

## **Outline For Lectures 10, 11, & 12**

### Properties of Semiconductors

LEDs

Laser Diodes

Photodiodes

Energy bands in solids

Bands and Bandgaps

Direct and Indirect gaps

p – n junctions

### Applications

Atomic Physics

Communication

Entertainment

- low power, compact and low cost

## 4061- Lecture Ten

### Band Structure in Semiconductors

For free electrons  $\Rightarrow p = \hbar k_e$  where  $k_e = 2\pi/\lambda$

$$E(k) = p^2 / 2m = \hbar k_e^2 / 2m$$

Free electron wavefunction is  $\psi \sim e^{ik_e x - \omega t}$  (plane wave) where  $\omega = E/\hbar$   
 $|\psi|^2$  is independent of  $x$

### Contrast with localize electron

In this case wavepacket is superposition of plane waves with different  $\omega$  and  $k$

$$v_g = d\omega/dk = 1/\hbar (dE/dk) \text{ where } v_g \text{ is the group velocity}$$

### Characteristics of electrons in Solid

- Scattering from periodic lattice
- $e^-$  wave packet not free to propagate (standing wave)
- reflection satisfies Bragg condition  
 $2a = n\lambda_e$  where  $a$  is the lattice spacing and  $n$  is an integer

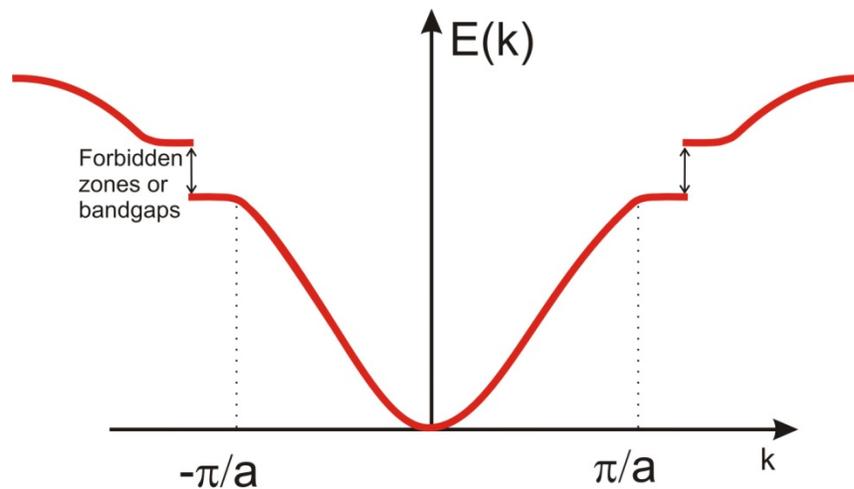
$$k_n = 2\pi/\lambda_n = n\pi/a$$

The values of  $k_n$  are discrete

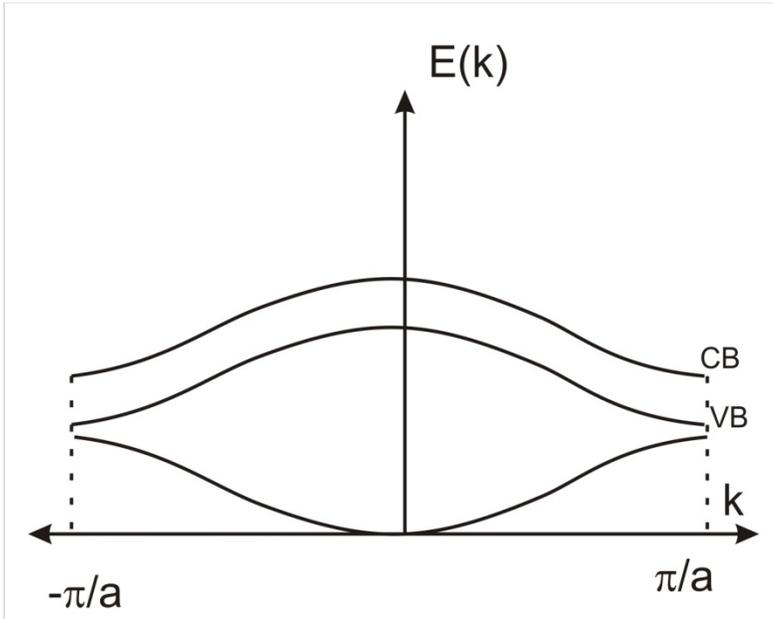
$$v_g = 0$$

$$dE/dk = 0$$

These ideas explain bandgaps

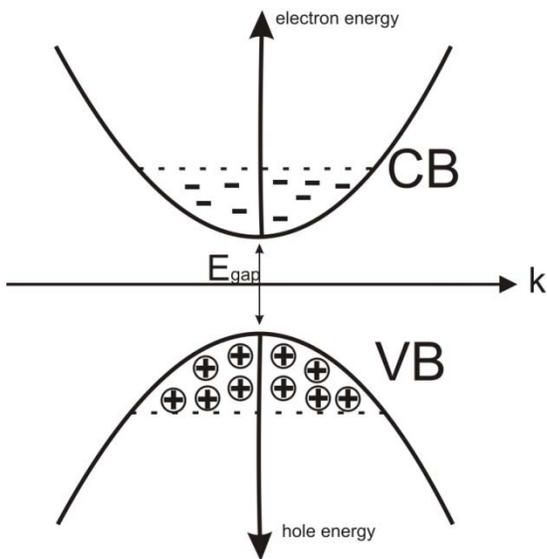


Allowed Energies can be obtained by translating each part of  $E(k)$  curve  $2\pi/a$ .



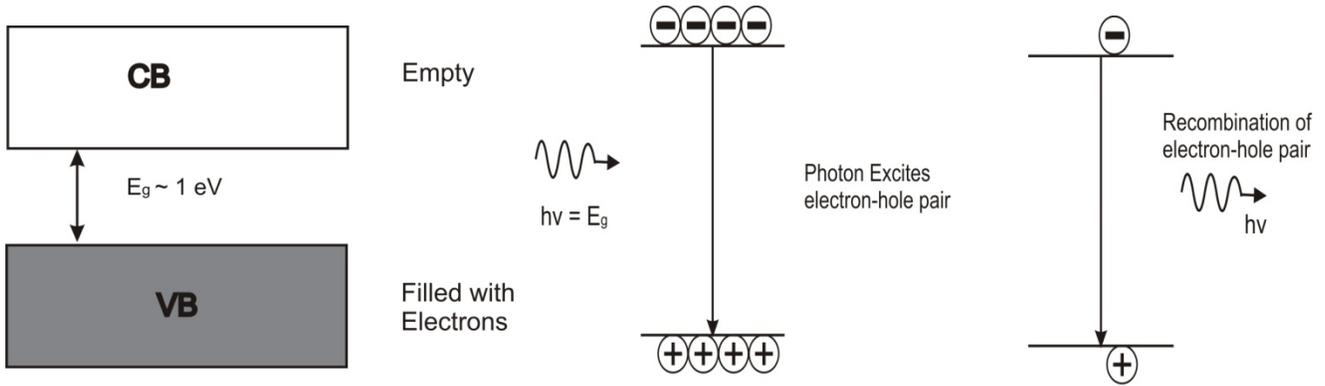
VB = Valence Band  
CB = Conduction Band

Picture of Charge Carriers in Semiconductors



- Hole/defect  $\rightarrow$  positive particles
  - o Holes at top of VB
  - o  $e^-$  at bottom of CB
- excess energy from photon dissipated by collisions and photons

## Excitation of Charge Carriers in Semiconductors



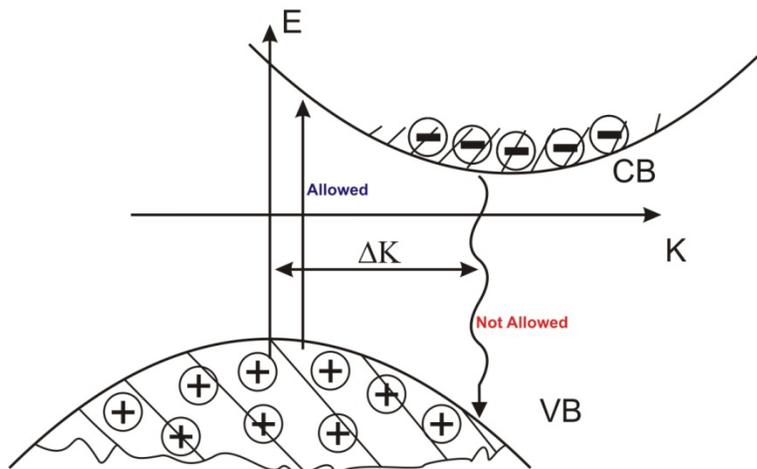
In a photodiode,  $e^-$  are swept into circuit using bias fields

In a LED/Laser diode material light emission is due to radiative recombination of charge carriers injected into junction

The table below summarizes properties of commonly used semiconductors.

Material	Band Gap	Type	Application
Si	1.12 eV	Indirect	Photodetector
Ge	0.66 eV	Indirect	Photodetector
InGaAs	0.74 eV	Direct	LED/Laser Diode
GaAs	1.4 eV	Direct	LED/Laser Diode

## Indirect Band Gap Semiconductor (Photodetector)

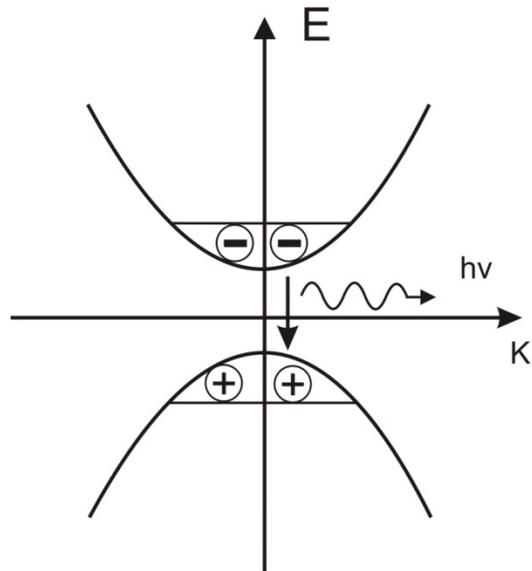


Transfer of holes to empty CB is allowed but recombination is not allowed since VB is full.

Also note that phonons are required for momentum conservation

ie  $\hbar\Delta k \gg P_{\text{photon}}$

## Direct Band Gap Semiconductor (Laser/LED Diode)



Here this is no offset between VB and CB

$$- \quad P_{\text{photon}} = h/\lambda = \hbar k_e$$

Electrons and holes equilibrate and recombine