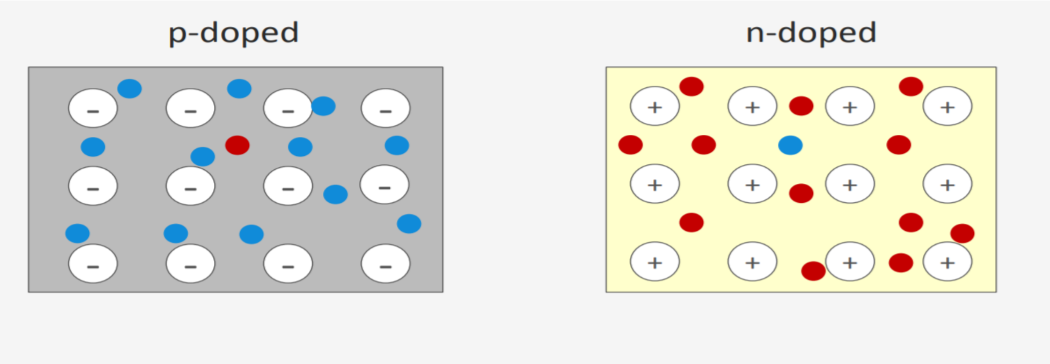
CHAPTER 2

PHOTOVOLTAIC (PV)

In this chapter, we are going to build a solar module, discuss its type and PV components in any type of PV system.

Most solar cells are based on a p-n junction. The question is: What is a p-n junction?
we take as an example the case for silicon. If we have semiconductor (silicon) in which one part is doped p-type and another part is doped n-type, we have created a so-called p-n junction. In p-type the holes are the majority charge carriers and in n-type the electrons are the majority charge carriers.

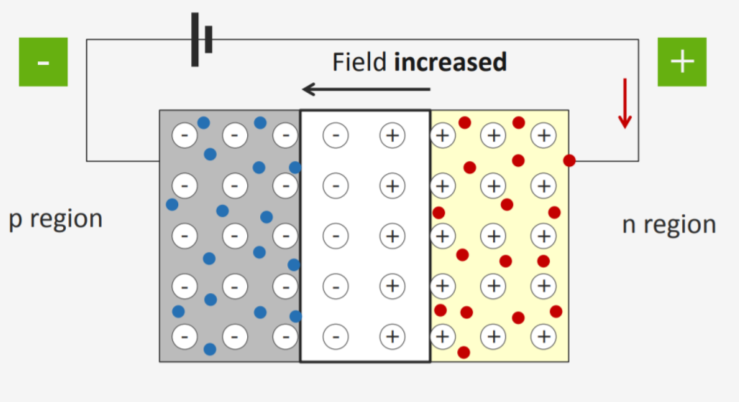


There are two different mechanisms control the transport of charge carriers in semiconductors: diffusion and drift
Diffusion is controlled by a density gradient.
Drift is controlled by electric fields, which you can build in the p-n junction or apply externally. light absorption only affects the density of the minority charge carriers in doped semiconductor materials.

2.1 In the dark and in thermal equilibrium

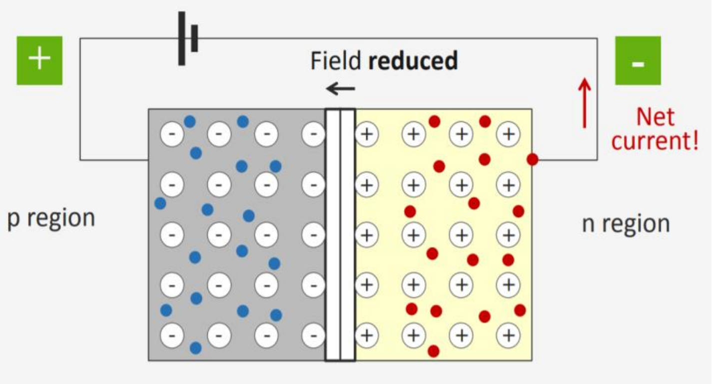
drift of minority charge carriers and diffusion of majority charge carriers are in balance.

If we apply a reverse bias on such p-n junction in the dark, the depletion zone gets wider, the diffusion of majority charge carriers is suppressed and only an extreme small current



related to drift of minority charge carriers is generated.

or in other words, The density gradient is becoming smaller. The current density related to diffusion of both electrons and holes is reduced. The drift is enhanced. Since the electric field E is larger, the drift of the electrons and holes is slightly enhanced. In this case the drift current density is dominating the diffusion current density. Since the drift current density is ruled by the density of the minority charge carriers in the p- and n-region, the total net current is extremely small. In the reverse bias condition an extreme small current will move from the contact at the p-region to the n-region. This means that on average electrons are walking from the contact of the n-region to the p-region as shown in the figure.

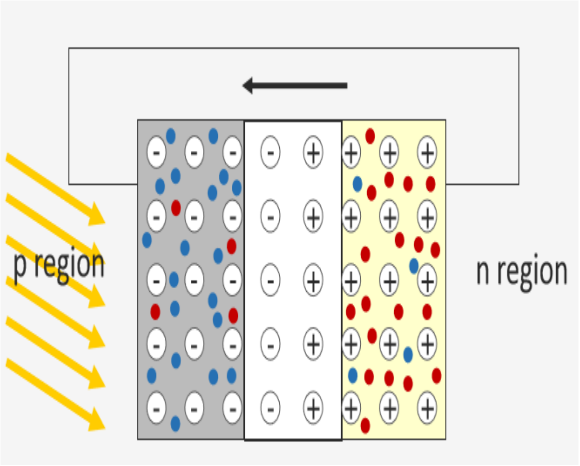


If we apply a forward bias on such p-n junction in the dark, the width of the depletion zone is getting smaller, the diffusion of the majority charge carriers is significantly enhanced and overrules the drift of minority charge carriers. The p-n junction becomes conductive and is able to generate a current.

or in other words, the density gradients become much larger. As a consequence, the current density related to diffusion becomes significant larger. On the other hand, the electric field E is reduced, which means that the current density related to drift is getting slightly smaller.
Note that the effect of the increased flux due to diffusion is much larger than the small change in drift. This means that we generate a net current over the depletion zone. More electrons are diffusing from the n-region to the p-region, than are drifting from the p-region to the n-region. More holes are diffusing from the p-region to the n-region, than are drifting for the n-region to the p-region. This means by applying a forward bias over a p-n junction in the dark we produce a net current through the electrical circuit as shown in figure.

Summarized, in the dark under forward bias the diffusion of charge carriers over the depletion zone is dominant, whereas under reversed bias the drift of charge carriers over the depletion zone is dominant. Under forward bias in the dark, the p-n junction can produce relatively large currents, whereas in reverse bias, it generates very small currents. Such a device is called a diode. It has a high conductance in forward bias, but has a low conductance in reverse bias.

2.2 In the light



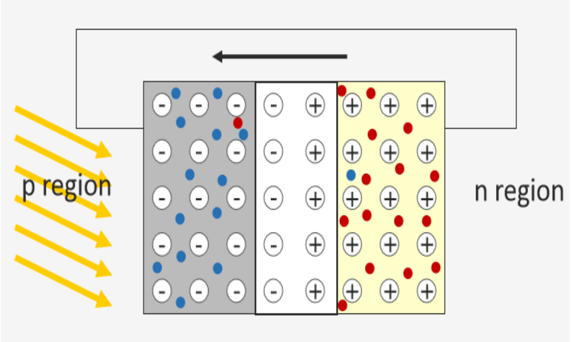
Now we are going to shine light on the device. This means that we are looking at a solar cell. Light is incident from the left on the p-region. For the moment we assume the light is being absorbed in the p-region and the n-region. The absorption of the photon will generate electron and hole pairs. Important to realize and as discussed earlier, light absorption only affects the density of the minority charge carriers in doped semiconductor materials. This means that the light excited charge carriers significantly increase the density of the electrons in the p-region and the density of the holes in the n-region.

Subsequently we increase the drift. This can be easily recognized by looking at the equations for the current densities ($J_e = nq\mu_e E$). We see that we are significantly increasing the drift over the depletion zone, which is indicated by the larger arrows. Many electrons drift from the p-region to the n-region and many holes drift from the n-region to the p-region. The current density related to drift can be easily increased by many orders of magnitude under illumination in reference to the p-n junction in the dark. By illuminating a p-n junction we can generate a current.

2.2.1 Short circuit current and open circuit voltage of the solar cell

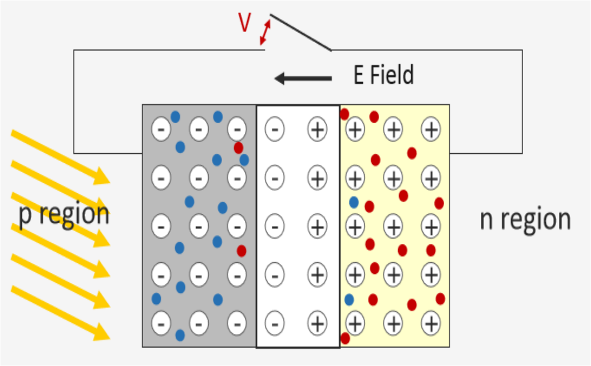
Finally, we're looking at the working principle of a solar cell. Using an electrical circuit we connect the contact at the p-doped silicon with that of the n-doped silicon, or in other words we short-circuit the p-n junction.

Short circuit



In this condition, the illuminated p-n junction will produce only an electrical current. We call this current the short-circuit current of a solar cell. We can make a very simplified animation of the journey of the generated charge carriers. On average a minority electron will drift to the n-type material and diffuses to the metal contact in which the electron is injected. The electron moves to the contact at the p-side and is injected into the p-type silicon. and recombines with a hole. The minority holes in the p-type drift across the depletion zone and diffuse to the back contact to recombine with the electrons.

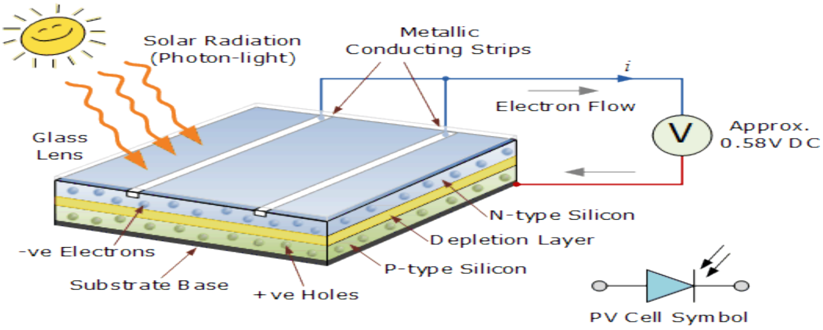
open circuit

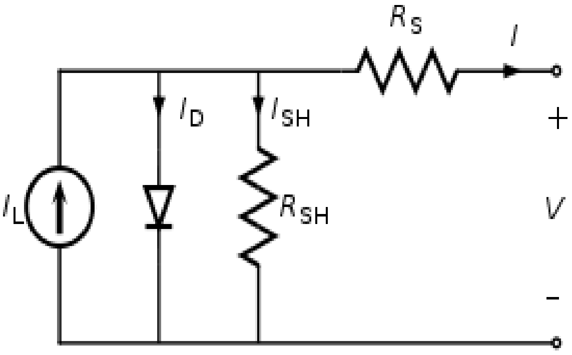


However, no current is created when we open the electrical circuit. In that case, the dominant drift current of light excited charge carriers will positively charge the p-region with holes and negatively charge the n-region with electrons. This charging creates an electric field opposite to the built-in electric field and reduces the net drift current again. This charging of free holes in the p-region and free electrons in the n-region will build up until both the drift currents are in equilibrium. This means that the device does not generate a current, but builds up an electric field, or voltage. The voltage created by an illuminated solar cell under open-circuit conditions is called the open-circuit voltage.

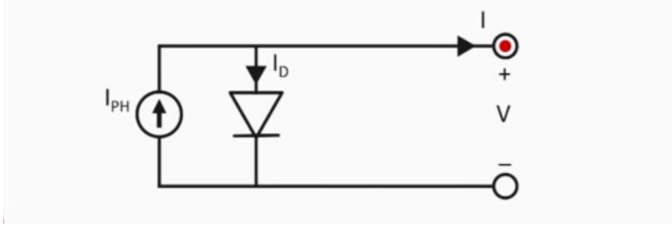
2.3 Equivalent circuit of pv cell:-

To understand the electronic behavior of a solar cell in light, it is useful to create a model which is electrically equivalent. An ideal solar cell may be modelled by a **current source** in parallel with a **diode**; in practice no solar cell is ideal, so a **shunt resistance** and a **series resistance** component are added to the model as shown in the figure blow.





To understand the main parameters of solar cell we are going to simplify the above circuit by eliminating the **shunt resistance** and the **series resistance** as shown below.



The equivalent circuit of an illuminated ideal solar cell