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Institute of Science and Technology

DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

Module 2 Lecture 13

1. ***Semiconductor material for optoelectronic applications – Introduction***
2. ***Photocurrent in a P-N junction diode***

Semiconductor material for optoelectronic applications – Introduction

Major semiconducting materials used for optoelectronics are III – V and II – VI groups.

Among the two groups of semiconductors, III – V is more suitable as they are direct band gap materials which is necessary condition needed for opto electronic devices to convert electrical energy into light energy conversion.

III – V materials – Column III and V in the periodic table

III column – Al, Ga, In

V column - N, P, As, Sb

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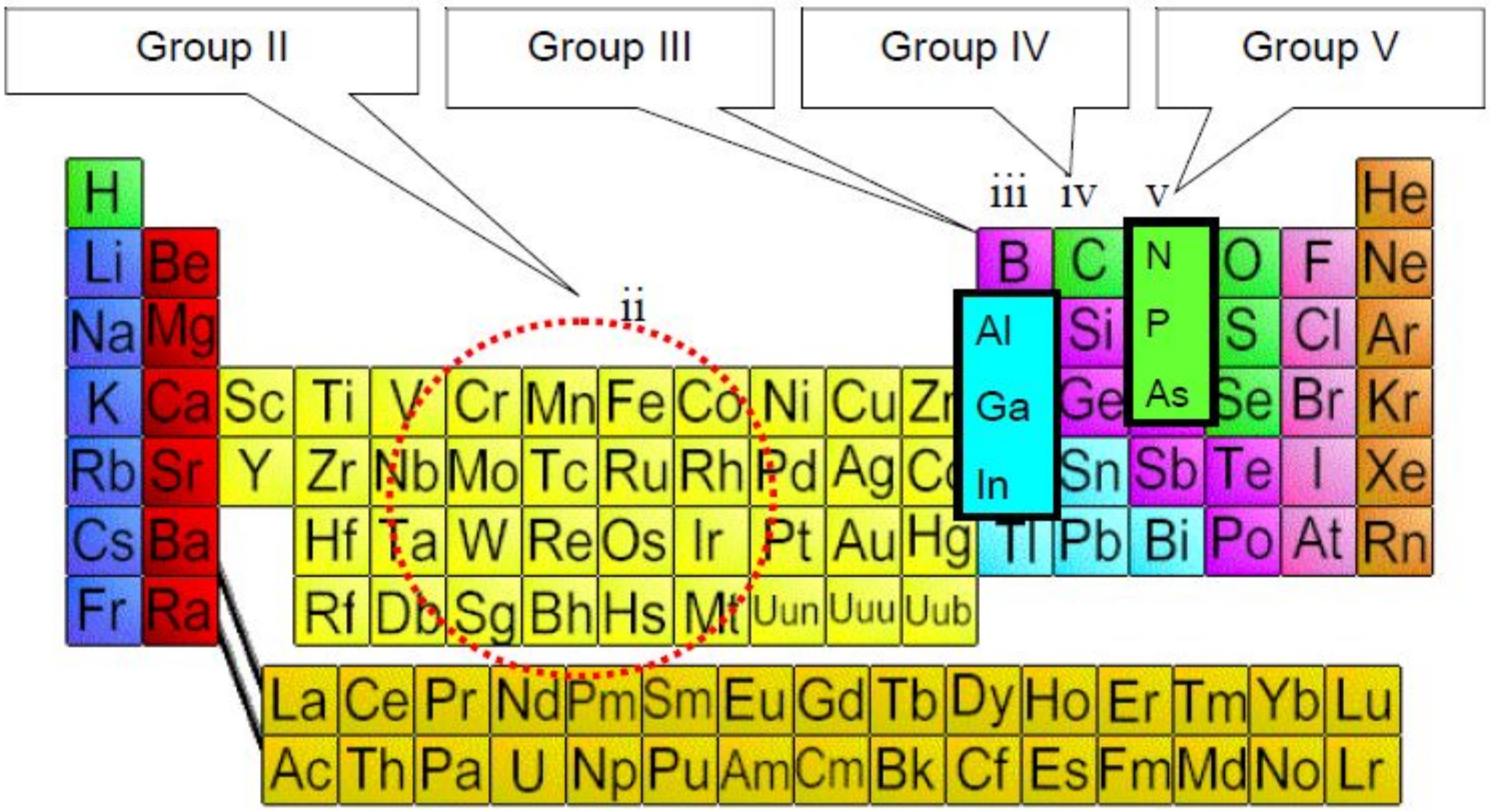
Candidate Materials
Group III-V & Group II-VI



Semiconductor material for optoelectronic applications – Introduction

Important applications for some III – V semiconducting materials

AlGaAs – Light emitter and modulator

GaInAsP – Optoelectronic device

AlGaInP – Red Emitter LED

GaAsP – Visible LED

AlGaAsSb – Light emitter and detector

Semiconductor material for optoelectronic applications – Introduction

The suitable choice of above materials depends on their quantum dimensions (1D, 2D or 3D) for optoelectronic applications.

II – VI semiconducting materials – column II and VI in periodic table. They are having wide range of optoelectronic properties ranging from far IR to UV region. This can be easily tuned to different band gap (Eg) by incorporating magnetic ions. They have stronger polarity due to ionic bonding character.

Semiconductor material for optoelectronic applications – Introduction

Important applications of some II – VI semiconductors

ZnSe – Blue-Green LEDs

ZnS – UV emitters, Display

ZnO – UV emitters

CdS – Visible light LEDs

CdSe – Colour LEDs (Short wave)

Semiconductor material for optoelectronic applications – Introduction

Color Name	Wavelength (Nanometers)	Semiconductor Composition
Infrared	880	GaAlAs/GaAs
Ultra Red	660	GaAlAs/GaAlAs
Super Red	633	AlGaInP
Super Orange	612	AlGaInP
Orange	605	GaAsP/GaP
Yellow	585	GaAsP/GaP
Incandescent White	4500K (CT)	InGaN/SiC
Pale White	6500K (CT)	InGaN/SiC
Cool White	8000K (CT)	InGaN/SiC
Pure Green	555	GaP/GaP
Super Blue	470	GaN/SiC
Blue Violet	430	GaN/SiC
Ultraviolet	395	InGaN/SiC

WHAT IS PHOTO DIODE?

- It is a form of light-weight sensor that converts light energy into electrical voltage or current. Photodiode is a type of semi conducting device with PN junction. Between the p (positive) and n (negative) layers, an intrinsic layer is present. The photo diode accepts light energy as input to generate electric current.
- It is also called as Photodetector, photo sensor or light detector. Photo diode operates in reverse bias condition i.e. the p – side of the photodiode is connected with negative terminal of battery (or the power supply) and n – side to the positive terminal of battery.

WHAT IS PHOTO DIODE?

- Typical photodiode materials are Silicon, Germanium, Indium Gallium Arsenide Phosphide and Indium gallium arsenide.
- Internally, a photodiode has optical filters, built in lens and a surface area. When surface area of photodiode increases, it results in more response time. Few photo diodes will look like Light Emitting Diode (LED). It has two terminals as shown below. The smaller terminal acts as cathode and longer terminal acts as anode.

PHOTO CURRENT IN PN JUNCTION DIODE (PHOTO DIODE)

- In a photodiode, the incident optical signal generates electron-hole pairs that gives rise to a photo current across PN junction.
- When a PN junction is illuminated with light of photon energy (E) greater than E_g, photons are absorbed in semiconductor and electron-hole pairs are generated both in n-region and p-region of the junction.

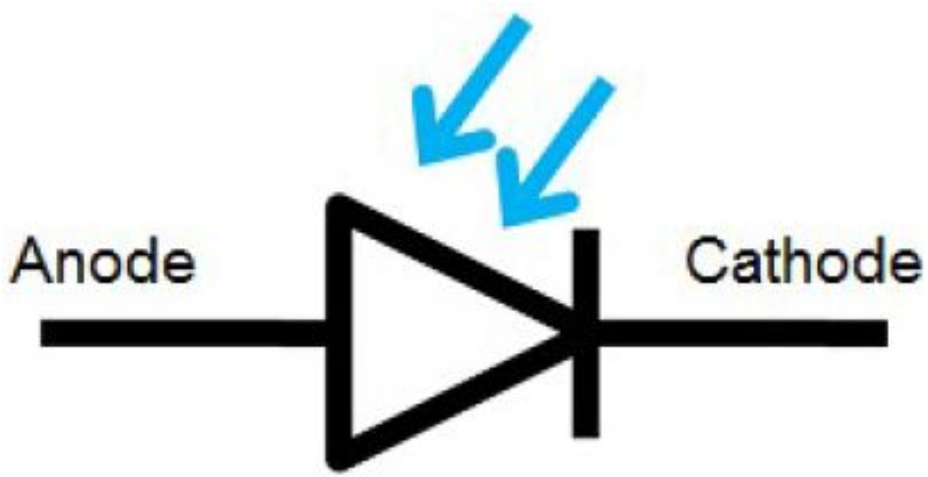


PHOTO CURRENT IN PN JUNCTION DIODE (PHOTO DIODE)

- For the electron-hole pair to contribute towards current in external circuit, the generated electron and holes must be separated before they recombine.
- Once electron-hole pairs are generated in the depletion layer, the electric field in the built-in-potential or contact potential sweeps away the electron and holes in opposite directions.
- The photo generated minority carriers which are generated within one diffusion length from the depletion layer edge, can also diffuse to the depletion region without recombining.

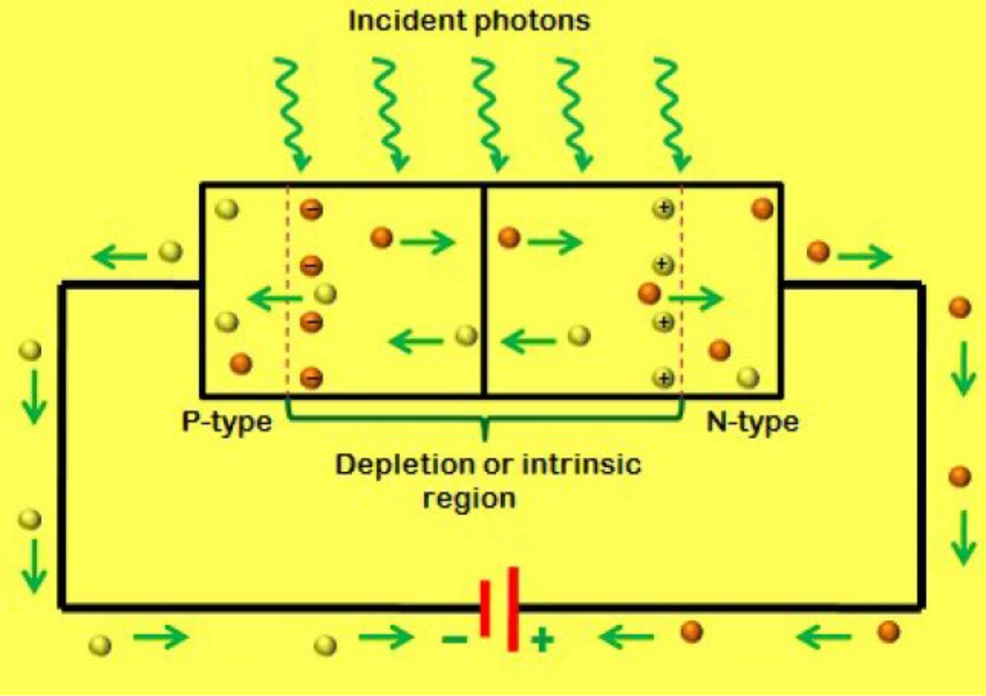
PHOTO CURRENT IN PHOTO DIODE

- They are then swept across the junction due to the electric field present in the depletion region. Due to the direction of electric field being from the n-region to p-region, the holes flow towards the p-region and electrons to the n-region.
- Since the direction of this photo generated current I_L is opposite to that in a forward- biased diode, the total current in the illuminated PN junction diode is

$$I_L = I_n L + I_p L + I_d$$

WORKING OF A PHOTODIODE

- Generally, when a light is made to illuminate the PN junction, covalent bonds are ionized. This generates hole and electron pairs. Photocurrents are produced due to generation of electron-hole pairs. Electron hole pairs are formed when photons of energy more than 1.1eV hits the diode.
- When the photon enters the depletion region of diode, it hits the atom with high energy.
- This results in release of electron from atom structure. After the electron release, free electrons and hole are produced.



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WORKING OF A PHOTODIODE

- In general, an electron will have negative charge and holes will have a positive charge. The depletion energy will have built in electric filed. Due to that electric filed, electron hole pairs moves away from the junction.
- Hence, holes move to anode and electrons move to cathode to produce photo current. The photon absorption intensity and photon energy are directly proportional to each other. When energy of photons is less, the absorption will be more. This entire process is known as Inner Photoelectric Effect.

ENERGY BAND DIAGRAM OF A PHOTODIODE

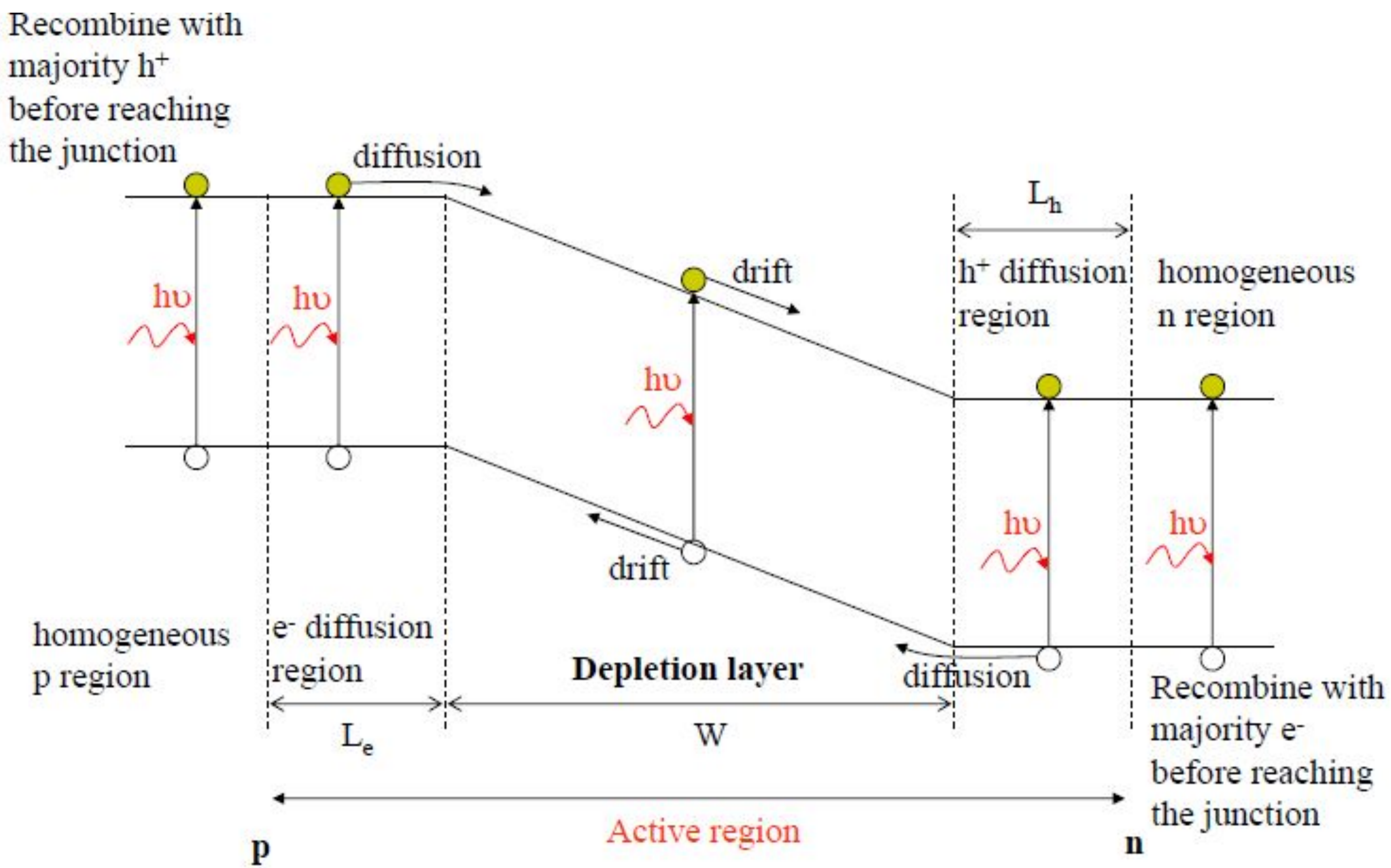
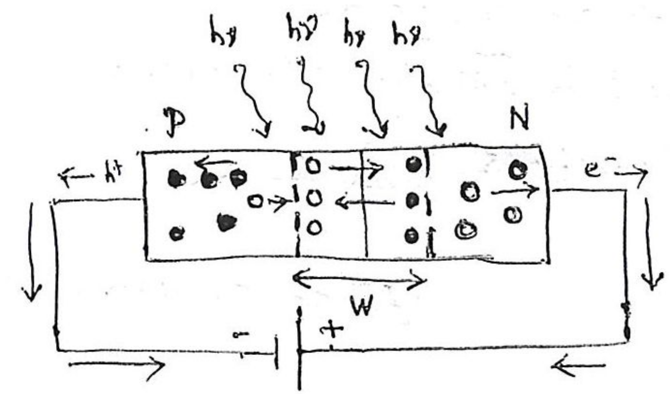


PHOTO CURRENT IN PHOTO DIODE

The photocurrent generated in photodiode has three component

1. Photo generated current in space-charge region
2. Photo generated current in n-region
3. Photo generated current in p-region



If G is the generation rate of excess carrier and A is diode area then photo current, the excess carrier in depletion region quickly moved by electric field (electron to n-region and holes to p-region).

PHOTO CURRENT IN PHOTO DIODE

- The photo generated current in the depletion region is

$$I_1 = Ae\int Gdx = eGWA$$

where W is the depletion width and this current is very fast (prompt photocurrent).

- In addition to the carriers generated in the depletion region, electron-hole pairs are generated in the neutral n-region and p-region of the diode.

PHOTO CURRENT IN PHOTO DIODE

- We may expect that holes generated within a distance L_p (the diffusion length) of the depletion region edge will be able to enter the depletion region from where the electric field will sweep them into p-side.

$$I_p = eG_L L_p A$$

- Similarly, excess electrons produced in p region will give photo current.

$$I_n = eG_L L_n A$$

PHOTO CURRENT IN PHOTO DIODE

- So total current due to carriers in the neutral region and the depletion region is given by

$$I_L = eG_L(L_p + L_n + W)A$$