Structure and Materials of PV Modules

A crystalline silicon module must withstand various influences in order to remain functional for 25 years or even longer.

To ensure this lifetime, the materials used to create PV modules have to be carefully chosen.

Not only in terms of performance, but also stability. In this video, we will discuss the various materials used in solar cells. We will also look into the packing density of solar cells in order to optimize the module area.

Let’s take a look at the structure of a crystalline silicon module. The figure shows a PV module from the front.

The black lines on the left represent the side view of three solar cells, specifically the ones indicated by the red arrows. A PV module consists of a number of interconnected solar cells. The electrically-connected cells are then encapsulated into a single, long-lasting, stable unit.

The main purpose of the encapsulating layers, is to protect the cells and the interconnecting wires from the environment.

Since the individual solar cells are relatively thin, they would be vulnerable to mechanical damage without encapsulation. In addition, the metal grid on the top surface of the solar cell and the wires interconnecting the individual solar cells are susceptible to corrosion by water or water vapour.

Therefore, a good encapsulation and a solid frame are essential to prevent mechanical damage and corrosion. The structure and the cables must also be resilient, for example against animals that could bite the cables at the back of the panel.

The exact PV panel structures will differ between technologies and companies, but in general the more resistant and sturdier panels are, the more expensive their cost will be.

We will now break down a PV panel layer by layer. In general, it consists of a transparent front cover, a polymeric encapsulation, mono- or polycrystalline silicon cells with metal grids on the front and rear and solder bonds electrically connecting the individual cells.

Following these layers, a rear layer is placed at the back of the cells and a frame is mounted around the outer edge. Let’s look at this module in some more detail.

The front surface of a PV module must have low reflection in the wavelengths range between 350 nm to 1200 nm, which is the active range of silicon solar cells. In order to minimize front surface reflection, an anti-reflection coating can be applied.

However, in practice these coatings are generally not robust enough to withstand the conditions in which most PV systems are used.

An alternative technique is to texture the surface, but this also has a downside. With a standard sub-millimetre textured surface, the dust and dirt is more likely to attach itself to the top surface, and less likely to be dislodged by wind or rain.

The advantages of the reduced reflection are therefore quickly outweighed by losses incurred due to increased shading by dust particles. Some additional requirements of the front cover are a good impact resistance, a low thermal resistivity and the cover should be stable under prolonged UV exposure.

Among the possible choices for a top surface material there are acrylic and polymers.

The most commonly used cover is tempered low iron-content glass, since it is low cost, strong, stable, highly transparent, impervious to water and gases and has good self-cleaning properties.

Then there is the encapsulation, which is used to provide adhesion between the solar cells and the top surface and rear surface of the PV module. This encapsulant material should be stable at elevated temperatures and under high UV exposure.

The encapsulant should also be optically transparent and have a low thermal resistance.

The most commonly used polymer material is ethyl vinyl acetate, or EVA in short. EVA has a refractive index very close to that of glass, so the reflection losses caused by the encapsulation are minimal.

EVA arrives in thin sheets, that are used to sandwich the solar cells. The layers are then heated to 150 °C for polymerization and to create cross-links, that bond the module together. In this way, especially the metallic contacts can survive for many years. For thin film modules, the encapsulation is an important part of module price.

That is because these technologies use transparent conductive oxides, or TCO, as a front contact.

TCO's are generally very vulnerable to degradation by water vapour, which means that the encapsulant must be really good in order to enhance the lifespan of the module.

Let's now focus on the backside of the module. Like the front and the encapsulation, the rear layer must have low thermal resistance and prevent the in-diffusion of water vapour.

In most modules, a thin polymer sheet, typically Tedlar, is used as the rear surface. Some special kind of modules are designed to absorb light from both sides of the panel. In these so-called bifacial modules, the rear surface must also be optically transparent.

The final structural component of the module is the edging or framing of the module. The frame is typically made of aluminium and should be free of projections which could result in the lodgement of water, dust or other matter.

Note that at the rear side and additional glass sheet may be used for added strength.

Here we see an additional PV module component, namely the junction box. This plastic box, located at the rear of the module, is designed for outside operation and to withstand heat cycles.

Inside the junction box, we can find a switch that enables all the cells to be either connected in series or some cells in series and some rows in parallel.

This way, the output voltage and current of the module can be modified. Usually the junction box also contains some bypass-diodes.

An important parameter to consider during the design of a module, is the packing density of solar cells.

The packing density is defined as the combined area of all the solar cells solar cells with respect to the total module area. Let's again consider c-Si modules.

For the PV modules fabricated two decades ago, high purity crystalline silicon was produced in circular rods, using the Czochralski or the float zone methods. Consequently, the cells were cut in circular shapes like the one on the left. It can be easily noted that this will not lead to a high packing density. Nowadays, with improvements in silicon casting, it is possible to grow much larger ingots and obtain semi-squared wafers. These octagonal wafers are obtained by cutting off the rounded parts of the circular rods.

The excess silicon is then melted to produce a new ingot. In the case of multicrystalline silicon, the ingot is just cast in a cubic mold, resulting in a lower purity silicon. From the cubic mold, the cells are cut in squared wafers.

Even with this high packing density however, light can still go in between the cells. The packing density is important, because it directly affects the output power of the module as well as its operating temperature.

Let's recap. In this video, we saw the different layers used to create a crystalline silicon module.

The first layer is a front cover, followed by two layers of encapsulant that sandwich solar cells and then a rear layer and a frame, ultimately providing mechanical stability. We discussed the packing density for monocrystalline and multicrystalline silicon, which depends on the fabrication method used. In the next video, we will see different techniques used to create an interconnection between cells.