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CHARACTERIZATION OF DYNAMIC LOADS ON SOLAR MODULES WITH RESPECT TO FRACTURE OF SOLAR CELLS

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INVENTED IN GERMANY — SOLARVALLEY Mitteldeutschland

Motivation

- Cracks in solar cells are identified as a key issue in module reliability concerning stability of performance as well as product safety [1].
- Large scale cracks are initiated by mechanical loading (wind, snow, transport, handling).
- Wind loads usually come with a static portion of the load superposed by dynamic portion (vibration) [2].
- Frequencies up to 14 Hz and an amplitude of 1.6 mm [2] leads to a deflection ramp of ~5200 mm/min. *
- Polymeric encapsulant transfers strain from glass to solar cell [3]. *

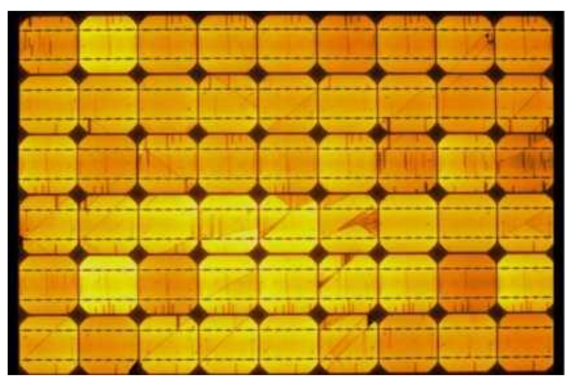


Fig. 1: EL image of cracks in solar cells

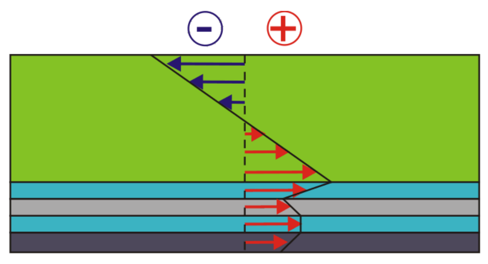


Fig. 2: Strain gradient across laminate cross section

Material Modeling

- Polymers show temperature and strain rate dependent stiffness *
- visco-elastic modeling of polymer material required (i.e. frequency sweeps in DMA) *
- development of Prony-series and translating in generalized Maxwell * model *
- utilization of time-temperature-superposition *

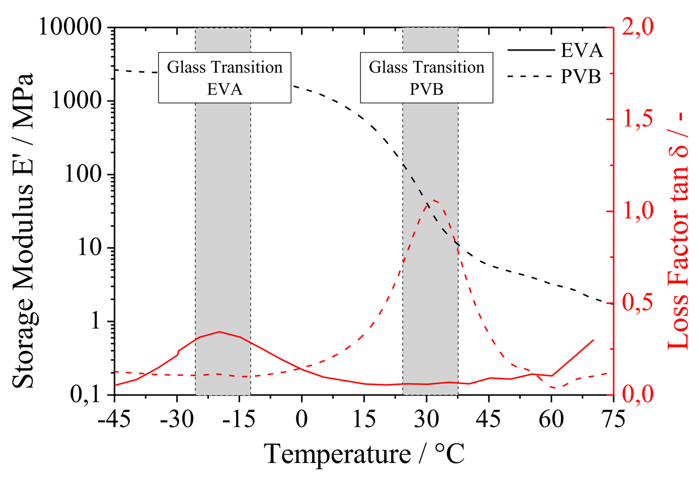


Fig. 3: Dynamic-Mechanical-Analysis of an EVA and PVB at 1 Hz

Finite-Element-Model Approach

- superposition of mechanical stress field from each simulation step

Soldering	Lamination	Temperature Change	Mechanical Load
183 °C → 20 °C	140 °C → 25 °C	25 °C → 75 °C 25 °C → -35 °C +	4-Point-Bending +

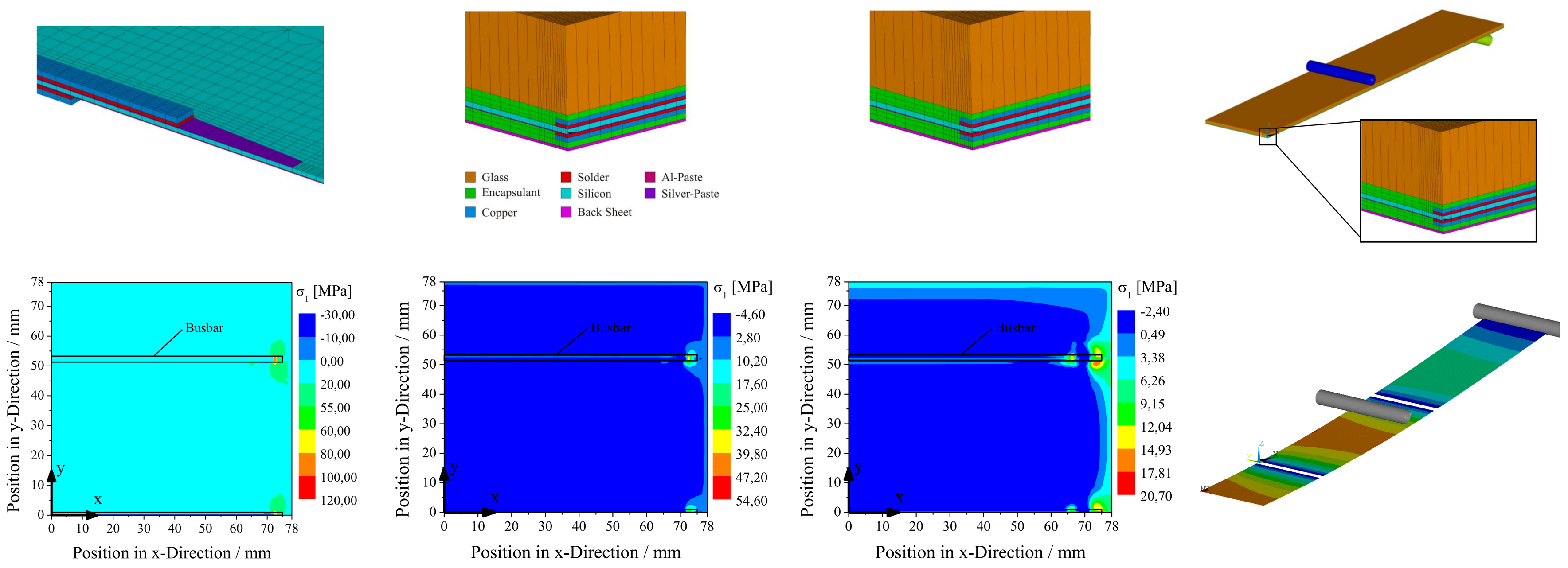
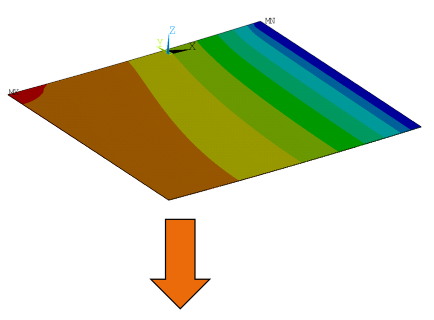


Fig. 4: 1st Principal Stress in top side of silicon at several temperature steps and 4-point-bending top: Finite- Element- Model; bottom: 1st principal stress plots in top side of silicon

Results – Superposition of Loads

1st Principal Stress &



Probability of Failure P_f

$$P_f = 1 - exp\left[-A_e\left(\frac{\sigma_{max}}{\sigma_0}\right)^m\right]$$

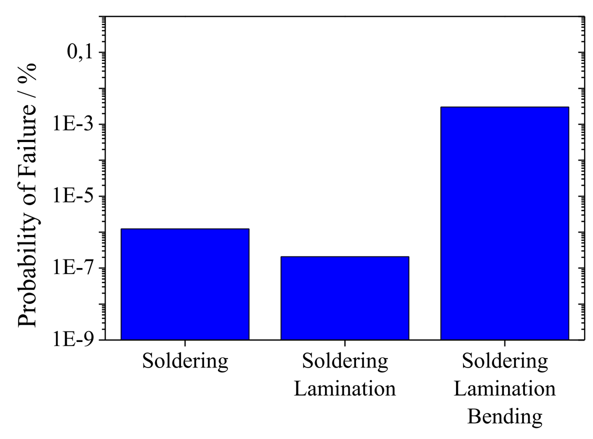


Fig. 5: Superposition of soldering, lamination and 4-point-bending

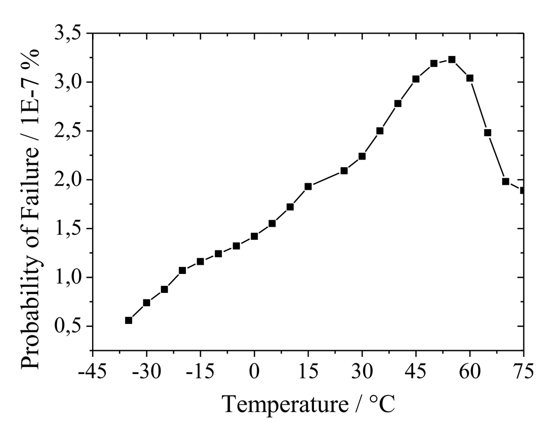


Fig. 6: Probability of failure during of a solar cell during cooling / heating of module laminate (for EVA)

Results – 4-Point-Bending &

- reduction of P_f after lamination (Fig. 5) due to increased pressure load across cell (Fig. 4)
- PVB shows higher stiffness level and larger dependency on time (Fig. 6)
- visco-elastic behavior of encapsulant characterizes the load on solar cells (Fig.7) *
- generally at low temperatures strain rate dependency decreases (Fig. 8)
  - but: glass transition increases damping (i.e. see loss factor for EVA) *

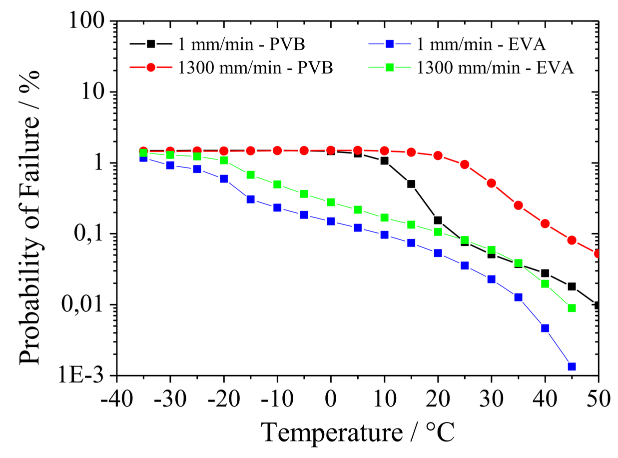


Fig. 6: Development of probability of failure over temperature

Discussion

- time-temperature superposition important for definition test conditions at room temperature (Fig. 8) *
- example EVA *
  - influence of load ramp similar in the range between -15C and +30C with mirror axis at +10C
  - adjustment of magnitude of load required (see Fig. 6 and 8) *
- example PVB
  - glass transition in the range of RT
  - temperature during testing should be carefully controlled *
  - testing at RT with high load ramp can simulate load on cells at low * temperatures (Fig. 6 and 8) *

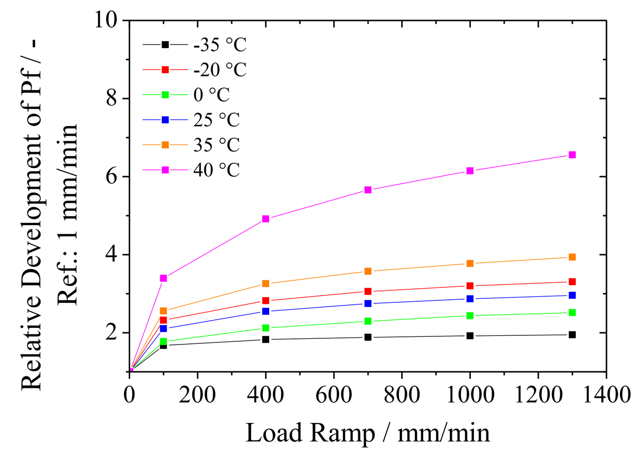


Fig. 7: Relative development of probability of failure over load ramp (for EVA) *

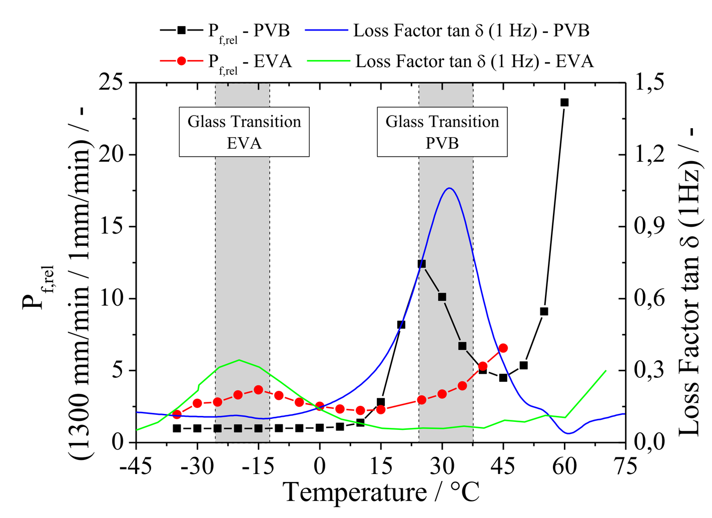


Fig. 8: Relative difference of probability of failure between 1 mm/min and 1300 mm/min * over temperature for EVA and PVB

Results – Modules

- IEC CD 62782 "Dynamic Mechanical Load Testing"
  - 1000 Pa
  - 7 sec dwell time at elevated load
  - 1 – 3 cycles/minute
  - room temperature
- number of cycles / min crucial to applied load on cells *

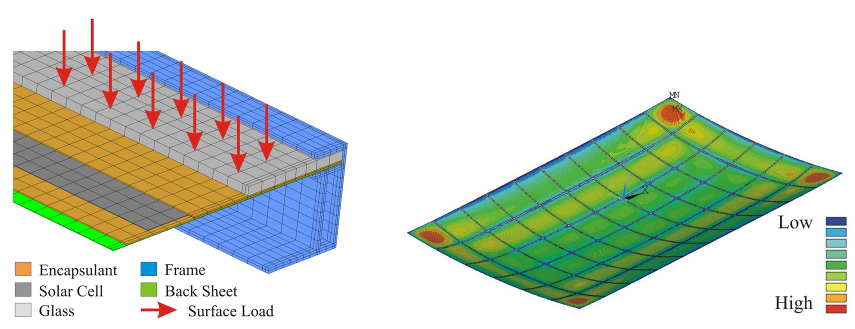


Fig. 9: left: Finite-Element-Model for complete solar modules with distributed surface load; right: 1st Principal Stress in solar cells *

Cycles [min⁻¹]	Dwell Time [sec]	Time [sec/1000 Pa]	Ramp [Pa/sec]	Ramp [N/sec]	Ramp [mm/min]	P_f Relative Change + [-]
0.02	7	746.5	1.34	2.14*1	1*2	1.00 / 0.65
1.00	7	11.50	87	139*1	70*2	1.53 / 1.00
3.00	7	1.50	666	1067*1	533*2	1.81 / 1.18
3.66	7	0.60	1671	2674*1	1300*2	1.95 / 1.28
4.00	7	0.25	4000	6400*1	2834*2	2.08 / 1.37

*1 Module size 1.6 m²
*2 Example from FE-Simulation for 1.6 m² Module (1000 Pa)
Simulations carried out for EVA at 20 °C

Bibliography &

[1] J. Wohlgemuth et al., "Long term reliability of PV modules" Proc. 20th EU-PVSEC, 2010 *

[2] M. Assmus et al., "Experimental investigation of the mechanical behavior of photovoltaic modules at defined inflow conditions" J. of Photonics for Energy Vol. 2, 2012

[3] S. Dietrich et al., "Interdependency of mechanical failure rate of encapsulated solar cells and module design parameters", Proc. SPIE Optics & Photonics, 2012