ET3034Tux - 2.1 – How to transform light into electricity

Why do we need semiconductor materials for solar cells?

This week I discuss the important properties of semiconductors and how these properties are being used in solar cells.

This means that we have to take a tour in the world of physics.

This week will be the most theoretical part of the course, but don't worry, I will guide you through it, using some visual figures and animations.

Let's start with answering the question: What is a semiconductor material?

Materials can be categorized in terms of their electrical properties.

Let's consider metals.

We know that metals can conduct electricity very well.

The origin of the high conductivity of metals is based on the fact that the outer electrons of the atoms in a metal are weakly bound.

This results in an ocean of free mobile electrons in the material indicated by the red dots.

Electrons are negatively charged and therefore the conduction in a metal is based on mobile negative charge.

These electrons move around in a background of atoms indicated by the blue dots.

As many of the atoms donated an electron, they can be considered as fixed positively charged ions.

Materials which do not conduct electricity are called insulators.

In insulator materials the ocean of free moving electrons are missing.

All electrons are bounded to the background atoms.

As you can see in the figure, the red dots represent the electrons and are glued to the blue atoms.

Semiconductors are materials which have a conductivity between that of a metal and insulator.

The outer electrons of the atoms are more strongly bound to the background atoms than in metals, but under certain conditions some of the electrons can leave their background atoms and become freely mobile electrons as well.

These few electrons that are separated from its atom, leave a positively charged entity behind.

This positively charged entity is called a hole.

The small blue dots in the illustration represent the holes.

These holes are able to move around, just like electrons.

As a result the charge transport in a semiconductor is facilitated by negatively charged electrons and positively charged holes.

The properties of metals, insulators and semiconductors can easily be illustrated using the electronic band structure of a material.

An electronic band reflects the potential energy levels an electron could occupy in the material.

Metals have a broad electronic band which is not fully filled with electrons.

This electronic band corresponds to the energy levels in which the electrons can freely diffuse around in the metal.

An insulator and a semiconductor, to the contrary, have two distinct bands with a large forbidden gap between them.

Most electrons fill the lower electronic band, the so-called valence band.

If electrons reside in the valence band, they are not mobile, they are well bound to the atoms in the lattice.

The upper electronic band is the so-called conduction band.

Electrons in the conduction band are free and mobile and contribute to the conduction, just like the mobile electrons in a metal.

The forbidden energy gap between the valence and conduction band is called the band gap.

In this gap no energy states exist, which can be occupied by electrons.

The difference between insulators and semiconductors is that the band gap of an insulator is much larger than the band gap of a semiconductor.

The band gap of an insulator is typically larger than 3 eV.

The larger the forbidden gap, the smaller the probability that an electron can have enough energy to occupy a state in the conduction band.

For a semiconductor, the band gap is smaller.

If the band gap of a material is smaller than 3 eV, the material can be considered to be a semiconductor.

In a semiconductor, some electrons can have enough thermal energy to jump from the valence band to the conduction band.

This energy can also be provided by light, if the photon has an energy equal or larger than the band gap.

This means that when you shine light with photons having an energy larger than the band gap, you can make a semiconductor more conductive.

The blue dots located in the valence band represent a positively charged hole.

While electrons in the valence band are glued to their background atoms, the positively charged holes can diffuse through the valence band, just like the electrons in the conduction band.

So, up to this point I have introduced the basic properties to describe semiconductor materials.

The conductivity properties are determined by the electrons in the conduction band and the holes in the valence band.

The energy gap between the conduction and valence band is called the band gap.

The question now is: what is the principle behind the existence of the forbidden band gap between the valence and conduction band?

Or in other words: what determines how strongly the electrons are bound to the atoms in the lattice?

I will discuss that in the next two blocks.

First, in the next block we will look at how electrons are bound to the nucleus within an atom.