Multi-field and multi-scale Computational Approach to design and durability of Photovoltaic Modules

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Frontier research:

“... classical distinctions between ‘basic’ and ‘applied’ research have lost much of their relevance at a time when emerging areas of science and technology often embrace substantial elements of both. The report therefore adopts the term frontier research, rather than basic research, to reflect this new reality. Frontier research, because it is at the forefront of creating new knowledge, is an intrinsically risky endeavour that involves the pursuit of questions without regard for established disciplinary boundaries or national borders.” (European Commission, 2005)

Features:

• World class excellence
• Uncertain but potentially high impact outcomes
• New trajectories
• Sufficient mass and scope to address interdisciplinary topics
• Impact on business and society
Photovoltaics (PV)

The Silicon Solar Cell
- Bus bar
- Finger
- ARC
- Junction
- Back contact

Components:
- Glass
- EVA
- Solar cells
- EVA
- Tedlar
- Aluminum
- Tedlar
Applications:
from PV parks to building-integrated PV
Main focus of the PV community: solar energy conversion efficiency
Some failure modes of PV modules:
1. Cracks
2. Decohesion of the encapsulant
3. Moisture-induced degradation
Open issues

- Standard accelerated aging tests provide pass/fail criteria based on electrical output only; they reproduce failure modes never observed in the field
- Lack of simulation tools for durability
- Lack of guidelines for nondestructive monitoring in the field

Innovative methods

- Move from the solar cell to the whole PV module laminate
- Multi-physics framework requiring an interdisciplinary view
- New testing methods
- New design criteria for PV modules insensitive to cracking

Impact on society

- More reliable expectation on lifetime of PV technologies
- Better quality control and rating of PV productions
- Reduction of degradation rate from 1%/year to 0.5%/year is equivalent to an increase of the solar energy conversion efficiency from 25% to 27%
Multi-physics modelling & simulation

Nonlinear semiconductor device PDEs

Nonlinear heat conduction

Nonlinear thermo-elasticity & fracture mechanics

Nonlinear moisture diffusion

Fracture and deformation

Temperature

Mech. degradation polymers

Fracture
Length and time scales

Time scale

- Moisture diffusion
  - 20 yrs
- Temperature cycles
  - 1 day
- Brittle fracture
  - 1 s
- Recombination effects
  - 1 µs

Length scale

- 10^{-6} m
- 10^{-4} m
- 10^{-1} m
- 1 m

PV module
Silicon solar cell
p-n junction
Recombination effects

Brittle fracture
Temperature cycles
Moisture diffusion
Multi-physics testing

www.imtlucca.it/research/laboratories/musam-lab

Effect of mechanical field on electric response

Peeling of Silicon thin films inside a SEM
Endorsement and collaborations

International Energy Agency
Photovoltaic Power Systems Programme (PVPS)
Task 13 on Performance and Reliability of Photovoltaic Systems

Joint Research Centre
Institute for Energy and Transport

Institute for Solar Energy Research
Hamelin, Germany

Solbian Energie Alternative S.r.l.
Avigliana, Italy

Applied Materials Italia S.r.l.
Olmi di S. Biagio di Callalta, Italy

Jabil, Industrial and Energy
San Petersburg, Florida, USA
Multi-field and multi-scale Computational Approach to design and durability of Photovoltaic Modules – CA2PVM

http://musam.imtlucca.it/CA2PVM.html

Mid-term scientific report:
http://musam.imtlucca.it/Mid-term-report.pdf

MUSAM Annual Report 2014: