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FEM-SIMULATION OF WATER VAPOR INGRESS INTO GLASS-GLASS-MODULES WITH POLYMERIC EDGE SEALANT AND A NEW EXPERIMENTAL SET UP FOR PERMEATION TESTS FOR SEALING MATERIAL

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ABSTRACT: PV module designs using glass plates as front and as back covers are often used to minimize moisture ingress. Both effects, moisture ingress and moisture leakage are found to contribute to the degradation of the PV-modules. The moisture transport for different material combinations for PV modules was numerically simulated by Finite Element Methods (FEM) and validated by permeation tests [1]. Previously simulated water vapor ingress through back sheets is compared to simulations on water vapor ingress through edge sealants. Edge sealant properties were determined in a literature survey. Finally, a new in-house developed upgrade for the permeation test method enables measurements of edge sealants based on the existing permeation equipment.
Keywords: Glass-Glass Modules, Edge Sealant, Water Vapor Ingress, Permeation Test Method, FEM Simulation, Modelling

1 WATER VAPOR INGRESS

Up to now, it is uncertain whether an edge sealant that is perfectly tight against moisture ingress is to be preferred for glass-glass modules, in order to prevent water-related degradation effects like corrosion. Main influences on the reliability of photovoltaic (PV) modules are the environmental conditions. Glass-glass-PV-modules use glass plates for the front and back cover to protect the PV-cells against ingress of water vapor and other gasses. Thereby, the benefit of using glass is the very small diffusion cross-section for water vapor and other gases limited to edges and openings, which could otherwise contribute to degradation of the PV-modules. This paper gives an overview on a FEM-simulation of mass transport through polymeric edge sealants into glass-glass PV-modules. The Finite Element Method (FEM) offers the advantage of facilitating a preliminary comparison and qualification of PV module materials without long-term permeation measurements. The aim was to compare edge sealant types and materials in different module design and climatic conditions to evaluate possible material matches for a reliable module built-up. Subsequently, an in-house permeation test stand was upgraded to measure water vapor ingress into elastic edge sealant materials.

2 SIMULATION OF MOISTURE IN GLASS-GLASS MODULES

2.1 The theoretical simulation model

The simulation by finite element method with COMSOL multi physics implements material properties of commercially available edge sealant products like polyisobutylene (PIB) or silicone. These were found in literature or can be determined by permeation measurements. Subject of the presented simulation is a glass-glass module with PIB as high-barrier edge sealant with following properties, listed in Table 1 [2].

Table I: Diffusion properties at ambient temperature of a common butyl material

Property		value	unit
Max. Moisture Uptake	u	0.02	%
Diffusion coefficient	D	$4*10^{-14}$	m²/s
Actication energy (Diffusion)	$E_A(D)$	54,8	kJ/mol

2.2 Simulation boundaries

Water vapor ingress was simulated through the bulk of the edge sealant. Diffusion processes at interfaces were neglected.

The water concentration due to specific diffusion coefficients was calculated with the help of the Arrhenius equation. The equation allows a transformation of the real world climatic data to the micro climate around a PV-module and incorporates the strong temperature dependency of polymeric material properties.

A simulation model according to real module dimensions (Figure 1) was set up.

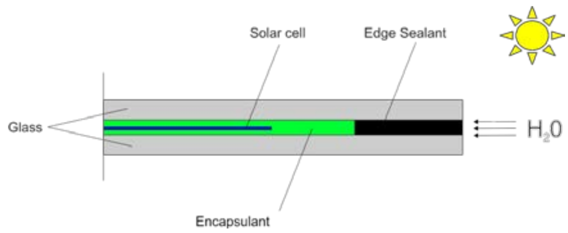

Figure 1: Schematic model of water vapor ingress into the glass-glass PV-module.

2.3 The climatic adaption for PV modules

All calculations were performed taking into account the micro climate around the module. Therefore, real world climatic data, mainly the parameters ambient temperature T_a, relative humidity φ and solar irradiance H, were used. Module temperature T_{mod} was estimated according to the Faiman Model.

Based on the fitted model, several specific climatics were simulated to represent the influence of temperature and relative humidity. The objective of the simulation was the determination of the impact of high relative humidity and high temperature climates on the diffusion rate as well as on the moisture equilibrium in the material including moisture concentration at equilibrium conditions and time until the equilibrium is reached.

2.4 Simulation and permeation measurement

A validation of the numerical calculation was performed previously by permeation measurements of standard encapsulant material EVA with an existing permeation test stand [1]. A permeation measurement test stand enhancement for edge sealant material is developed in-house as described in the following section 3.

3 PERMEATION MEASUREMENT

3.1 The measurement setup

An in-house developed measurement setup was used to perform water vapor permeation tests. The sample holder consists of a stainless steel tube with stainless steel screw-on endcaps.

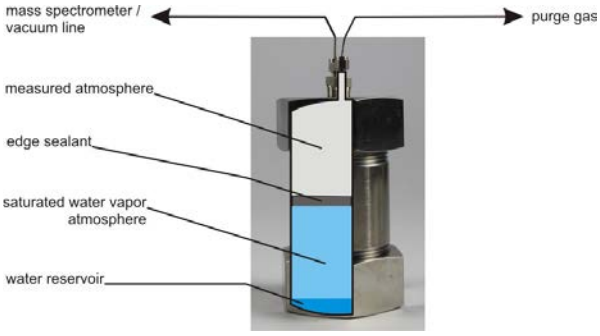

Figure 2: Sample holder for water vapor measurements with illustrated functional principle.

The sample holders can be connected to a mass spectrometer (OmniStar^{TM} GSD 320 O1, Pfeiffer Vacuum, Germany) for the measurement of the gas phase above the material. The signal detection and data analysis has been described before [3].

3.2 Measurement of edge sealant material

Edge sealant materials can be tested in a specially developed sample holder for water vapor measurements. The innovative component is the developed sample holder enabling the measurement of edge sealant materials over a prolonged period of time. For this purpose, the sample holders are stored at a constant temperature and gas concentration is measured after defined intervals (

Figure 3).

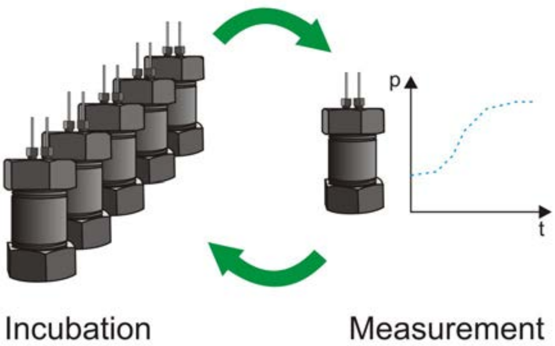

Figure 3: Procedure for the measurement of the cartridges: the sample holders are stored at the permeation temperature and measurements are performed in certain time intervals.

4 RESULTS

4.1 FEM

With the aim of simulating degradation processes in PV modules, our first approach is to simulate water vapor ingress into PV modules. Water vapor ingress depends on the climatic conditions. Figure 4 shows the calculated moisture concentration within the EVA encapsulation of a glass-glass module equipped with a PIB edge sealant over time in 4 different climatic conditions:

- Cologne, Germany (moderate)
- Negev Desert, Israel (arid)
- Serpong, Indonesia (tropic)
- Zugspitze, Germany (alpine)

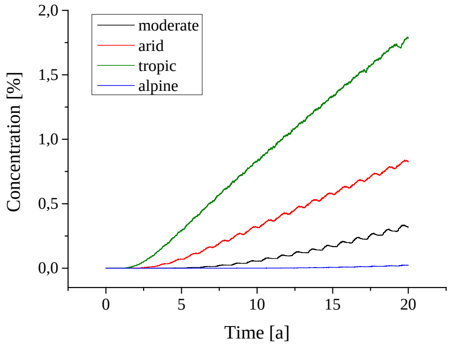

Figure 4: Moisture concentration over 20 years within the glass-glass module with edge sealant (EVA / PIB) at different climatic conditions, calculated for the diffusion path from the module edge to the center line of the closest solar cells.

The hot-humid tropic climate enables more moisture to penetrate into the PV module`s encapsulant. But within the simulated time frame of 20 years, the development of moisture over time shows for none of the scenarios an equilibrium within the encapsulant EVA, which has been found in outdoor exposed material to be around 50 % [4]. Thus, in regions with high relative humidity and high temperatures high diffusion rates and hence a faster increase of the moisture concentration should be expected. To prevent this moisture ingress, a certain material configuration for the edge sealant as moisture barrier is needed. Figure 5 shows results for different length (LD) of the edge sealant. The length LD gives the distance between environment and encapsulation material, which the moisture has to pass on its way into the PV module. As reference a graph without edge sealant (LD=0 mm) is given.

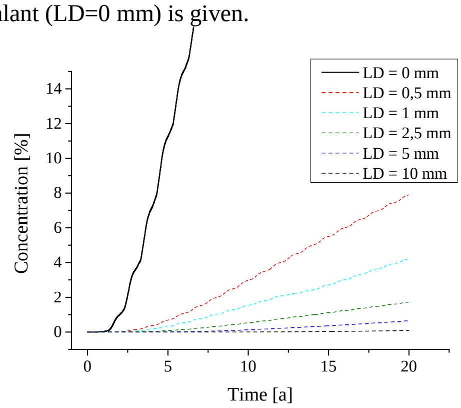

Figure 5: Moisture concentration over 20 years moderate climate within the glass-glass module with edge sealant (EVA / PIB) of different length, calculated for the

diffusion distance to the first solar cells center line.
The graph shows that even short length distances of edge sealant with accordingly small diffusion coefficient can dramatically decrease the moisture concentration inside PV-modules and thus protect the sensitive metallization of the cells. In addition, the diffusion coefficient was modified to investigate impacts of sealant material aging as shown in Figure 6.

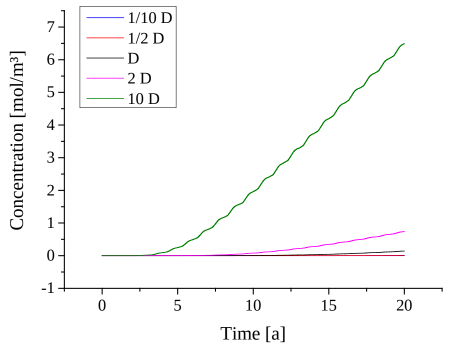

Figure 6: Moisture concentration over 20 years within the glass-glass module with edge sealant (EVA / PIB) at different diffusion coefficients, calculated for the diffusion distance of the first solar cells center line

The result of the simulation using edge sealant materials with different diffusion properties and also various geometric dimensions of the edge sealant demonstrate the potential savings of edge sealant material. Already a thin layer of the edge seal material polyisobutylene is sufficient to slow the diffusion rate significantly.

5 CONCLUSION AND OUTLOOK

The simulation result shows that especially in regions with high relative humidity and high temperatures there is a high rate of diffusion and thus a higher moisture concentration is reached faster. With these results it is possible to give a forecast on the moisture concentration in a PV-module depending on defined conditions by FEM simulations.

Measurements of the real water vapor ingress during permeation tests allow not only the validation of the simulation results but form also the basis for further simulations. In order to screen most promising product alternatives a detailed knowledge of the water vapor transmission properties of the individual material is required. Due to technical difficulties of the permeation measurements of adhesive sealing materials, like ductile edge sealant material, only little data is available until now. Therefor a new developed permeation test method for difficult ductile material is designed and currently under evaluation. With the proposed experimental approach these technical obstacles can be reduced and such difficult or up to now impossible measurements can be made possible.

6 REFERENCES

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