UNIT-IV OPTICAL PROPERTIES OF MATERIALS

INTRODUCTION

- The materials which are sensitive to light are known as optical materials.
- The interaction between electrons and photons in a material is the basis of all opto-electronic devices.

CLASSIFICATION OF OPTICAL MATERIALS

- Based on the optical properties materials can be classified into three

1. ***Transparent materials:***Materials that are capable of transmitting almost light with very little absorption and reflection i.e., we can see through them. ***Ex:*** Plain glass, Clear water, etc.,
2. ***Translucent materials:***Materials that allow only certain abount of light to pass through itand absorbs rest of the light. Therefore, we can see the object diffusely or are not clearly. ***Ex:*** Smoke, fog and clouds.
3. ***Opaque materials***:Materials which does not allow any light to pass through it and absorbs or reflect all the light. So we cannot see the through them. ***Ex:***Metals, Wood, brick, stone, etc.,

CARRIER GENERATION AND RECOMBINATION PROCESS

CARRIER GENERATION

- Carrier generation is a process whereby electron-hole pairs are created by exciting an electron from the valence band of the semiconductor to the conduction band, thereby creating a hole in the valence band.
- In simple words *"A process whereby electrons and holes are created"*
- Basically there are three carrier generation process.

   1. Photo generation 2. Phonon generation 3. Imapct Ionization

1. Photo generation

- When light photon with frequency 'υ' and energy'hυ'falls on a semiconductor,one electron jumps from the valence band to conduction band and generating electron hole pair.
- this process is called *photogeneration*.

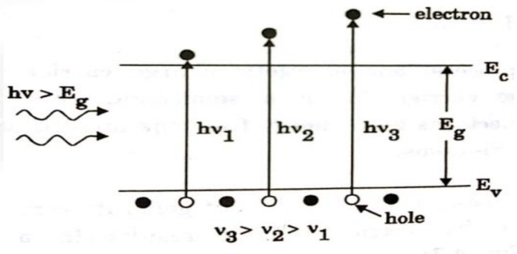

Fig. 4..5

2. Phonon generation

- It occurs when the semiconductor in thermal excitation.
- When the temperature increases, lattice vibration increases and producing more phonons.
- Due to lattice vibrations, covalent bonds break and more electron hole pairs are generated.

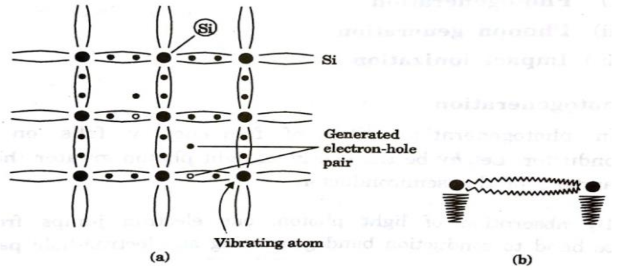

Fig. 4.6 (a) Phonon generation
(b) Lattice vibration generating phonon

3. Impact Ionization

- In this, one carrier will creat another charge carrier.
- When we apply electric field to semiconductor, electrons gain energy and hitting the atoms.
- So the covalent bond breaked and generating more carriers.
- When we apply very large field, avalanche breakdown may occur.

Fig. 4.7 Impact ionization

RECOMBINATION

- Recombination is the process where electrons and holes from the conduction band and valence band respectively, recombine and are annihilated (or destroyed).
- In simple words *"A process whereby electrons and holes (carriers) are annihilated or destroyed"*
- Recombination occurs in three ways. They are,

  1. Radiative Recombination 2. Shockley-Read-Hall Recombination 3. Auger Recombination

1. Radiative Recombination

1. It occurs for direct bandgap semiconductors (*Ex:* GaAs).
2. Electrons from conduction band falls to valence band without changing the momentum.
3. In this process one photon of energy (E_g = hʋ) is emitted.
4. So emitted light having the photons of energy E_g = hʋ. It is also called "***direct recombination".***

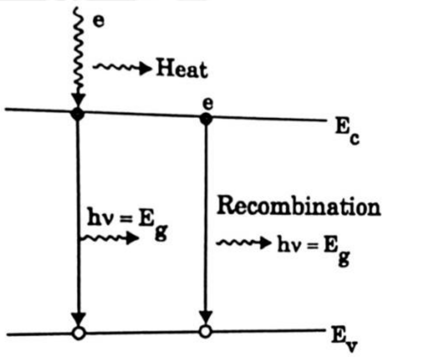

Fig. 4.8 Radiative recombination

2. Shockley-Read-Hall Recombination

1. Conduction electrons come to defect level between E_C& E_V by emitting energy as photons or phonons.
2. Then electron goes to the valence band.
3. It occurs on impure semiconductor which has defects levels.
4. The defect level lies in the middle of forbidden gap.

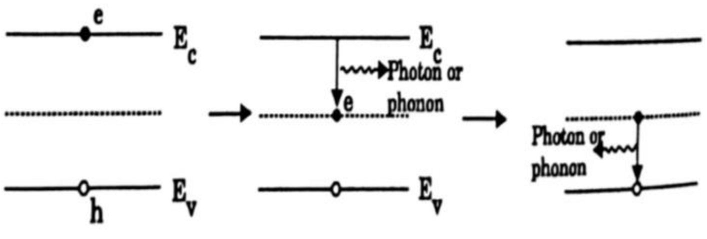

Fig. 4.9 SRH recombination process

3. Auger Recombination

1. In this, three carriers are involved.
2. Here, an electron and hole recombine and the emitted energy (photon) is given to the third free electron in conduction band.
3. So, that electron comes back to the conduction band by emitting energy as heat.
4. It occurs for a heavily doped semiconductors.

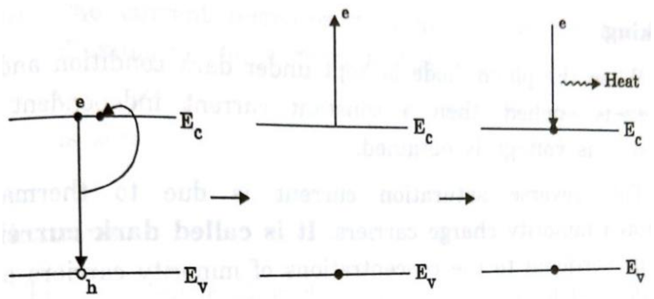

Fig. 4.10 Auger - Recombination process

ABSORPTION, EMISSION AND SCATTERING OF LIGHT IN METALS

ABSORPTION

1. Metals are opaque because incident light excites electrons to energy states above Fermi level.
2. As a result, the incident radiation is absorbed.
3. Total absorption area is less than 0.1 µm.
4. Metals are opaque to all electromagnetic radiation.
5. Metals are transparent to X-rays and γ-rays.

EMISSION

1. Absorbed radiation will be emitted as reflected light.
2. An electron transition with emission is shown in figure 4.2 (b).
3. The reflectivity of metal is between 0.90 and 0.95.

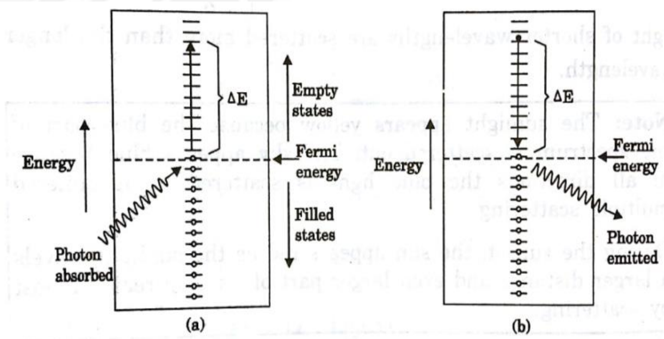

Fig. 4.2 (a) Photon absorption in which an electron is excited into a higher energy unoccupied state
(b) Photon emission by the direct transition of an electron from a higher to a lower energy state

4. Rest is dissipated as heat.
5. The color metal is determined by the wavelength of reflected radiation.
6. Some metals when exposed to white light show a bright “silvery” appearance.
7. It indicates that the metal is highly reflective and reflects all the parts of the visible spectrum.

SCATTERING (NOTE: Scattering is common for all i.e., for metals, insulators and semiconductors)

1. It is a process by which the intensity of the wave attenuates as it travels through a medium.

2. Light scattering is a common phenomenon in everywhere including metals, insulators and semiconductors.
3. There are three types of scattering occurs.

(i) Rayleigh scattering

1. Here, wavelength of the scattered light is same as that of the incident light, then it is called as Rayleigh scattering.
2. This is an elastic scattering of light.
3. Here light behaves like a wave.
4. Intensity of scattered light is inversely proportional to the fourth power of wavelength $\left(\propto \frac{1}{\lambda^4}\right)$.
5. Light of shorter wavelengths are scattered more than the longer wavelength.

(ii) Raman scattering

1. When the wavelength of the scattered light is different from that of incident light, then the scattering is called Raman scattering.
2. This is an inelastic scattering of light.
3. The intensity of the scattered light by Raman scattering is about 0.001% of Rayleigh scattering.

(iii) Compton scattering

1. A smaller wavelength of ultraviolet and X-ray scattering occurs by electrons.
2. This results in scattered radiation having smaller frequency (longer wavelength) than the incident wave.
3. This scattering is called Compton scattering.

ABSORPTION, EMISSION AND SCATTERING OF LIGHT IN INSULATORS

ABSORPTION

1. Absorption of light photon occurs in an insulator.
2. It results in excitation of an electron from valence band to conduction band.
3. A free electron in conduction band and a hole in the valence band are created.
4. The excitation of an electron can takes place only if the light photon energy ($\Delta E = h\upsilon$) is greater than that of band gap E_g.

EMISSION

1. When the excited electron is deexcited or coming back to old position, it emits a light photon as in fig. 4.3 (b).
2. Some insulators are transparent and colourless if they are high purity state.

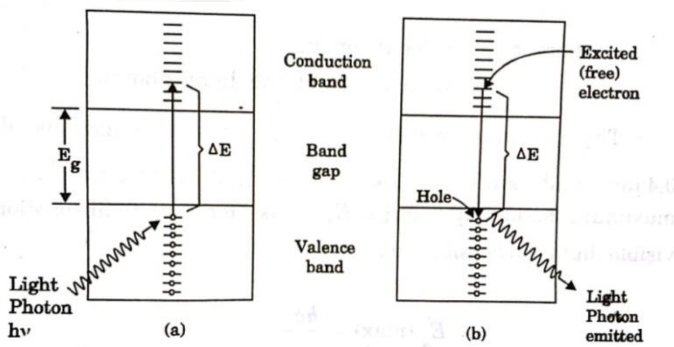

Fig. 4.3 (a) Electron excitation due to absorption of photon of energy ΔE in insulators
(b) Electron deexcitation resulting in the emission of photon in insulators

ABSORPTION, EMISSION AND SCATTERING OF LIGHT IN SEMICONDUCTORS

ABSORPTION

1. In semiconductors, light photons are absorbed in several ways.

2. Absorption of photon results in excitation of an electron from valence band to conduction band as shown in fig 4.4 (a).
3. A free electron in conduction band and a hole in the valence band are created.

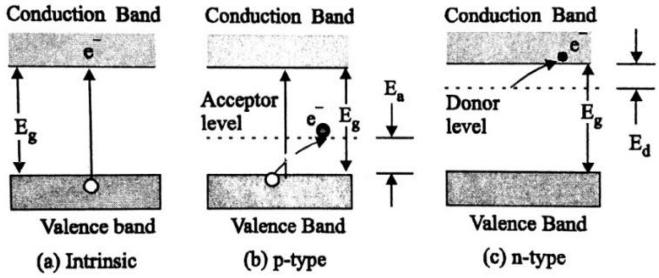

Fig. 4.4 Absorption of photons in semiconductors

4. The excitation of an electron can takes place only if the light photon energy ($\Delta E = h\upsilon$) is greater than that of band gap E_g.
5. If band gap energy less than 1.8 eV, then it absorbs all visible light. So these are opaque.

EMISSION

1. When the semiconductor is forward biased, electrons and holes will cross the junction and they will recombine with each other.
2. Due to one recombination one photon will be emitted.
3. The emitted photon will strike other electrons and holes to recombine.
4. So large number of recombinations takes place and large numbers of photons are generated.