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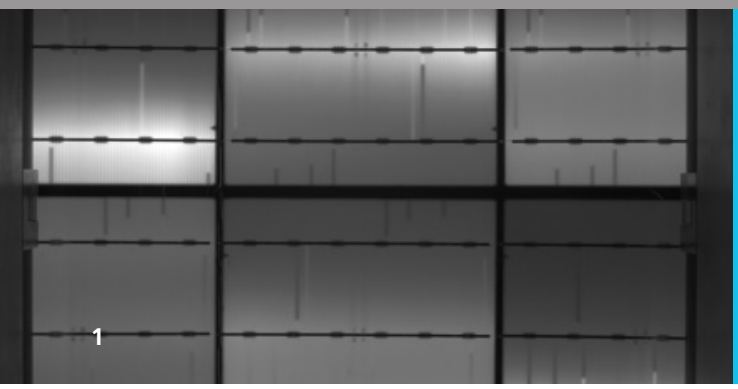
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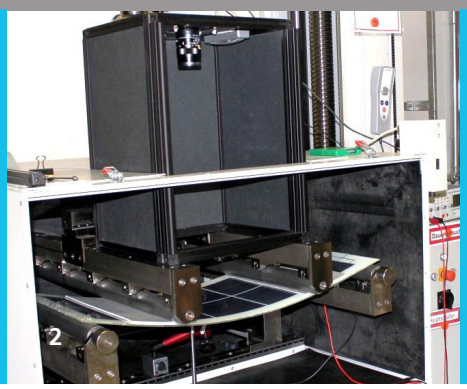
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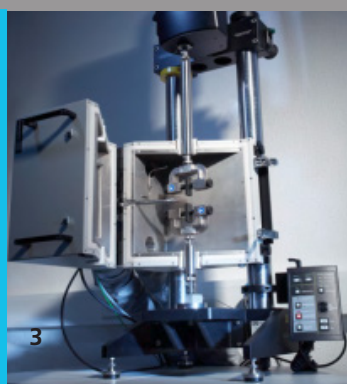
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1 *Module with broken interconnectors.*
2 *Mechanical in-laminate fatigue testing setup.*
3 *Universal mechanical testing machine.*

FATIGUE ANALYSIS OF SOLAR CELL INTERCONNECTORS

Competencies

- Interconnector material characterization
  - ⇨ yield strength
  - ⇨ elongation at breakage
  - ⇨ fatigue life data
- Adaption of material and fatigue models for simulation purposes
- Accelerated mechanical in-laminate fatigue testing
- Stress analysis of ribbons in modules with FEA (finite element analysis) under mechanical and thermal loads
- Parameter studies and design optimization based on simulation results
- Lifetime estimation for different climate conditions

Approach

Fraunhofer CSP characterizes the constitutive (stress-strain relationship) and fatigue behavior of interconnector materials with specific experiments. The material data is used in finite element models to estimate interconnector lifetime (cycles to failure) within a specific PV module under cyclic mechanical and thermo-mechanical loading.
With help of these models the influence of external load parameters (e.g. temperature, load frequency) and layouts can be simulated in order to optimize module design with respect to module reliability.
Furthermore ribbon fatigue strength predictions under arbitrary loading conditions (e.g. extreme climates) can be achieved.

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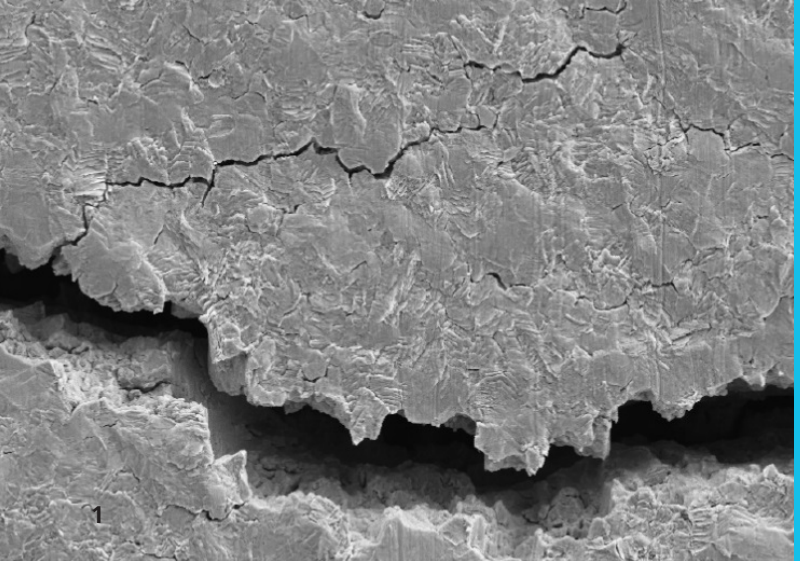
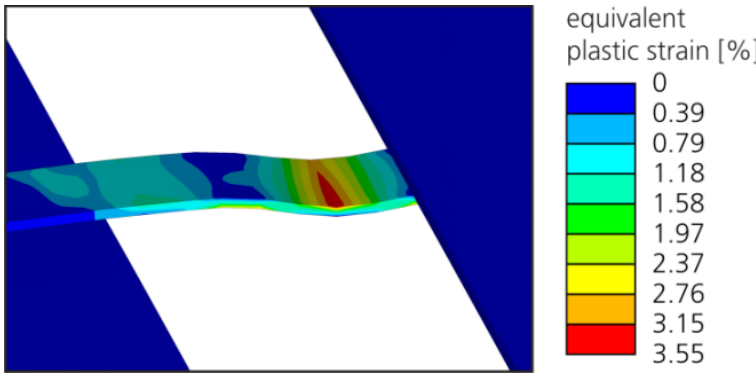




Mechanical Fatigue Testing of Interconnectors

Fatigue experiments basically involve strain-controlled testing with different amplitudes until failure for the ribbon material. This data can be used for comparison of different ribbon manufactures and quality assurance purposes.
Effects of ribbon geometry and thermal treatment are investigated.

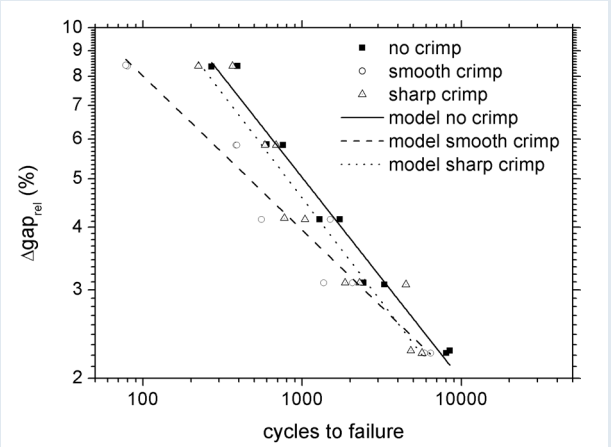
In-laminate Fatigue Testing

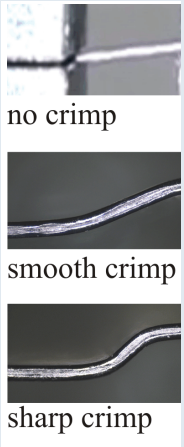
These tests are performed in four point bending test setup which ensures a well-defined and reproducible load situation. The testing machine allows different load profiles (amplitude, frequency) and different temperatures. During testing modules operate in forward bias and voltage is continuously monitored. It is possible to perform regular electroluminescence imaging during testing to identify failed ribbons.
The effects of different encapsulants and testing temperatures on ribbon fatigue strength can be characterized.

Lifetime Estimation

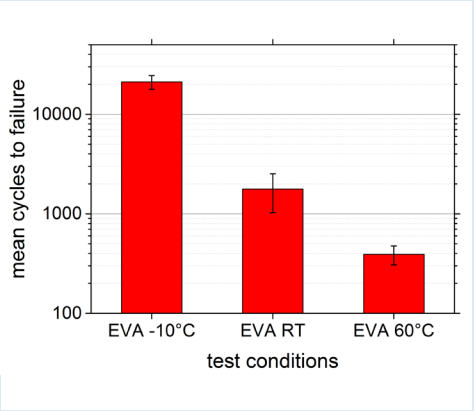
On basis of climate data, material testing results and finite element simulation ribbon related lifetime estimations are possible. For this purpose representative climate data is transferred to load profiles for the interconnectors in the module. With finite element models the stress and damage contribution for these loads are simulated. Damage accumulation theories are then used to determine accumulated damage and finally give lifetime estimation.

1 *Scanning electron microscopy image of ribbon crack front.*
2 *Plastic strain contour plot from FEA.*





3 *Results of fatigue experiments for different ribbon shapes.*



4 *Mean cycles to failure in cyclic mechanical load test for EVA samples at different temperatures.*