Moisture ingress into PV modules: long-term simulations and a new monitoring technique

Eleonora Annigoni¹, Federico Galliano¹,², Marko Jankovec², Heng Yu Li¹,³, Laure-Emmanuelle Perret-Aeb³, Christophe Ballif¹,³, Fanny Sculati-Mellaud¹

¹ Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Photovoltaics and Thin Film Electronics Laboratory, Rue de la Maladrerie 71b, 2000 Neuchâtel, Switzerland
² University of Ljubljana, Faculty of Electrical Engineering, Laboratory of photovoltaics and optoelectronics, Trzaska cesta 25, SI-1000 Ljubljana, Slovenia
³ CSEM, PV-center, Jaquet-Droz 1, 2000 Neuchâtel, Switzerland
e-mail: eleonora.annigoni@epfl.ch

Goals and Motivations

- Predict moisture ingress into PV modules during long-term outdoor exposure, identifying impact of climate conditions and encapsulation scheme
- Improve modules life-time by better understanding water-related degradation mechanisms (e.g. delamination [1,2], potential induced degradation (PID) [3])
- Water ingress is modeled with 2D Finite Elements Method (FEM) as a diffusion problem and simulated for:
  - three different climatic conditions
  - two different encapsulation schemes.
- A new monitoring technique is then employed to measure the relative humidity inside the PV modules and validate the simulation model.

Simulations model

- Water ingress in PV module materials described by Fick’s Second Law of Diffusion:
  \[ \frac{\partial c(x,t)}{\partial t} = D \left( \frac{\partial^2 c(x,t)}{\partial x^2} \right) \]
- Solved by FEM with experimentally determined water diffusion coefficient \( D \) and solubility \( S \) of EVA and backsheet
- Water concentration at the outer surface calculated with Henry’s law:
  \[ c_{surf}(t) = S \cdot P_a \cdot o(t) \]
- 2-D geometry assuming infinite length in the 3rd dimension
- Symmetries (dotted lines) exploited to reduce computational times, with Glass/Glass (G/G) scheme also vertically symmetric
- Modules assumed initially dry
- Output: time-evolution of water concentration in different positions in the module (edge, front, back)

Glass/Backsheet: 1 climate, 1 yr

- Observations:
  - As expected: fastest moisture ingress in tropical climate (high temperature and high relative humidity), with clear seasonal variations, particularly at the edge
  - G/G reduces moisture accumulation with respect to G/BS (moisture content at cell back already larger in G/BS after 1st year than in G/G after 20 years).
  - In G/BS, seasonal variations clearly visible at the cell back (increase in water concentration during cold and humid winter).
  - G/B simulations must now be extended to longer time-scales, such as in [4].

Working principle

- Miniature digital relative humidity (RH) and temperature (T) sensors were soldered on a Printed Circuit Board (PCB) strip.
- The PCB strip was then laminated in G/G and G/BS samples.

New monitoring technique: Encapsulated relative humidity sensors

- First results: Good agreement between measurement and simulation

Simulations vs Measurements

- Water concentration inside PV modules was simulated for different climates and encapsulation schemes:
  - As expected, tropical climate induces fastest water ingress, however cool & humid climate also features high water content after 20 years
  - G/BS after 1 year already shows higher water content than G/G after 20 years
  - For G/BS, good agreement between simulated results and outdoor monitoring. But further (ongoing) experiments required, also in climatic chambers.
- Optimized choice for encapsulant materials, and in-depth investigation of moisture-related failure modes (e.g. delamination, PID) can be performed based on this analysis.

Conclusions/Outlook

- Water concentration inside PV modules was simulated for different climates and encapsulation schemes:
  - As expected, tropical climate induces fastest water ingress, however cool & humid climate also features high water content after 20 years
  - G/BS after 1 year already shows higher water content than G/G after 20 years
  - For G/BS, good agreement between simulated results and outdoor monitoring. But further (ongoing) experiments required, also in climatic chambers.
- Optimized choice for encapsulant materials, and in-depth investigation of moisture-related failure modes (e.g. delamination, PID) can be performed based on this analysis.

Acknowledgments

This work has been supported by Swiss Federal Office For Energy (grant SI500750-01) and EOS Holding.

References