TEMARIO DEL CURSO DE FUNDAMENTOS DE DISPOSITIVOS ELECTRONICOS

1. Introducción a Física Electrónica

1.1 Propiedades de cristales y crecimiento de semiconductores

1.2 Átomos y electrones

1.3 Bandas de energía y portadores de carga en semiconductores

1.4 Exceso de portadores en semiconductores

2. Uniones

2.1 Fabricación de uniones p-n

2.2 Condiciones de equilibrio

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Excess Carriers in Semiconductors

- Most semiconductor devices operate by the creation of charge carriers in excess of the thermal equilibrium values and once the excess carriers arise, they can dominate the conduction processes in the semiconductor material.

- In this section we will study the creation of excess carriers by optical absorption and the resulting properties of photoluminescence and photoconductivity, the mechanisms of EHP recombination and the effects of carrier trapping.

- The difussion of excess carriers due to a carrier gradient, which serves as a basic mechanism of current conduction (along with the mechanism of drift in an electric field) will be discussed as well.

Excess Carriers in Semiconductors

- An electron excited to the conduction band by optical absorption ***may initially have more energy than is common for conduction band electrons***.
- The EHP created by this absorption process are ***excess carriers; since they are out of balance with their environment, they must eventually recombine***.
- While the excess carriers exist in their respective bands, ***they are free to contribute to σ.***

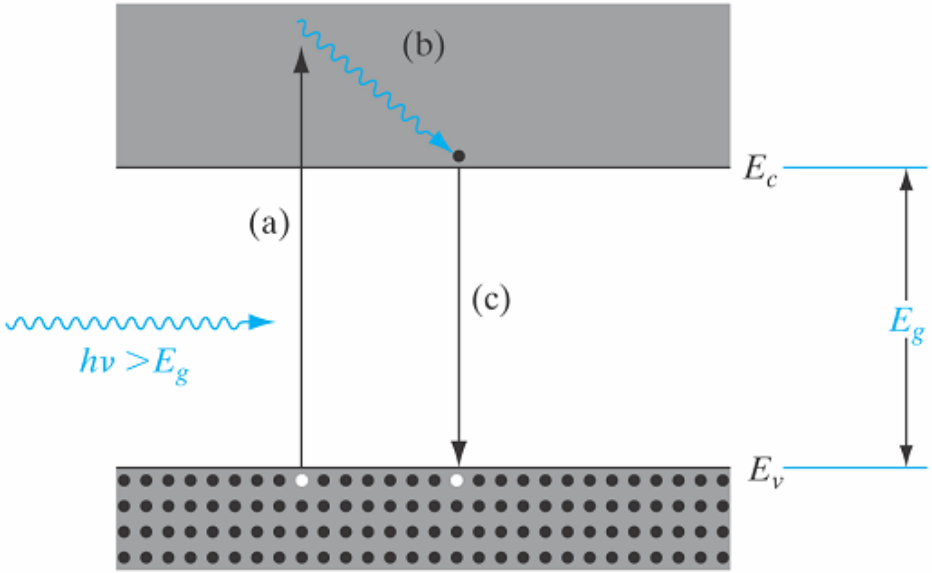


Figure 4.1

Optical absorption of a photon with $h\nu > E_g$: (a) An EHP is created during photon absorption; (b) the excited electron gives up energy to the lattice by scattering events; (c) the electron recombines with a hole in the valence band.

A photon with $h\nu < E_g$ is unable to excite an electron from the balance band to the conduction band.

Excess Carriers in Semiconductors

If a beam of photons whit $h\nu > E_g$ falls on a semiconductor, there will be a predictable amount of absorption, determined by the properties of the material. We would expect the ratio of transmitted to incident light intensity to depend on the photon wavelength and the thickness of the sample.

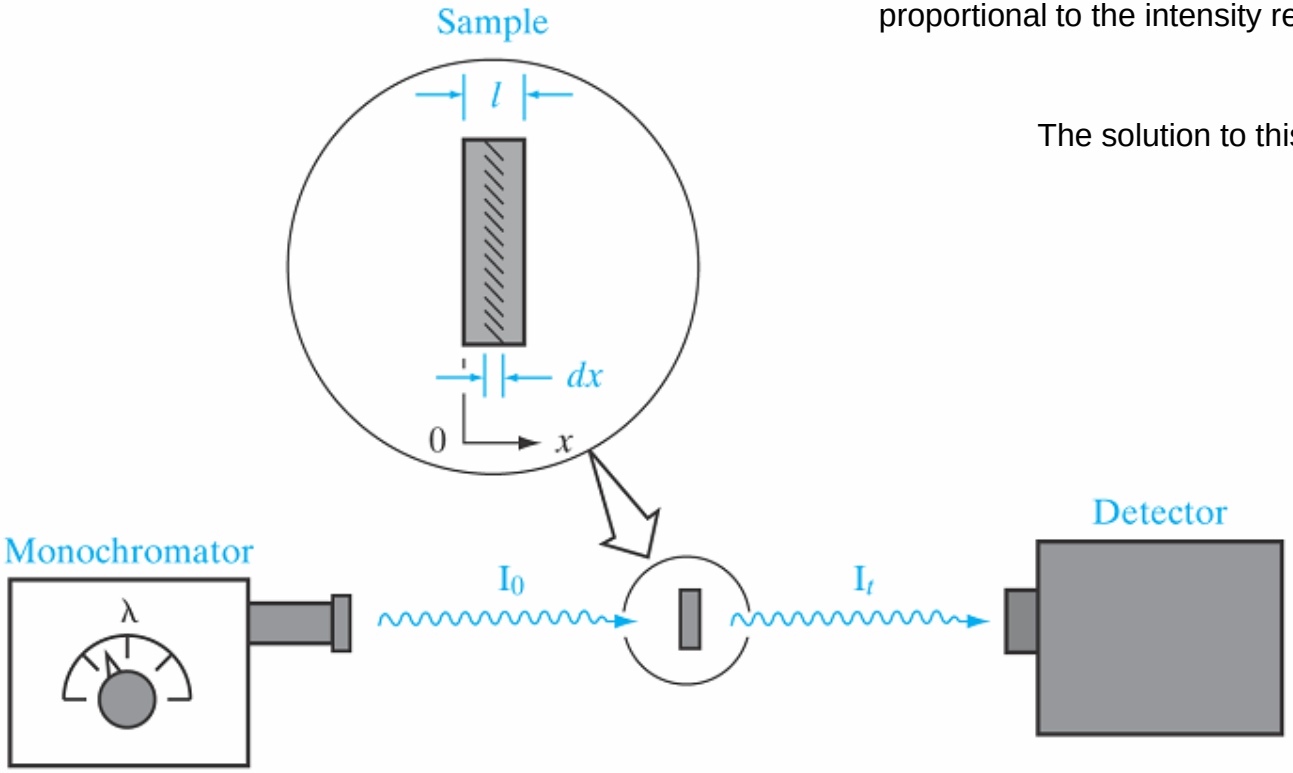


Figure 4.2

Optical absorption experiment.

The degradation of the intensity $-dI(x)/dx$ is proportional to the intensity remaining at x:

$$-\frac{dI(x)}{dx} = \alpha\, I(x)$$

The solution to this equation is:

$$I(x) = I_0 e^{-\alpha x}$$

The intensity of light transmitted trough the sample thickness l is:

$$I_t = I_0 e^{-\alpha l}$$

Where ***α is called the absorption coefficient*** [cm^{-1}]. This coefficient will vary with the photon wavelength and with the material.

Light Intensity (which is proportional to the number of photons), decays exponentially with distance into the semiconductor.

In a typical plot of α vs. wavelength, there is negligible absorption at long wavelengths ($h\nu$ small) and considerable absorption of photons with energies larger than E_g.

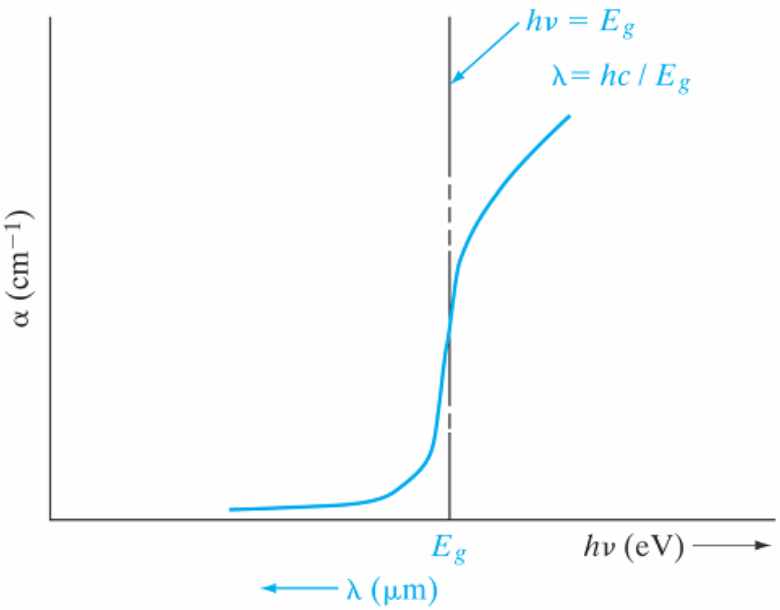


Figure 4.3

Dependence of optical absorption coefficient α for a semiconductor on the wavelength of incident light.

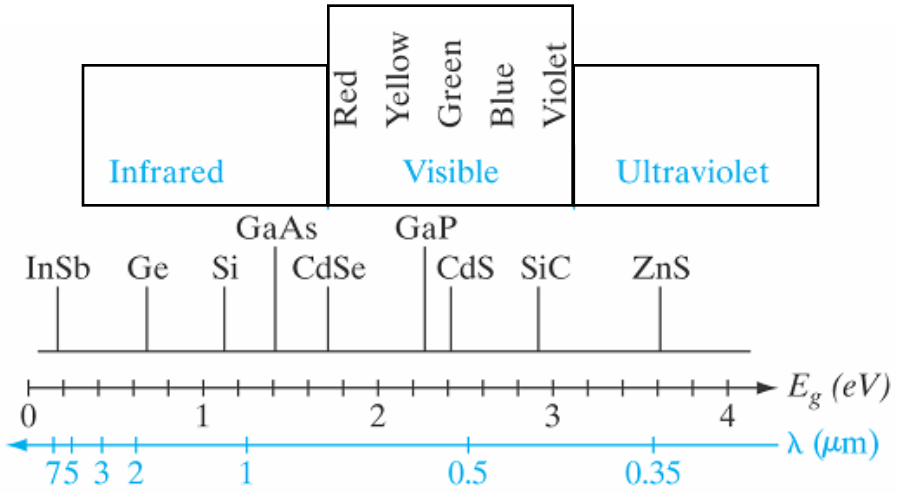
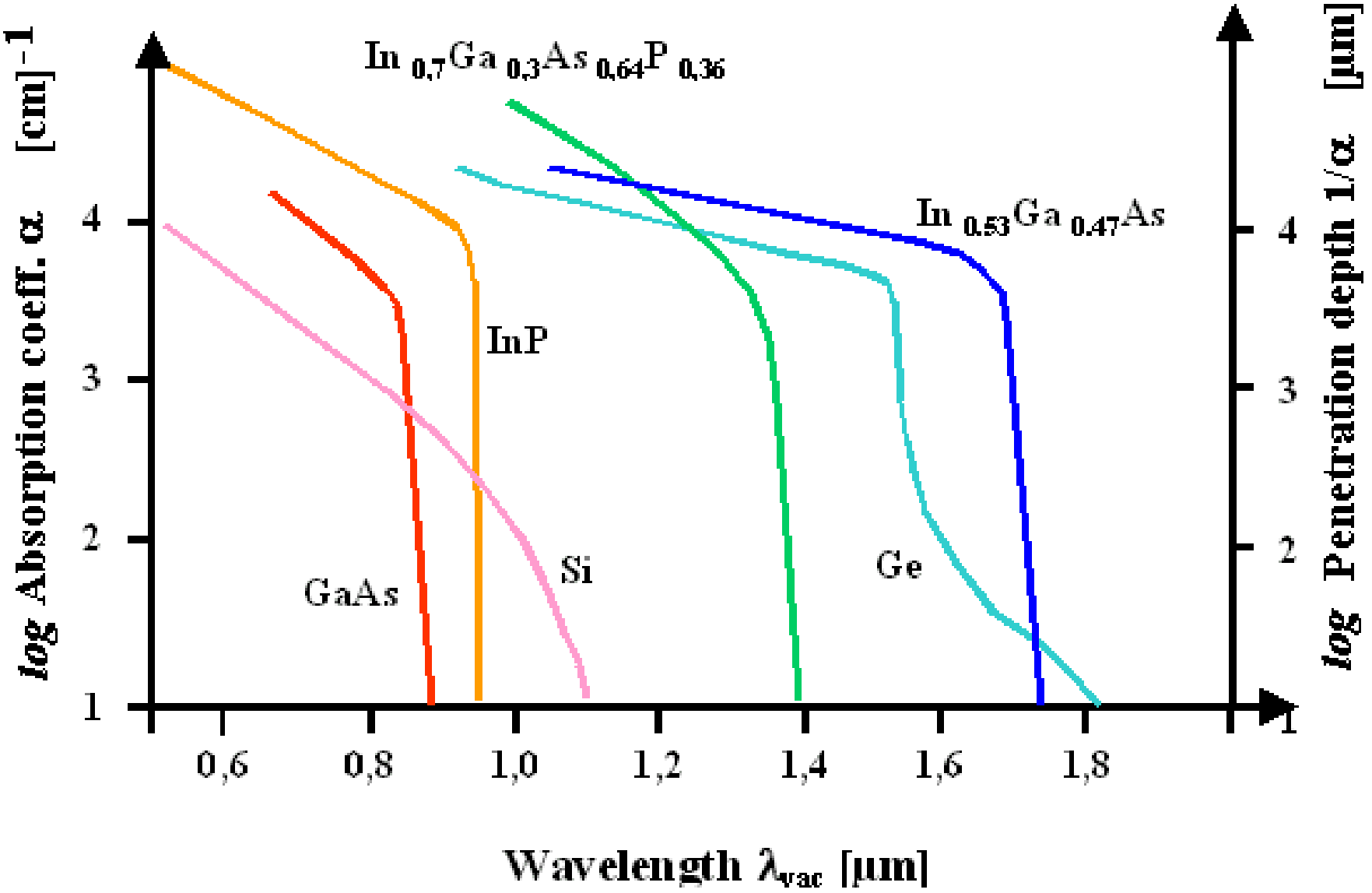


Figure 4.4

Band gaps of some common semiconductors relative to the optical spectrum.

The relation between photon energy and wavelength is: E = hc/λ. If E is given in electron-volts and λ in micrometers, this becomes $E = 1.24/\lambda$.

Si absorbs band gap light of ~1μm and shorter λ's, including those in the visible part of the spectrum.


In 0,7Ga 0,3As 0,64P 0,36
In 0.53Ga 0.47As
InP
GaAs
Si
Ge
log Absorption coeff. α [cm]-1
log Penetration depth 1/α [µm]
1
2
3
4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
Wavelength λvac [µm]

Luminescence

When EHP are generated in a semiconductor, ***light can be given off by the material when these carriers fall to their equilibrium energy states***. The III–V compound semiconductors with direct band gaps are the most widely used mat for light emission.

The general property of light emission is called luminescence, and this phenomenon can be subdivided according to *excitation mechanism*:

1. *Photoluminescence*. If the carries are excited by photon absorption.
2. *Cathodoluminescence*. If the carries are created by high-energy electron bombardment of the material.
3. *Electroluminescence*. If the excitation occurs by the introduction of current into the sample.

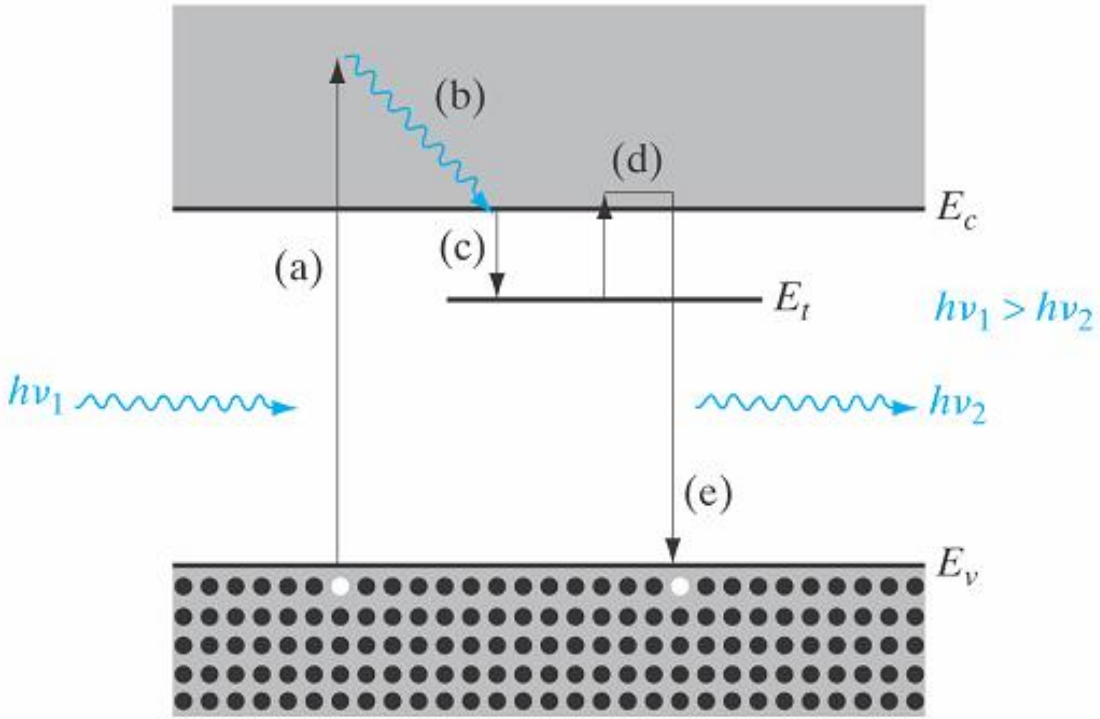


Figure 4.5

Excitation and recombination mechanisms in photoluminescence with a trapping level for electrons.

Direct recombination is a fast process, the mean time life of the EHP ~ $1x10^{-8}$ s or less. Thus, the emission of photons stops $1x10^{-8}$ s after the excitation is turned off. Such fast luminescence processes are often referred to as *fluorescence*.

In some materials emission continues for periods up to seconds or minutes after the excitation is removed. These slow processes are called *phosphorescence*.

Carrier Lifetime and Photoconductivity

When excess of electrons and holes are created in a semiconductor, there is a corresponding increase in the conductivity of the sample: $J_x = q(n\mu_n + p\mu_p)\boldsymbol{E}$.

If the excess carries arise from optical excitation, the resulting increase in conductivity is called photoconductivity.

- The mechanisms by which excess electrons and holes recombine (recombination kinetics) are important to the analysis of photoconductive devices.
- However, the importance of recombination is not limited to cases in which the excess carriers are created optically.
- In fact, virtually every semiconductor device (diodes, transistors, lasers, etc) depends in some way on the recombination of excess electrons and holes.

Direct Recombination

- In direct recombination, an excess population decays by electrons falling from the conduction band to empty states (holes) in the valence band. *The energy lost by the electron in making this transition is given up as a photon*.

- The probability that an electron and hole will recombine is constant in time. As in the case of carrier scattering, *this constant probability leads us to expect an exponential solution for the decay of the excess carriers*.

Net rate of change in the conduction band electron concentration:

$$\frac{dn(t)}{dt} = \alpha_r n_i^2 - \alpha_r n(t)\,p(t)$$

α_r: constant of proportionality for recombination.

thermal generation rate — recombination rate.

As the EHP recombine, the instantaneous concentrations of excess carriers $\delta n(t)$ and $\delta p(t)$ are equal. The total concentration of former eq. can be written in terms of n_0 and p_0:

$$\frac{d\delta n(t)}{dt} = \alpha_r ni^2 - \alpha_r\left[n_0 + \delta n(t)\right]\left[p_0 + \delta p(t)\right]$$
$$= -\alpha_r\left[\left(n_0 + p_0\right)\delta n(t) + \delta n^2(t)\right]$$

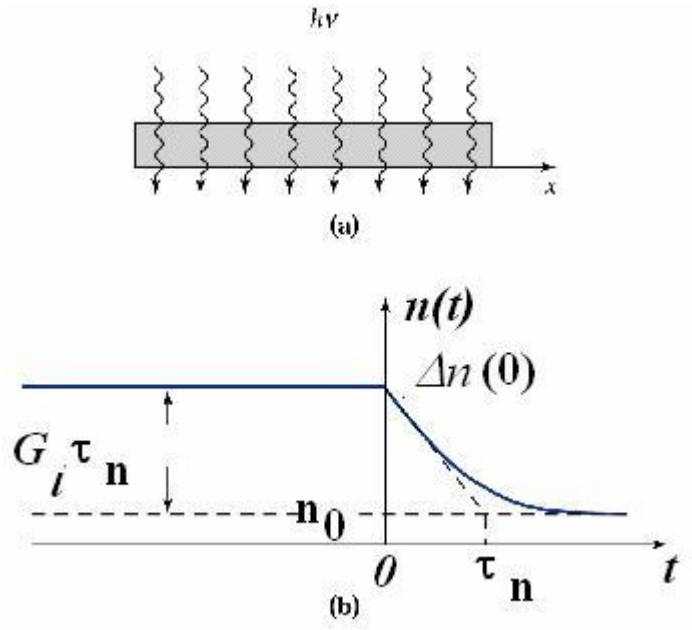
Which can be simplified for the case of low-injection and when the material is extrinsic. If the material is p-type ($p_0 >> n_0$):

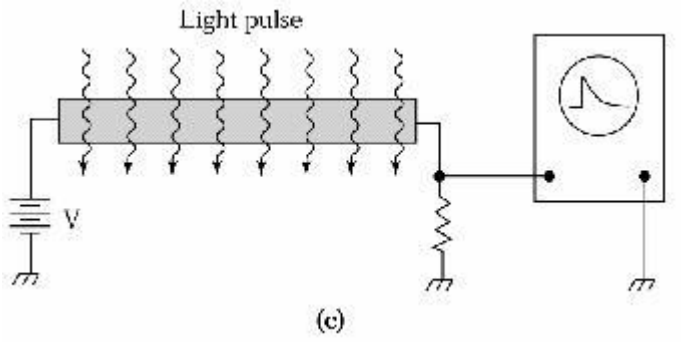
$$\frac{d\delta n(t)}{dt} = -\alpha_r p_0 \delta n(t)$$

The solution to this equation is an exponential decay from the original excess carrier concentration.

$$\delta n(t) = \Delta n \exp\left[-\alpha_r p_0 t\right] = \Delta n \exp\left[-\frac{t}{\tau_n}\right]$$

Excess electrons in a p-type semiconductor recombine with a decay constant $\tau_n=(\alpha_r \cdot p_0)^{-1}$, ***called the recombination lifetime***. Since the calculation is made in terms of the minority carries, τ_n *is often called the minority carrier lifetime.*





Indirect Recombination

- For indirect-bandgap semiconductors, a direct recombination process is unlikely. The dominant recombination process in such semiconductors is ***indirect transition via localized energy states in the forbidden gap (recombination levels)***.
- These states act as stepping stones between the conduction band and valence band.

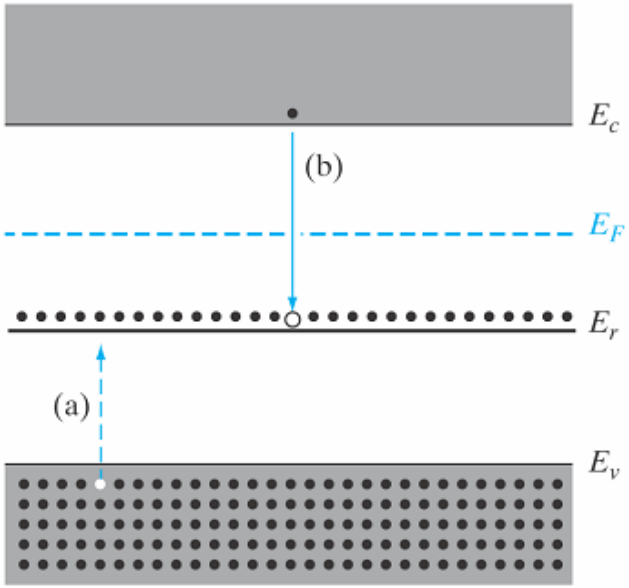


Figure 4.8

Capture processes at a recombination level: (a) hole capture at a filled recombination center; (b) electron capture at an empty center.

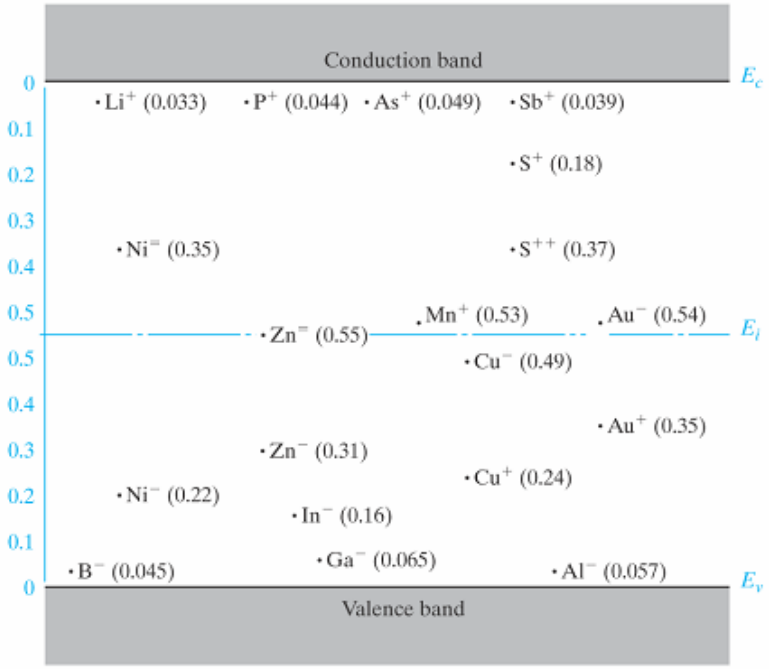


Figure 4.9

Energy levels of impurities in Si. The energies are measured from the nearest band edge (E_v or E_c); donor levels are designated by a plus sign and acceptors by a minus sign.

Homework

- Read section 4.3.3

  Steady State Carrier Generation; Quasi-Fermi levels

- Read section 4.3.4

  Photoconductive Devices