

Light emitting diode (LED)

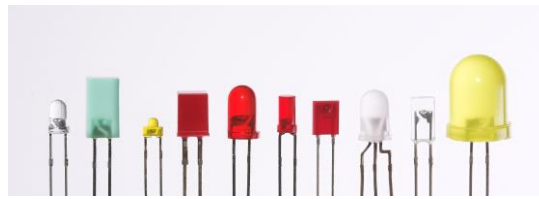


Figure 1: Different LED's (Source: Wikipedia)

Describe a light emitting Diode:

- How should the diode be biased?
- Where do the electrons and holes recombine?
- Is the semiconductor direct or indirect?
- How is the bandgap related to the photon frequency?
- What role does total internal reflection play?

Light emitting diodes (LED) are basically pn-junctions. At zero bias there is a diffusion current, and because of the band bending there is also a electric field, which pushes the electrons back to the n-region and holes back to the p-region, this is called the drift current. The diffusion current cancels the drift current. If you forward bias it, the electric field gets smaller. The positive charge on the p-side pushes the holes towards the junction and the negative charge of the n-side pushes the electrons towards the junction. The depletion layer gets smaller, diffusion current increases and the drift current decreases. If you reverse bias it, the electric field gets bigger, the depletion layer and drift current bigger and the diffusion current smaller. So there will not flow a current, or only a small current. Because of that you have to forward bias the LED.

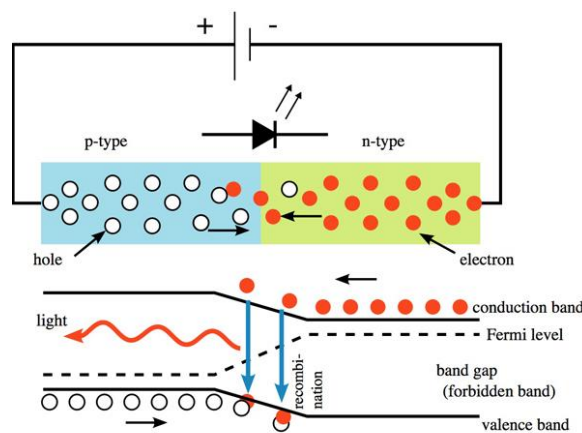


Figure 2: LED with pn-junction (Source: www.dikikey.com)

As i described above and because of the p- and n-types, there are holes in the valence band on the p-side and electrons in the conduction band on the n-side. The forward bias will push the electrons and the holes to the depletion region (the change from p- to n-type). So the electrons will recombine close to the depletion region with the holes. If the electrons recombine they release an energy.

Wheter you get an energy in form of a photon (light) or not depends on the semiconductor. There are semiconductors with a direct or an indirect band gap (band gap = energy difference between the conduction band and valence band). A direct band gap means that the minimum of the conduction is

directly above the maximum of the valence band ($\Delta\vec{k} = 0$). At an indirect band gap the minimum of the conduction band is not exactly above the top of the valence band ($\Delta\vec{k} \neq 0$). For example GaAs has a direct band gap and silicon has an indirect band gap. The minimum of the conduction band and the top of the valence band have the same \vec{k} vector at direct band gap, as you can see in the picture below (GaAs). The \vec{k} vector is related with the momentum \vec{p} by the formula: $\vec{p} = \hbar \cdot \vec{k}$. So the momentum of the holes and electrons is the same at a direct band gap, and no momentum has to be transferred at the recombination \rightarrow So you get an energy in form of a photon at the recombination. But if you have an indirect band gap the electrons and holes have a different \vec{k} vector, and so a momentum has to be transferred \rightarrow you will get a lattice vibration, which means you will get the energy in form of a phonon at the recombination.

Summarization:

- direct band gap \rightarrow Photons
- indirect band gap \rightarrow Phonos

Because of that a LED has a semiconductor with a direct band gap.

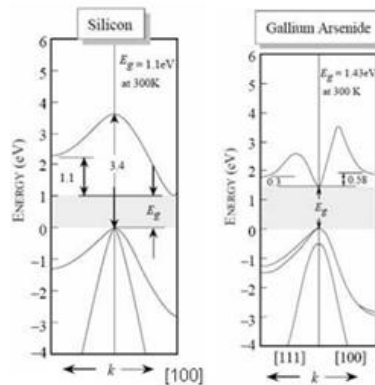


Figure 3: Banddiagramm for Si and GaAs (Source: lecture notes)

The emitted photons has the same energy as the bang gap of the semiconductor. With the einstein relation you can calculate the frequency: $E_g = h \cdot f$

You can also calculate the wavelength and determine which color you will get from the semiconductor:

$$E_g = h \cdot f = \frac{h \cdot c}{\lambda} \rightarrow \lambda = \frac{h \cdot c}{E_g}$$

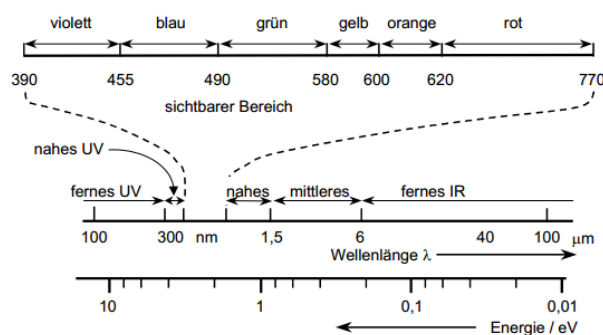


Figure 4: Spektrum of light (Source: Thuselt)

Example with GaAs:

$$E_g = 1.43 \text{ eV}$$

$$h = 6.626 \cdot 10^{-34} \text{ Js}$$

$$\text{Charge of electrons} = -1.6022 \cdot 10^{-19} \text{ C}$$

$$E_g = 1.6022 \cdot 10^{-19} \cdot 1.43 \text{ J} = h \cdot f = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_g} = \frac{6.626 \cdot 10^{-34} \cdot 2.998 \cdot 10^8}{1.6022 \cdot 10^{-19} \cdot 1.43} = 867 \text{ nm}$$

The wavelength is in the infrared (for remote control – TV).

The total internal reflection causes a problem for light emitting diodes. Snell's law describes how light goes through two different isotropic materials:

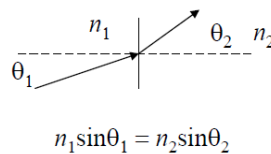


Figure 5: Snell's law (Source: lecture notes)

There is a critical angle where there is no solution any more: $\sin(\theta_2) = \frac{n_1 \cdot \sin(\theta_1)}{n_2}$

If the right side of the equation is bigger than one, there will no solution for the equation (sin has values from 0 to 1). So the light don't get into the other material, it will get reflected back and this is called total internal reflection. For Example you are diving in water and try to look out.

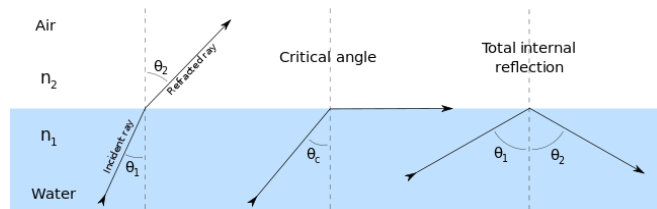


Figure 6: Snell's law for different angles (Source: Wikipedia)

At an LED you have spontaneous emission and the light just goes out in random directions. If some photons hits the interface at a low angle, they will be reflected down and get absorbed by the substrate on the bottom (GaAs – on the left picture). Only the light which goes up in a certain angle, can get out of the diode. You can use a different substrate with a higher band gap, the photons will pass through it. On the backside of this contact you fabricate a metal. So if a photon gets emitted down, passes through the substrate and gets reflected at the metal and get back up and out.

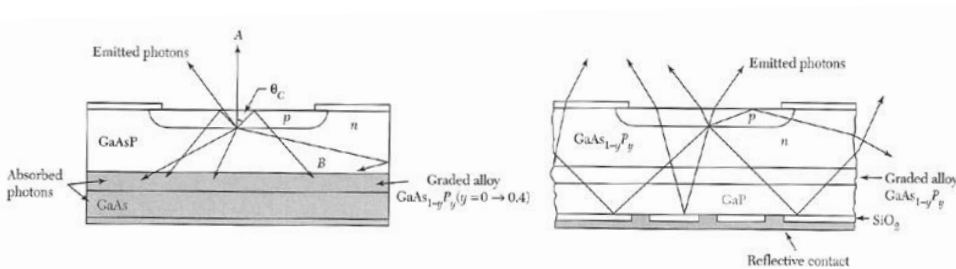


Figure 7: total internal reflection at a LED (Source: lecture notes)