Void Evolution during the Encapsulation Process of PV modules

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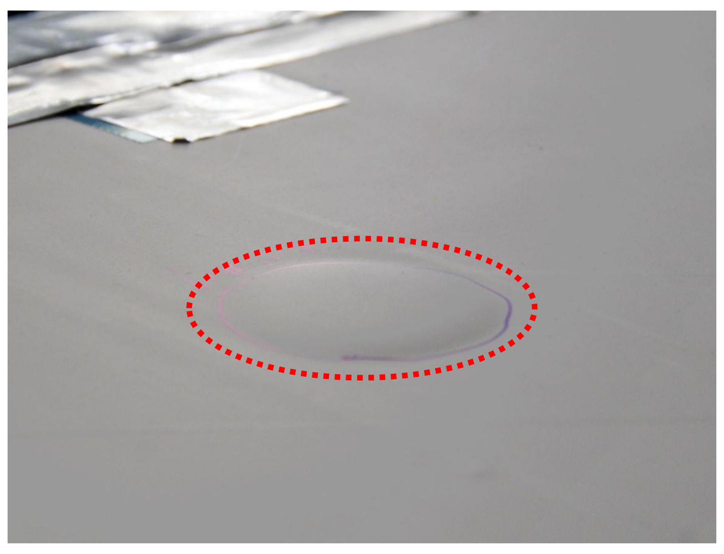
Motivations and goals

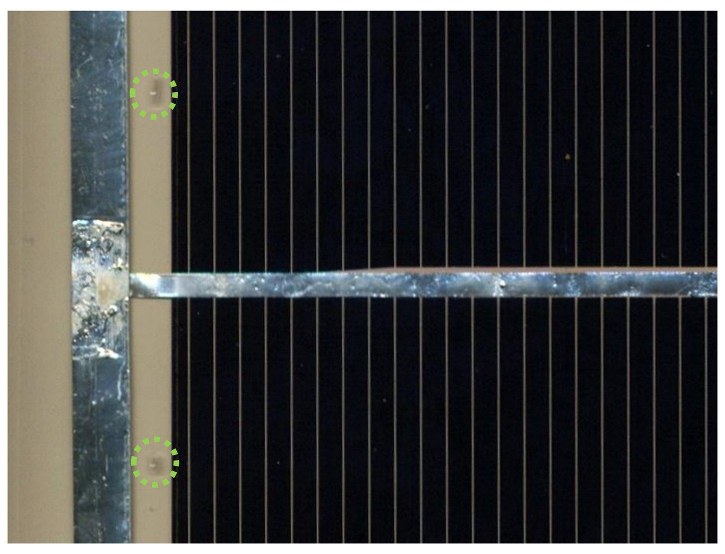
- **Voids formation is an important criteria for judging the encapsulation quality of PV modules.**
- **Deep understanding on the voids evolution is key to the development of voids-free encapsulation process of PV modules.**

Types of voids

Type-I voids



Type-II voids



H.-Y. Li et al., Void Evolution during the Encapsulation Process of Photovoltaic modules. Submitted (2014)

Type-I voids

Characteristics
- Flat packet
- Mostly at module back

Possible origins
- Mechanically entrapped air due to insufficient evacuation
- Delamination
- Great amount of volatiles during encapsulation (e.g., from Al paste at cell back)

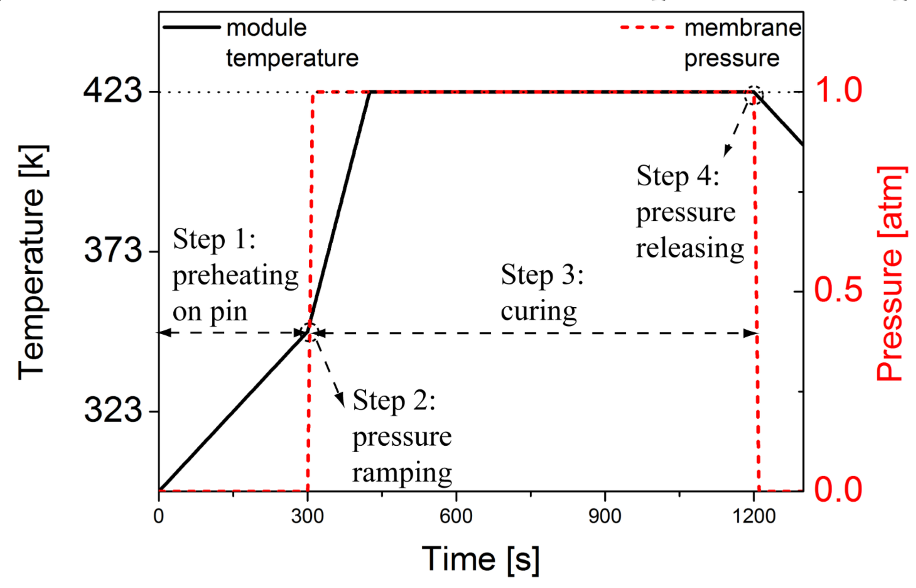
Type-II voids

Characteristics
- Quasi-spherical
- Mostly embedded in encapsulant

Possible origins
- Residual solvent in EVA film;
- Volatile from soldering flux;
- Dehydration between silane primer and glass surface;
- Surface contaminations;
- EVA volumetric shrinking;
- **Pre-dissolved wet air**

Modeling approach

T-P-t profiles of the module encapsulation process



Diffusion-controlled voids evolution model

$$\beta = \frac{C_{resin} - C_{vs}}{\rho} \quad (1)^{[1]}$$

$$C_{vs} = 8.651 \times 10^{-14} e^{9784/T} \cdot P_{water}^{\ 2} \quad (2)$$

$$\rho = (1 - X_{air}) \cdot \left(\frac{M_{water} \cdot P}{R \cdot T}\right) + X_{air} \cdot \left(\frac{M_{air} \cdot P}{R \cdot T}\right) \quad (3)$$

$$P_{water} = (1 - X_{air}) \cdot P \quad (4)$$

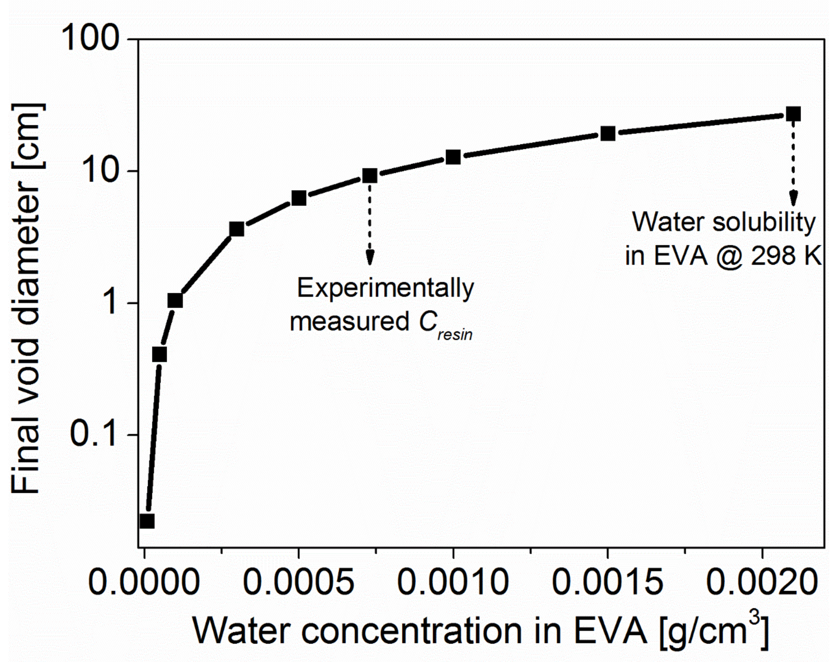
$$X_{air} = \left(\frac{P_0 \cdot T}{P \cdot T_0}\right) \cdot \left(\frac{a_0}{a}\right)^3 \quad (5)$$

$$a = 4\beta \cdot \sqrt{D \cdot t} \quad (6)$$

$$D = D_0 \cdot e^{\frac{-Ea}{R \cdot T}} \quad (7)^{[2]}$$

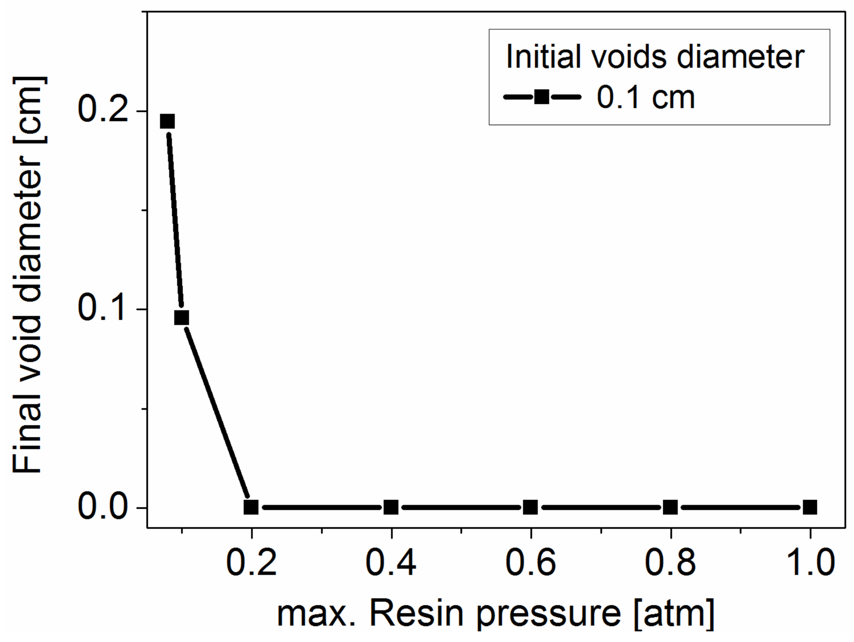
- When $\beta<0$, voids will shrink; when $\beta>0$, voids will grow;
- Parameters for modeling the voids growth are taken from the typical EVA encapsulation process in flat-bag vacuum-bag laminator.

Selected results: Step 1



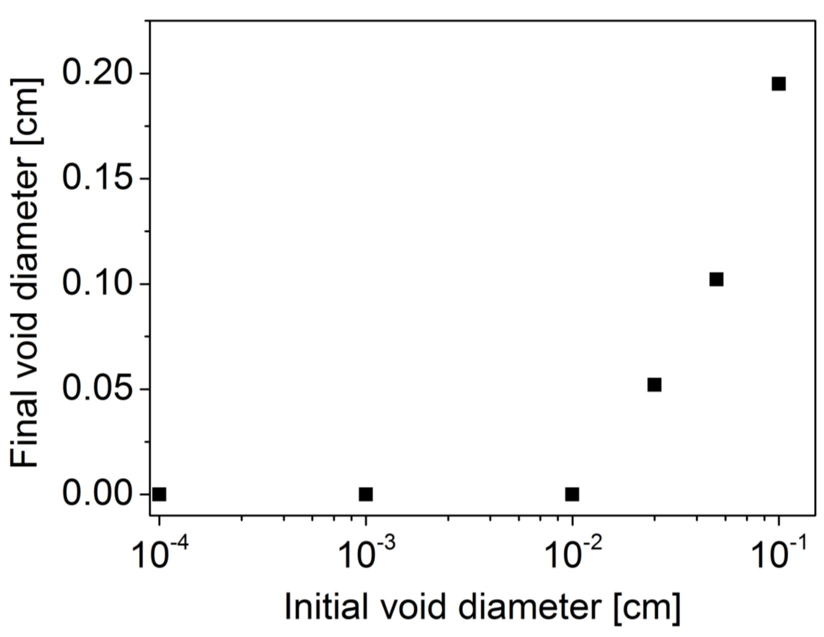
Parameters governing voids evolution
- Duration: moderately long is favored;
- Lower-chamber pressure: lower is favored;
- Water concentration in EVA: minor effect.

Selected results: Step 2



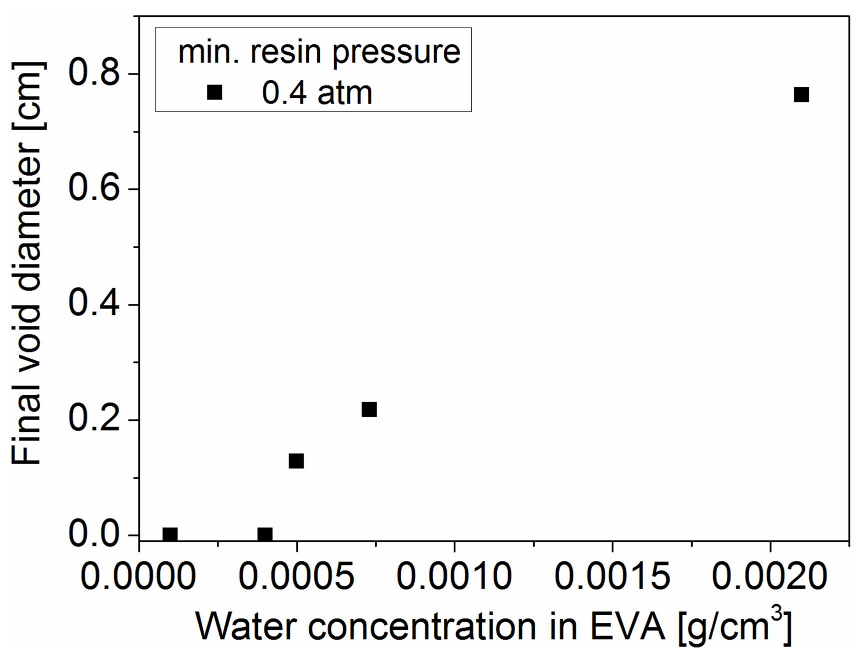
Parameters governing voids evolution
- Upper-chamber pressure: higher is favored;
- Water concentration in EVA: lower is favored.

Selected results: Step 3



Parameters governing voids evolution
- Initial voids size at start: smaller is favored;
- Water concentration in EVA: lower is favored.

Selected results: Step 4



Parameters governing voids evolution
- EVA gel content: higher is favored;
- Water concentration in EVA: lower is favored.
- EVA resin pressure: higher is favored

Summary

- Voids appearing in the PV modules after encapsulation are grouped into 2 types. Possible origins are analyzed.
- A diffusion-controlled model has been adapted to simulate the evolution of voids consisting of wet air in EVA.
- Governing parameters over voids evolution in EVA encapsulation process are analyzed and listed in the 'Results' section.
- Effect of Type-II voids on the PV module reliability in DH testing was studied and presented elsewhere.

[1] Kardos JL, et al. Adv Polym Sci 80 (1986): 102–123.
[2] Kempe. MD. Energy Materials & Solar Cells 90 (2006): 2720–2738.