Basic Semiconductor Terms

Basics

In this module we list some basic semiconductor properties and the corresponding lingo in alphabetical order. *Some*, but not *all* !

- It is assumed that you are familiar with these subjects at the level insinuated here.
- Some, but not all topics are explained in some detail in the backbone modules.

Acceptors

- Doping defects that introduce an energy state in the band gap close to the valence band.
- At medium temperatures – generally meaning room temperature – electrons from the valence band will completely fill these states leading to a density of holes in the valence band that is about equal to the density of the acceptor states.

Conductivity σ

- A specific propery of any material, defined as the relation between electrical field ***E*** and current density ***j***

$$j = \sigma \cdot E$$

- Generally, the conductivity σ is a tensor of second order and may depend on other parameters including the firld strength ***E***.
- As long as the current–field relationship is linear (demanding $\sigma \neq \sigma(E)$), the material exhibits *ohmic* behavior.
- σ can always be expressed in terms of the density ***n*** of carriers reponsible for conduction, their charge ***q***, and their mobiltiy **μ**, via

$$\sigma = q \cdot n \cdot \mu$$

Diffusion length

- The diffusion length ***L*** always refers to minority carriers. It is the average distance a minority carrier moves away from its point of origin, given by

$$L = \left(D \cdot \tau \right)^{1/2}$$

- With ***D*** = diffusion coefficient and **τ** = time for the movement (= life time for a minority carrier).
- The diffusion length is a *prime material parameter* that comes up in many formula, it can be rather large (up to **mm**) in indirect semiconductors and it is very sensitive to certain lattice defects.

Donors

- Doping defects that introduce an energy state in the band gap close to the conduction band that is occupied by an electron at low temperatures.
- At medium temperatures these electrons will move to the conduction band leading to a density of electrons in the conduction band that is about equal to the density of the donor states.

Doping

- Controlled introduction of lattice defects that introduce energy states for electrons in the band gap
- Often done with substitutional atoms that are to the left or right of the element they replace in the periodic table
- But all defects – e.g. dislocations and grain boundaries – may have energy levels in the band gap, too, and thus may introduce doping.

Electrons in semiconductors

- Mainly refers to the *free* electrons in the conduction band, contributing to the conductivity.

- In addition, this may also refer to electrons present on various additional states inside the band gap (e.g., the energy levels of donors and/or acceptors).
- However, although the valence band is mainly filled with electrons, one avoids considering them explicitly – by just treating the empty valence band places (called holes; see below).

Holes in semiconductors

- States in the valence band not occupied by electrons. Quasiparticles; behave for all practical purposes like *free* positively charged electrons.

Intrinsic semiconductors

- Undoped "perfect" semiconductors with properties exclusively governed by the crystal. The Fermi energy is in the middle of the band gap; electron and hole densities are equal (**= n_i**).

Life time

- Usually the average time τ a minority carrier, after it was generated by thermal fluctuations or other energy expenditures, "lives" before it disappears again by recombination. Refers to thermal equilibrium in this case.
- In more complicated circumstances – e.g. in space charge regions or in non-equilibrium conditions – life times must be considered more carefully; a distinction between generation and recombination life time, e.g., might be necessary.

Majority carriers

- The kind of carrier – electrons or holes – being present in the larger density.
- Majority carriers are electrons in the case of doping with donors, and holes in the case of doping with acceptors.

Mass action law

- Traditional, albeit somewhat misleading name for the relation between the *equilibrium* densities of electrons, n_e , holes, n_h, and the intrinsic density, n_i, in doped semiconductors:

$$n_h \cdot n_e = n_i^2$$

- Directly obtainable by using the Boltzmann approximation for the occupation of the bands.

Minority carriers

- The kind of carrier – electrons or holes – being present in the smaller density.
- Minority carriers are holes in the case of doping with donors, and electrons in the case of doping with acceptors.

n-type semiconductor; **n**-doped, **n**-doping

- Semiconductors with the majority carriers being electrons. Doping thus was done with *donors* .

p-type semiconductor; **p**-doped, **p**-doping

- Semiconductors with the majority carrierers being holes. Doping thus was done with *acceptors* .
- Do not mix up **p**-doped with **P**-doped ("P": phosphorous) in silicon! **P** is a donor in **Si**; **P**-doped **Si** is an **n**-type semiconductor.

p-n junction

- A transition from **p**-type to **n**-type within one piece of material. Electrically, a **p-n** junction is a diode (i.e. it has rectifying properties).
- The "ideal" **p-n** junction is a paradigm of semiconductor science. It is usually highly idealized and considered to be

  - An *abrupt* junction, i.e. the doping changes from **p**-type to **n**-type abruptly,
  - with *constant doping* levels on both sides of the junction, being
  - *one-dimensional*, and being
  - "*large*", i.e. the **p** and **n** areas are much longer than the diffusion length of the carriers.

- Real **p-n** junctions, especially in integrated circuits, do not even come close to these assumptions. Nevertheless, the results of the ideal **p-n** junction contain almost everything needed to tackle the real junctions and thus should be well understood.

Perfect semiconductors

- Ideally, a perfect crystal contains only those crystal defects necessary for device function – i.e. doping atoms and perfect interfaces. What makes an interface perfect is hard to define; in case of doubt: the absence of interface states in the band gap.
- **Si** crystals are closer to being perfect then anything else (in the unanimated world, that is). Their dislocation density is zero (which has not been possible to achieve for practically all other (large) crystals), the level of unwanted point defects is in the **(1 . . . 10) ppm** region for **O** and **C**, respectively, and in the low **ppb** if not **ppt** region for everything else.
- There are, however, unavoidable remnants of the intrinsic point defects (vacancies and self-interstitals) that were present in thermal equilibrium at high temperatures. They may occur in any forms of microclusters; not yet fully understood.