EC21101: Basic Electronics

Instructors:

Prof. Shailendra K. Varshney (Sec. 1)

Prof. Goutam Saha (Sec. 2)

Prof. Sudip Nag (Sec. 3)

Debashis Sen (Sec. 4)

Contact Email: dsen@ece.iitkgp.ernet.in

Course webpage (Sec. 4):

https://sites.google.com/site/dseniitkharagpur/be2016s4

&

Register in usebackpack.com, search for the course (Basic Electronics - Section 4) page and join using the code: 0d11ef

Class Timings @ F102, EECE Building:

Monday 10.00 am – 10.55 am

Tuesday 8.00 am – 9.55 am (with a 5 min break in between)

Thursday 10.00am – 10.55am (class /tutorial)

Office Hours:

Thursday – 3 to 5pm

(Room A111, EECE Building)

Syllabus:

- Semiconductor Materials and Diodes
- Diode Circuits
- The Bipolar Junction Transistor
- Basic BJT Amplifiers
- The Field-Effect Transistor
- Basic FET Amplifiers
- Ideal Operational Amplifiers and Op-Amp Circuits
- Digital Electronics

Detailed in Course Webpage or usebackpack.com

Books :

Text Book -

- Microelectronics: Circuit Analysis and Design by Donald A. Neaman

Reference Books -

- Microelectronic Circuits by Adel S. Sedra and Kenneth C. Smith
- Microelectronics by Jacob Millman and Arvin Grabel
- Fundamentals of Microelectronics by Behzad Razavi
- Electronic Devices and Circuit Theory by Robert L. Boylestad and Louis Nashelsky

Evaluation Process:

Mid-Semester Examination : 30 Marks

End-Semester Examination: 50 Marks

TA: 20 Marks

- Class Tests (14 marks)
- Tutorial (3 marks)
- Attendance (3 marks)

Technical queries:
basicelectronicst@gmail.com

Semiconductor Materials and Properties

GOAL:

- Two types of charged carriers exist in a semiconductor
- Two mechanisms that generate currents in a semiconductor

Semiconductor:

Conductor - Materials that support generous flow of charge (electron) when a finite voltage is applied across two terminals.

Insulators - Materials that allow very little conductivity even when under severe pressure from an applied voltage source.

Semiconductors - In between Conductor and Insulator

Intrinsic Semiconductor:

Atomic structure – Atoms have negatively charged electrons orbiting around nucleus having positively charged protons and neutral neutrons

- The electrons are distributed in various shells at different mean distance from the nucleus.

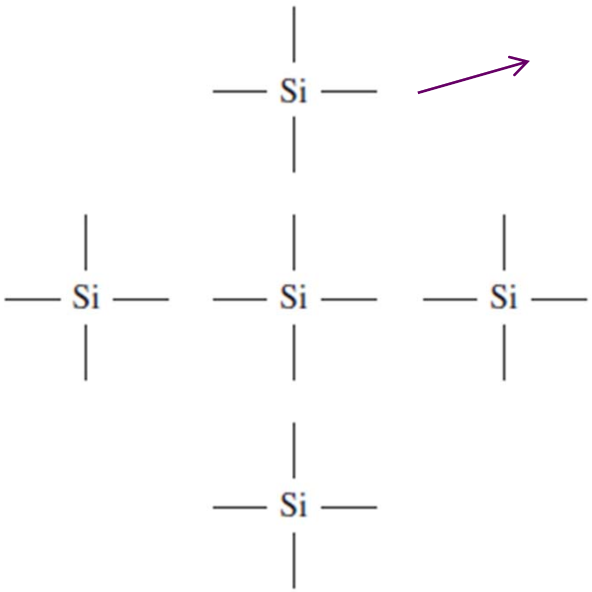
- Electron energy increases with increase in the distance.

- Hence, the outermost shell has electrons with highest energy and are called the valence electrons

Example –

Silicon is a well known intrinsic semiconductor

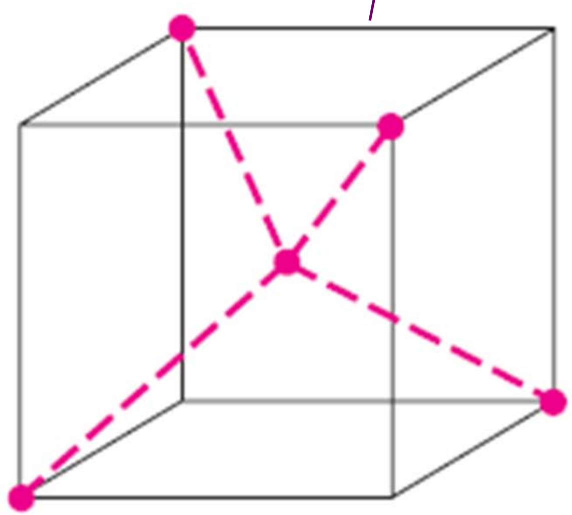
Five noninteracting Silicon atoms:

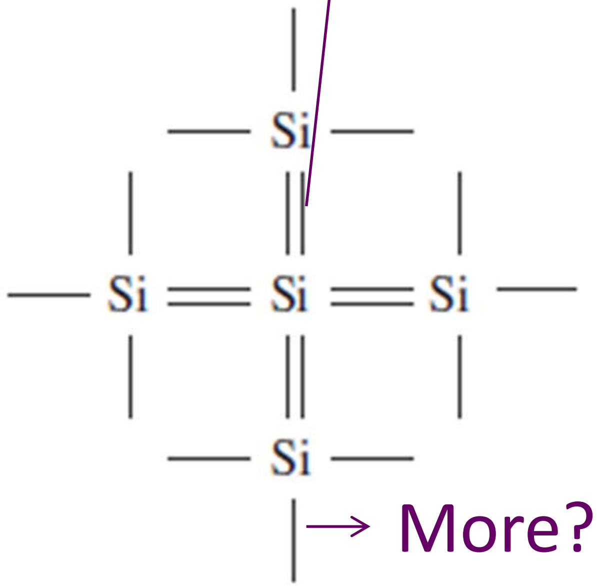


4 valence electrons in the outermost shell

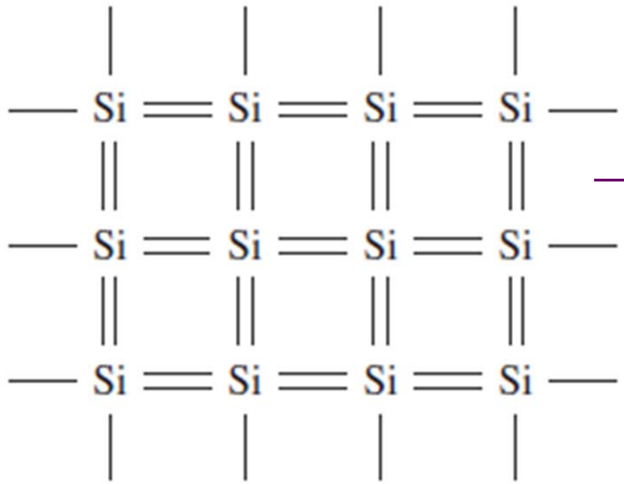
When Silicon atoms come into close proximity of each other the valence electrons interact to form crystal.

The crystal is tetrahedral and valence electrons are shared among atoms forming covalent bonds.





More?? Yes!



2D representation of Silicon crystal at 0 Kelvin temperature.

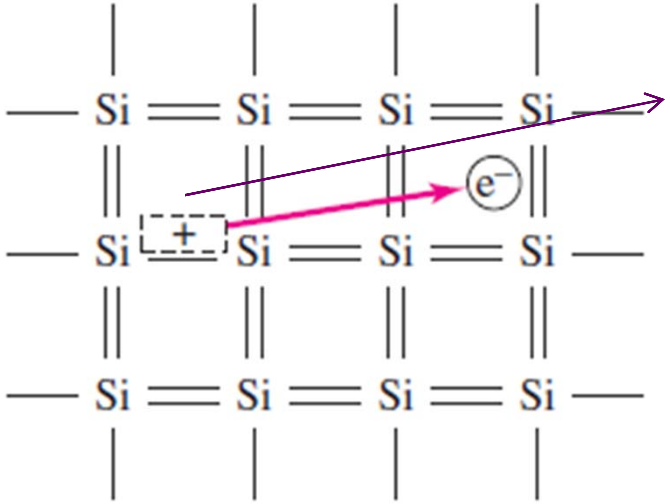
At 0 Kelvin, the valence electrons are at its lowest possible energy held in covalent bond

There is no electron free of the bond and electrons will not move. So at 0 K Silicon is an insulator.

- Silicon in 0 K crystal form has electrons that occupy some allowed energy bands. Among them the valence electrons occupy the valence energy band.

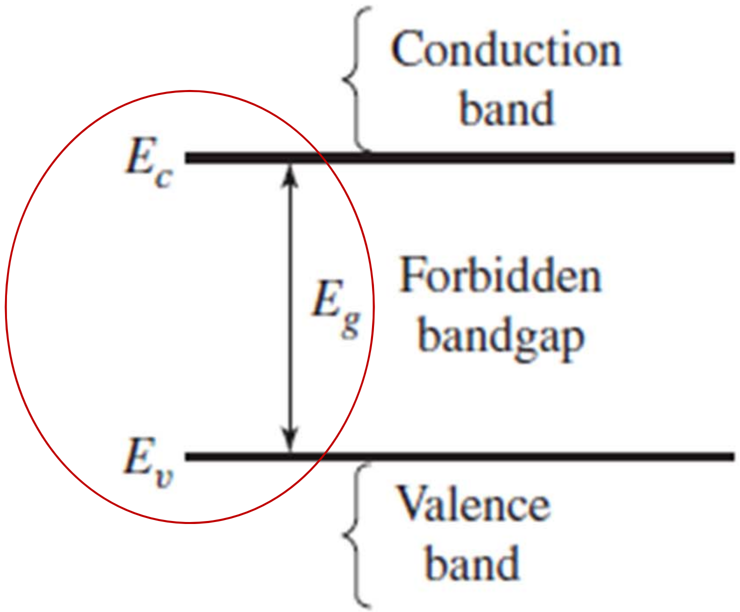
- If the temperature rises, the valence electrons can gain enough thermal energy to break the covalence bond and move.

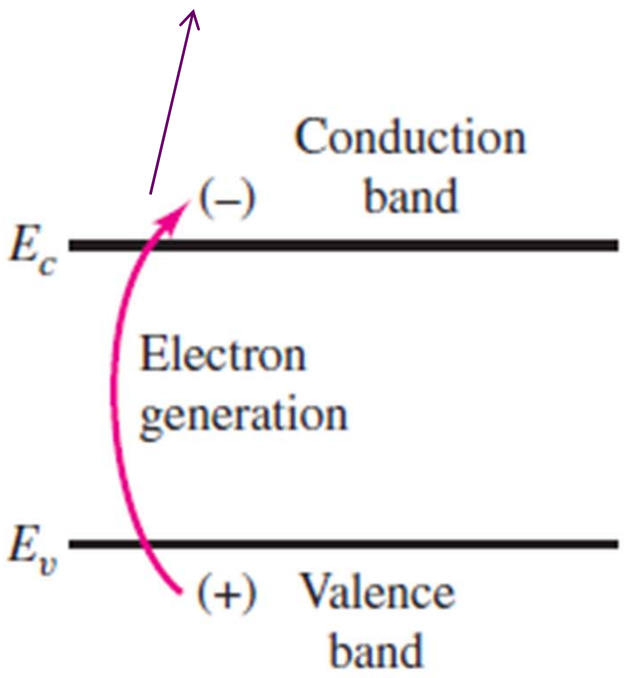
- The valence electrons need to gain a minimum energy called the bandgap energy for the above to happen. After absorbing the energy the electrons now exist in conduction band.



Positively charged empty state

Energy gain





Materials –

- Large bandgap 3 to 6 eVs (@ 0 K) are insulators, no free electron at room temperature.
- Large number of free electrons (@ 0 K) in the conduction band are conductors at room temperature.
- In a semi conductor the bandgap is of the order of 1eV (@ 0 K).

The net charge of a semiconductor is zero. Negative free electrons and positive “empty” state.

A list of some semiconductor materials

Elemental semiconductors		Compound semiconductors	
Si	Silicon	GaAs	Gallium arsenide
Ge	Germanium	GaP	Gallium phosphide
		AlP	Aluminum phosphide
		AlAs	Aluminum arsenide
		InP	Indium phosphide

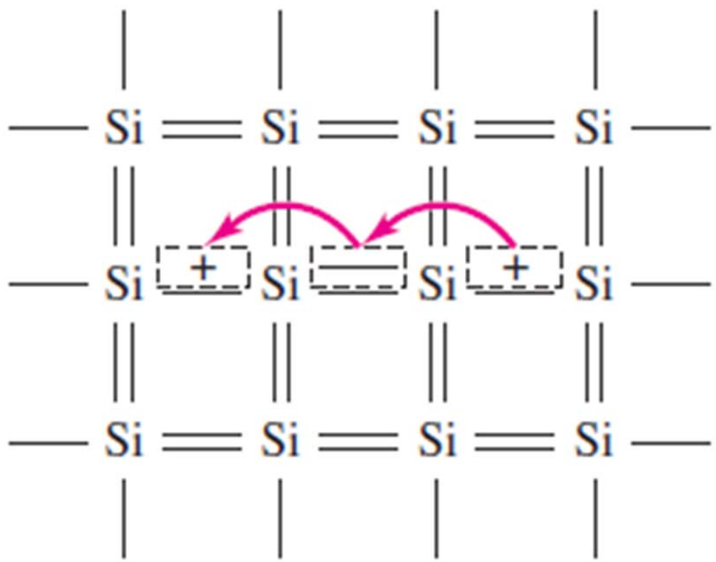
A portion of the periodic table

III	IV	V
5 B Boron	6 C Carbon	
13 Al Aluminum	14 Si Silicon	15 P Phosphorus
31 Ga Gallium	32 Ge Germanium	33 As Arsenic
49 In Indium		51 Sb Antimony

Group IV (transitional metal)
Group III & V together

- As the temperature increases, more covalent bonds are broken, and more free electrons and positive empty states are created.

- A valence electron acquiring thermal energy can move to adjacent empty state. This movement of a negatively charged electron also signifies the movement of positively charged "hole".



In semiconductors, then, two types of charged particles contribute to the current:

- The negatively charged free electron
- The positively charged hole

Concentration of electrons and holes are important parameters related to the magnitude of the current

Intrinsic semiconductor -

- Has no other types of atom
- Thermally generated electrons and holes are only source of such particles.

So intrinsic carrier concentration of free electrons is same as holes.

$$n_i = BT^{3/2} e^{\left(\frac{-E_g}{2kT}\right)}$$

B - Specific to a semiconductor material

k - Boltzmann's constant

T - Temperature in K

Eg - Bandgap energy

- The bandgap energy Eg and coefficient B are not strong functions of temperature.
- The intrinsic concentration is a parameter used in current–voltage equations for semiconductor devices.

Semiconductor constants		
Material	***Eg* (eV)**	***B* ($cm^{-3}\,K^{-3/2}$)**
Silicon (Si)	1.1	5.23×10^{15}
Gallium arsenide (GaAs)	1.4	2.10×10^{14}
Germanium (Ge)	0.66	1.66×10^{15}

Issue:

Concentration of electrons and holes in intrinsic semiconductors are less and suitable for carrying only small currents.

Extrinsic Semiconductor:

- Electron / hole concentration can be hugely increased (controlled) by adding controlled amount of impurities.

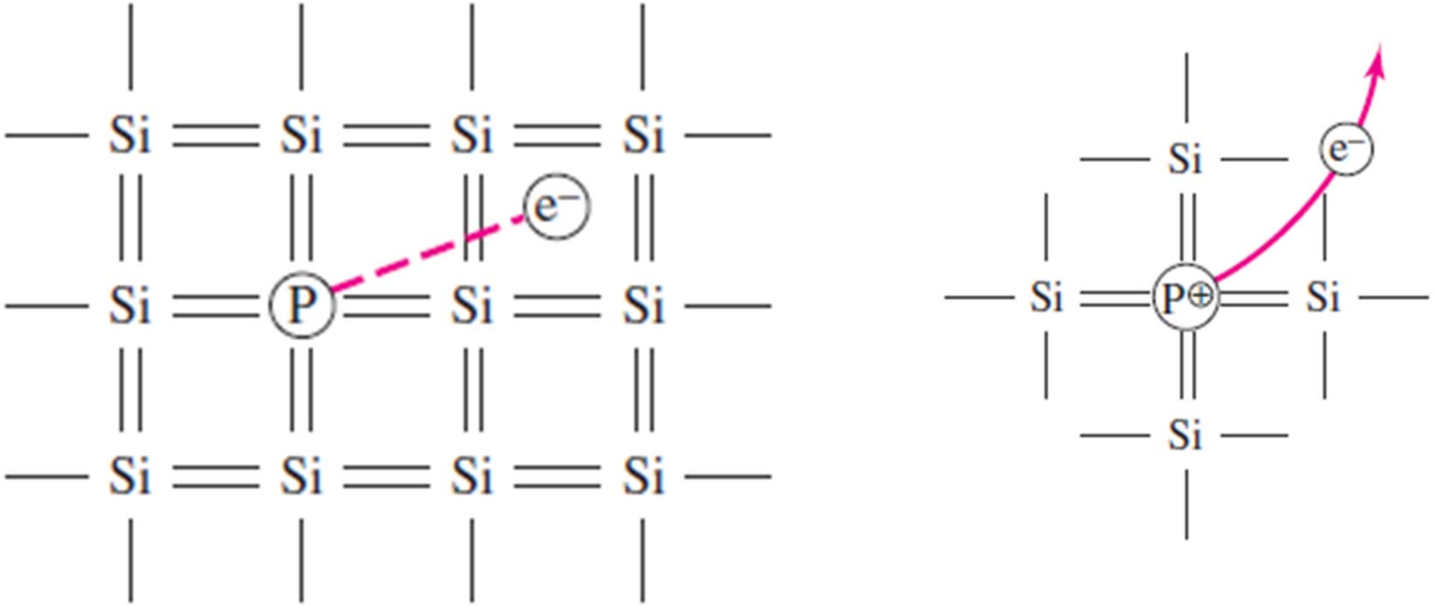
- Desired impurity is one that enters the crystal lattice and replaces one of the semiconductor atom. Most preferred are the Phosphorous (Group III) or Boron (Group V) elements.

Phosphorous Impurity –

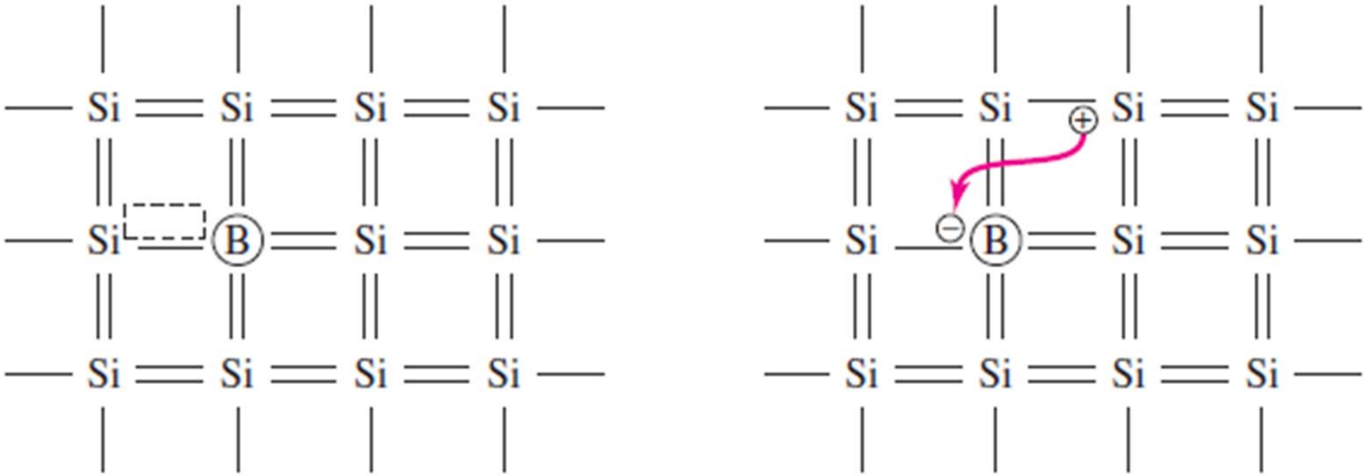
- 4 valence electrons of Phosphorous atom forms covalent bonds with that of Silicon, whereas the 5^{th} one is loosely bound.
- The 5^{th} electron is already in the conduction band.
- When the 5^{th} electron moves to conduction band, a positively charge Phosphorous ion is created but no hole is created!

Phosphorous Impurity –

- The phosphorus atom is called a donor impurity, since it donates an electron that is free to move.
- A semiconductor that contains donor impurity atoms is called an n-type semiconductor.
- This process of generation of free electrons without generating a hole is called doping.



Boron Impurity – ?



Boron Impurity –

- 3 valence electrons of Boron atom forms covalent bonds with that of Silicon, whereas 1 Silicon electron is loosely bound.
- Another electron from nearby silicon atom moves to make the 4th covalent bond, at room temperature.
- A Hole is created. The Boron atom has a net negative charge, but no electron is free.

Boron Impurity –

- The Boron atom is called an acceptor impurity, since it accepts an electron and a hole is created.

- A semiconductor that contains acceptor impurity atoms is called an p-type semiconductor.

- This process of generation of holes without generating a electrons is also called doping.

- Materials containing impurity atoms are called extrinsic semiconductors, or doped semiconductors.
- Doping process allows us to control the concentration of free electrons and holes.

Fundamental relation between electron and hole concentration when the semiconductor is in thermal equilibrium:

$$n_o p_o = n_i^2$$

At room temperature (T=300K), each donor / acceptor atom donates / accepts an electron. If the donor / acceptor concentration is assumed much higher than the intrinsic one we have:

$$p_o = \frac{n_i^2}{N_d} \longrightarrow$$ Donor impurity

$$n_o = \frac{n_i^2}{N_a} \longrightarrow$$ Acceptor impurity

Holes or electrons whose concentration is higher (lower) is called the majority (minority) carrier