Dark JV measurement

In this video you will learn about the dark current density voltage measurement or dark JV measurement.

First we will explain the purpose of measuring a dark JV curve and how it can be used to characterise the diode properties of the solar cell.

Then we will demonstrate a measurement setup and discuss the measurement principle.

Finally we will show how Dark JV characterisation is used to determine the activation energy and mobility gap of thin film silicon solar cells.

Here we see the illuminated JV curve and Dark JV curve of a crystalline silicon solar cell plotted in one figure. The ultimate use of a solar cell is to generate electricity from sunlight. This is achieved by operating the solar cell in forward voltage, such that the photo-generated charge carriers can be separated and collected, shifting the current density down to the fourth quadrant in this graph as the solar cell produces current. When the cell is operated in dark conditions, there will not be any photo-generated current and measuring this JV curve seems pointless, however…

A solar cell is a rectifying diode. This implies that when operated in reverse bias, it will not conduct current. In forward voltage the current will gradually increase, but will be very small if the shunt resistance of the diode is high. When the applied voltage exceeds the built-in voltage of the diode, the current will rapidly increase and show exponential increase with voltage.

This point of the curve is commonly called the knee.

When we now plot the same JV curve on a logarithmic y-axis, it becomes a lot more interesting. Up to the knee voltage several processes contribute to the current density, which is completely overshadowed when the cell is operated in illuminated conditions.

From this dark JV curve, we can for instance determine the shunt resistance of the solar cell with better accuracy than with the same curve measured under 1 sun illumination.

The series resistance can be determined in the higher applied voltage region when comparing the dark JV curve with the illuminated curve. At that point the current density is substantial.

Finally, the diode's ideality factor, n, and saturation current density, J_naught, relating to the charge transport mechanisms in the cell, can be determined from the slope of the dark JV curve when fitting the curve to the single diode Shockley equation. We can already tell that different charge transport mechanisms dominate the operation of the solar cell in different voltage ranges. Altogether these parameters dictate the electronic performance of the solar cell and it is important to determine these with the highest possible accuracy.

We have seen that important diode parameters can be determined from the dark JV curve. We will now demonstrate a fairly simple setup to measure the dark JV characteristic of a lab-scale solar cell.

As the dark current will be very small for low forward voltage, and will increase rapidly after passing the knee voltage, the setup requires an accurate electrometer. An electrometer is an instrument that can simultaneously source voltage and measure current. But more importantly, it is capable to autoscale the current range from nano amperes up to milli amperes. Some diodes conduct a lot of current and then the four-point probe measurement might be necessary. When a voltage is applied over the solar cell in dark conditions, charge carriers will be injected into the device. A current flow can only be generated if the charge carriers recombine inside the cell.

Similar to the illuminated JV measurement, the solar cell is placed on a thermal chuck, such that good control over the operating temperature of the cell can be achieved. This is important since the generation and recombination processes are temperature dependent.

The setup is controlled by a computer that defines the voltage range of the measurement, as well as the step size and temperature of the chuck.

Depending on the type of solar cell that is measured the voltage sweep when measuring the dark JV curve can be set, for instance by sweeping from high to low forward voltage. For the highest accuracy, it can be important to wait for the current to stabilize before recording the value, since the current will take some time to stabilize after changing the voltage. This is due to the fact that depending on the current level it might take some time for the generation and recombination processes to stabilize after changing the voltage.

If we compare the operation of an illuminated solar cell with a dark JV measurement, there is an essential difference in the current flow.

For a homogeneously illuminated cell with a p-type base and n-type emitter, the electron current through the p-n junction will enter the n-type emitter layer fairly evenly distributed.

The electrons will then be conducted laterally towards the front contacts of the cell.

For a dark JV measurement, however, charge is not generated in the cell, but is injected through the contacts. Most of the electrons will hereby travel directly across the emitter layer and enter the base of the solar cell. This is a limitation of the dark JV curve to accurately determine the total series resistance of the solar cell compared to illuminated operation.

As an example I will show how dark JV characterisation can be used on thin film silicon solar cells by measuring the characteristics at different temperatures and determining the voltage dependent activation energy. Using this measurement we can find the mobility gap of the material.

The mobility gap is equivalent to the bandgap of a single crystal semiconductor, however in the case of an amorphous or microcrystalline structure there are energy states in between the valence band and conduction band, such that there is not a real band gap. When we compare the density of states distribution for crystalline and amorphous silicon, you can see the energy states between the valence and conduction band in the form of tail and defect states. The mobility energy gap of amorphous and microcrystalline silicon is an important quantity to measure, as it quantifies the energy gap between states that contribute to the transport of charge. The physics underlying the derivation of the mobility gap from dark JV characterisation is rather complex, but is ultimately based on the temperature dependence of the dark current.

When the dark JV characteristic is measured over a wide temperature range, the activation energy of the dark current can be evaluated at every applied voltage by using the Arrhenius equation.

The activation energy gives the relation between thermal energy and the rate of a certain physical or chemical process, in this case the increase of dark current.

Under several assumptions, Pieters et al. derived an expression to determine the mobility energy gap from the voltage dependent activation energy. This equation includes a thermal ideality factor, m_th, which characterizes the temperature dependence of the recombination in the cell.

To summarise this video, you have learned how a dark JV measurement can be used to characterise the diode parameters of a solar cell with better accuracy than with an illuminated JV measurement.

Secondly, we have discussed a basic setup that operates with a very accurate electrometer that can measure very small currents in the range of nano amperes up to milli amperes.

Finally we have discussed another application of the dark JV measurements specifically for thin-film silicon solar cells, where the temperature dependence of the dark current is used to determine the mobility gap of the solar cell.