Flexible CIGS Modules – Selected Aspects for Achieving long-term stable Products

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Introduction

Technology

Solarion develops and produces solar modules, based on **CIGS thin-film solar cells on ultra thin polymer substrate** employing a proprietary **ion beam-assisted manufacturing process** that deposits a thin layer of copper indium gallium selenide (CIGS) on the lightest substrate available at **reduced deposition temperatures**. The cell materials are deposited in a continuous roll-to roll-process on the 25 micron PI-substrate. A thin layer of Ag-based contact grid is printed on top of the cell. These will be converted to single cells and sorted to several power classes.

Applications

Due to the **light weight**, the **flexibility** and the possibility of the assembly of **cell matrix in many variations** there is a **wide range of possible module designs, e.g. for BIPV, automotive etc.**

Module R&D Activities

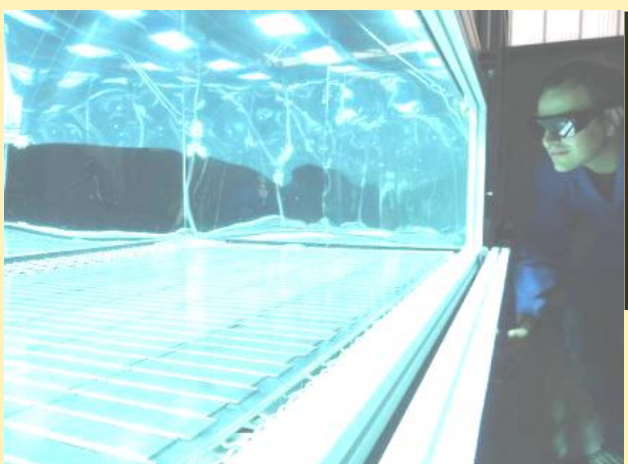
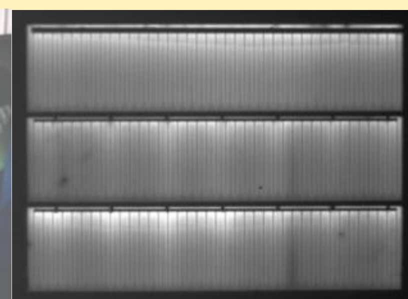
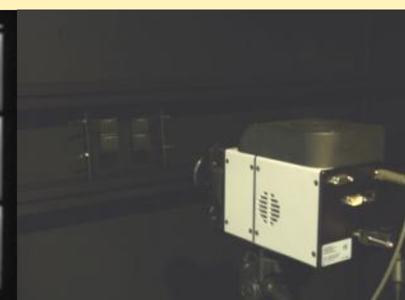
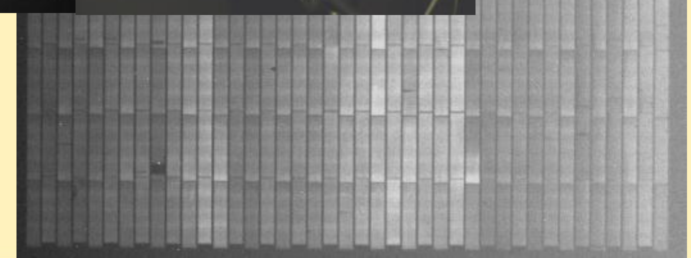
Besides its solar cell R&D, Solarion performs an **intensive solar module research** with focus on **product and technology development, reliability and safety testing**. The majority of the common standard tests are executed **in-house** and advanced reliability tests were conducted by partners.

A flexible encapsulation technology was developed for Solarion's cell technology using several polymeric materials. The optimal materials and their system compatibility, also to the solar cell, were identified by intensive research and **testing of 25 conductive adhesives, about 20 barrier films, 20 encapsulants, six edge sealings and several back sheets** over the last years.

Methodes of Material Testing

The following methods were applied to materials, material combinations and module test samples:

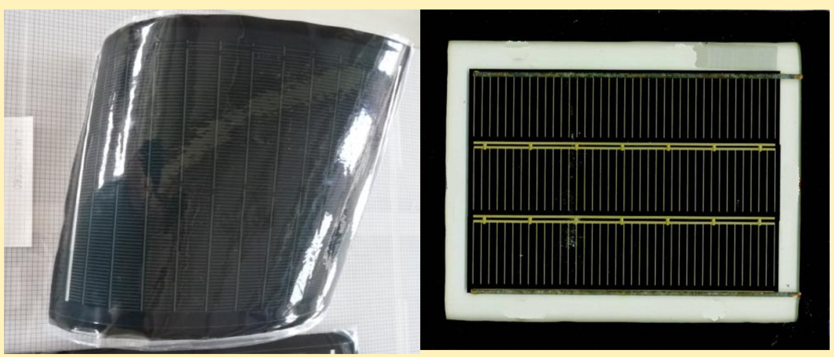
- Climate testing according to IEC61646 (TC, DHT, HF, UV), also with extended testing times
- Sequential moisture-UV testing according IEC61646: one week DH – one week UV (alternating)
- Dynamic-Mechanical Analysis (DMA) for investigating thermo-mechanical behavior of polymers (encapsulants, edge sealings, interconnection materials)
- Adhesion testing (peel tests)
- Electrical characterization using steady state and pulsed solar simulators
- Damage analysis using EL, IR thermography, LBIC, LIT and microscopy

Key Factors for reliable flexible CIGS Module Encapsulation

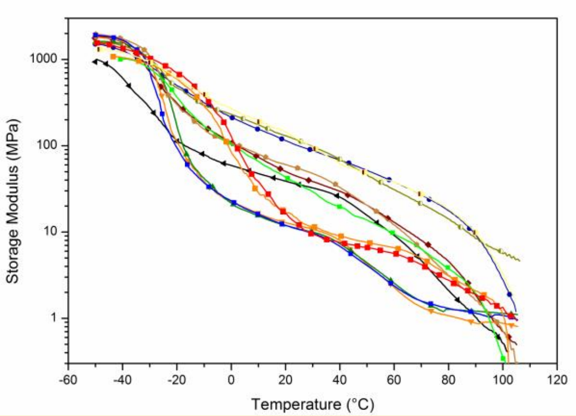
The following key factors, esp. regarding polymeric materials, were identified by experimental work:

- Adhesion and chemical compatibility to neighboring materials
- Thermomechanical behavior (viscoelasticity, creep behavior, CTE, fracture strength)
- Shrinkage
- Phase changes
- Water vapor transmission, moisture resistivity under tensile strain
- Reactive residues
- Conductivity and contact resistance of interconnection materials



Deformation after TCT80 due to unmatched materials (left) and interactions between conductive adhesive / silver paste and encapsulant after UV exposure (right)

Key Results: Encapsulants

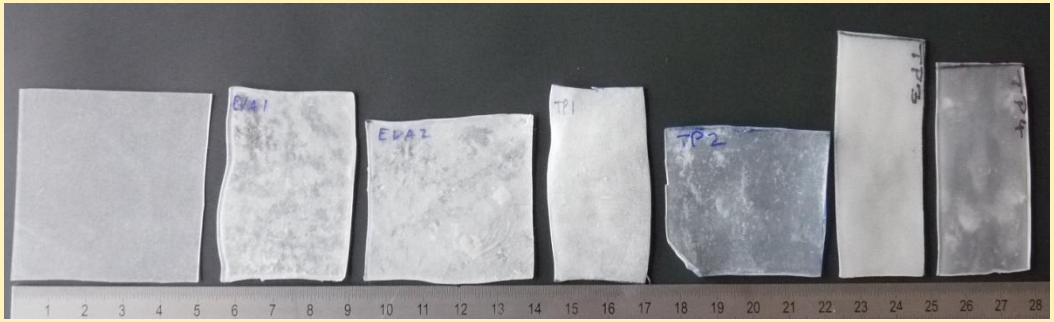


Wide range of Storage Modulus, partly phase changes and glass transitions in relevant temperature range, see also [1]

→ **mechanical stress at interfaces**

Creep behavior at higer operation temperatures

→ **Critical for product stability, delamination**



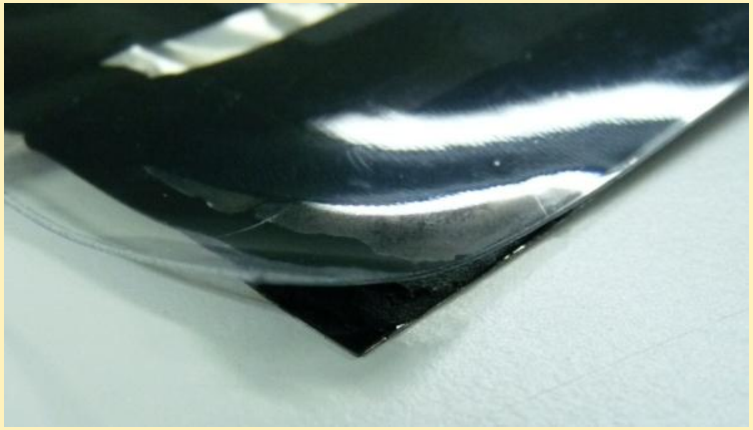
Shrinkage during processing

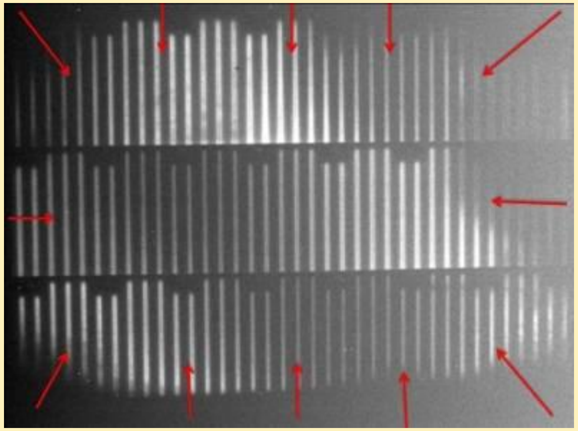
→ **internal stress** at interfaces, destruction of cell and/or interconnection structures

[1] Michael D. Kempe: Rheological and Mechanical Considerations for Photovoltaic Encapsulants; 2005 DOE Solar Energy Technologies Program Review Meeting November 7–10, 2005 Denver, Colorado

Key Results: Edge Sealings

- **General function and stability shown** in [2] and confirmed by own work



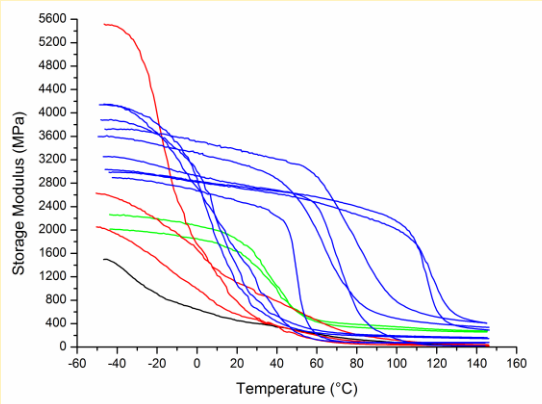


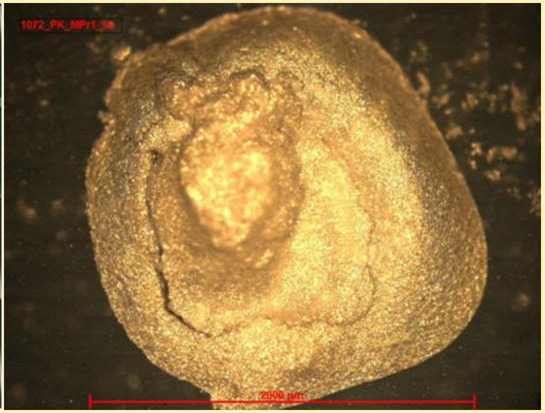
- Adhesion issues possible → Degradation
- Partly, interface degradation under UV-moisture influence observed

[2] Michael D. Kempe, Arrelaine Dameron, Matthew Reese: Calcium Based Test Method for Evaluation of Photovoltaic Edge-Seal Materials; 2011 NREL PV Module Reliability Workshop

Key Results: Polymer-based Interconnection Material

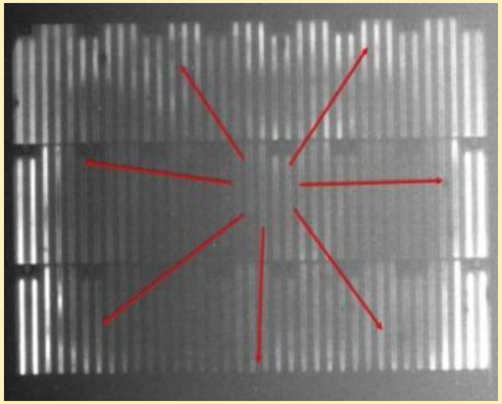
- **Adhesion** to different materials on cell surface has to be qualified
  → Mechanical Stability of interconnection
- **Stability of contact resistance** to different materials on cell surface during temperature cycling has to be approved
  → Risk of electrical serial resistance changes
- **Bulk conductivity** has to be increased → Serial resistance reduction
- **Wide range of Young's modulus**, glass transitions at operation temperature range for different interconnection materials
  → materials with high Young's modulus fail / break due to mechanical stress





Key Results: Front- and Back Sheet Materials

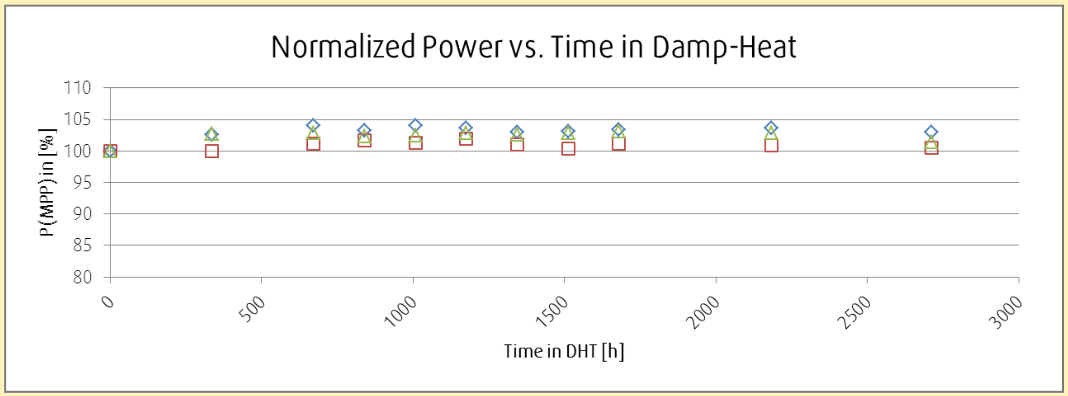
- Stability in climate testing shown with different front and back sheet materials
- Stable adhesion to encapsulants and especially to edge sealings is mandatory
- “functional adhesion” of about 2..3 N/cm apparently enough for a working encapsulation system but too low for mechanical resistivity in the field
- WVTR close to zero necessary

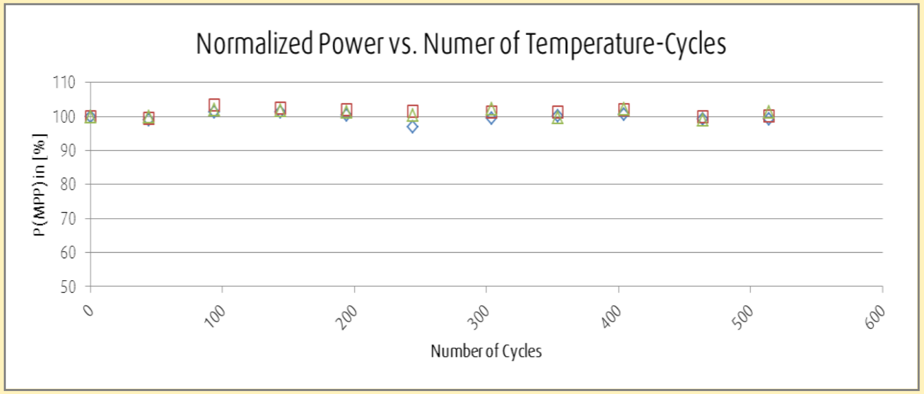


Cell degradation due to moisture ingress via front barrier film

Results on Module Level

A **high long term stability** of flexible modules as shown in following figures can only be achieved by **developing a general understanding regarding the single materials** used in the module sandwich and testing their interactions. This background allows pre-qualifying and selecting suitable materials and material combinations under different ambient or testing conditions.





Normalized power of flexible Solarion modules in DHT (85 °C / 85 % r.h.) and TCT (-40 to +85 °C)