Semiconductor Fundamentals

Presented to

EE2187 class in Semester 1 2019/20

Shiv Govind Singh

sgsingh@iith.ac.in

Professor, Electrical Engineering

IIT Hyderabad , India

भारतीय प्रौद्योगिकी संस्थान हैदराबाद

Indian Institute of Technology Hyderabad

Lecture 12

Course information

- ❖ Semiconductors Materials - Types of Solids, Space lattice, Atomic Bonding,
- ❖ Introduction to quantum theory, Schrodinger wave equation, Electron in free space, Infinite well, and step potentials, Allowed and forbidden bands
- ❖ Electrical conduction in solids, Density of states functions, Fermi-Dirac distribution in Equilibrium,
- ❖ Valence band and Energy band models of intrinsic and extrinsic Semiconductors. Degenerate and non degenerate doping
- ❖ Thermal equilibrium carrier concentration, charge neutrality
- ❖ Carrier transport – Mobility, drift, diffusion.

Reference

Text Book:

1. Physics of Semiconductor Devices, *S. M. Sze*, John Wiley & Sons (1981).
2. Solid State Electronics by *Ben G. Streetman and Sanjay Banerjee*, Prentice Hall International , Inc.
3. Semiconductor Physics and Devices, Donald A. Neamen, Tata Mcgraw-Hill Publishing company Limited.
4. Advanced Semiconductor Fundamentals by Pirret

Reference Book:

1. Fundamentals of Solid-State Electronic Devices, *C. T. Sah*, Allied Publisher and World Scientific, 1991.
2. Complete Guide to Semiconductor Devices, *K. K. Ng*, McGraw Hill, 1995.
3. Solid state physics, Ashcroft & Mermins.
4. Introduction to Solid State Electronics, *E. F. Y. Waug*, North Holland, 1980.

Recap

$$n_o = \int_0^{E_{top}} f(E)g(E)dE$$

$$DOS\ in\ 3DCrystal,\ \ g(E) = \frac{m*}{2\pi^2\hbar^3}\sqrt{2m*(E-Ec)}$$

$$n_o = \int_E^{\infty} \frac{\frac{m_n^{*3/2}}{\hbar^3}\sqrt{(E-E_c}dE}{\exp(E-E_F)/kT} = N_c e^{-(\frac{E_c-E_f}{kT})}$$

$$E_F = \frac{E_C+E_V}{2} + kT\ln\frac{m^*_{p_{dos}}}{m^*_{n_{dos}}}$$

$$p_o = \int_E^{\infty} \frac{\frac{m_p^{*3/2}}{\hbar^3}\sqrt{(E_v-E}dE}{\exp(E-E_F)/kT} = N_v e^{-\frac{(E_F-E_v)}{kT}}$$

Intrinsic carrier concentration

Product of n_0 and p_0

$$p_0 = NV\, e^{-\frac{(E_F - EV)}{KT}}$$

$$n_0 = NC\, e^{-\frac{(E_C - EF)}{KT}}$$

$$n_o p_o = N_v e^{-\frac{(E_F - E_v)}{kT}} N_c e^{-\frac{(E_c - E_F)}{kT}}$$

$$n_o p_o = N_v N_c e^{-\frac{(E_c - E_v)}{kT}} = N_v N_c e^{-\frac{E_g}{kT}}$$

$$n_i^2 = N_v N_c e^{-\frac{E_g}{kT}} = n_o p_o$$

Where E_g is band gap,

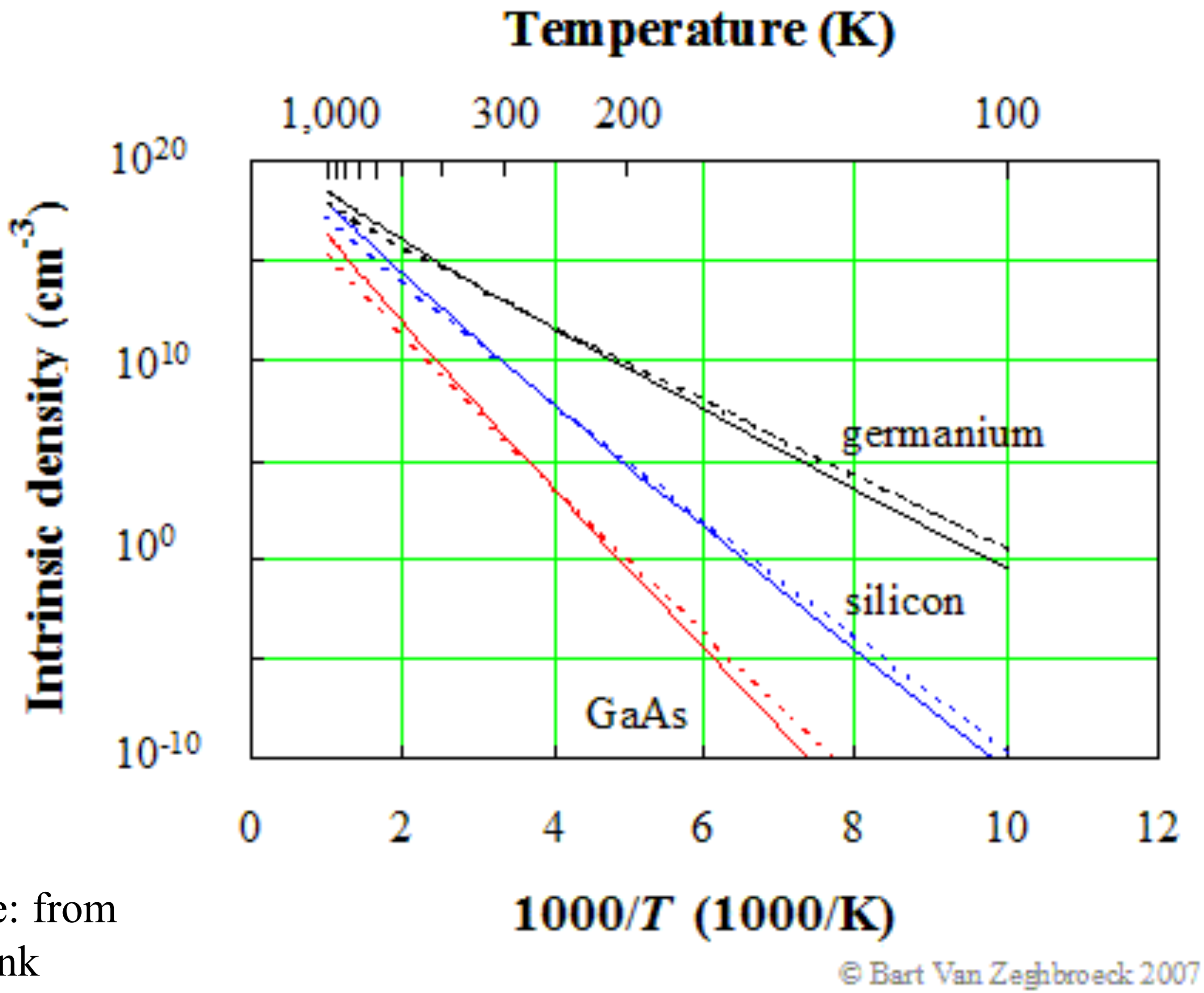
At equilibrium $n_o = p_o = n_i$

n_i depends upon temperature and band gap

	N_c (/cm³) (10^{18})	N_v (/cm³) (10^{18})	$\frac{m_n^*}{m_o}$	$\frac{m_p^*}{m_o}$
Si	28	10.4	1.08	.56
Ge	10.9	6	.55	.37
GaAs	.47	7	.067	.48

	E_g (eV)	Concentration (/cm³) 300K	Concentration (/cm³) 400K
Si	1.12	$1.5 10^{10}$	~10^{13}
Ge	.72	$2.4X10^{13}$	~10^{16}
GaAs	1.42	$1.8X10^{6}$	-
SiC	3.5	10	100

Intrinsic carrier density with temperature



$$n_i = N(\frac{1}{p})^{-E/kT}$$

$$Log n_i \propto -E/kT Log(\frac{1}{p})$$

$$n^2{}_i = N_V N_C\, e^{-\frac{(E_g)}{KT}}$$

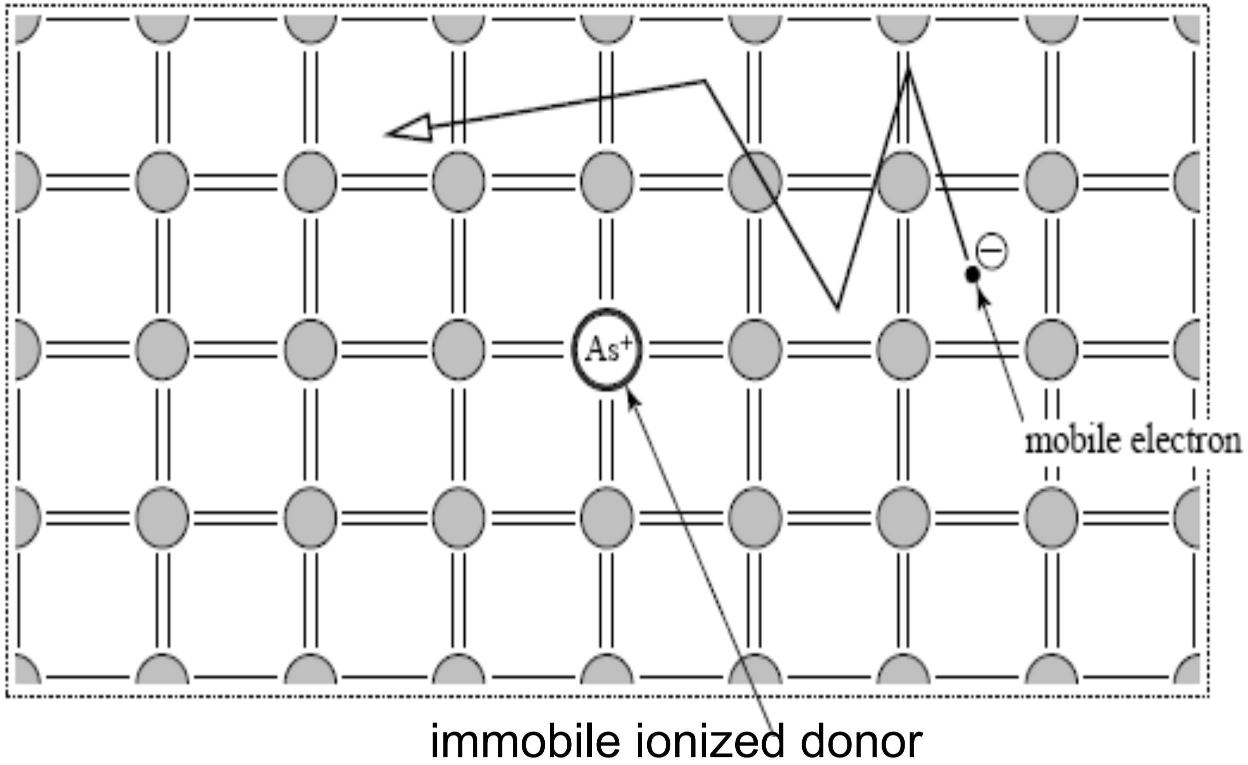
Source: from web link

Doping

(Impurity Incorporation)

Donors: Introduce electrons to the semiconductor (but not holes)

IIB	IIIA	IVA	VA	VIA
	5 B	6 C	7 N	8 O
	13 Al	14 Si	15 P	16 S
30 Zn	31 Ga	32 Ge	33 As	34 Se
48 Cd	49 In	50 Sn	51 Sb	52 Te



- 4 electrons of donor atom participate in bonding
- 5th electron easy to release

– **at room temperature, each donor releases 1 electron** that is available for conduction

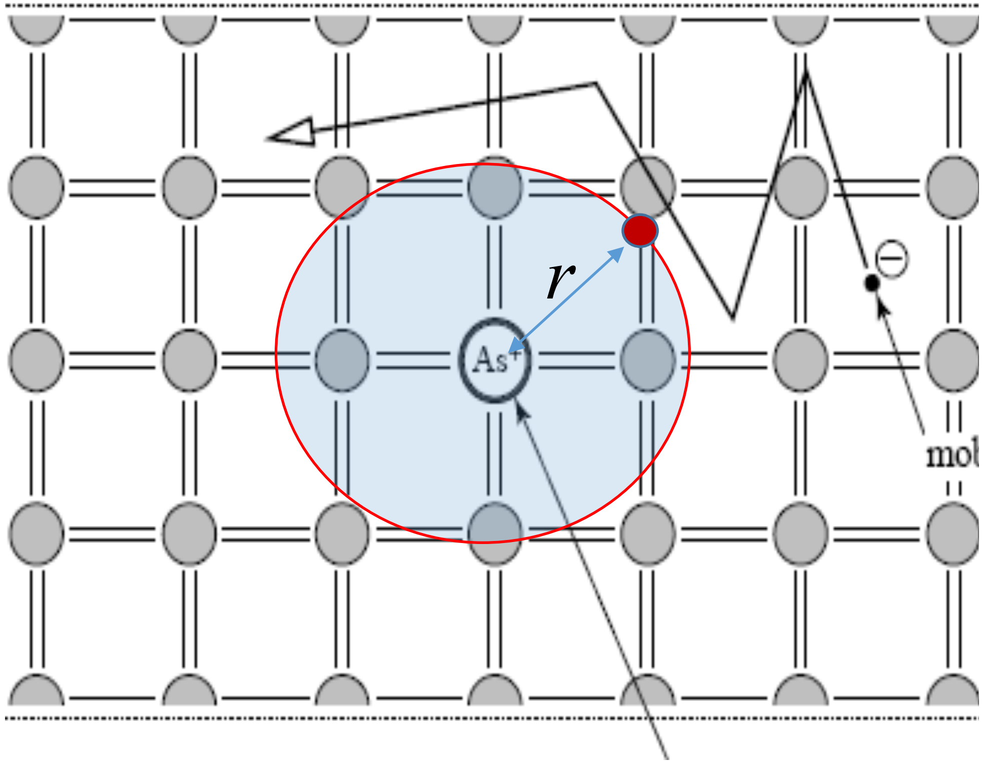
- donor site become positively charged (fixed charge)

Question to ask

Can we have holes?

Can we get electron by some other mechnasim

More Insight (Bond Model)



At T=0K

It look like hydrogen atom
i.e. the electron (excess, which come because of As atoms) circulating the “As”.

Binding force between As^{+} nucleus to circulating e^{-}

$$F = \frac{-q^2}{4\pi \in 0 \in {}_r r^2} \qquad F \propto \frac{1}{\in {}_r}$$

Dielectric constant of Si which is ~12.

Binding Energy of Electron of ground state

$$E = \frac{-mq^4}{8\pi \in 20 \in 2_r h^2} = \frac{-13.6eV}{\in {}^2{}_r} \qquad E \propto \frac{m*}{\in {}^2{}_r}$$

$$m* \sim 0.4m_n \qquad \in {}_r \sim 12$$

This is very small also known as ionization energy, so effectively this electron level lying just below E_c

This is called Donor state

Electrons Concentration and Band Diagram

Total Electron concentration $n_{n0} = Nd^{+}$

Charge Neutrality $n_{n0} = Nd^{+} + pn_{0}$