Properties of encapsulation materials and their relevance for quality control and recent field failures

Module defects | The properties of module encapsulant materials are coming under closer scrutiny as their role in a number of common field failures becomes better understood. Juliane Berghold and Tsuyoshi Shioda report on new testing methods being developed to analyse the composition of encapsulants and improve the quality control of this crucial material

Figure 1. Different module field failures with indirect or direct influence of encapsulation material

An increasing number of frequent and energy yield-relevant field failures are not covered by IEC testing. In this context the properties of the encapsulation material are coming increasingly into the focus due to their impact on the long-term stability of solar modules in the field. Furthermore, in the future the majority of PV installations worldwide will be exposed to more stressful conditions, since the market share of installed PV in desert-like and tropical surroundings will further increase in the coming years. Accordingly, the long-term stability of the encapsulation material will become crucial. For instance electrical and chemical properties of the encapsulation material have been shown to play an important role for the occurrence and avoidance of various module field failures, such as potential-induced degradation(PID), 'browning', delamination, corrosion and 'snail trails' (from left to right in Figure 1).

Relevance of encapsulant for field failures

The vast majority of PV panels worldwide are still produced with ethylene vinyl acetate (EVA) as the encapsulation material, although there are also other promising materials (e.g. POE) with desirable properties entering the PV market. The impact of the EVA material on frequently observed field failures can be either indirect or direct, which shall be shortly illustrated here.

Indirect impact of the encapsulant

As 'media' for charge carrying and mass transportation within the PV module the electrical properties of the selected EVA material determine the level and distribution of leakage current. The leakage current and the resulting ion transport in a PV module is very relevant for field failures such as PID. In Figure 2 the leakage current distribution is shown for two different EVA materials – with very high and very low volume resistivity.

For PID as one of the frequently observed module field failures today, the leakage current distribution in PV modules is crucial and it is not only impacted by the encapsulant but also by environmental conditions the PV module is exposed to (such as temperature and humidity). As a result the specific 'failure pattern' for PID that is observed in a PV plant can be very different as illustrated in Figure 3.

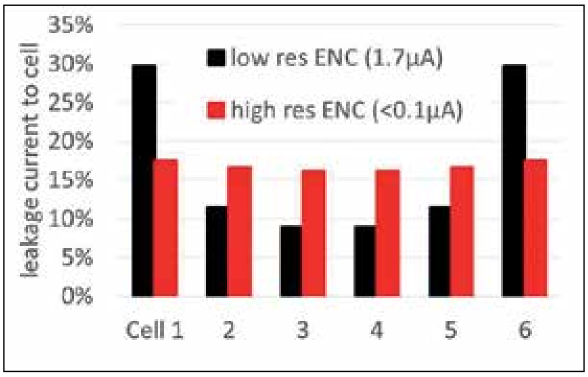


Figure 2. Leakage current distribution depending on kind of encapsulation material (high volume resistivity (10^{15} Ωcm) versus low volume resistivity (10^{13} Ωcm)) [1]

Direct impact of the encapsulant

Furthermore, components or decay products (e.g. acetic acid) of the EVA can also serve directly as a 'reaction partner' for chemical processes within the PV module resulting in visible failures such as corrosion. Moreover, the additives in the EVA – with the purpose of securing specific material properties – could be unstable, added in insufficient concentration or simply missing altogether, causing module failures such as delamination or browning.

As a result it turns out that the specific formulation of the EVA material – which is usually unknown (to the end customer but mostly also to the module manufacturer) – has a very direct impact on the likelihood of certain module defects at specific locations.

An example of the impact of different EVA formulations on the trend for yellowing/browning is given in Figure 4. The difference for the yellowing index is highlighted for 17 and 27 years of outdoor exposure for a location in Japan. However, the difference for these two EVA formulations would be even more

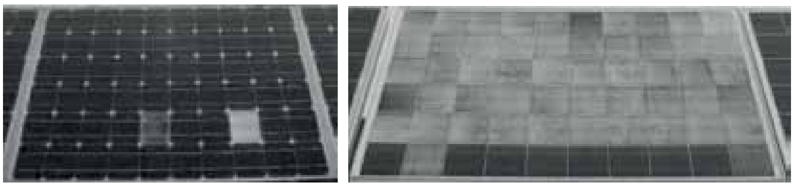


Figure 3: electroluminescence images from PID-affected modules in field: 'surface' PID (left) and 'frame' PID (right) depending on different leakage current distribution in PV modules [1]

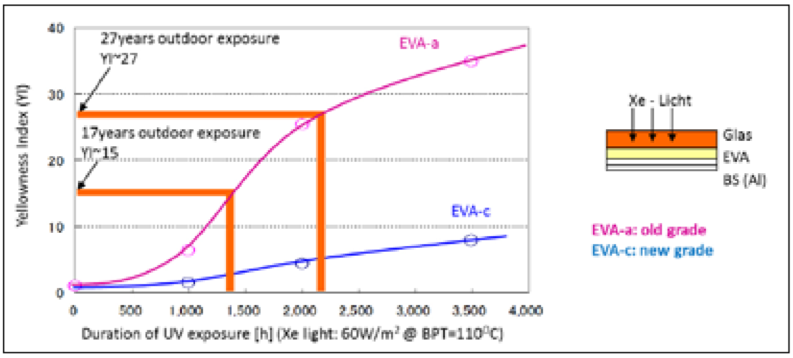


Figure 4. Different trends for the yellowness index for two different EVA formulations

Figure 5. Snail trail formation in indoor experiment and outdoor exposure depending on chemical agents and additives in the EVA (red: clear snail trails; orange: light snail trails) [2]

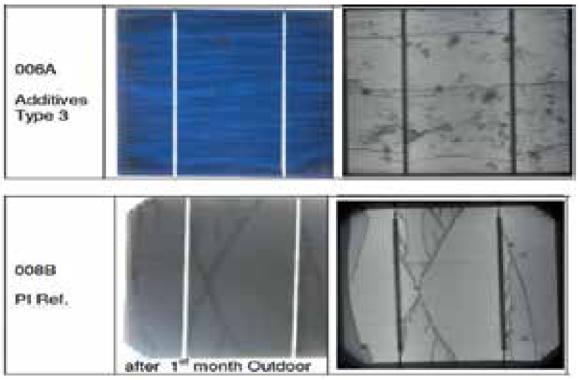


Figure 6. Different visual appearance of snail trails depending on additives in EVA [2]

pronounced for locations with very high irradiance, such as Chile.

Another example of the direct impact of the encapsulant is the frequently observed so-called snail trail formation on PV modules in solar plants. Snail trail formation was investigated for its dependence on the specific EVA formulation, including specific chemical agents and additives. The results of indoor and outdoor experiments (Figure 5) revealed that the formation of snail trails was dependent on the presence of certain additives in the EVA material.

Also the visual appearance of the snail trails was found to be different depending on the specific additives involved (Figure 6).

Quality control and failure analysis

For avoidance and root cause analysis of module field failures related to the encapsulation material different analysis methods are applied by PI Berlin

Additives	Type	Fresh EVA	Cured EVA
Curing agent	a	Detected	Detected
	b	Detected	Detected
	c	Not detected	Not detected
	d	Not detected	Not detected
UV absorber	e	Detected	Detected
	f	Not detected	Not detected
Light stabiliser	g	Detected	Detected
	h	Not detected	Not detected
Anti-oxidant	i	Detected	Detected
	j	Detected	Detected
	k	Not detected	Not detected
Coupling agent	m	Detected	Detected

Table 1. Comparison of the results of the qualitative analysis of selected additives for two EVA samples ('fresh/uncured' (e.g. taken from an EVA roll in production) versus 'cured'(e.g. taken from a PV module in field))

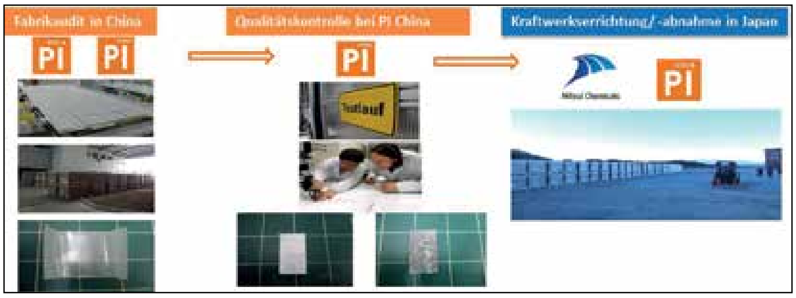


Figure 7. EVA sampling for finger print test during quality control for PV plant

– including volume resistivity measurements, peel testing and gel contents determination.

Furthermore, recently a powerful tool for chemical analysis was developed in cooperation with Mitsui Chemicals – the 'finger print test' for EVA materials. This test procedure includes qualitative and quantitative chemical analysis of selected additives in the EVA material and therefore allows for all sorts of applications relevant for practical purposes – such as quality control, root-cause analysis in case of module defects and resulting reclaim processes.

One straightforward application is for example the confirmation of the 'bill of materials' (BOM) of commercial PV modules. With the finger print test it is now possible to evaluate if the specific EVA in commercial PV modules (in a specific solar plant) is the 'correct' material and therefore in accordance with the 'agreed' BOM or specification (e.g. for a solar project or for a production slot manufactured by an OEM supplier etc.). In Table 1 the comparison of the qualitative chemical analysis for 'cured EVA' (taken from a commercial PV module) and the 'fresh/uncured EVA' (according to BOM/specification) is demonstrated for selected additives.

Furthermore, with the finger print test 'critical' EVA compositions can also be identified. This can be used for the identification of module failures in field. For example if a specific additive (e.g. the coupling agent) in the EVA is missing ('not detected') or found only in insufficient concentration, this can then be identified as a root cause for observed delamination of the PV modules in field.

"In the future the majority of PV installations worldwide will be exposed to more stressful conditions, since the market share of installed PV in desert-like and tropical surroundings will further increase within the next years. Accordingly, the long-term stability of the encapsulation material will become crucial"

Module number	Status	PMMP (W)	Power deviation (%)	PID quality category (PI Berlin)
1	Initial	205.0		C
	After PID	Not detectable	**-100**	
2	Initial	205.6		C
	After PID	Not detectable	**-100**	
3	Initial	204.2		C
	After PID	Not detectable	**-100**	
4	Initial	205.8		C
	After PID	Not detectable	**-100**	
5	Initial	205.2		C
	After PID	Not detectable	**-100**	
6	Initial	205.7		C
	After PID	Not detectable	**-100**	

Table 2. PID lab results for modules from OEM supplier

Examples for finger print testing

In the following two examples from praxis shall be given for the confirmation of the BOM/specification ('correct' EVA material) introduced in section III.

Example 1: Quality control for 20MW plant in Japan

PI Berlin carried out the quality control for a 20 MW plant in Japan in cooperation with Mitsui Chemicals – from production audit and quality control testing of the modules in China until the construction and commissioning of the solar plant in Japan. During the production audit in China EVA samples were taken from a designated EVA roll in production (as specified according to BOM).

For the verification that the modules shipped to the site in Japan were manufactured with the same materials, EVA samples were taken from the PV modules during the QC sampling test in China and finger print testing was conducted with the fresh EVA sample from production and the cured EVA sample taken from the modules designated for shipment to Japan (Fig ure 7).

In this case the finger print test revealed the nonconformity of the two samples. For selected additives the concentration of selected additives were drastically different – for the reference material from production compared with the EVA material utilised for the production of the PV modules for the solar project in Japan.

Example 2: Reclaim regarding xMW of production capacity of an OEM supplier

This case started with first warranty claims from end customers of PV modules (manufactured by an OEM module supplier) at different locations worldwide. PI Berlin was instructed as technical adviser and confirmed PID sensitivity of the modules in lab testing and also progressed PID in different solar plants and locations.

As the PID sensitivity of these modules was found to be extreme with no detectable power after testing (see Table 2), the aim of employing the finger print test for these modules was to evaluate whether or not the EVA material used was in accordance with the specification/BOM agreed with the OEM supplier of these modules.

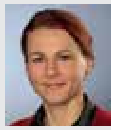
However, in this case the fingerprint test results confirmed that the utilised EVA was in accordance to the agreed specification.

Summary and conclusion

Long-term stability aspects of the encapsulation material are becoming increasingly important as more and more module defects in field are found to be correlated to the EVA material. In the root cause analysis for different field failures (snail trails, delamination etc.) the specific chemical composition of the EVA – which is mostly unknown to module manufactures and end customers – is moving into focus. The relevance of the chemical composition – including the type and quantity of certain additives – will further increase also in more stressful climates (in terms of radiation, temperature and humidity).

The finger print test is an innovative new tool for quality control, root cause analysis and reclaim processes for PV modules. ■

Authors



Juliane Berghold received her Ph.D. in physical chemistry in 2006 from Freie Universität Berlin. She has more than 15 years' experience in PV technology, including R&D, consultancy and management. She currently heads the PV module technology and R&D services business unit at PI Berlin.

Tsuyoshi Shioda received his M.Eng. degree in electronics in 1997 and his Dr.Eng. degree in chemistry in 2005 from Tohoku University, Japan. In 1997, he joined Mitsui Chemicals, Inc. He has been an expert of Japanese NC of IEC/TC82/WG2 where standardisation for PV modules has been discussed. He has conducted researches related to reliability of PV modules and PV materials since 2008. Now he focuses on running new businesses concerning diagnosis of a PV power plant and a PV module utilising his expertise.

References

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[2] Berghold et al., *Electrochemical Corrosion within Solar Panels*, Conference Paper • September 2012, Conference: 27th European Photovoltaic Solar Energy Conference, At Frankfurt a. M. / Germany, Volume: page 3511-3517