ET3034TUx - 3.3.4 - Light trapping 1 - Absorption and optical losses

The last engineering tool is light trapping.

In the ideal solar cell, we want all light that is incident on the solar cell to be absorbed in the absorber layer.

However, nature has not made our life that easy.

Let's start with absorption.

How does absorption work?

Let's consider the simple system of a single absorbing medium with a thickness d.

From the left we have a light ray which is coupled into the film into the x-direction.

Part of the light is absorbed in the film.

Consider X=0 to be the front side of the medium and x=d is the back side of the medium.

At the moment we make an simplification.

First, we neglect the reflection or potential scattering at that interfaces.

Secondly, we assume the light is monochromatic, which means that all photons have the same energy or wavelength.

The absorption of a medium can be defined in terms of an absorption coefficient alpha.

The dimension of the absorption coefficient is one over the length and the typical unit of the absorption coefficient used is one over centimeter.

The light intensity drops exponential with distance in the absorber layer.

This behavior can be described by the Lambert-Beer's law.

This law states that there is a logarithmic dependence between the intensity of the transmitted light through the layer and the product of the absorption coefficient and the path length.

Or presented in another way, over an infinitely small distance dx, the decrease in light intensity due to absorption, dI/dx, is equal to the product of the absorption coefficient and the light intensity at position x.

This is the differential form of the Lambert-Beer's law.

Lambert-Beer's law shows that the light intensity is decreasing exponentially in the x-direction of the absorbing medium.

It also means that at the side, at which the light is entering the film, more light is absorbed in reference to the back side.

The total light intensity absorbed in the material is equal to the light intensity entering the absorber layer minus the intensity transmitted through the absorber layer.

For a solar cell we would like the absorption to be 100%.

In this condition the absorber would be called optically thick.

This means the transmission is 0%.

From Lambert-Beer's law it can easily be seen that this can be accomplished by either large values for the thickness d, so very thick films, or large values for the absorption coefficients.

It is important to realize that the absorption coefficient for materials is not the same at every wavelength.

In this figure the absorption coefficients for four different semiconductor materials are plotted: germanium, silicon, gallium arsenide and indium phosphide.

First you see that germanium has the lowest band gap.

Germanium starts to absorb at high wavelengths, which means low photon energy.

Gallium arsenide has the highest band gap, as it starts to absorb light at the smallest wavelength, or the highest photon energy.

Secondly, if we focus on the visible spectral part from 300 nm up to 700 nm, we see that the absorption coefficient of InP and GaAs is significantly higher than that for silicon.

This is related to the fact that InP and GaAs are direct band gap materials as discussed earlier.

Materials with an indirect band gap, like Si and Ge, have smaller absorption coefficients.

Only in the very blue part below 400 nm, silicon has a direct band gap transition.

Silicon is a relative poor absorber and therefore thicker absorber layers are required in reference to GaAs to absorb the same fraction of light.

In general all semiconductor materials show that the absorption coefficient in the blue is orders of magnitude larger than in the red.

This means that the penetration depth of blue light into the absorber layer is rather small.

Let's take as an example, the normalized light intensity with position in the silicon bulk.

As you can see in this graph, the blue light is already fully absorbed within a few nanometers.

The red light requires an absorption path length of 60 microns to be fully absorbed.

The infrared light is hardly absorbed, and after an optical path length of 100 microns only 10% of the light intensity is absorbed.

As the absorption of photons generates excited charge carriers, the wavelength dependence of the absorption coefficient determines the local generation profile of the charge carriers.

At the front side where the light enters the absorbing film, the generation of charge carriers is significantly higher than at the back side.

It means if we look at the EQE of a solar cell, the EQE values measured in the blue correspond to charge carriers generated close to the window layer, whereas the EQE in the red part represents charge carriers generated through the entire absorber layer.

Now, we are going look at some optical loss mechanisms.

Let's consider a simple crystalline silicon solar cell.

Next week, we will focus on this PV technology in more detail.

The example of the c-Si solar cell shown in this figure, consists of a p-type crystalline silicon bulk with a thin n-type layer on top, referred to as the n-emittor.

At the top and the back we have the metal contacts.

Using this relatively simplified solar cell configuration, we will demonstrate the various optical losses.

Or in other words, which mechanism prevents that all light is being absorbed in the p-type crystalline silicon solar cell.

First, we consider the metal contacts.

These contacts shade a certain area, preventing light to be absorbed in the PV active layers.

The second optical loss mechanism is the reflection at the front interface of the solar cell.

The light passing through an interface between two media with different refractive indices, will always be partly reflected and partly transmitted at the interface.

As all types of solar cells suffer from this loss mechanism, I would like to spend some time on this in the next block.

I will discuss some concepts which are being used as anti-reflection coatings.

A third optical loss mechanism is parasitic absorption losses in the non-active PV layers.

In this example the green top layer can be an anti-reflection coating or a passivation layer to reduce the number of defects at the surface of the emitter layer.

If this layer absorbs photons, these photons will not contribute to charge carrier generation that will be collected at the contacts.

This is what we address as parasitic absorption.

This means that in a design of solar cells we preferentially would like to use materials for the non-active part of the solar cell that have high transmissions for the spectral part utilized by the solar cell.

Finally, if the absorber layer is not thick enough to absorb all the light, part of the light will be transmitted.

This loss mechanism starts to play a role for solar cells based on thin films.

In the next final block of this week, I will discuss methods to reduce the reflection at the front surface of a solar cell and I will discuss under which conditions light might be trapped in the absorber layer.