A multi-scale and multi-physics numerical approach to microcracking in photovoltaic laminates

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Structural mechanics models for renewable energy applications

Photovoltaics (POLITO)
MEMS for wind energy harvesting (UNISAL)
Solid oxide fuel cells (UNITN)

- Composites, heterogeneous materials
- Fracture, damage and contact at interfaces
- Multi-physics problems

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**Composite geometry**

- Glass
- EVA
- Solar cells
- EVA
- Tedlar
- Aluminum
- Tedlar

Polycrystalline Silicon cells

Micro-cracking and power-loss

Electroluminescence image of microcracking

A multiphysics approach

Thermal field

Elastic field

Electric field

Thermo-electric field

Electro-elastic field

Electro-thermo-elastic field

Thermo-elastic field

Electro-thermo-elastic field

Thermo-electric field
A multiscale solution strategy

**Macro-model:**
Multi-layered plate (homogeneous cells)

**Micro-model:**
Polycrystalline Si cells with grain boundaries
A multiscale solution strategy

Macro-model of the PV panel
- Displacements in the cell plane
- Electric response

Micro-model of the Si cell
- Microcracking
  - Stiffness
  - Electrically inactive areas

Updated homogenized stiffness, inactive cell area

Displacement BCs, thermal field
**Computations at the micro-scale using NLFM**

\[ G_{int} = \int_S \delta g^T t \, dS = \delta u^T R^T \int_S B^T t \, dS \]

**Weak form of the interface**

\[ \Delta G_{int} = \delta u^T R^T \int_S B^T C B \, dS R u \]

**Linearization for the Newton-Raphson method (FEAP)**


Electric circuit model of the PV module

p-n junction:

Electric circuit:

\[ I = I_{ph} - I_s \left[ e^{\frac{q(V+IR_s)}{AkT}} - 1 \right] - \frac{V + IR_s}{R_p} \]

\[ I_s (D) = I_s, D=0 \left( 1 - D \right) \]
Damage variable and electrically inactive cell area

\[ D = \frac{A_{\text{inactive}}}{A} \]

Numerical simulations

Simply supported plate subjected to a uniform (snow) pressure of 5400 Pa

Real microstructure → Grains identification → Mesh generation
Macro- vs. micro-scale stress fields in the $x$-direction

Macro-stress $\sigma_{xx}$

Micro-stress $\sigma_{xx}$
Micro-crack pattern in Silicon cells
Distribution of crack orientation angles

(5) Center

(9) Right corner
Distribution of crack orientation angles

(5) Center  (9) Right corner  (7) Left corner  (9) Right corner
Electrically inactive cell areas: numerical results
Electrically inactive cell areas: electric damage $D$

- $D=32\%$
- $D=11\%$
- $D=12\%$
- $D=4\%$
- $D=79\%$
- $D=5\%$
- $D=12\%$
- $D=0\%$
- $D=30\%$
Effect of microcracking

Electric efficiency of the intact module (fill factor): 95%
Electric efficiency of the microcracked module: 48%
Conclusions

- The effect of microcracking on the electric performance can only be quantified according to a multi-physics approach.
- A multiscale solution strategy is effective to reduce the computational cost in case of large panels and to simplify the 3D problem.
- Future investigations will regard the coupling with the thermal field to predict the degradation rate of PV panels exposed to environmental conditions.