Purpose

• Review of solar cell/module degradation and failure diagnostic tools.

• Coring technique to acquire samples and evaluate interface toughness.

• Accelerated testing and failure mechanisms in PV.
Outline

• Basic Module Types
• Diagnostics
• Distributed vs localised
• Definition of reliability
• Accelerated testing in PV
• Failure mechanisms
• Summary
Wafer Type Module

Cell Interconnect
Thin-Film Type Module

Cell Interconnect
Thermal Imaging, Forward Bias

0 y @ NREL

5 y @ NREL
Two-Terminal, Non-destructive Shunt Resistance Technique

5 y @ NREL

7 y @ NREL

R (ohms/Cell)

Cells 1 thru 48

R (ohms/Cell)

Cells 1 thru 48
Two-Terminal, Non-destructive Shunt Resistance Technique

PV module
H-series cells

Calibrated So 1000 ohm Produces 1 mV
CdTe cell Weak Diode: IR and IVs

4.5 - 6 % after stress.
Hot in forward bias.
Not in reverse bias
NEDT 25 mK

1225 h at Voc at 100 °C
Weak Diode Removal

1225 h at Voc at 100 °C

WD @ Corner Removed

4.5 - 6 %

9 %
P-Spice circuit w/WD

4.5 - 6 %

$V_{olts}$

$I_{A/cm^2}$

$V$(volts)
P-Spice/AMPS (crossover/rollover)
Si Wafer Modules

Cracked cell

Shorted interconnect
Shear Strength Measurement at Front Cell/EVA Interface

### Diagram

- **TPE Backsheet**
- **EVA**
- **Si Cell**
- **EVA**
- **Tempered Front Glass**

### Diagram

- **Si Cell**
- **EVA**
- **Tempered Front Glass**
Torque-Twist-Toughness

Torque (N-m)

0 0.1 0.2 0.3 0.4 0.5

Angle (°)

0 10 20 30 40

I II III

Torque-Twist-Toughness

Elastic core

Plastic annulus

Image of a solar panel with a circular opening and Whatman paper.
Outdoor/Chamber UV Toughness Aging of Si/EVA Interface

- Control
- UV Tubes
- XR-260
- Outdoor
- OATS-1X
- OATS-3X

Exposure Conditions:
- Unexposed
- 1975 MJ/m² 50-65 °C
- 2900 MJ/m² 45-60 °C
- 1568 MJ/m² 45-55 °C
- 1300 MJ/m² 45-55 °C
- 1750 MJ/m² 45-70 °C
Failure Mechanisms (FMs)

• Packaging vs Cell
  – Packaging is 90% of the field returns \(^*\) \(^^\)
  – 50% of the cost

• Distributed vs Localised

• General vs Technology Specific

\(^*\) Includes cell interconnects.

\(^^\) Failure rate and cause depend on how mature the technology is, e.g. BP Silicon is 1/4200 module year; Newbee modules are 1/10 - 1/100.
Service Life Prediction

Technology "i"
Manufacturer "j"
Process "k"

Failure Mode "l"
revealed with
acceleration parameter
for each stress.
Validate with the full
range of field conditions.

Time-To-Failure calculated
under any and all Use
Conditions, for each i, j, k,
and l.
Mixed, composite, and
competing risk models are
used to combine failure
modes as appropriate.
FMs: Modules General
Field returns and anticipated failures

- Front Sheet/Encap failure
- Cell/Encap failure
- Back Sheet/Encap failure
- Stress breakage of glass/glass laminate
- Glass edge damage/breakage
- Corrosion of grid lines / ohmic contact / $R_{\text{series}}$
- Poor solder joint(string ribbons and J-boxes)
- By-pass diode failure
- Frame/mounting failure
- Failure of electrical safety/Hi-Pot isolation
FMIs: Modules Technology Specific

Field returns and anticipated failures

Wafer Si:
• Crack formation in thinner cells
• Solder joint degradation on cells
• Ribbon related open circuit or shunting

Thin Film:
• Flexible packaging interconnect failure
• Laser scribe interconnect failure
• De-adhesion of device layers, inc. CTOs and metal contacts
• Busbar adhesion and electrical contact
• Weak diode or shunt defects
• Decreasing ff (E-field collection or series resistance issues)
• Moisture ingress problems, esp. flexible with CIS
• Diffusion, esp. Cu in CdTe
• Staebler-Wronski, esp. single junction a-Si
• SnO₂ corrosion in superstrate cells
Conclusions

• Artificially accelerating environmental stress on PV cells and modules is used to test for their reliability under field conditions.
• Failure diagnostic techniques are used to locate, identify, and evaluate resulting failure modes.
• A new core torque-twist technique used to evaluate module packaging durability and obtain sample specimens for failure analysis is reviewed.
• Proposed failure mechanisms for the different module technologies.