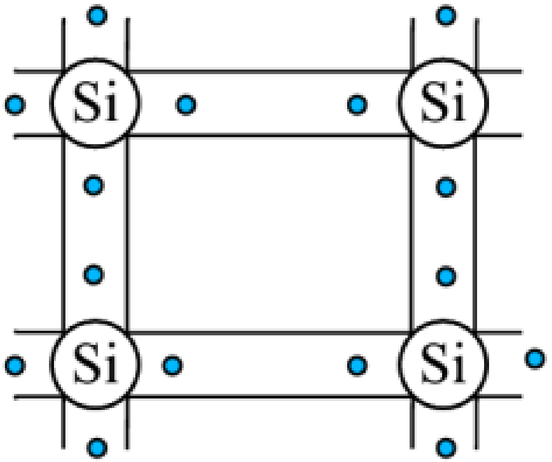
Intrinsic Semiconductors

- ❑ A perfect semiconductor crystal with no impurities or lattice defects is called an **intrinsic** semiconductor.

At T=0 K :

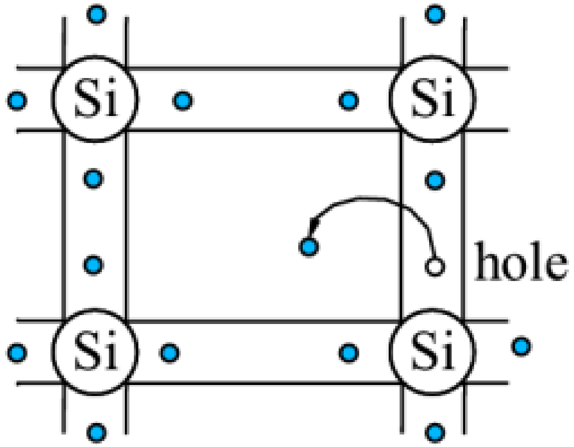
- No charge carriers.
- Valence band is filled with electrons.
- Conduction band is empty

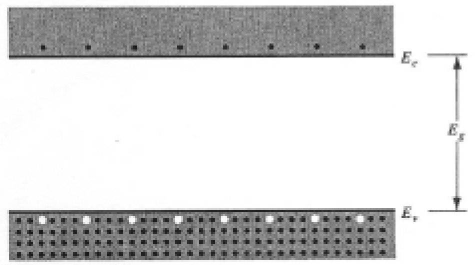


For T>0 :

- some electrons in the valence band receive enough thermal energy to be excited across the band gap to the conduction band.
- The result is a material with some electrons in an otherwise empty conduction band and some unoccupied states in an otherwise filled valence band.

  An empty state in the valence band is referred to as a **hole**.
- If the conduction band electron and the hole are created by the excitation of a valence band electron to the conduction band, they are called an **electron-hole pair** (EHP).



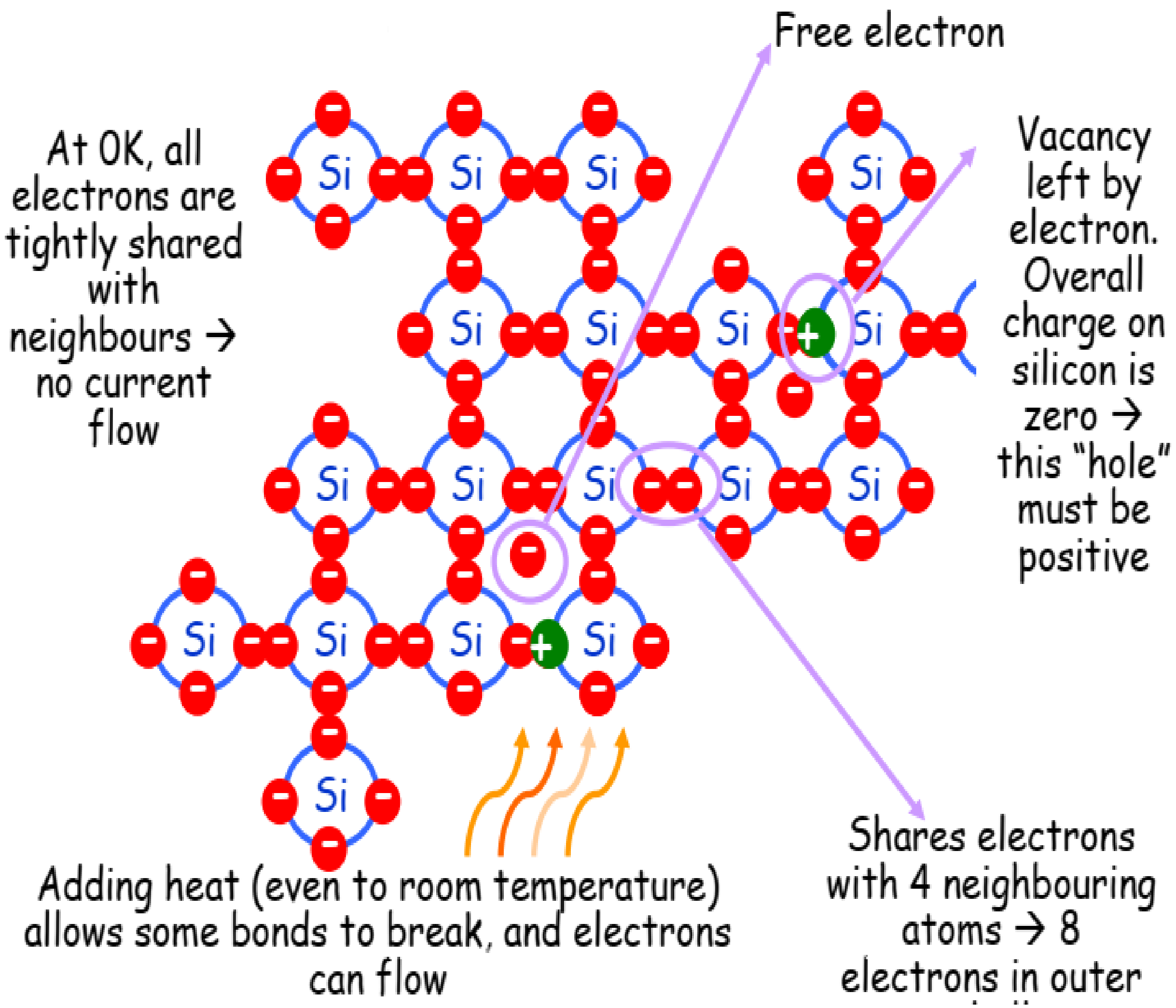


- Electron-hole pairs in a semiconductor.
- The bottom of the conduction band denotes as E_C and the top of the valence band denotes as E_V.

Intrinsic Semiconductors

For T>0 :

- Since electron and holes are created in pairs – the electron concentration in conduction band, **n** (electron/cm3) is equal to the concentration of holes in the valence band, **p** (holes/cm3).
- Each of these intrinsic carrier concentrations is denoted n_i



Free electron

At 0K, all electrons are tightly shared with neighbours → no current flow

Vacancy left by electron. Overall charge on silicon is zero → this "hole" must be positive

Adding heat (even to room temperature) allows some bonds to break, and electrons can flow

Shares electrons with 4 neighbouring atoms → 8 electrons in outer

Intrinsic Semiconductors

- At a given temperature there is a certain concentration of electron-hole pairs n_i . If a steady state carrier concentration is maintained, there must be **recombination** of EHPs at the same rate at which they are generated.

- Recombination occurs when an electron in the conduction band makes a transition to an empty state (hole) in the valence band, thus annihilating the pair.

- If we denote the generation rate of EHPs as g_i and the recombination rate as r_i, equilibrium requires that

$$g_i = r_i$$

- Each of these rates is **temperature dependent**. For example, $g_i(T)$ increases when the temperature is raised, and a new carrier concentration n_i is established such that the higher recombination rate $r_i(T)$ just balances generation.

- At any temperature, we can predict that the rate of recombination of electrons and holes r_i , is proportional to the equilibrium concentration of electrons n_0 and the concentration of holes p_0:

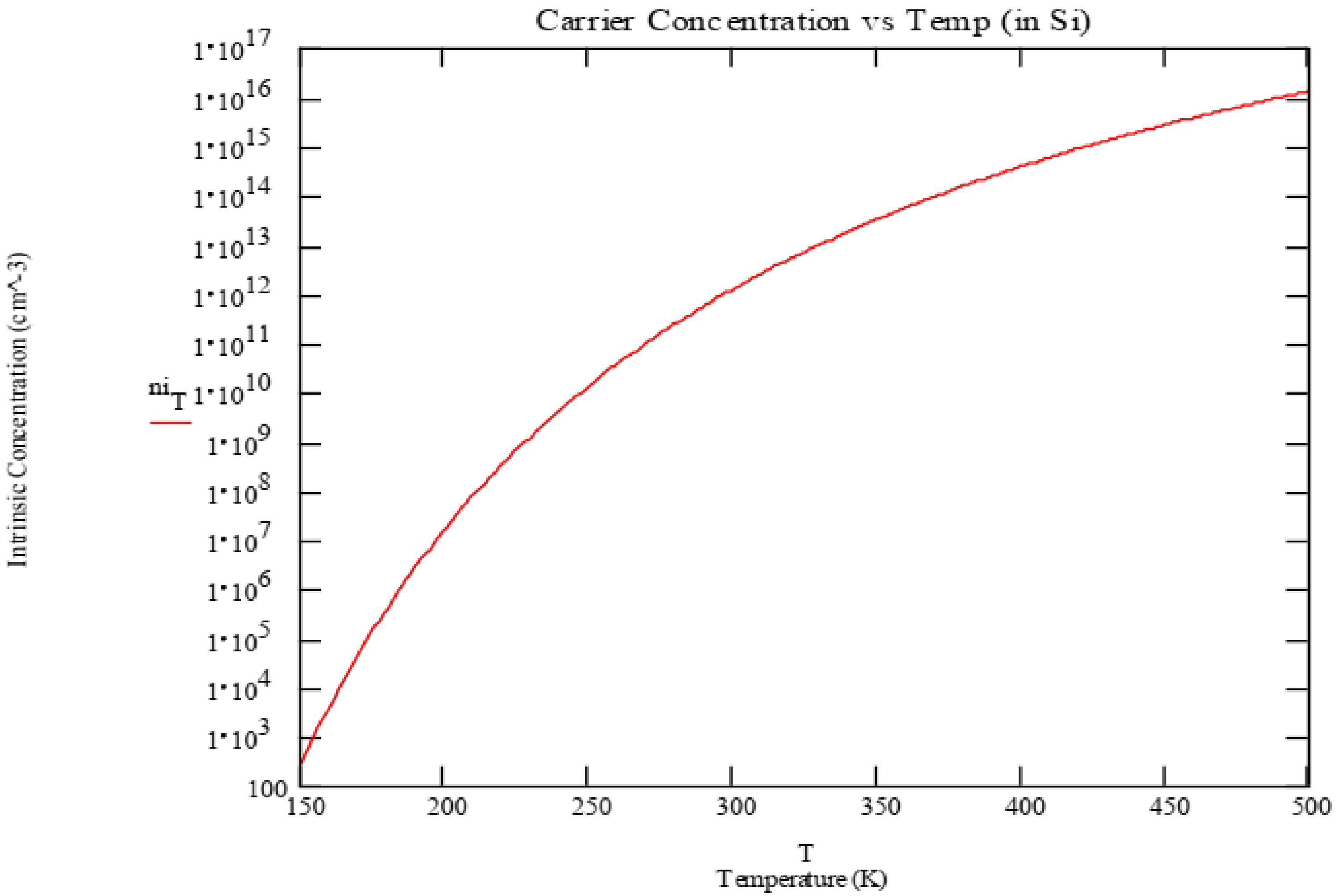
$$r_i = \mu_0 n_0 p_0 = n_i^2 = g_i$$

Intrinsic Semiconductors

Increasing conductivity by temperature

- As temperature increases, the number of free electrons and holes created increases exponentially.

- The conductivity of the semiconductor material increases when the temperature increases.
- This is because the application of heat makes it possible for some electrons in the valence band to move to the conduction band.
- Obviously, the more heat applied the higher the number of electrons that can gain the required energy to make the conduction band transition and become available as charge carriers.
- This is how temperature affects the carrier concentration.
- Another way to increase the number of charge carriers is to add them in from an external source. **(Doping)**



END OF LECTURE

BEST WISHES