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PV MODULE LIFE TIME FORECAST AND EVALUATION

Modelling and Monitoring of Moisture Diffusion in Encapsulants and PV Mini-Modules

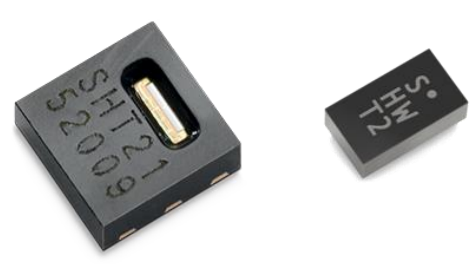
S. Mitterhofer, J. Slapšak, M. Topič, M. Jankovec
Faculty of Electrical Engineering, University of Ljubljana / Tržaška cesta 25, Ljubljana / +386 1 4768 848 / stefan.mitterhofer@fe.uni-lj.si

MOTIVATION

Water, in the forms of relative humidity in the air as well as precipitation and dew, is a crucial environmental factor affecting the degradation of PV modules. Moisture can ingress through the backsheet into the encapsulant. It has been linked to various degradation modes, for example corrosion and delamination.

MEASUREMENT METHOD

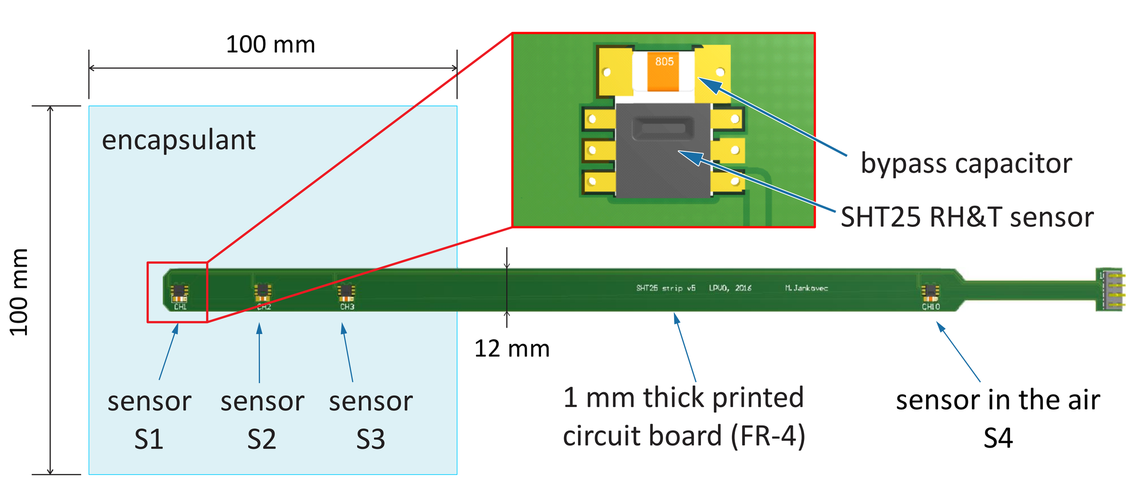
- Digital miniature temperature and humidity sensors mounted on printed circuit board strips
- Custom readout electronics and software



[sensirion.com]

EXPERIMENT – CLIMATIC CHAMBER

- Sensors laminated between two encapsulant layers
- Four used encapsulants: an ethylene-vinyl acetate (EVA), a thermoplastic olefin (TPO), a polyolefin elastomer (POE), an ionomer
- Measurements of ingress and egress between 20% and 40%, 60%, 80% relative humidity set in the climatic chamber
- Constant temperature



[Jankovec et al, 7th WCPEC, 2018]

FINITE ELEMENT SIMULATIONS

- Simulations based on Fickian diffusion model in two dimensions
- The governing differential equation is Fick's Second Law of Diffusion in two dimensions with constant diffusion coefficient:

$$\frac{\partial C}{\partial t} = D \cdot \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right)$$

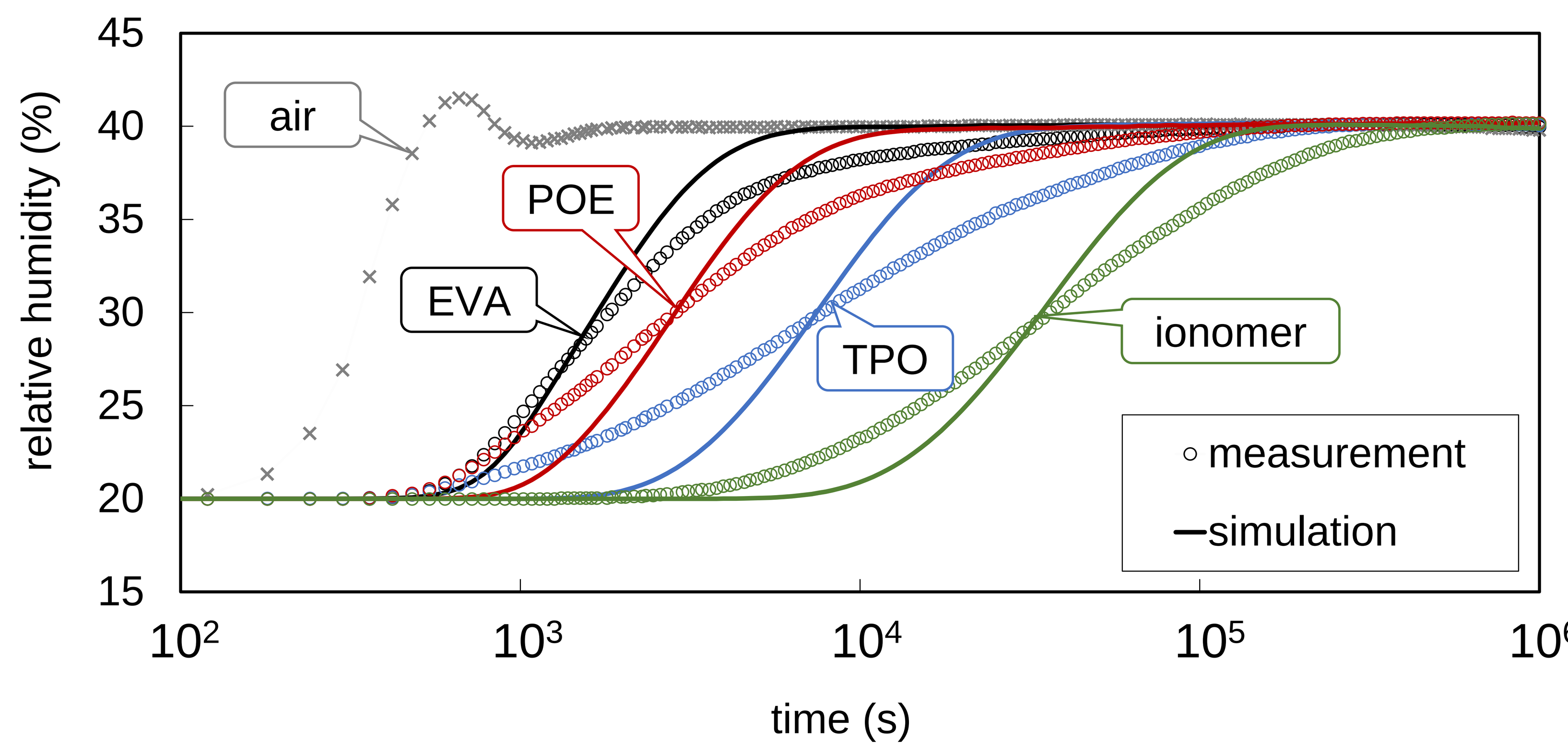
  - C: water concentration, proportional to the measured relative humidity at constant temperature
  - D: diffusion coefficient of the material
- Time discretization with Crank-Nicholson method
- Resulting weak form:

$$0 = \int_\Omega \left(C_m v + \frac{1}{2} D \cdot \delta t \cdot \nabla C_m \cdot \nabla v \right) d\Omega - \int_\Omega \left(C_{m-1} v + \frac{1}{2} D \cdot \delta t \cdot \nabla C_{m-1} \cdot \nabla v \right) d\Omega$$

  - v: any test function $v \in H^1(\Omega)$
  - m: number of time step
  - δt: duration of the time step between m and $m-1$
- Dirichlet boundary condition: C set to the measured relative humidity in the chamber
- Solved with FreeFEM++ software

RESULTS

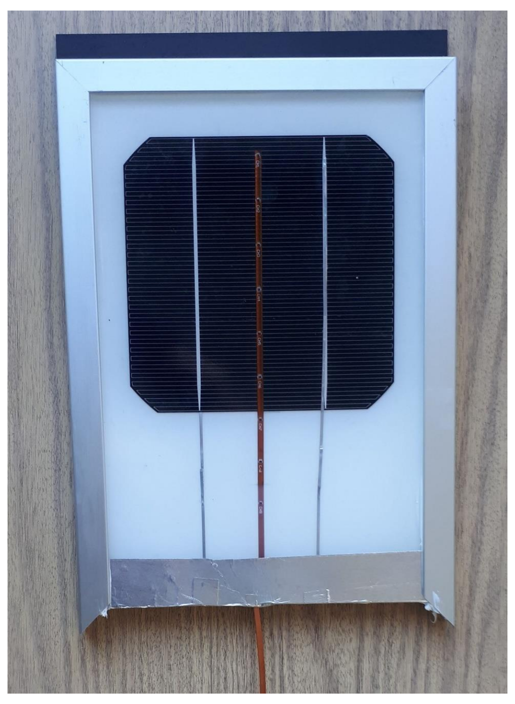
- Large variations of moisture transport properties of various encapsulants
- Accuracy of the Fickian model depends on the polymer

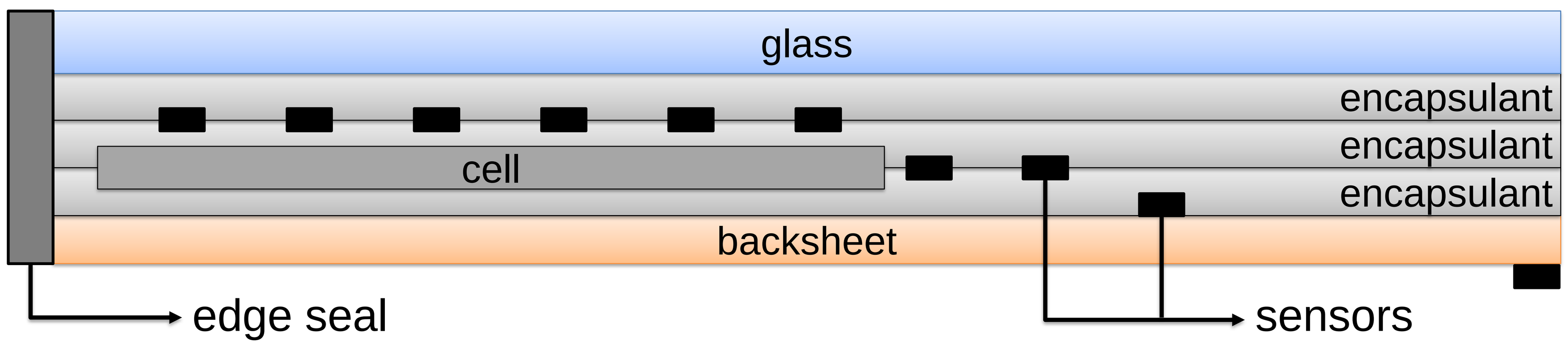


EXPERIMENT – OUTDOOR

Mini-modules

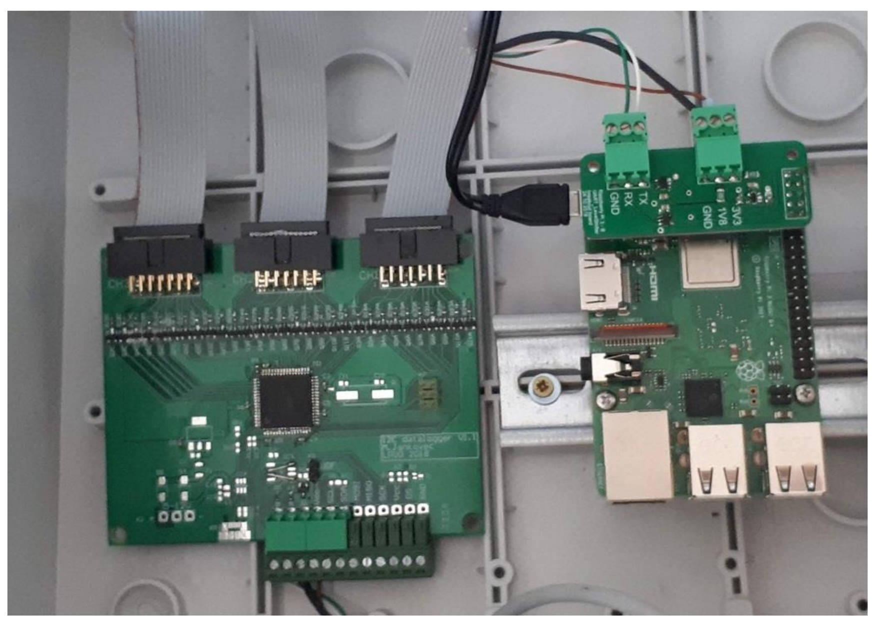
- Mini-modules out of various materials for outdoor moisture and temperature monitoring
  - EVA + white polyethylene terephthalate (PET)
  - EVA + black PET
  - TPO + white PET
- Miniature sensors at different positions inside the mini-modules
  - 9 inside
  - 1 outside, measuring the module surface at the backsheet

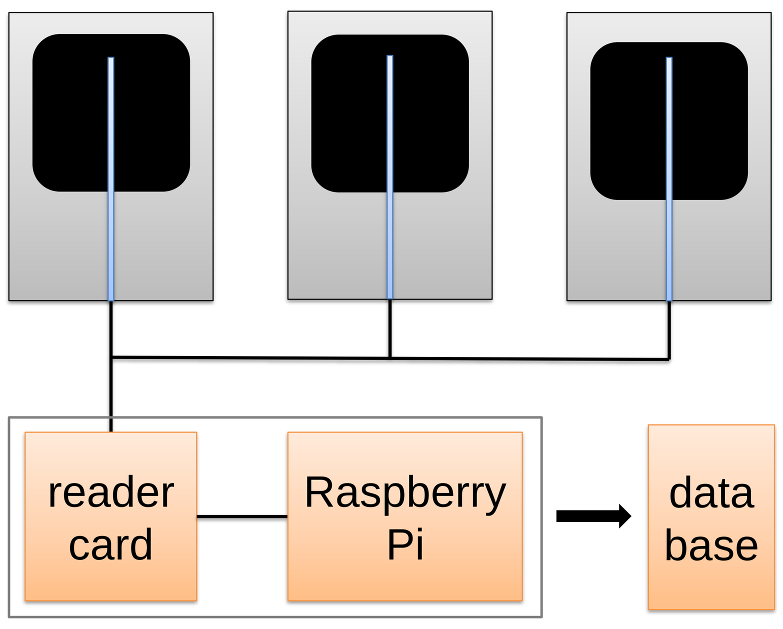




Setup

- Controlled with a RaspberryPi 3 Model B+
- Custom electronics (reader card) and software (Python, C)
- Electronics inside IP68 box, mounted together with 3 mini-modules
- Data stored locally and transmitted to database





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