The self-deception is the base of “the Emperor’s New Clothes” story.

Sometimes it is difficult to realize that something is not real. It requires that something or someone new comes up to help us to see the reality.

Yes, maybe is the time for the PV People to realize and see that the "King-module" is naked, from the PID perspective.

The Dielectrical Properties of Photovoltaic Encapsulants: Measurements and Values.

The triple role of Encapsulants in your Modules

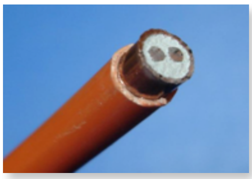
It is known that the encapsulants play an important role being the joining “glue” between all the parts of the modules: glass, cells, strings, connectors, backsheet… Not just that, the encapsulants are very important from the optic point of view. They are the key elements that facilitate that the sun radiation reaches the cells to be transformed into electricity. How much radiation the cells receive depends greatly on the encapsulant. A third important role is their electrical insulator functionality protecting the cells and contacts inside the module.

In this report we want to address how important electrical isolation property is and what is the best way to discriminate the dielectric properties of encapsulants. We want to dig into their functionality as “wrapping materials” to insulate cells and the electric currents generated by them.

Conductors and Dielectrics

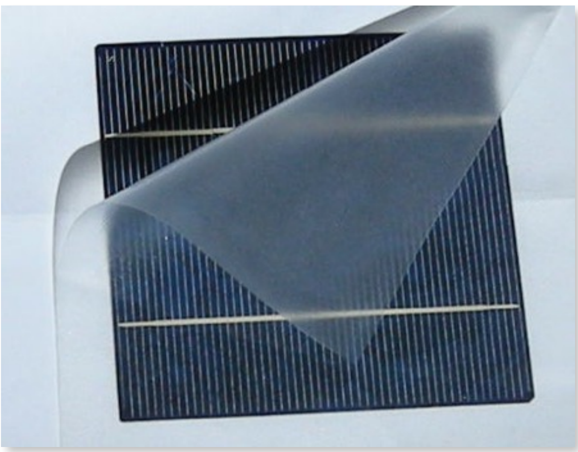
From physics we know that to transport electricity we need electrical conductors (normally metals like copper, are the best materials to conduct electricity). The electricity conductors need to be protected by dielectric materials (normally polymeric materials). All together are used to channel the transportation of electrons and ions safely in the distance without any or minor losses. A typical product that works in such a way are all the electrical cables.

If we take a look at electrical cables and how they fulfill their isolation requirements, we realize that normally several coating layers of different dielectrics are used to isolate the conductors and avoid electrical leaks. Each one of these barrier layers play a partial role avoiding losses when the electricity is transported in the distance. The isolation properties are determined in terms of the dielectric properties of each one of encapsulator materials. Needless to say that at higher dielectric values, a higher isolation is achieved. In some cases to reach the required levels of isolation is just a matter of a certain thickness of one single dielectric material but in other cases more than one layer of different types of dielectric materials is needed.



The Best Electrical Insulators for Photovoltaic Modules

Going back to the specific case of Photovoltaic modules, there is the need to use also very special wrapping insulators to protect the cells and their connectors from electrical leaks. Moreover, and of course, they have to be highly transparent!!!



Until now the EVA has been mainly the only one encapsulant used to laminate standard modules. It is a high transparency encapsulant. Other ones like PVB, Ionomers, Silicones …. have been less extensively used. That is because they have worse performance than EVA from the point of view of: lamination, dielectric properties and durability. In general it can be said that EVA has been the most extensible used encapsulant, because it delivers the best combined results.

Surprisingly a thin layer of EVA of around 460 μm it has been considered enough to protect the module internals. But how just a single EVA layer is enough to protect electrically the photovoltaic circuits? We can say that it is thanks to the glass and backsheets overprotection support. All together complement the dielectric capacity of EVA. A thin layer of 460 μm front and a similar one at back wouldn't be enough to protect the electrical device from malfunction.

The EVAs Dielectric Limits

Recently we have realized that the dielectric properties of EVA are not enough to insure the reliability of the modules, especially when Voltage Stresses show up during modules life. Therefore the need to increase the dielectrical properties of the encapsulants is becoming a necessity.

All we know about the voltage stresses in the modules. The stresses can move the modules away from their regular window of operation and have a massive impact on module reliability. The well

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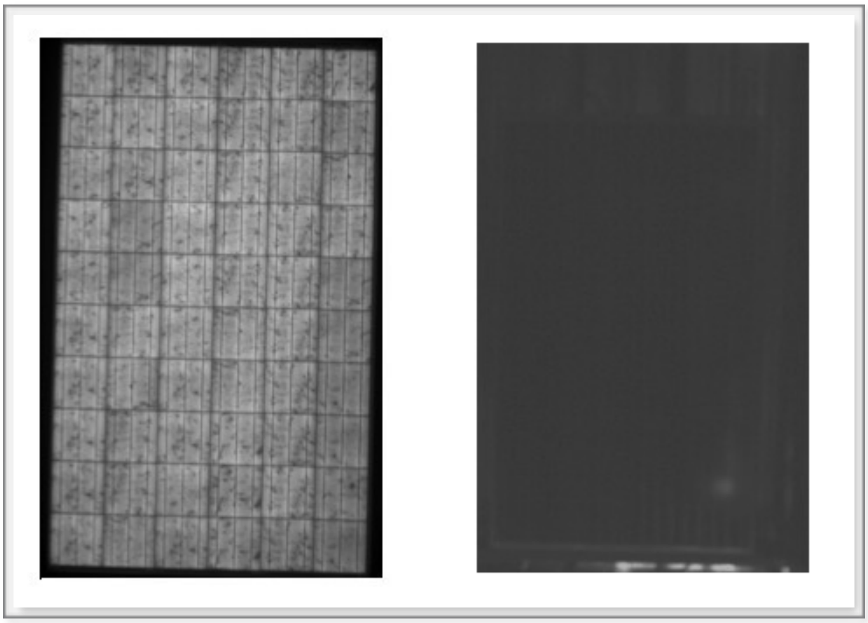
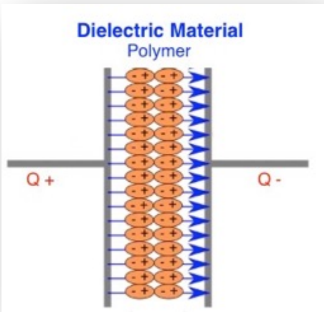
known PID defect is causing the degradation of the cells and the degradation of the module. This effect can be observed by electroluminescence test of PV cells as it is shown in the following picture. It can be seen cells not showing PID effect (on the left) compared with cells affected by PID (on the right). In that case the PID defect makes the right module a dead module.



To avoid this problem some actions need to be taken by module manufacturers. One action should be directed in terms of enhancing the dielectric properties of the encapsulants.

Possible Solutions to EVA Encapsulators Limitations

One way to increase the electrical isolation of the cells might result from the combination of layers of different encapsulants, as it is being done in cables. This possibility is both costly and also risky from the optics point of view. That is because all the dielectric layers have to have excellent optical properties. A second option might be the use of specially reformulated EVA encapsulants, with lower conductivity properties. This second option, very commonly used these days, is also a partial solution, subjected to failure. From our point of view a third option, based on the usage of a brand new encapsulant with the enhanced dielectric properties, is the best one.



In general, all organic polymers can be considered as electrical isolator materials. EVA is one of them. But not all of them have the same isolation capacity, and the differences between them depend on their chemical composition. The dielectric properties of polymer materials depend mainly on their molecular polarity (http://www.wikiwand.com/en/Chemical_polarity). Normally, the higher the polarity of the polymer molecules, the lower the dielectric properties of the material.

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Besides of their molecular structural composition, other related properties, linked in some way to their molecular polarity, such as: higroscopicity, density, crystallinity, and so on, might affect and influence indirectly their basic dielectric properties.

During module operation the surrounding ambient conditions, such us level of humidity and temperature might strongly influence the basic dielectric properties of each encapsulant, reducing them and making them more vulnerable to electrical losses. These deviations from their normal properties might move the encapsulants from their safe window of operation to a risky operation zone, facilitating the electrical leaks inside the module.

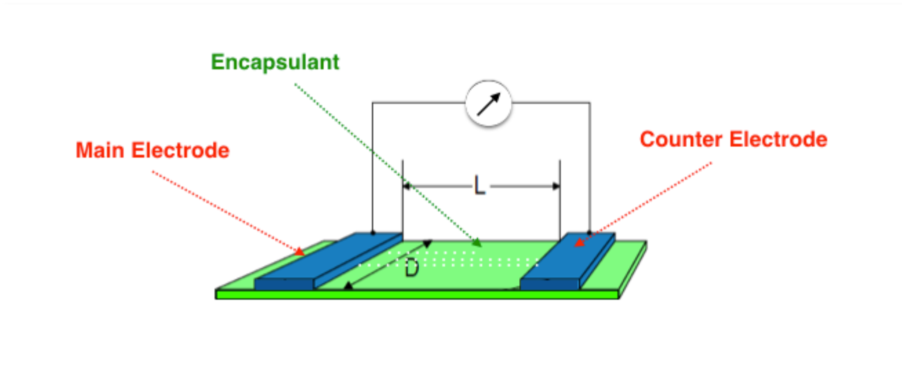
Measuring and Controlling the Limits

Until now, EVA has been the main encapsulator and almost the only one. Almost nobody has payed to much attention to measure, control and compare with other materials with different dielectrical properties.

So, now the question is: how to measure and rank the different materials based in their dielectrical (isolation) properties? Is there any? Yes, there are several already. So let's go through some of them in some detail to be able to "map the encapsulators" in terms of their dielectric properties.

The materials Resistivity measurement is a way to determine each material dielectric performance. The resistivity can be referred in terms of volume (as volume resistivity) or surface (as surface resisitivity). These measurements have been standard and described by the ASTM D257 and IEC 60093 norms. Following these norms it can be assigned a numeric value to each material.

Surface resistivity is the resistance to leakage current along the surface of an insulating material. The Surface Resistivity is measured as a resistance between two parallel electrodes in contact with the specimen surface and separated by a distance equal to the contact length of the electrodes. The resistivity is therefore the quotient of the potential gradient, in V/L, and the current per unit of electrode length, A/L. Since the four ends of the electrodes define a square, the lengths in the quotient cancel and surface resistivities are reported in ohms per square. To illustrate the measurement see the basic configuration figure below of the type of equipment that it is used to measure the resistance along the surface of the sample.



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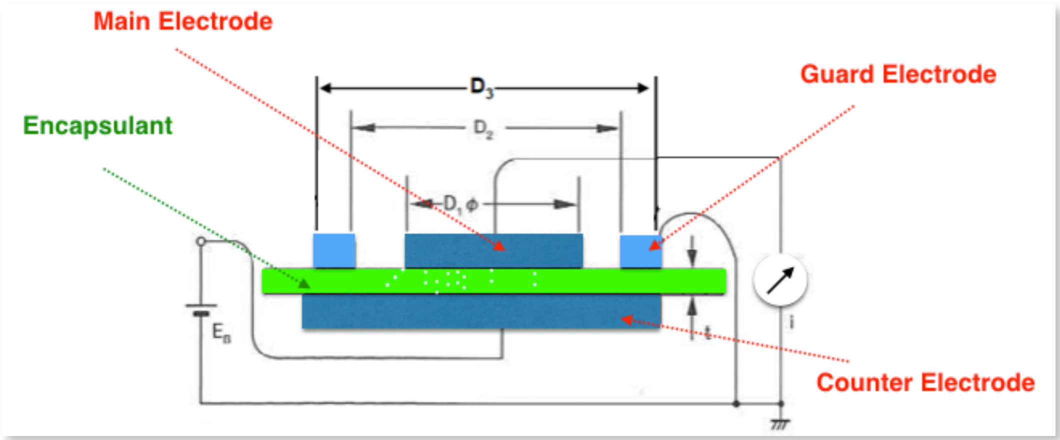
In the case of Photovoltaic modules instead of the Surface Resisitivity the Volume Resistivity is the most reasonable property to measure. We should not forget that the encapsulants are a mass of material, in a form of film (surface x thickness) with the purpose of isolating the currents generated inside the modules.

Volume Resistivity is the resistance to leakage current through the body of an insulating material. Volume Resistivity is numerically equal to the direct-current resistance between opposite faces of a one-meter cube of the material (Ohm-m). But in order to simplify, another parameter (not volumetric) it is used to refer Volume Resistivity. The term Ohms.cm, reduces the data to only one dimension (the simplest one). The value in Ohms.cm is the inherent resistance of a given material regardless of the shape or size.This normalized parameter is really useful to distinguish and classify between the different type of materials for our type of application. So knowing "what it is" and "what it means" we might use it from now on as a parameter to consider when analyzing and comparing between different materials.

The measurement of the current resistance is in some way different than the measurement of the Surface Resistivity. It is based to measure the resistivity of a fix volume of each material. The figure below presents schematically the type of equipment configuration that it is used to measure the resistance along the volume of a film sample.



With such equipment systems used in a standard way (as norms refer) it has been possible to measure and assign values to the different type of materials that have been used as photovoltaic encapsulators.

In general it is accepted that the baseline to consider that a polymeric material has acceptable electrical isolation properties is in the range of 10^{12} Ohms.cm (Ω.cm). Below that, materials cannot be considered as insulators.

The following table contains the Volumetric Resistivity data of the main encapsulants used until today:

Encapsulant	Volumetric Resistivity at 23ºC (Ω.cm)
PVB	10^{11}
EVA	10^{14}
Ionomer	10^{16}

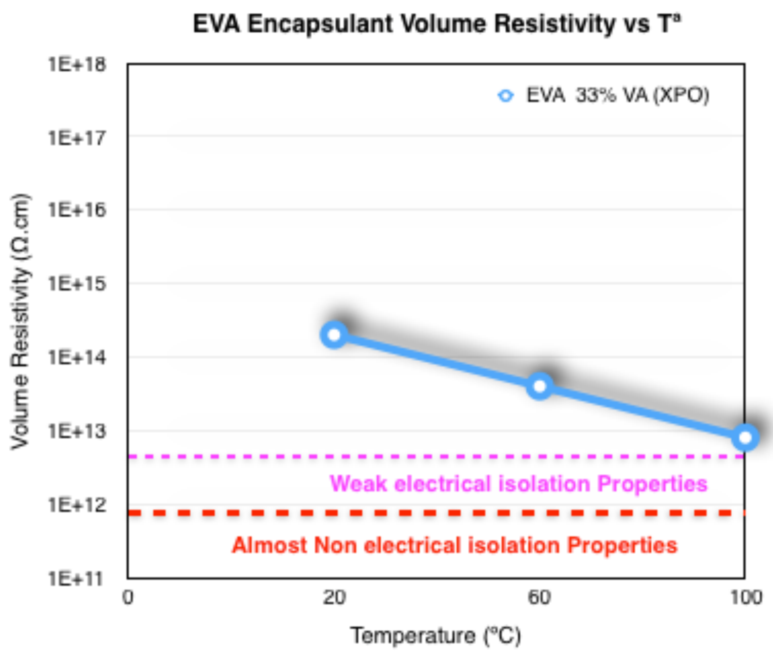
When looking at these data we should not forget that these values have been measured according standard norms. These values have been obtained applying 500 V to samples of 10 x 10 x 0,046 cm^3 dimensions and under fixed environmental conditions of 23ºC and 50% relative humidity.

From the table, the **Ionomers** are the encapsulants with the highest Volumetric Resistivity of all three encapsulants. Unfortunately they are not easily processable like EVA. In some cases for glass-glass thin film encapsulation the ionomers have been the better alternative to EVA and the "disastrous" original PVB option. (Ref.: *P Hacke et al. Proc. 25th EU PVSEC, Valencia 2010)*

Looking at **PVB encapsulants**, then it is easy to see how poor and week this material is to be used as a photovoltaic encapsulator. (*Ref.: G. R. Mo and R. G. Ross. Poc 18th IEEE PV Specialist Conference, Las Vegas 1985 pp 1142-1149*). Then…. the question is: Why it has been used for Thin film glass-glass type of modules? … but we are not going to answer here…. it looks that this is another example of the "the Emperor's new clothes" fable.

In the case of **EVA encapsulants**, as it is well known from chemistry, the EVA molecular structure is basically made of long chain elements in which they are two types of different chain shackles: the ethylene and the vinyl acetate groups. The polarity of the EVA encapsulators is directly dependent on the polarity of the vinyl acetate groups present in the EVA chains, that normally represent the 33% of the total shackles. Besides of the 33% vinyl acetate one, there are other EVAs with less contain of vinyl acetate. But unfortunately the decrease of vinyl acetate in the composition of EVAs drives us towards encapsulants with very low transparent properties and poor optics, limiting the possibilities of EVAs for photovoltaic applications.

Moreover, everybody knows that materials are working most of the time out of their reference test conditions used in the norms. Especially in the case of the polymers, the molecular suffer structural changes and deformations at different temperatures. So it makes sense to take a look at the variation of the Volume Resistivity properties of the EVA with temperature. The following table shows the variation of the dielectric properties of EVA from 20 to 100ºC.



At this point it is important to point out that inside the modules it is possible to reach temperatures of around 80ºC, especially in hot and sunny areas of the world. So it is convenient to look at the dielectric properties of the encapsulants at the range of high temperatures of operation, where they lose part of their dielectic shield to protect the cells and the electrical currents.

As it can be seen in the above graph, the dielectric properties go down with temperature. Being in this range of Volumes Resistivities (between 10^{14} -10^{13} Ω.cm), if any other factor shows up, like for example partial UV degradation of EVA, the encapsulant resistivity could go even down reaching the risky zones of Resistivities below 10^{13} Ω.cm. At these levels the EVA encapsulants are week and could start their electrical degradation, starting from small electrical leaks.

In order to try to overcome these risky situations some solutions are being proposed by several film companies to the module manufacturers. In most of the cases the only one option offered by the film manufacturers is to use EVA encapsulants with lower vinyl acetate contain. This is a partial remedy to the problem. Some advantages can be obtained but in all cases this is not a strong solution. As it can be seen in the graph below there is no sensitive improvement of the Volumetric Resistivity.

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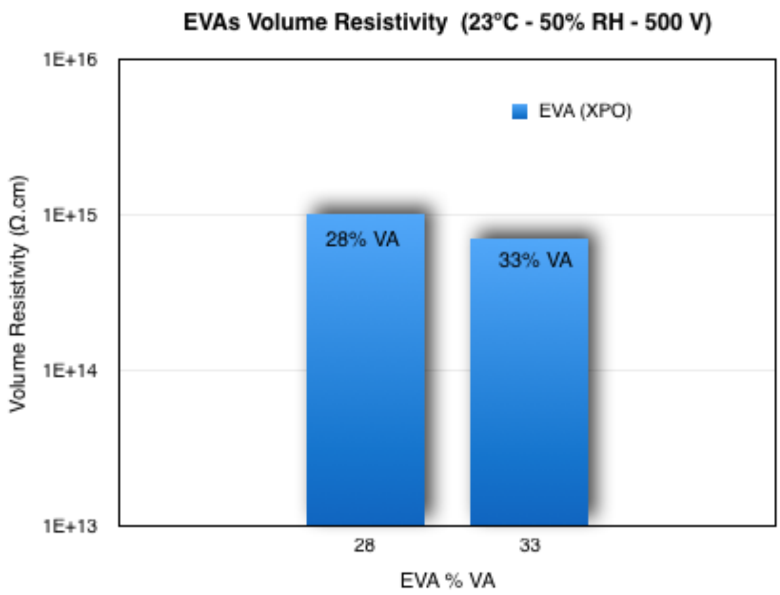

Knowing that the vinyl acetate contain determines the Volume Resistivity level of EVAs we decided to come up with some new encapsulant, non EVA based.

A dramatic and more consistent solution would require developing new encapsulants with no vinyl acetate at all in their molecular chains. A new encapsulant, with no molecular polarity at all, is not a straightforward thing to do. This is not an easy job because there are so many restrictions to be fulfilled: similar processing conditions than EVA film, high transparency, crosslinkable, no shrinkage, high adhesion, UV resistance….

We, at NovoGenio, developed a new encapsulant under these premises. This new encapsulant has been available in the market since 2012.

Overcoming for Sure the Limits: The New Encapsulator

NovoGenio XPO encapsulant (Crosslink PolyOlefin), NovoSolar® PL, with no vinyl acetate at all, fulfills all the above requirements at the time that have improved Volume Resistivity properties compared to EVA. The non polarity molecular property has allowed us to produce a new XPO encapsulant with Volume Resistivity values in the range of **10^{17} - 10^{18} Ω.cm** over the 10^{14} - 10^{15} Ω.cm of the EVAs.

Similar to EVA, the Volume Resistivity of our NovoSolar PL encapsulant decreases with temperature but even at high temperatures of operation (80°C) its resistance is much higher than of the EVA at room temperature.

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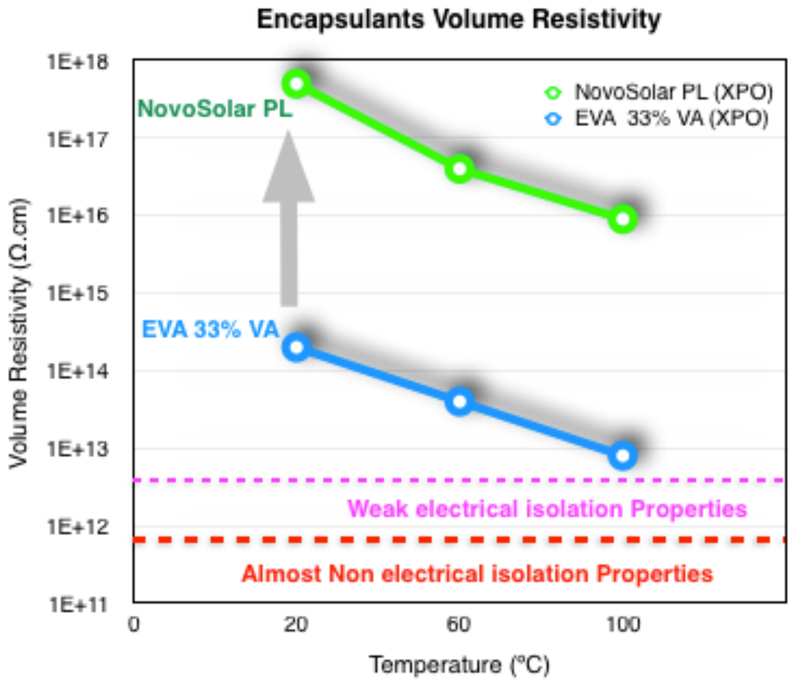

Knowing that we summited our encapsulator to a “fire test” in the Fraunhofer ISE labs. We checked how it behave under strict PID test runs.

The encapsulant was specially checked with a set of PID tests in continuous using the same samples. In all cases it was applied a negative voltage of 1000V between the cell and an aluminum foil (frame), which did cover the glazing at an ambient temperature of 25°C during 168 h. In order to accept ok or not ok test pass, the pass/fail criteria used was a maximum power loss of 5% comparing the measurement before and after the test.

PID test:

After the first round of 168h (one week test), as it can be seen in the table below, a second and third run were applied over the same sample. In summary it was a cumulative test over the same sample for three times in a row. After each run the measured power losses were low as the results plotted in the table below are showing.

Observe that the Power losses measured after the cumulative test (Column Pmpp/W) were lower than 5% (Pmpp/W > 0,9500) after each one of them. The test was done with two similar samples (duplo test): Sample A and Sample B. Each sample was a small module made of 4 cells.

Referenz		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M01	A	1,24	8,57	0,96	7,9	7,56	70,97
	B	1,25	8,57	0,96	7,8	7,45	69,71

1xPID		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M01	A	1,25	8,59	0,94	7,9	7,46	69,73
	168/Ref	1,0081	1,0023	0,9792	1,0000	**0,9868**	0,9825
	B	1,25	8,59	0,95	7,83	7,42	69,11
	168/Ref	1,0000	1,0023	0,9896	1,0038	**0,9960**	0,9914
2xPID		**Uoc / V**	**Isc / A**	**Umpp / V**	**Impp / A**	**Pmpp / W**	**FF / %**
M01	A	1,24	8,52	0,94	7,86	7,4	69,93
	336/Ref	1,0000	0,9942	0,9792	0,9949	**0,9788**	0,9853
	B	1,24	8,51	0,64	7,71	7,23	68,32
	336/Ref	0,9920	0,9930	0,6667	0,9885	**0,9705**	0,9801
3xPID		**Uoc / V**	**Isc / A**	**Umpp / V**	**Impp / A**	**Pmpp / W**	**FF / %**
M01	A	1,24	8,53	0,94	7,28	7,28	69,02
	504/Ref	1,0000	0,9953	0,9792	0,9215	**0,9630**	0,9725
	B	1,24	8,53	0,94	7,6	7,14	67,56
	504/Ref	0,9920	0,9953	0,9792	0,9744	**0,9584**	0,9692

Basic principles I-V curve of a photovoltaic device

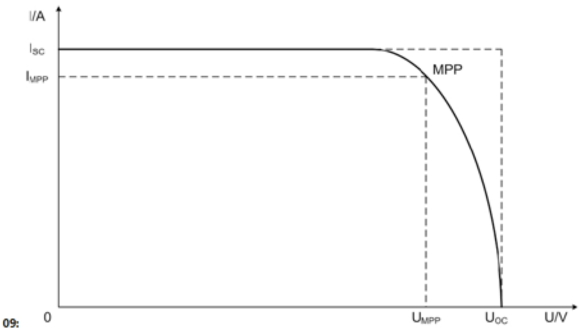

Abb. 09:
I-V curve of a photovoltaic device

By the contrary a similar module set with EVA as encapsulant, did not pass that first round, both cell strings lost about 6,5% of the power, as it can be seen in the table below.

Referenz		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M03	A	1,22	8,85	0,96	8,22	7,88	73,2
	B	1,25	8,85	0,94	7,75	7,27	65,7

1xPID		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M03	A	1,21	8,83	0,94	7,80	7,36	68,81
	168/Ref	0,9926	0,9979	0,9823	0,9494	**0,9341**	0,9400
	B	1,24	8,79	0,91	7,44	6,79	62,56
	168/Ref	0,9888	0,9931	0,9723	0,9594	**0,9343**	0,9522

2xPID		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M03	A	1,21	8,81	0,94	7,72	7,28	68,17
	336/Ref	0,9918	0,9955	0,9792	0,9392	**0,9239**	0,9313
	B	1,24	8,79	0,92	7,51	6,90	63,21
	336/Ref	0,9920	0,9932	0,9787	0,9690	**0,9491**	0,9621

3xPID		Uoc / V	Isc / A	Umpp / V	Impp / A	Pmpp / W	FF / %
M03	A	1,19	8,70	0,90	6,17	5,52	53,36
	504/Ref	0,9754	0,9831	0,9375	0,7506	**0,7005**	0,7290
	B	1,25	8,83	0,93	7,58	7,06	64,17
	504/Ref	1,0000	0,9977	0,9894	0,9781	**0,9711**	0,9767

These results show, with clear evidence, how the dielectrical differences between encapsulants are. They confirm our comments about encapsulants, based in the Volumetric Resistivity measurements.

Looking at the future of photovoltaics we foresee that the dielectric isolation inside of modules is becoming a very important requirement for the modules. The market tendency is going towards the construction of more powerful modules, now yet at 440 W. Obviously this trend is in some way linked to size savings and module surface yield objectives. Needless to say that his “market force” is linked to the installation of more and higher power cells per module. Such sizes modules, with higher voltages and more connectors, will require more strict and higher isolation encapsulants than the ones obtained with standard EVA encapsulants.

Our encapsulant has been developed and manufactured with this vision in mind. Moreover in favor of it, we have to say, that together with the excellent dielectric properties it has also other ones, not less important than its electrical isolation capacity. Characteristics such as UV resistance and humidity barrier properties, that have not been discussed in this document, reinforce the fact that the **NovoSolar® PL is the best interlayer that can be used for the construction of Silicon and Thin Film modules.** The excellent humidity barrier properties of this encapsulant, that are

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also extremely critical for Thin Film modules, reinforce the advantages of using it for this type of modules.

Please feel free to contact us to know more about this subject. You can find us at NovoGenio phone +34 968 981486 or by e-mail at CustomerCare@novogenio.com

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