Module Design, Materials, & Packaging Research

- T. J. McMahon (1.0)
- Steve Glick (1.0)
- Gary Jorgensen (0.85)
- Mike Kempe (1.0)
- John Pern (0.5)
- Kent Terwilliger (0.5)

FY 06 Total 4.85 FTEs
FY 07 Total 4.00 FTEs
Purpose of this Task

- Confirm reliability of new photovoltaic packaging materials and strategies to insure a 30-year module life. Usually Industrial collaborations.

- Give special attention to module reliability problems with developing technologies.

- Measurement techniques developed/acquired for module failure diagnostics: usually one technique developed each year.
Collaborations and Inquiries

- AKT
- Bucyk Glass
- AVA
- GE
- Plextronics
- Sol Focus
- TruSeal
- Madico
- Miasolé
- STR
- Fraunhofer Institute
- InnoSense LLC
- Solar Roofing Systems
- Planar Systems, Inc.
- Deerfield Urethane
- Pilkington Glass
- Dow Chemical
- Silicon Valley Solar
- Applied Films
- Saint Gobain
- Dow Corning
- Gen 3 Solar
- Sealed Air
- First Solar
- Siemens
- Prime Star
- DuPont
- PPG
- BRP
- Global Solar
Team Capabilities

- Characterization
  - Adhesion, cohesion, and **toughness**; peel, butt and lap shear strength, and **torque vs angle**
  - Electrical conductivity; surface and bulk
  - WVTR; water transmission, solubility, diffusion
  - Rheology; modulus
- Accelerated tests
  - UV, temperature, damp heat, acceleration factors
- Module and cell diagnostics
  - IR imaging, individual cell shunt, coring, transient currents, internal resistance
- SiONC barrier coatings
  - Sputtering and PECVD
  - characterization
- Modeling
  - Moisture ingress and egress
  - Cell-to-frame leakage current
  - Device(AMPS) and Module(PSpice)
Task Activities and Direction:

- Past and continuing problems: adhesion, cohesion, formation of T-F weak diodes, shunt and series resistance problems w/ aging, water ingress.
- SAI Accelerated Aging WKSHPS (w/ DOE and Sandia) now to replace Thin-film partnership reliability teams.
- Module level packaging issues addressed by our task
  - Alternatives to double glass for thin films(soft backsheets and hard coat barrier films).
  - EVA substitutes cheaper/better perhaps w/o transparency.
  - Hot/Humid survival: Field and 85%/85°C stress survival depend on adhesion, cohesion and water diffusion barriers.
  - Moisture; relevant properties of polymers and coatings measured. Modeling of moisture ingress and egress into module structures.
PV Packaging:

• 90% of the field returns *
• 50% of the PV module cost

* 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.
Budget / FTEs

$1,413,000  4.85 FTE  FY 06

$1,218,000  4.00 FTE  FY 07
Talk Outline

- Standard adhesion results

- Coring/Torque vs Angle Procedure for Adhesion, Cohesion, and Toughness
  (see Gary Jorgensen’s poster)

- DOE outdoor to Accelerated Aging correlation study.

- Infrared (3-5 micron) cell and module diagnostics.
Standard Adhesion Testing

Alignment Plate
Encapsulant / Backsheet
Substrate
Grip
Grip
Peel Adhesion Testing


- Interface peel strength values of various T-F module technologies. Damp heat stress reduces starting values of 7 N/mm to as little as 0.6 N/mm. Extended UV exposure can also reduce strength.

- Adhesion at higher T’s is greatly reduced: 7 N/mm @ 25°C > 1.1 N/mm @ 60°C >> 0.05 N/mm @ 80°C
  - Require a minimum adhesion strength perhaps at higher T and RH.
  - The softening of EVA near 85 °C can lead to failure.

- Achieve highest adhesion possible for corrosion and water ingress reduction.
Scratch Adhesion Testing


- For the T-F technology the ASTM D 3359-02 “scratch test” can be useful as a screening test.
Shear Strength and Toughness

Interfaces and layers of weathered PV modules

DOE sponsored meeting on “Accelerated Aging Testing in Photovoltaics” Feb 2006

A key recommendation by the attendees was to study a major failure mode and demonstrate that meaningful correlations between field data and accelerated test results could be derived.
System for Measuring Torque as a Function of Twist Angle of Cored Modules
Close-up Image Showing Details of Torque Sensor and Coupling Hardware
Shear Strength Measurement at Front Cell/EVA Interface

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<tbody>
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![Diagram showing the layers and shear strength measurement at the EVA/Back Cell Interface]
Details of the Cell Coring Process
Modeling the Torque-Twist Relationship

![Graph showing the relationship between torque and angle with three labeled sections: I, II, and III.](image)

\[ \tau_{\text{max}} = G \frac{\delta a}{\delta x} \]

- **I**: Initial linear increase
- **II**: Peak torque
- **III**: Decline in torque

Additional images depicting elastic core and plastic annulus.
Torque vs. Angle; Large Mono-Crystalline Si Modules; Control; Frontside of Si Cell/EVA
Integrated area (Toughness)
Toughness of Small Mono-Crystalline Si Modules

(see Gary Jorgensen’s poster for more details)
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I-R Image of Cells and Modules

CdTe cell weak diodes (WD).

CIGS module weak diodes, shunts, and series resistance.
CdTe cell WD: IR and IVs

1225 h at Voc at 100 °C

4.5 - 6 % after stress.

Hot in forward bias.

Not in reverse bias

NEDT 25 mK
CdTe cell WD removal

1225 h at Voc at 100 °C

WD @ Corner Removed

IR images; forward bias

#3044 Control

Uniform recombination heat.

#2994 5 y @ NREL

Localized WD heating
Two-Terminal, Non-destructive Technique

Siemens CIS module #2994

Siemens CIS module #2994 7 y @ NREL

Cell Shunt Resistances
CIGS Core from double glass module

CIGS 3023
1998 & 2003

Blue: new

Red: 5-years
CIGS CORE 6.24mA@4.0V
#3023 NREL 5-Years

NEDT 25 mK

WD @ P1

WD @ P3

WDs in cell
CIGS CORE 6.24mA@4.0V
#3023 NREL 5-Years

Visible image of scribe line

Optical beam induced current
30FS90mA(2mA)@+(-)9.6V20s-zero

Dry 85°C, 2280 h

Forward Bias

Reverse Bias

C: Recom. Area

B: Weak-Diodes

A: Shunts
32FS@+/-9.6V20s-zero
85%/85°C, 497h

+81 mA

-0.24 mA
Summary

• Provide relevant performance measures for new and existing packaging materials.
• Measurement techniques developed/acquired for module failure diagnostics: This year’s is twist strength and toughness.
• Give special attention to emerging module reliability issues; water and heat stress to CdTe and CIGS.
• Research and collaborations on barrier coatings.
• IR images used identify specific failure mechanisms.
• Support of DOE’s SAI reliability teams, PV industry and suppliers.