Fraunhofer CSP

FRAUNHOFER CENTER FOR SILICION PHOTOVOLTAICS CSP

MECHANICAL ISSUES ON SOLAR MODULES AND ENCAPSULATED COMPONENTS

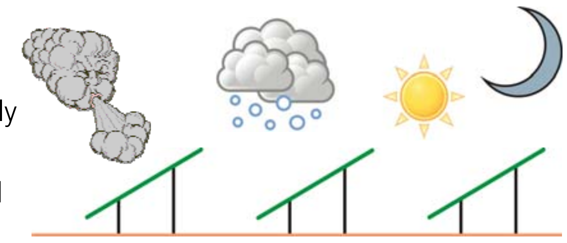
S. Dietrich, M. Pander, R. Meier, S.-H. Schulze, M. Ebert
Fraunhofer - Center for Silicon-Photovoltaics CSP, Walter-Hülse-Straße 1, 06120 Halle (Saale)
Telefon +49 (0) 345/5589-408
matthias.ebert@csp.fraunhofer.de

Bundesministerium für Bildung und Forschung

SOLARVALLEY Mitteldeutschland

Motivation

- demand on solar modules:
  - operation for a long period
  - low performance loss (typically less then 20 % in 25 years)
  - resist thermo-mechanical and mechanical loads



- loads on solar modules
  - mechanical (wind, snow)
  - thermal-mechancial (production process, day/night shift, seasons)
  - dynamic-mechanical (wind squall, hail)

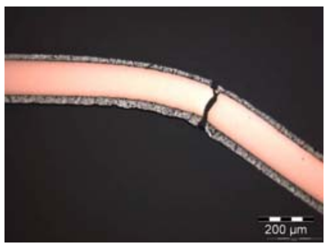


Fig. 1: broken copper ribbon [1]

- typical mechanical failures:
  - glass breakage
  - cell breakage
  - broken interconnector
  - delamination

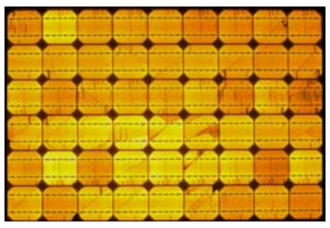


Fig. 2: EL image of a mono-Si solar module with microcracks due to thermal cycling [2]

Material Characterization

- solar module consists of various materials
  - → widely different CTE and Young's Modulus
  - → origin of thermal stresses due to mismatch of CTE
- properties of encapsulant exhibit a strong dependence on temperature
  - → distinct change in mechanical properties around glass transition
  - → strong influence on the amount of external loads, which is transferred to the solar cells

Material	Youngs Modulus [GPa]	CTE [10^{-6} K^{-1}]
Silicon	162 (multi)	2.6
Glass	70	8.5
Copper	86	16.65
EVA	0.07 – 0.001	90 – 360

Tab. 1: mech. properties of solar module components

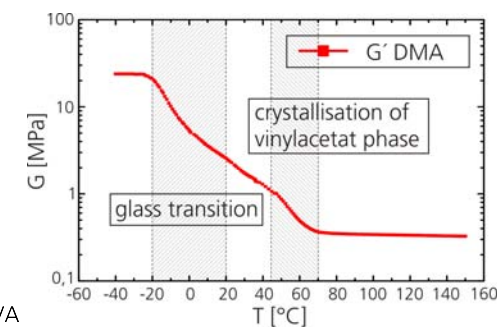


Fig. 3: characteristic development of shear modulus over temperature for an EVA

Simulation of Lamination Process

- stress free state at lamination temperature (150 °C) is assumed
- contraction of the materials leads to a change in the gap between solar cells
- plastic strain is induced into copper ribbons → pre-damage that influences lifetime
- enlarged initial cell gap reduces the amount of plastic strain

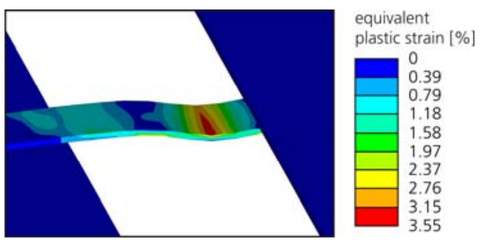


Fig. 4: plastic strain of copper ribbon after lamination

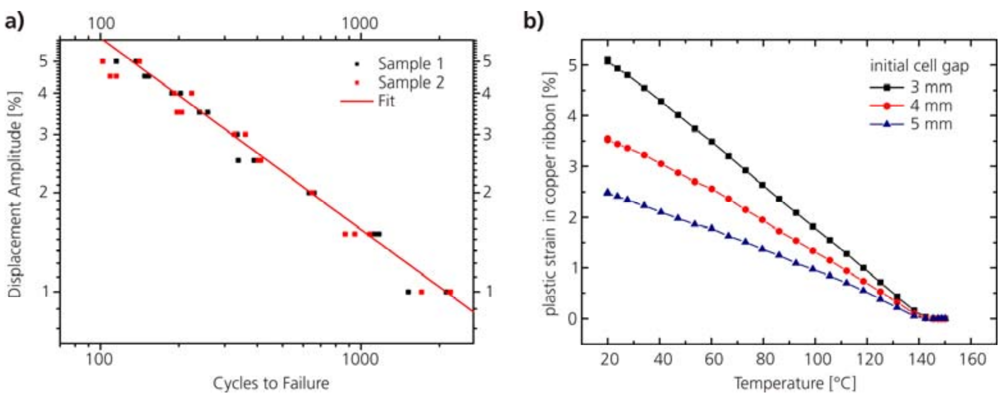


Fig. 5: a) lifetime model for copper ribbon under given geometric constraints [3]
b) plastic strain of copper over temperature for different initial cell gaps

Simulation of Mechanical Loads

- investigation of a module laminate with 3 cells under wind load
- deflection influenced by cells and temperature dependant polymer stiffness
- polymer mainly under shear deformation → amount of strain compensation depends on shear stiffness and thickness of polymer
- stress in solar cell considerably higher for low temperatures and thin polymer
- reduction of cell thickness leads to higher deformation and stress

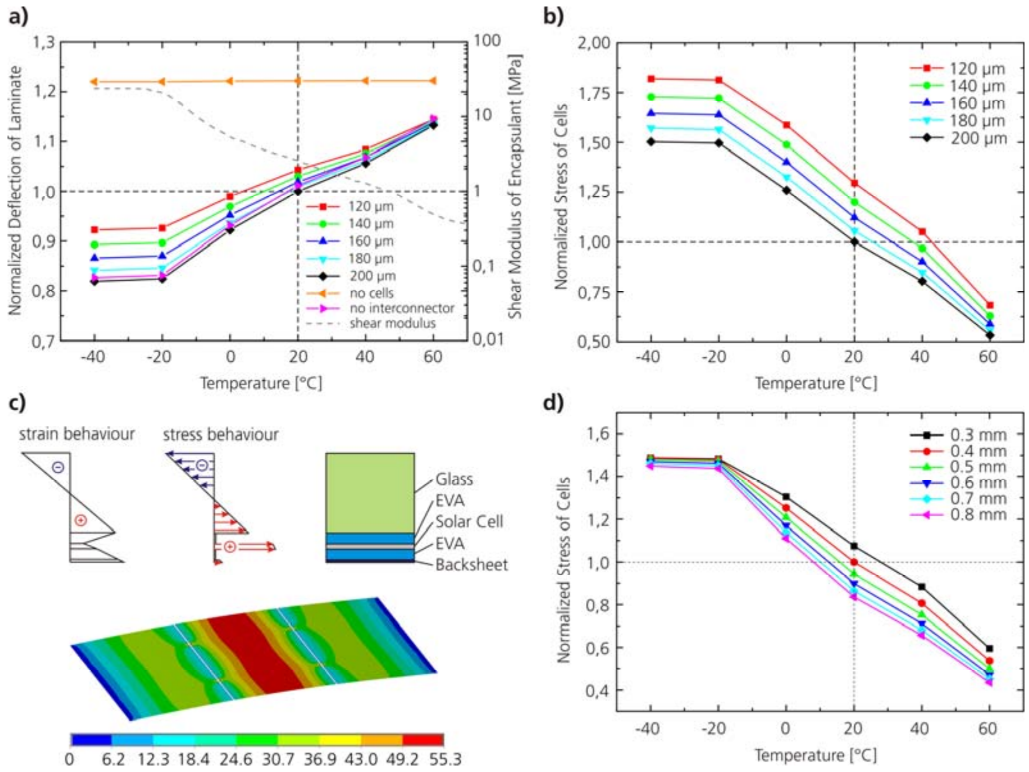


Fig. 6: a) Influence of deflection of module laminate on temperature → encapsulant [3]
b) Influence of normalized stress with respect to temperature/polymer stiffness [3]
c) strain and stress behavior of the laminate under a mechanical load, characteristic stress plot
d) Influence of normalized stress with respect to polymer stiffness and thickness [3]
Reference for all graphs: 200 µm, 20 °C, 0.4 mm

- reduction of glass thickness leads to higher deformation and strain in glass
  → increased strain is transferred to cells and induces higher stresses
- effect also applies to manufacturing tolerances → more than 10 % stress variation possible
- variation of shear modulus of encapsulant due to inhomogeneities
  → variation of shear modulus up to 60 %
  → low impact on deflection
  → effect on stress up to 20 %

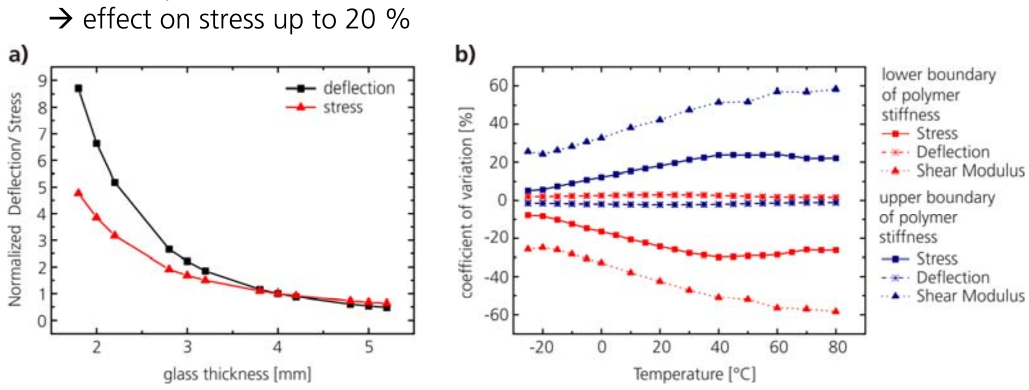


Fig. 7: a) impact of glass thicknesses including tolerances (± 0.2 mm) on stress and deflection, Reference: 4 mm glass, 200 µm cell, 20 °C
b) influence of the variation of the shear modulus of the encapsulant on deflection and stress

Acknowledgement

This work was supported by the Federal Ministry for Education and Research (BMBF) within the "Excellence Cluster" project "xµ-Module" (project no. 03SF0337A)

[1] Meier, R. et al.; Thermo-Mechanical behaviour of copper-ribbon materials, Proc. 24th EUPVSEC (2009), Hamburg
[2] Sander, M. et al.; PV Module defect detection by combination of mechanical and electrical analysis, Proc. 35th IEEE (2010), Hawaii
[3] Dietrich, S.; Mechanical and Thermo-Mechanical Assessment of Encapsulated Solar Cells by Finite-Element-Simulation, Proc. SPIE 7773, 77730F (2010); doi:10.1117/12.860661