DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

Explanation for carrier generation

Carrier **generation** describes processes by which electrons gain energy and move from the valence band to the conduction band, producing two mobile carriers; while **recombination** describes processes by which a conduction band electron loses energy and re-occupies the energy state of an electron hole in the valence band.

Semiconductors are characterized by two types of mobile carriers, electrons in the conduction band and holes in the valence band. The **generation rate** gives the number of electrons generated at each point in the device due to the absorption of photons..

Excess carriers, essential for device operation, are created by optical excitation, electron. bombardment, or injected across a forward-biased p-n junction. • These **excess carriers** can dominate the conduction process in semiconductor materials

Carrier generation is a process where 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. Recombination is the reverse process where electrons and holes from the conduction respectively valence band recombine and are annihilated. In semiconductors several different processes exist which lead to generation or recombination, the most important ones are:

photon transition or optical generation/recombination,

phonon transition or Shockley-Read-Hall generation/recombination,

Auger generation/recombination or three particle transitions, and impact ionization.

In thermal equilibrium the generation and recombination processes are in dynamic equilibrium. When the system is supplied with additional energy, for example through the absorption of photons or the influence of temperature, additional carriers are generated. The most important generation/recombination processes for the simulation of semiconductor devices are summarized in the following.

Photon Transition

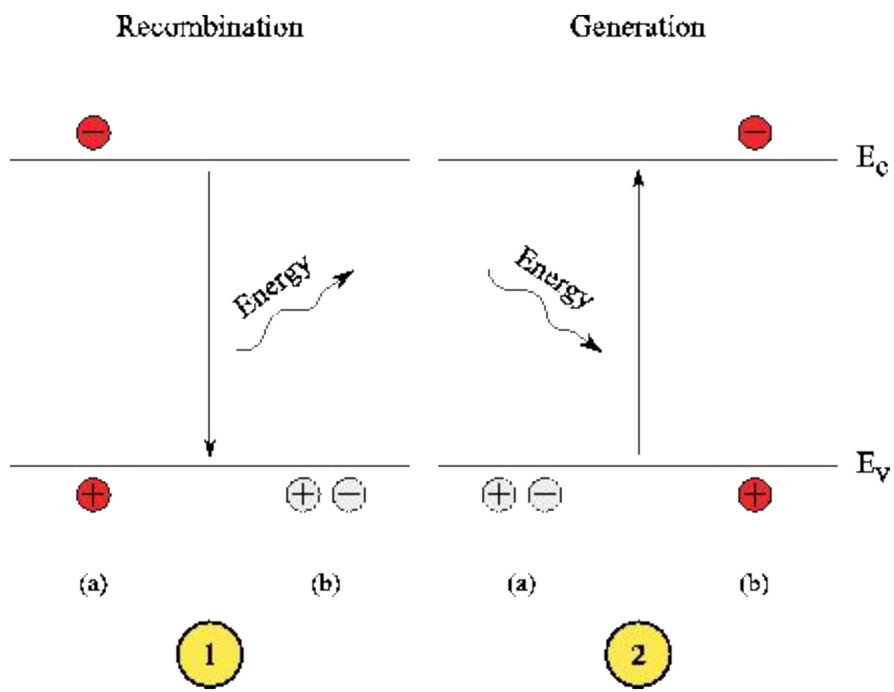


Figure 2.1: Direct generation/recombination process. During photon assisted recombination an electron from the conduction band re-combines with a hole in the valence band. The excess energy is transferred to a photon. The reverse process obtains its energy from radiation and generates an electron hole pair.

The photon transition is a direct, band-to-band, generation/recombination process. An electron from the conduction band falls back to the valence-band and releases its energy in the form of a photon (light). The reverse process, the generation of an electron-hole pair, is triggered by a sufficiently energetic photon which transfers its energy to a valence band electron which is excited to the conduction band leaving a hole behind. The photon energy for this process has to be at least of the magnitude of the band-gap energy .

Figure 2.1 gives an overview of this process. The initial electron/hole constellation is found in (a) while the constellation after the generation/recombination process is found in (b).

For these state changes in the semiconductor the energy *and* the momentum have to be conserved. The energy is emitted or absorbed via a photon with the energy

$$E = h\nu \,,$$

where is Planck's constant and is the frequency of the emitted or absorbed photon. However, as the momentum of a photon is very small no momentum transfer is possible in the transition process. Therefore, only direct band-to-band transitions are possible, where no change in momentum is necessary. As silicon and germanium are indirect semiconductors and have their valence band maximum and their conduction band minimum on different positions in momentum space, direct transitions are very unlikely to occur and can in most cases be neglected for those materials. In direct semiconductors like GaAs, this effect is very important. This process always strives for thermal equilibrium. For an excess concentration of carriers $np - n_i^2 > 0$ and carrier recombination dominates, while for low carrier densities $np - n_i^2 < 0$ and carrier generation prevails.

At equilibrium, the product of the majority and minority carrier concentration is a constant, and this is mathematically expressed by the Law of Mass Action as

$$n_0 p_0 = n_i^2$$

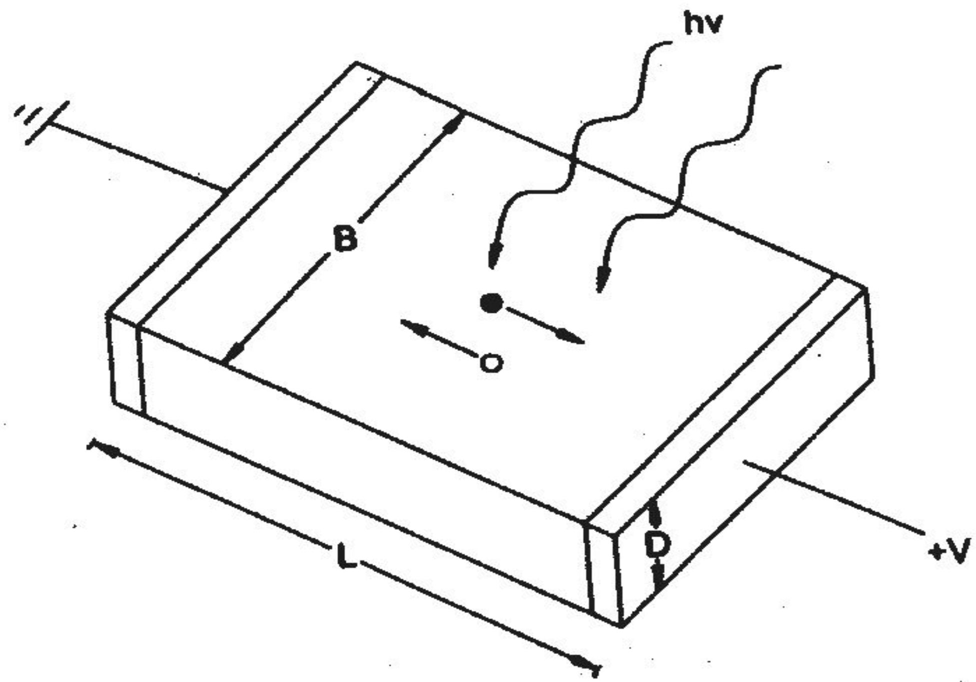
PHOTOCONDUCTING MATERIALS

An ILLUSTRATIVE Example for carrier Generation

INTRODUCTION

- The photoconductive device is based on the decrease in the resistance of certain semiconductor materials when they are exposed to both infrared and visible radiation.

- The photoconductivity is the result of carrier excitation due to light absorption and the figure of merit depends on the light absorption efficiency. The increase in conductivity is due to an increase in the number of mobile charge carriers in the material.



Sketch of a photoconductive device

THEORY

Let us consider a photo conducting slab. It is simply a light sensitive semiconductor material with ohmic contacts on both ends.

When the material is illuminated with photons of energy $E \geq E_g$

electron hole pairs are generated and the electrical conductivity of the material increases.

Where E_g is the bandgap energy of the semiconductor material given by

$$E_g = \frac{hc}{\lambda}$$

Where λ is the wavelength of the incident photon .

Let I_0 be the intensity of monochromatic light falling normally onto the slab. Then the intensity of transmitted light I is given by

$$I = I_0 \exp(-\alpha D).$$

Where α is the absorption coefficient of the material and D is the thickness of the slab.

Let L and B be the length and breadth of the photoconductive slab respectively. Also let us assume that the slab absorbs the entire light falling on it.

Now the light energy falls on the sample per sec is given by I_0 BL

where I_0 is the light energy falling per second on unit area of the slab. Therefore the number of photons falling on the photoconductor per second $= \frac{I_0 BL}{h\nu}$

Let η- be the quantum efficiency of the absorption process. It is nothing but the fraction of incident energy absorbed.

Therefore the number of photons absorbed per second $= \eta \frac{I_0 BL}{h\nu}$

Now the average generation rate of charge carriers is given by

$$r_g = \frac{\eta I_0 BL}{h\nu BLD} \qquad r_g = \frac{\eta I_0}{h\nu D}$$

Let Δn and Δ P be the excess electron and hole density per unit volume in the device. If τ_c is the life time of charge carriers,Then the recombination rate

$$r_r = \frac{\Delta n}{\tau_c} = \frac{\Delta p}{\tau_c}$$

At equilibrium, the recombination rate = generation rate

Therefore $\Delta p = \Delta n = r_g \; \tau_c$

We know the conductivity of a semi conducting material is

$$\sigma = ne\mu_e + p.e\,\mu_h$$

SRM Institute of Science and Technology

Under illumination the conductivity will increase by an amount is

$$\Delta\sigma = \Delta n e \mu_e + \Delta p . e \mu_h$$

$$= \Delta n e (\mu_e + \mu_h)$$

$$= r_g \tau_c e(\mu_e + \mu_h)$$

When a voltage is applied to the contacts, electrons and holes move in opposite directions resulting in a photocurrent given by

$$\Delta i = \frac{BD}{L} \Delta\sigma V$$

$$\Delta i = \frac{BD}{L} r_g \tau_c e(\mu_e + \mu_h) V$$

The quantum efficiency of a photoconductor device is defined by the term photoconductor gain G. Photoconductive gain is defined as the ratio of rate of flow of electrons per second to the rate of generation of electron hole pairs within the device.

$$G = \frac{Rate\ of\ \ flow\ of\ electrons\,/\,sec}{Rate\ of\ \ generation\ of\ electron - hole\ pairs}$$

But rate of flow of electrons per sec=$\Delta i/e$

Rate of generation of electron hole pairs = $r_g BLD$

$$G = \frac{(\Delta i / e)}{r_g BLD}$$

$$G = \frac{\tau_c (\mu_e + \mu_h) V}{L^2}$$

The photoconductive gain G can be increased by increasing the voltage V and decreasing the length, L of the device.

The photoconductive gain can also be defined as the ratio of the minority carriers life time and the transit time t.

i.e.,

$$G = \frac{\tau_c}{t}$$