National Center for Photovoltaics

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

NREL National Renewable Energy Laboratory

Sandia National Laboratories

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.

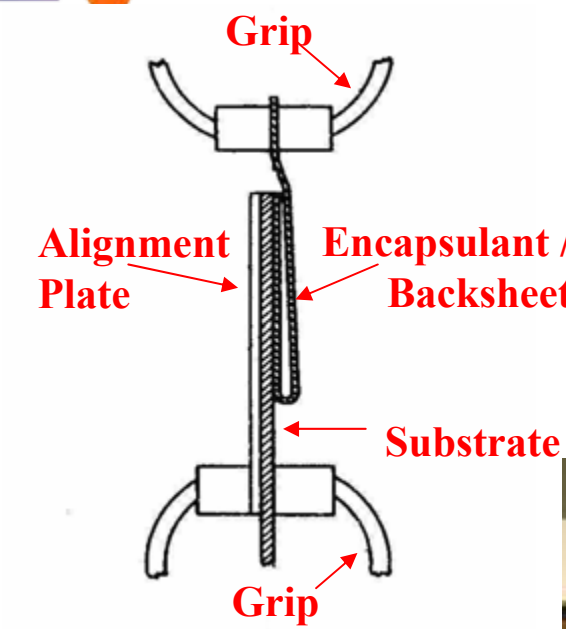
Budget / FTEs

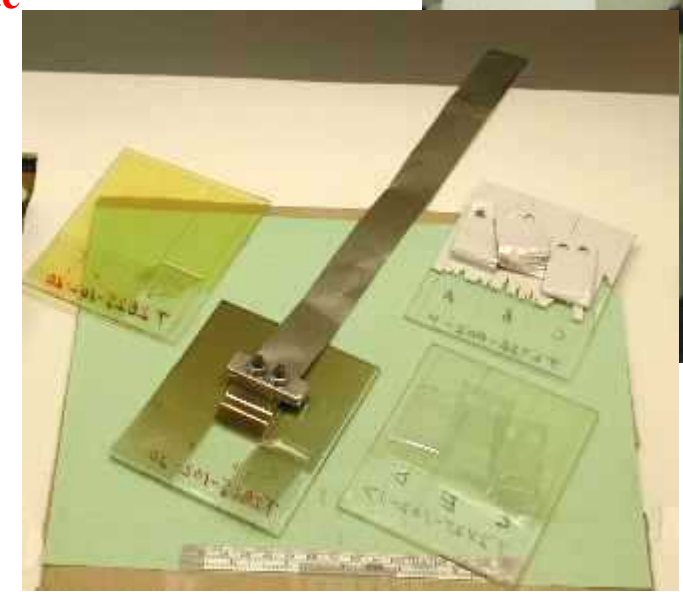
$1,413,000	4.85 FTE	FY 06
$1,218,000	4.00 FTE	FY 07

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

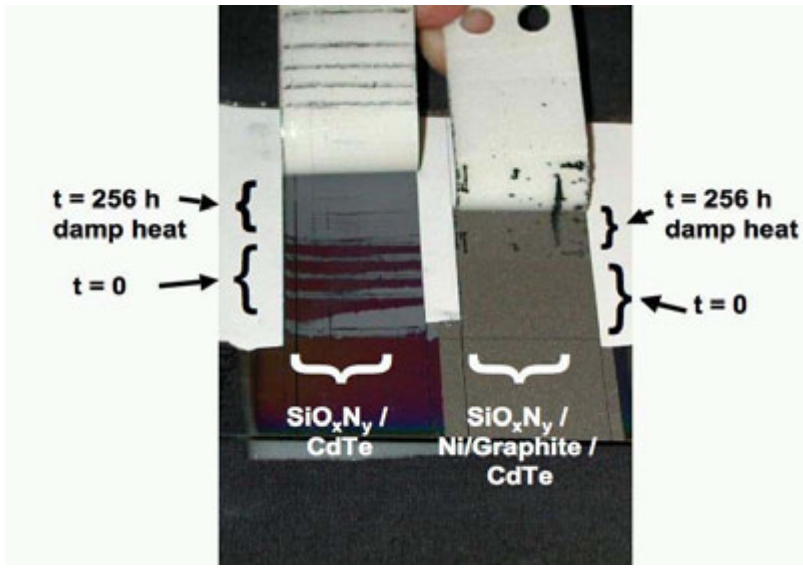


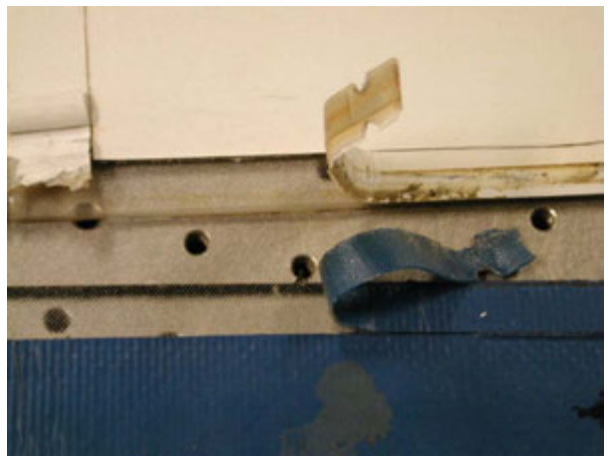


Peel Adhesion Testing

"Adhesion And Thin-Film Module Reliability," T.J. McMahon and G.J. Jorgensen, IEEE Photovoltaic Specialist Conference, May, 2006

- 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.

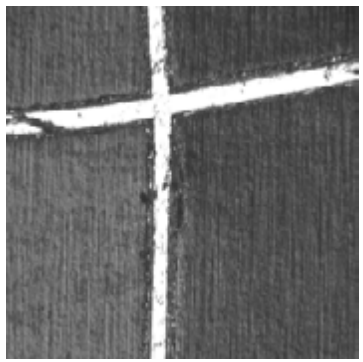
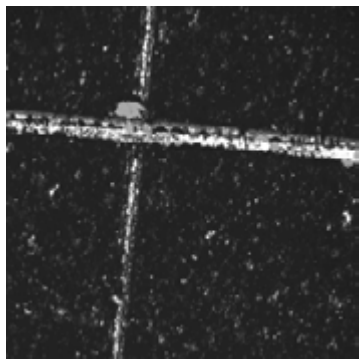
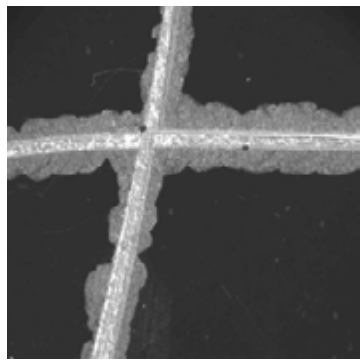
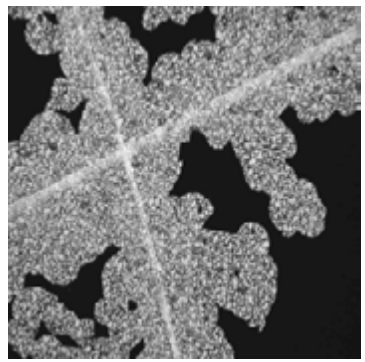




Scratch Adhesion Testing

"Adhesion And Thin-Film Module Reliability," T.J. McMahon and G.J. Jorgensen, IEEE Photovoltaic Specialist Conference, May, 2006

- For the T-F technology the ASTM D 3359-02 "scratch test" can be useful as a screening test.

Shear Strength and Toughness

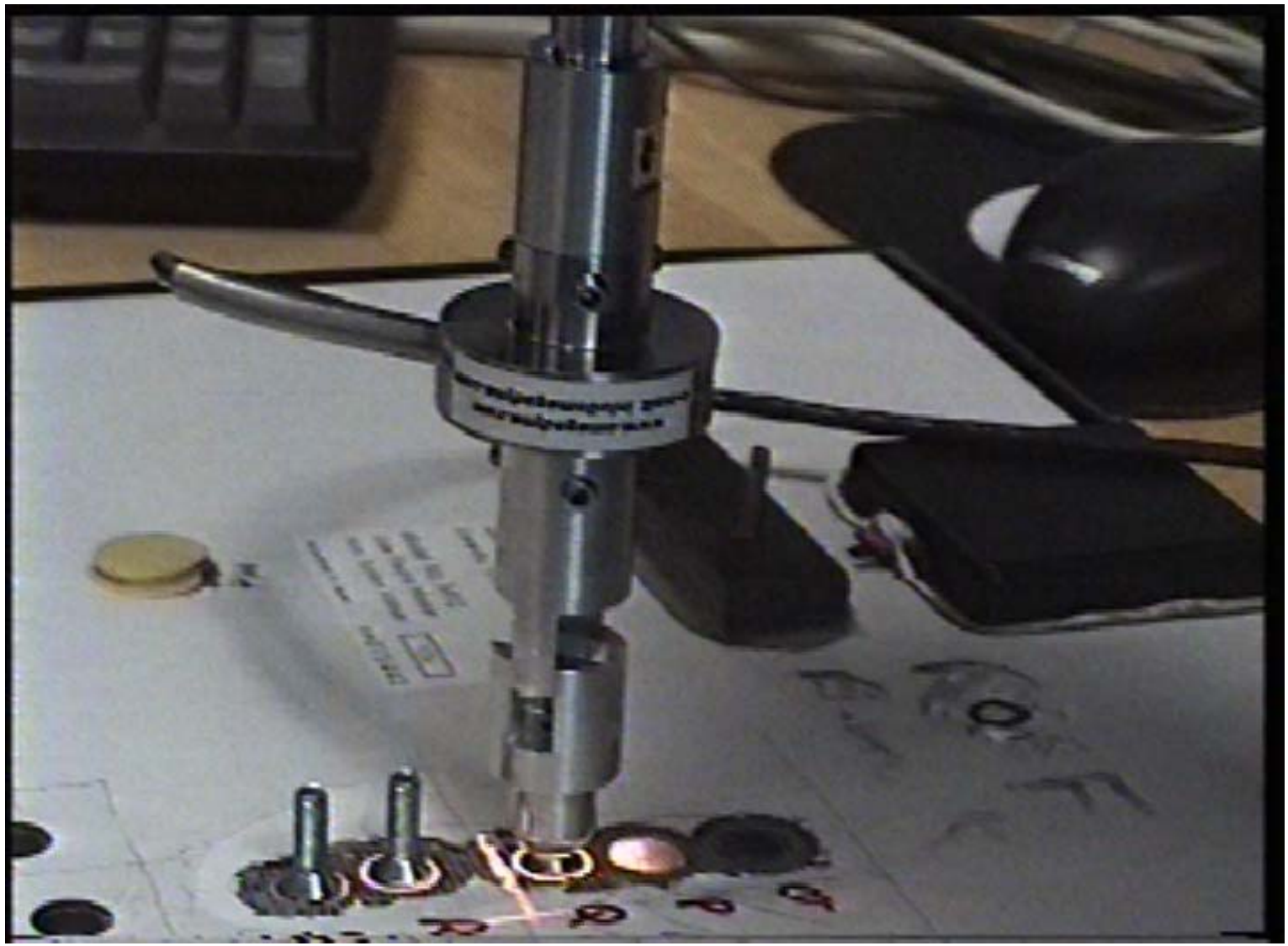
Interfaces and layers of weathered PV modules

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

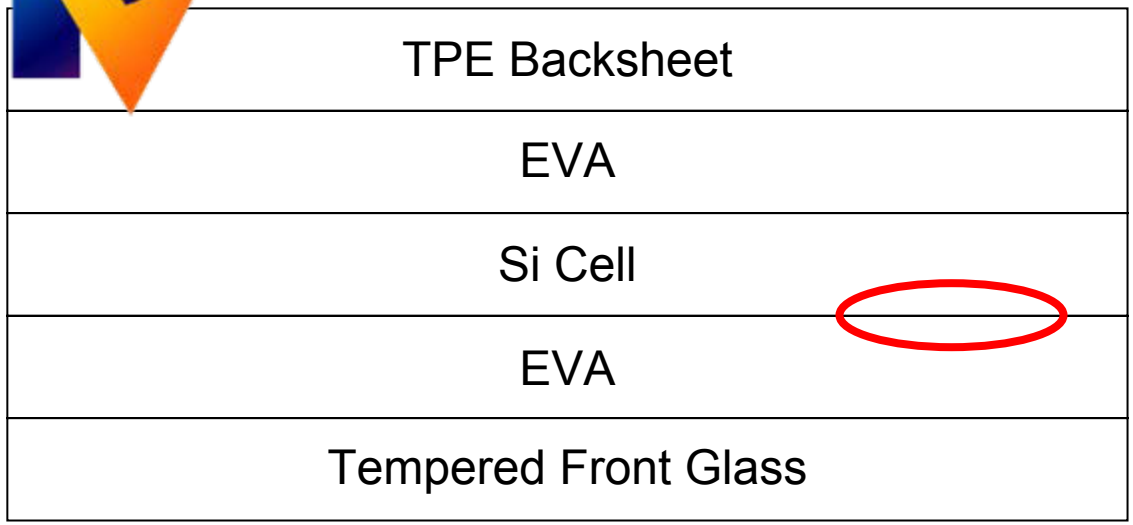
A key recommendation by the attendees was to study a major failure mode and demonstrate that meaningful correlations between field data and accelerated test results could be derived.

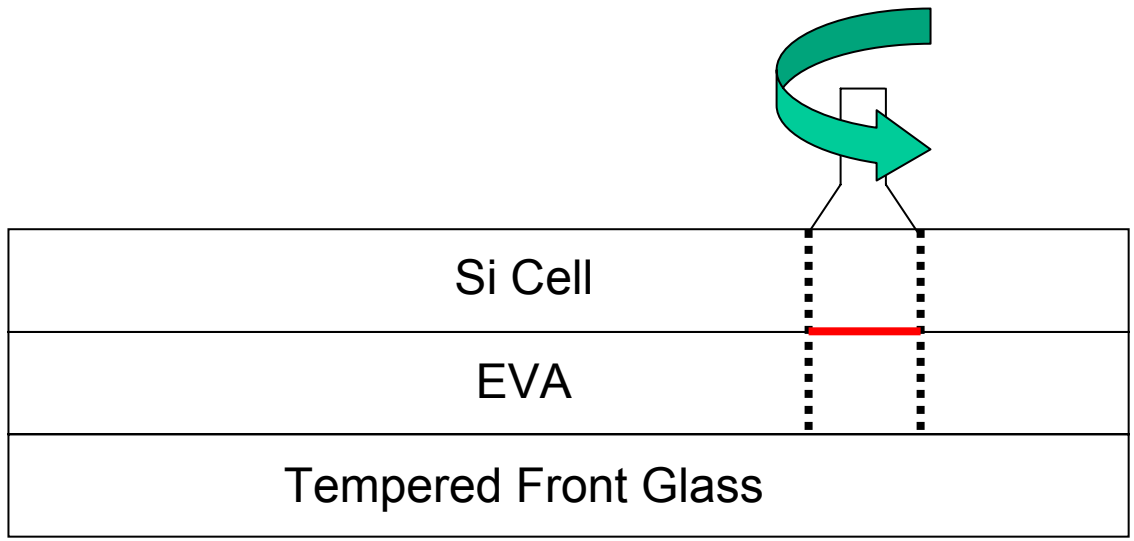
System for Measuring Torque as a Function of Twist Angle of Cored Modules

Close-up Image Showing Details of Torque Sensor and Coupling Hardware

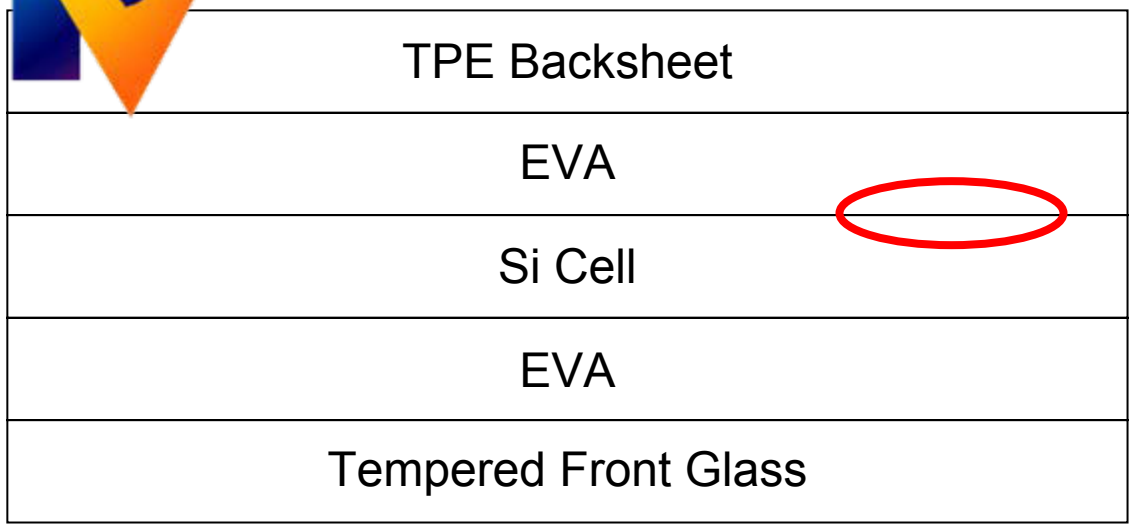


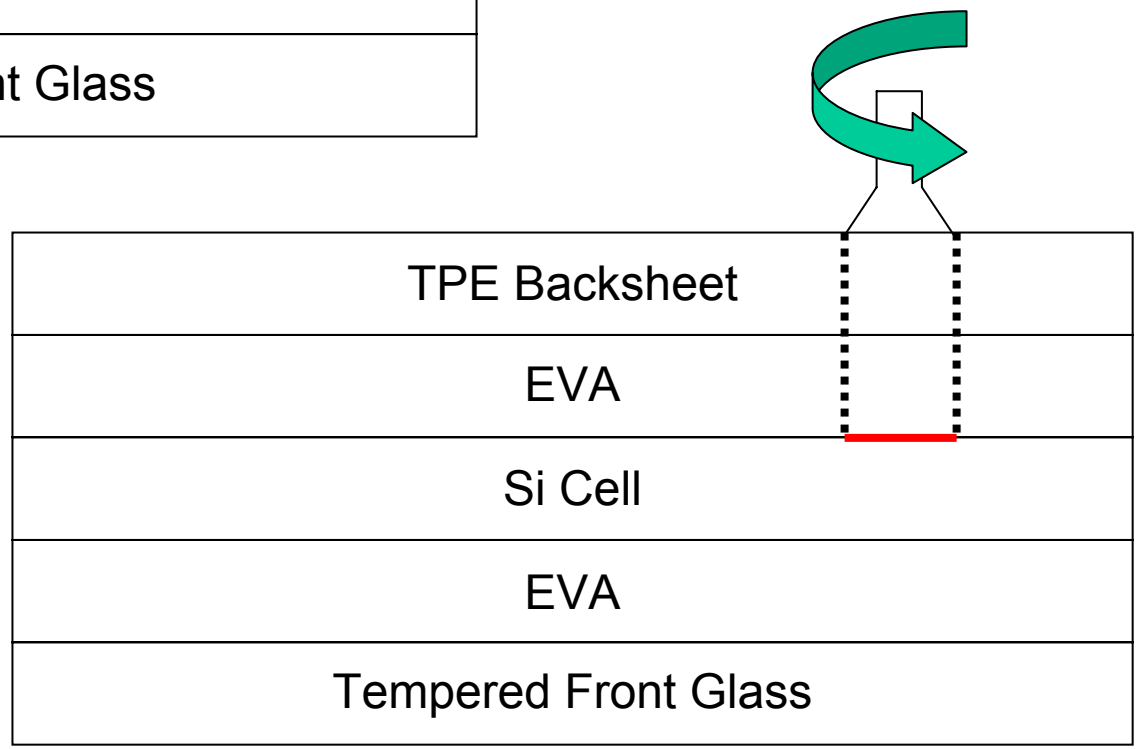
Shear Strength Measurement at Front Cell/EVA Interface



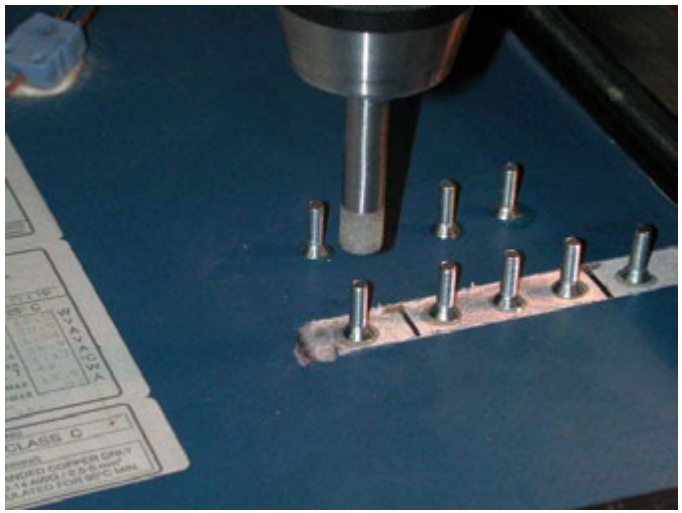


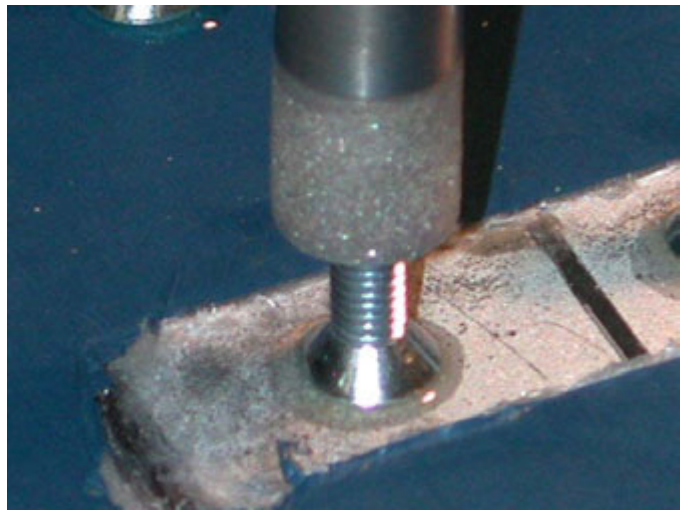
Shear Strength Measurement at EVA/Back Cell Interface

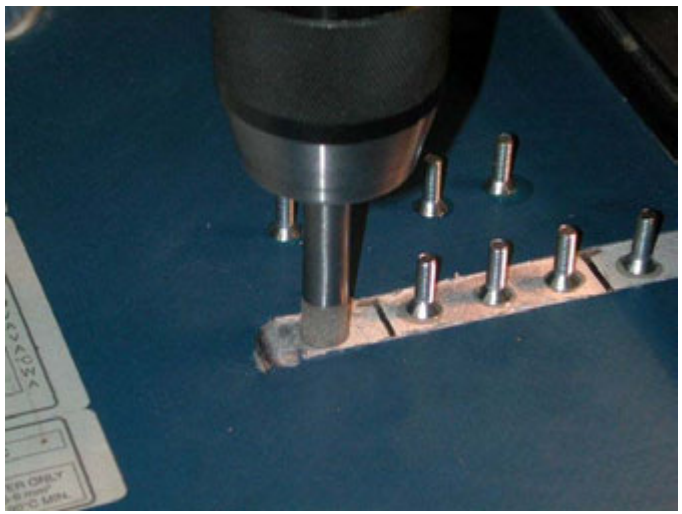


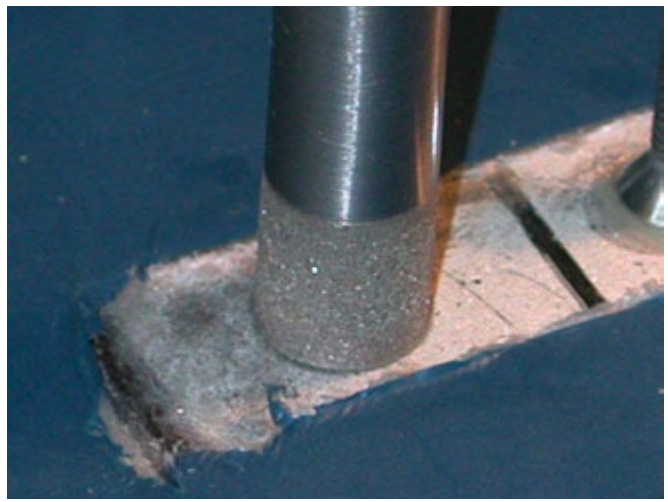


Details of the Cell Coring Process

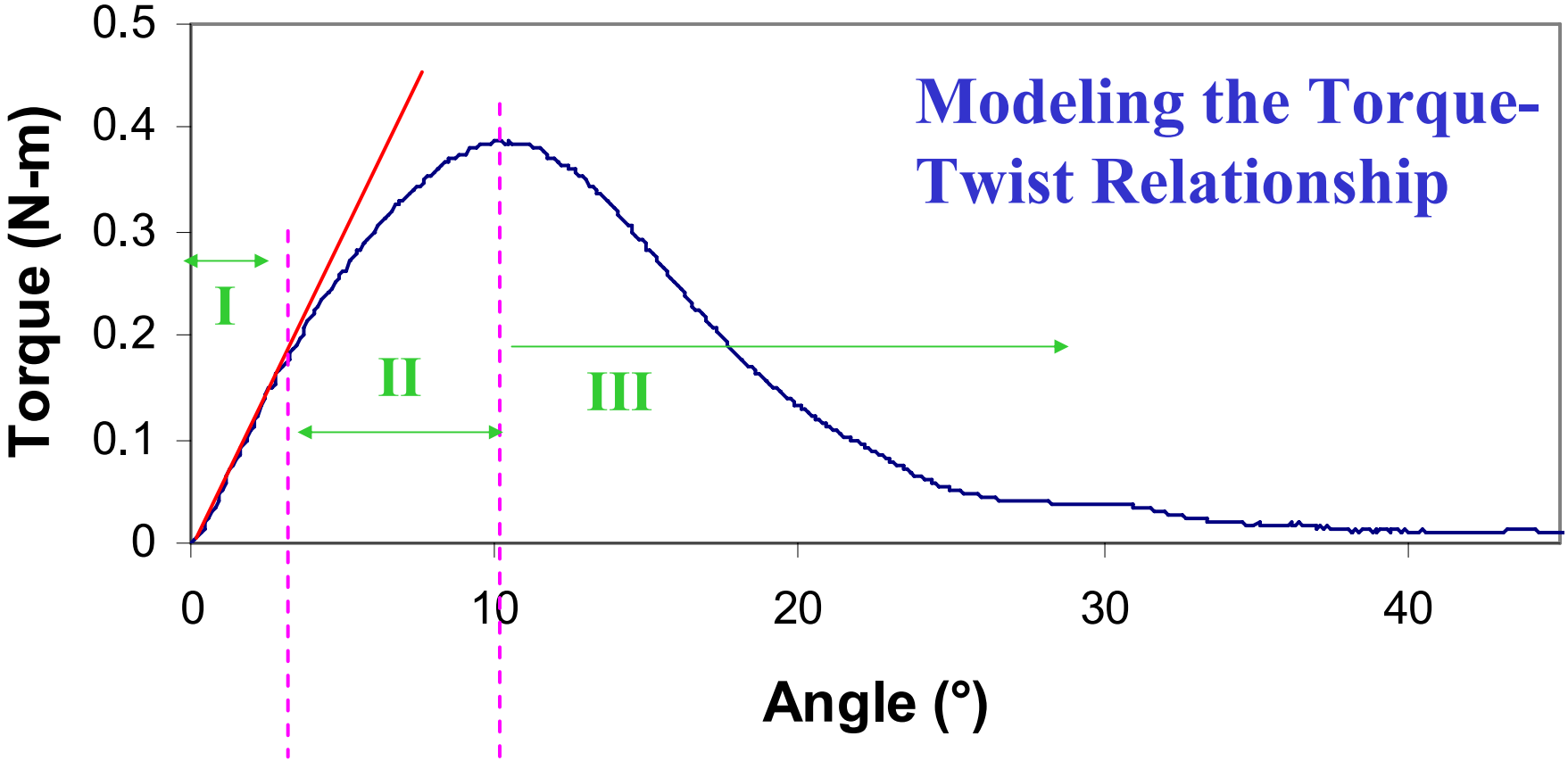


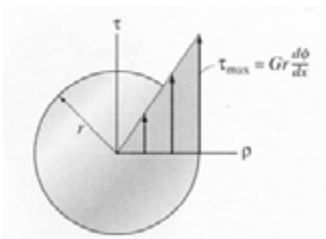


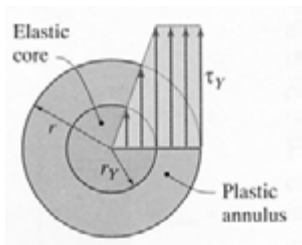


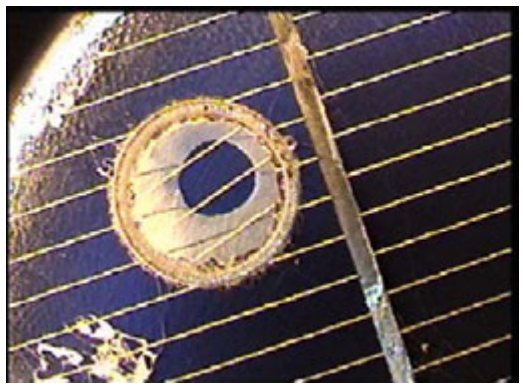


Modeling the Torque-Twist Relationship

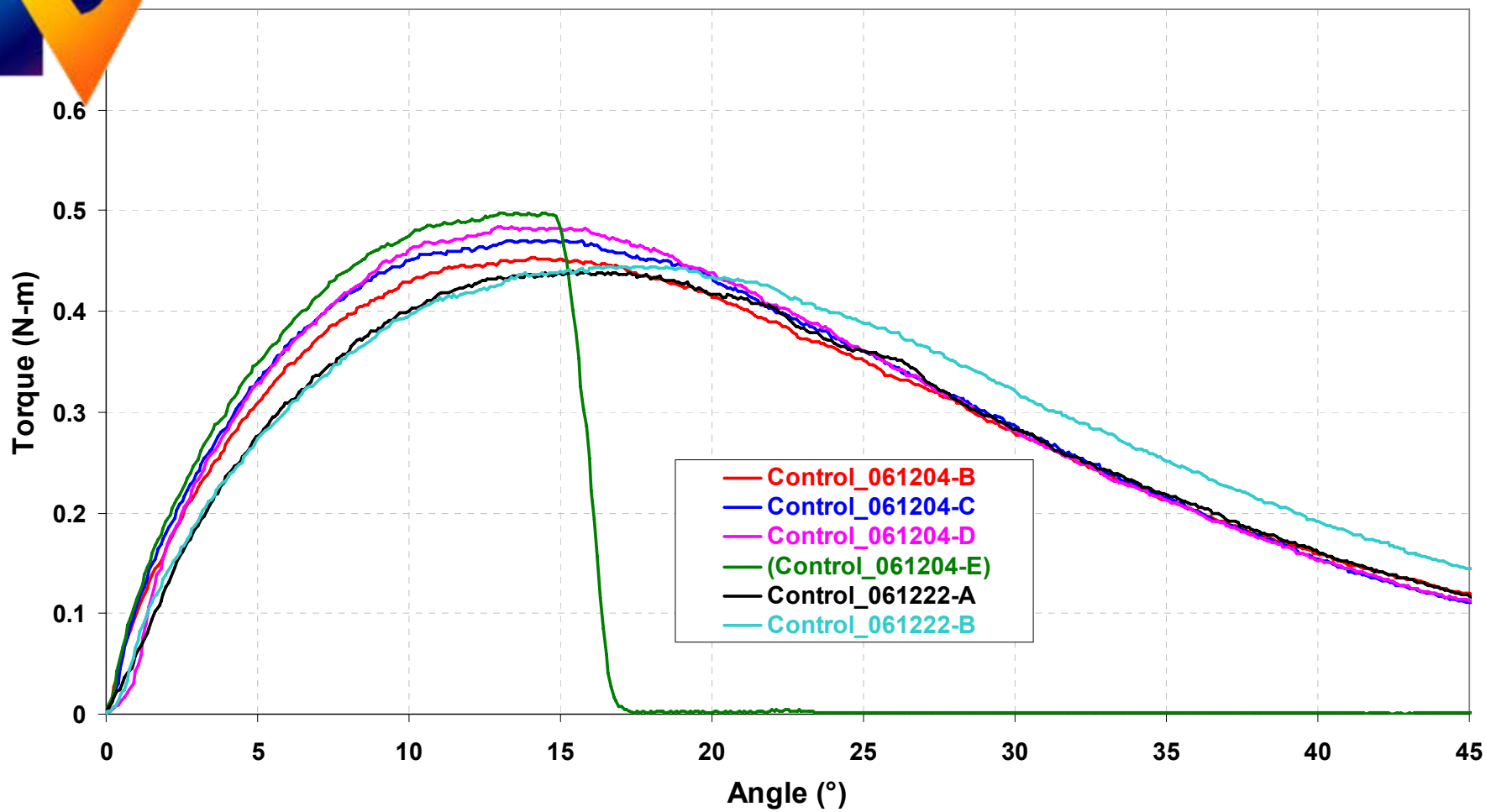


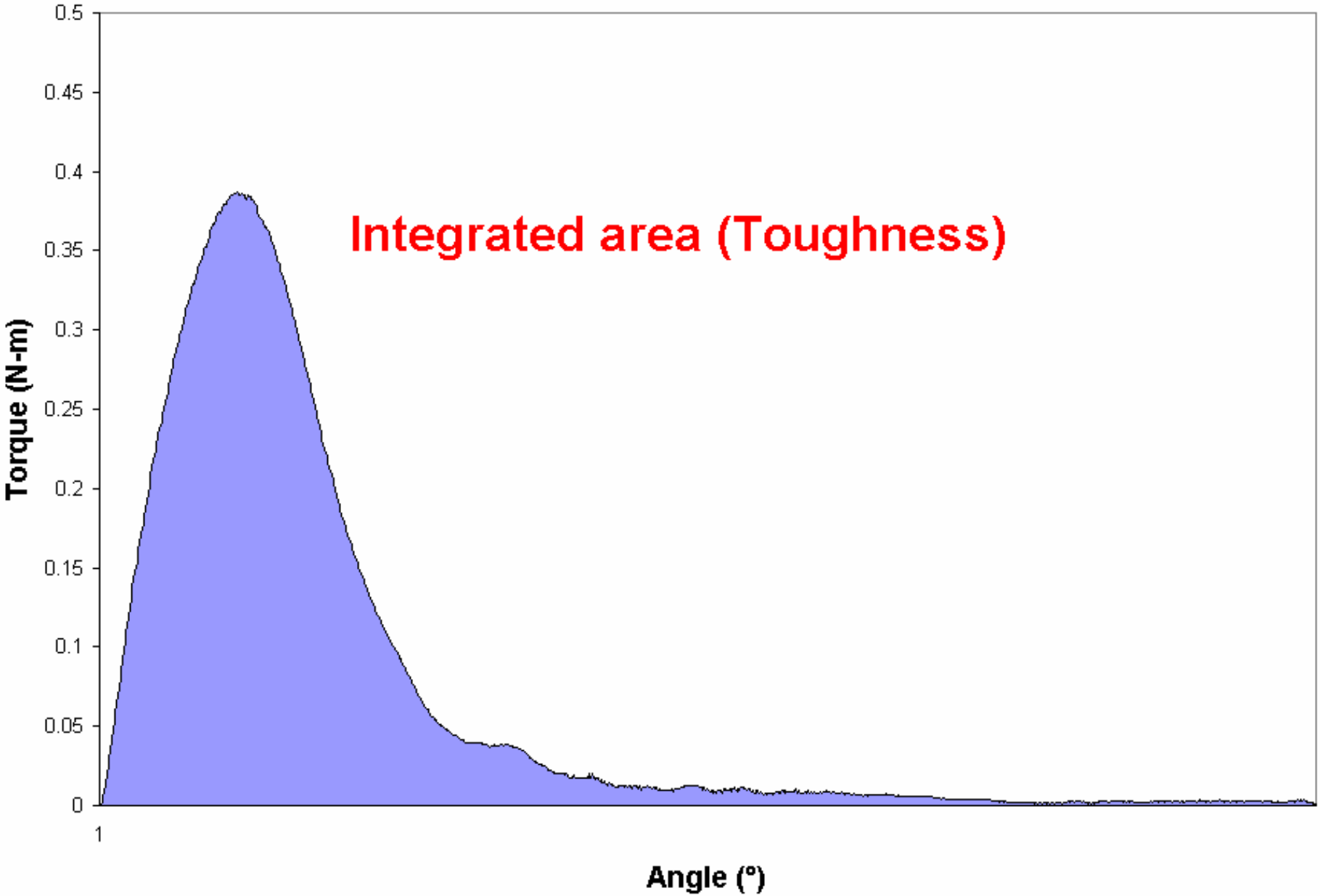




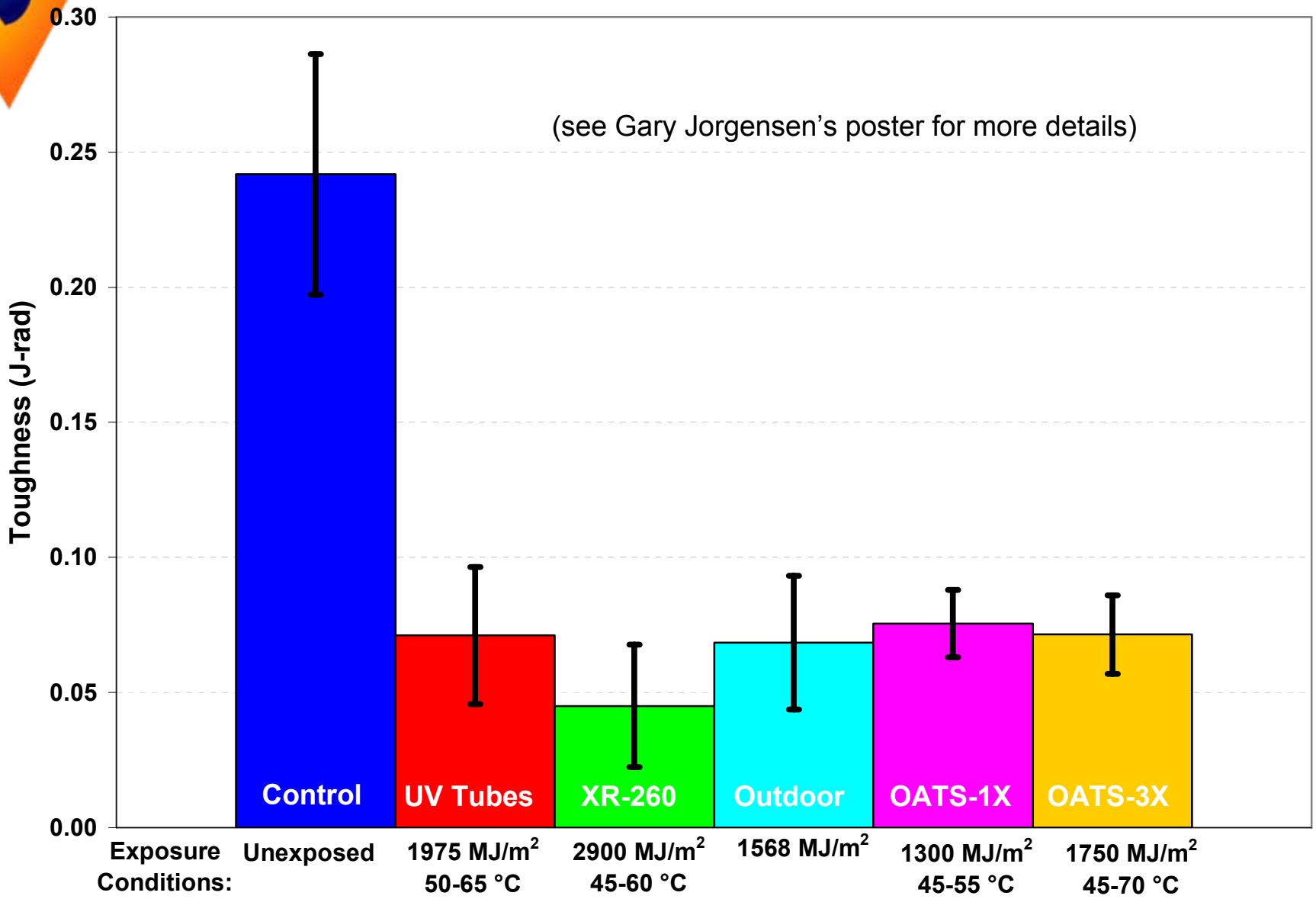


Torque vs. Angle; Large Mono-Crystalline Si Modules; Control; Frontside of Si Cell/EVA




0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Torque (N-m)
Integrated area (Toughness)
1
Angle (°)

Toughness of Small Mono-Crystalline Si Modules



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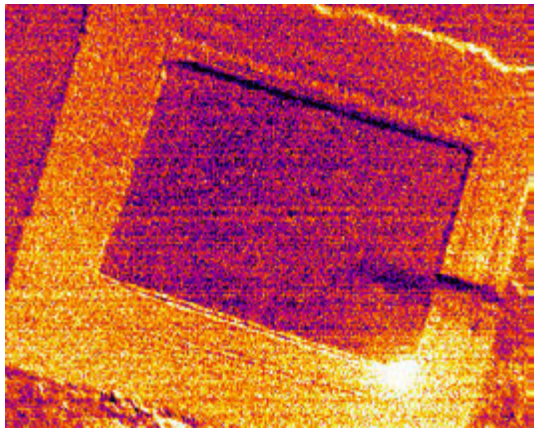
- Infrared (3-5 micron) cell and module diagnostics.

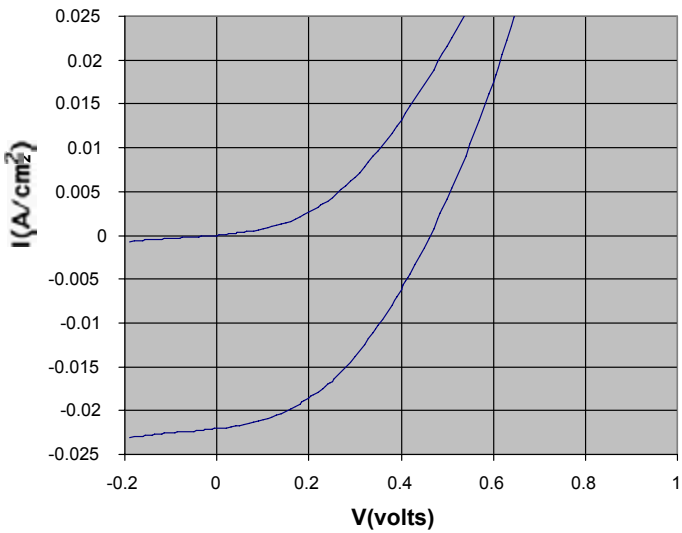
I-R Image of Cells and Modules

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.

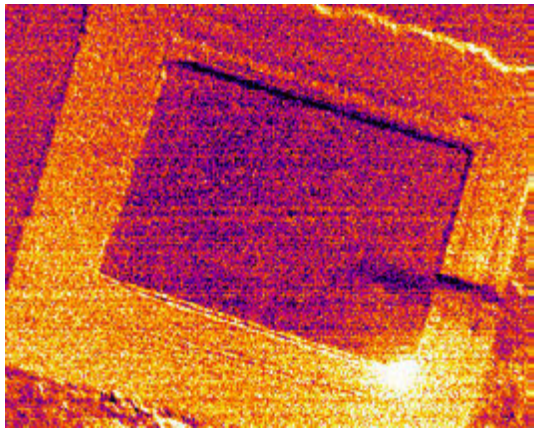
Hot in forward bias.

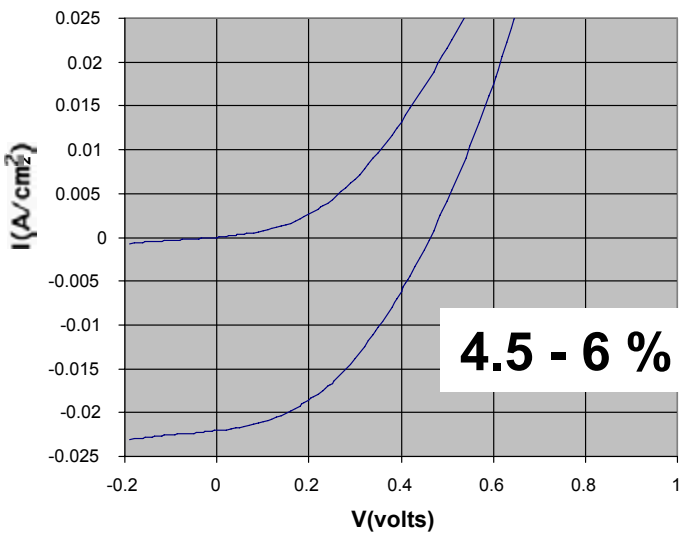
Not in reverse bias

NEDT 25 mK

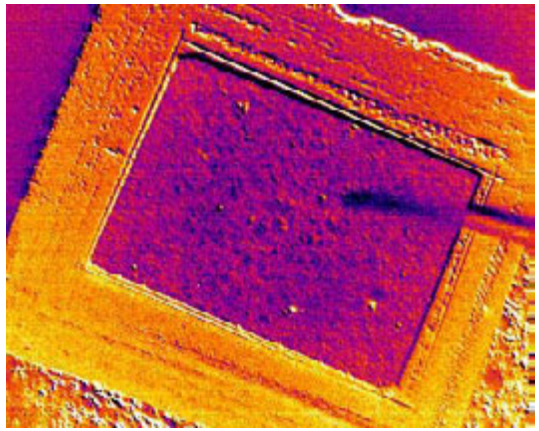
CdTe cell WD removal

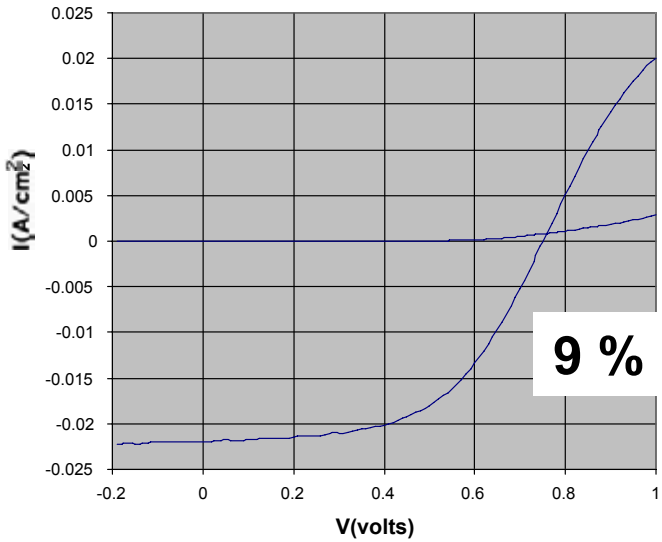
1225 h at Voc at 100 °C





WD @ Corner Removed

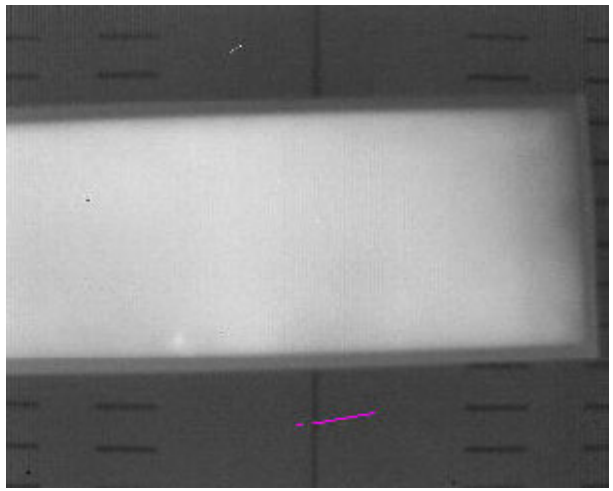




T.J. McMahon, T.J. Berniard, and D.S. Albin, " Non-linear Shunt Paths in Thin-Film CdTe Solar Cells," T.J. McMahon, et al., J. Appl. Phys. 97, (2005) 054503

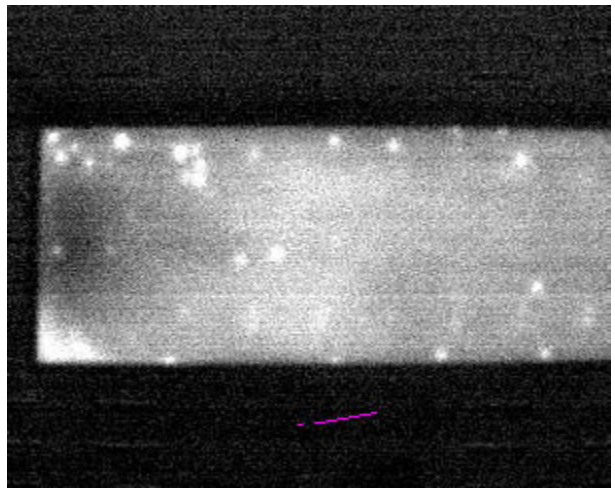
IR images; forward bias

#3044 Control



Uniform
recombination heat.

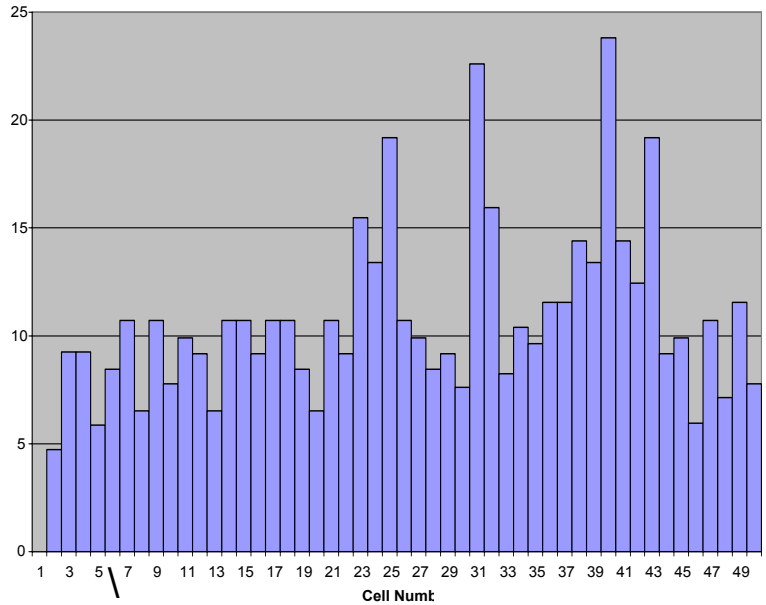
#2994 5 y @ NREL



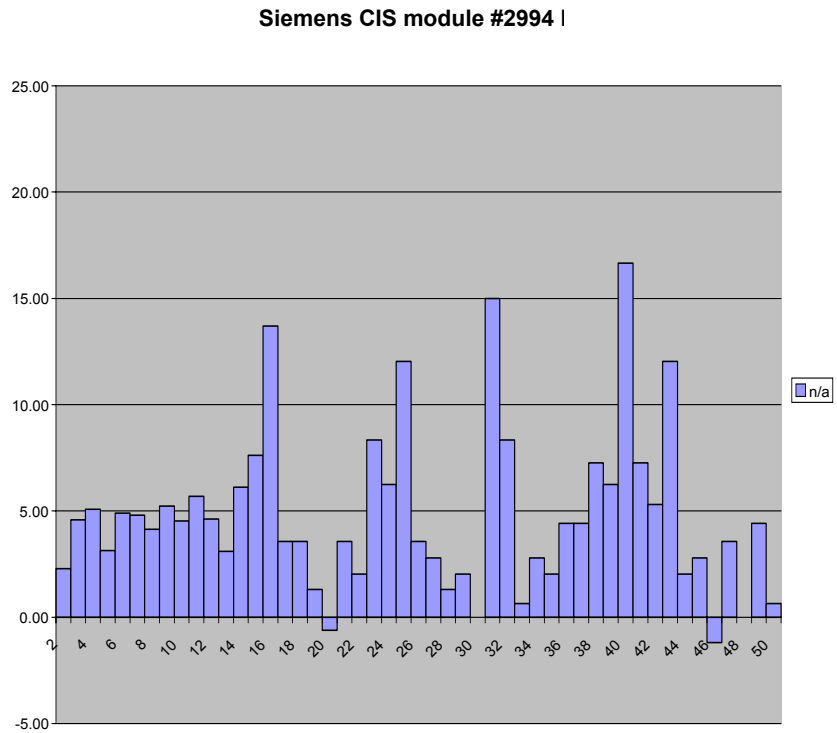
Localized
WD heating

Two-Terminal, Non-destructive Technique

#2994 5 y @ NREL

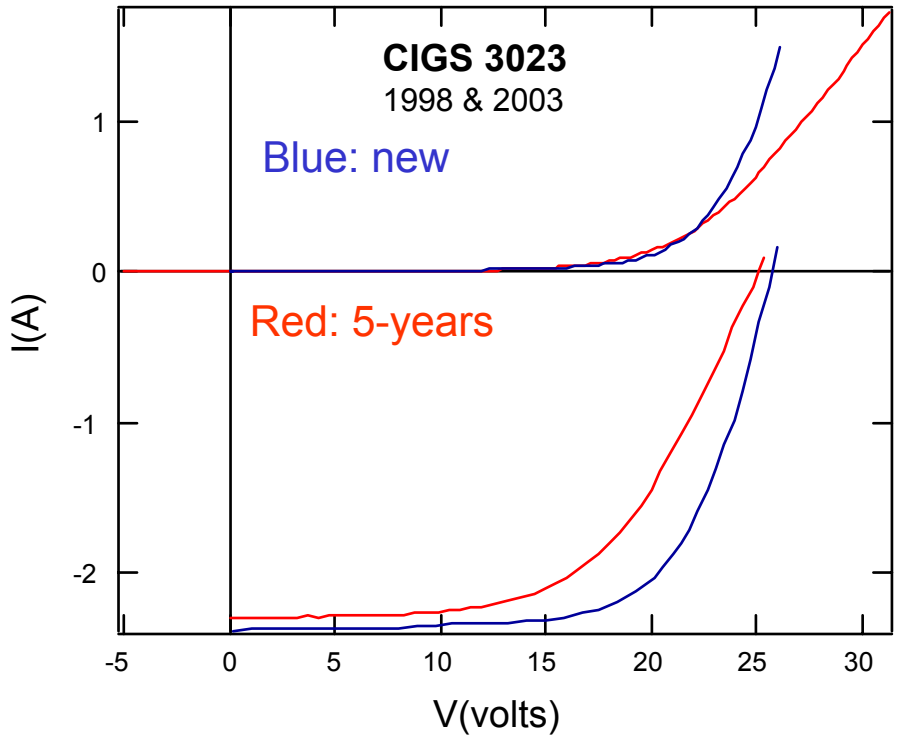


#2994 7 y @ NREL



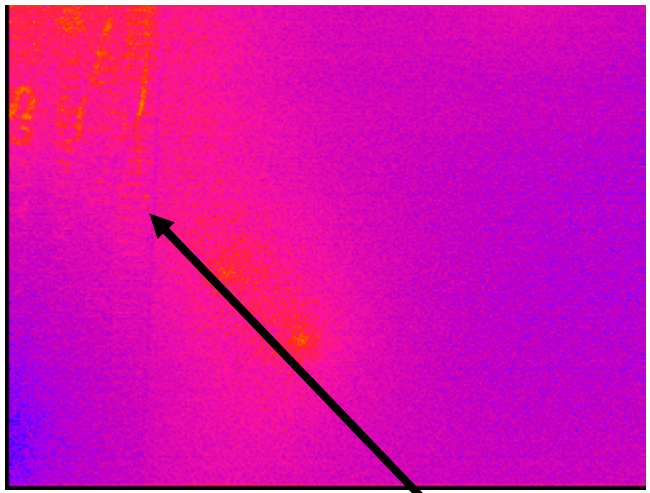
Cell Shunt Resistances

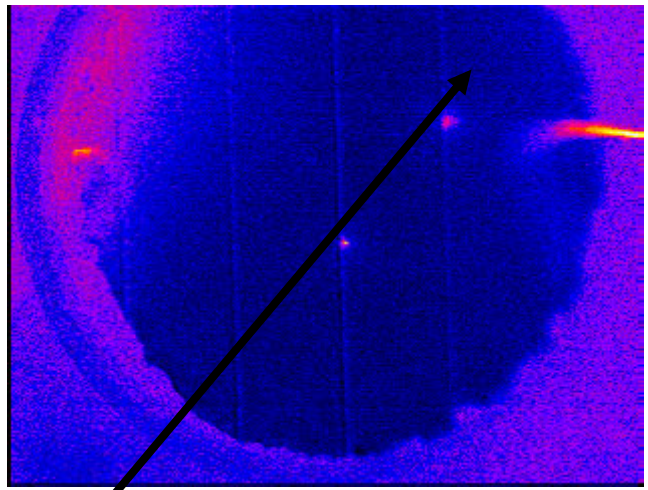
CIGS Core from double glass module

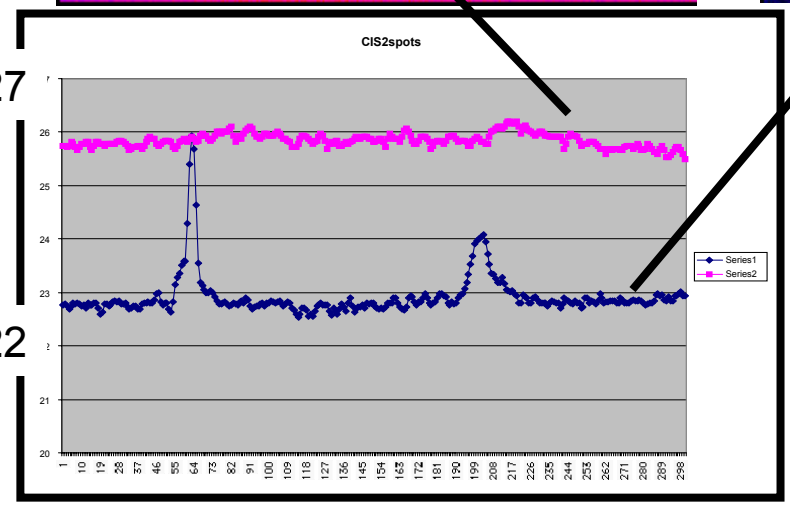


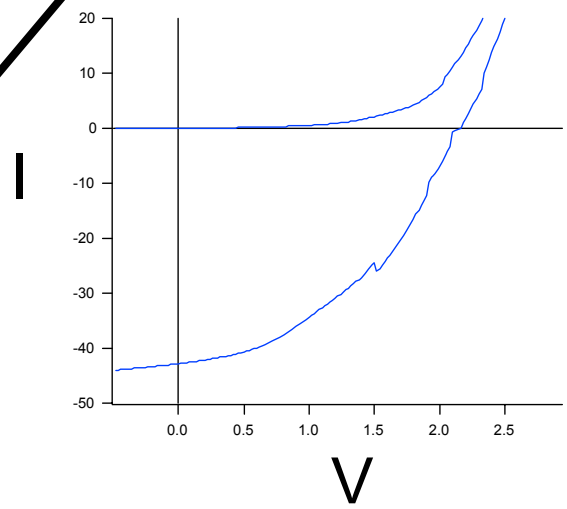
IR Image of Core-In and Out

NEDT 125 mK



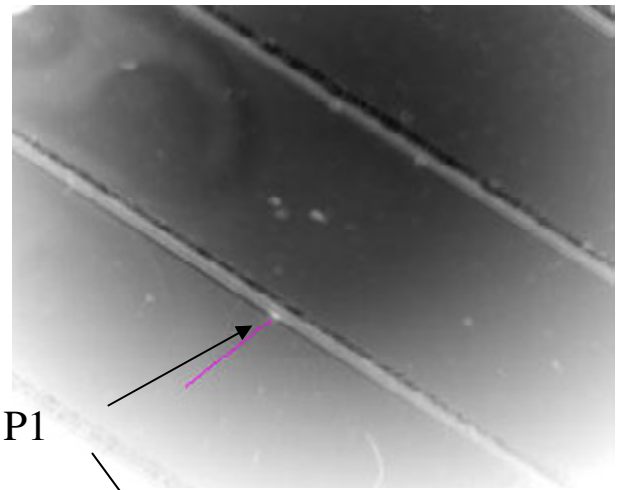




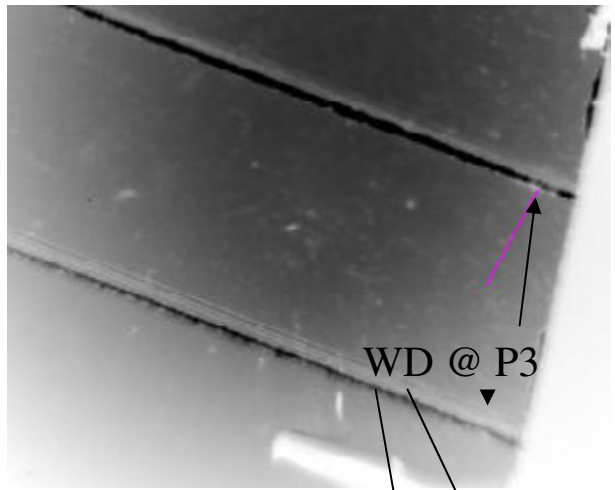


CIGS CORE 6.24mA@4.0V
#3023 NREL 5-Years

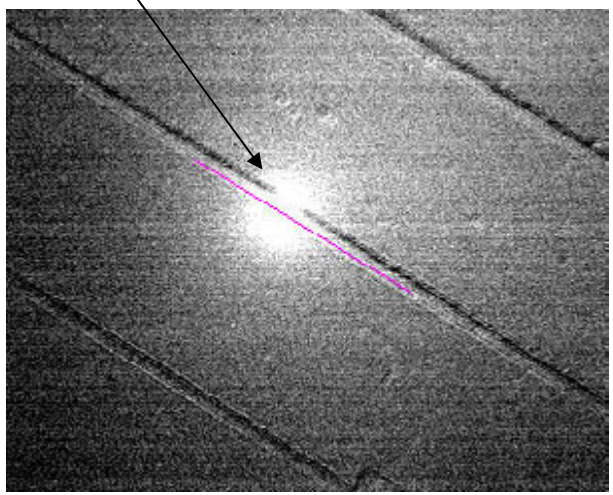
NEDT 25 mK

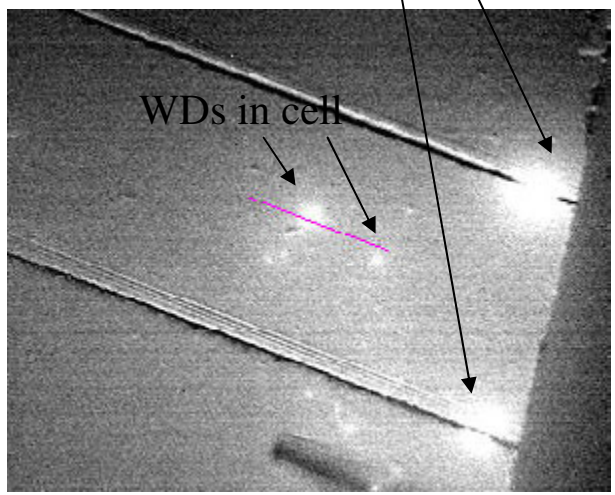


WD @ P1



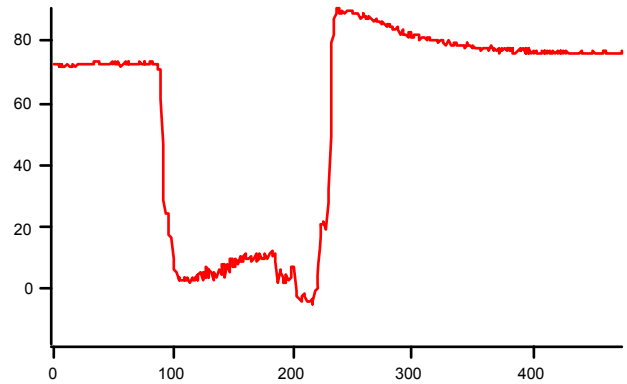
WD @ P3





WDs in cell

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



Visible image of scribe line

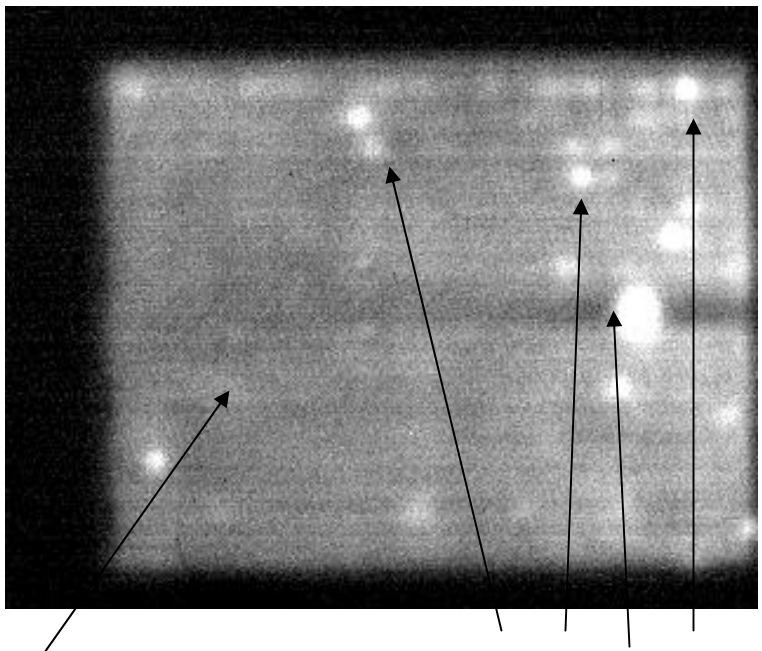
Optical beam induced current

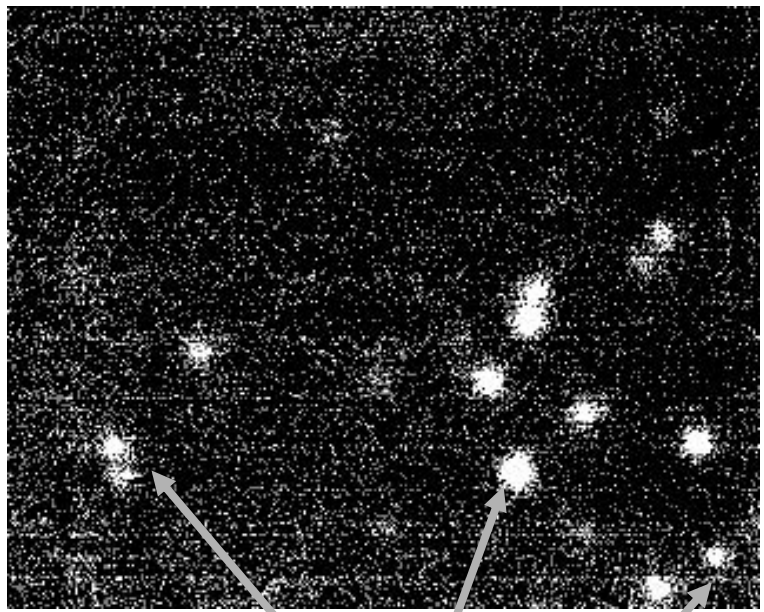
30FS90mA(2mA)@+(-)9.6V20s-zero

Dry 85°C, 2280 h

Forward Bias

Reverse Bias





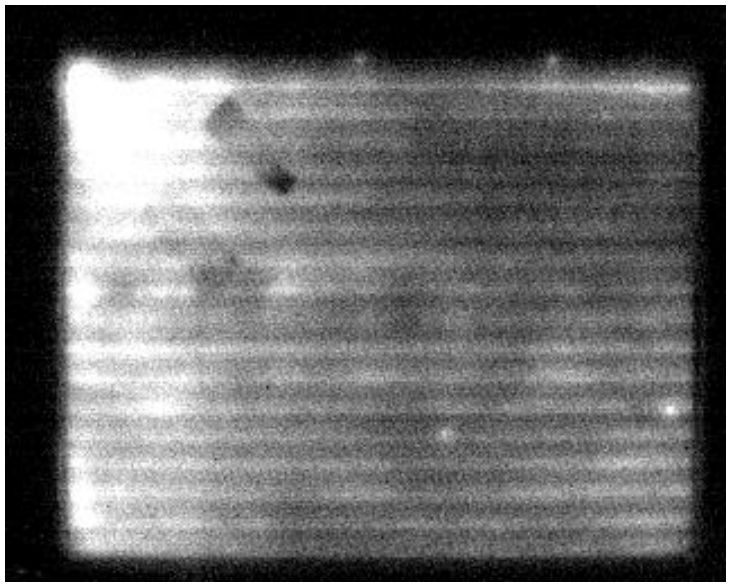
C:Recom. Area

B:Weak-Diodes

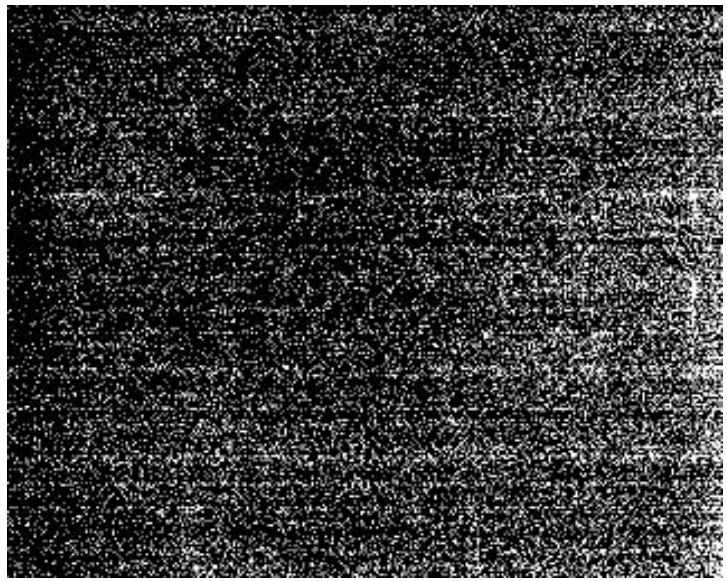
A:Shunts

32FS@+/-9.6V20s-zero

85%/85°C, 497h



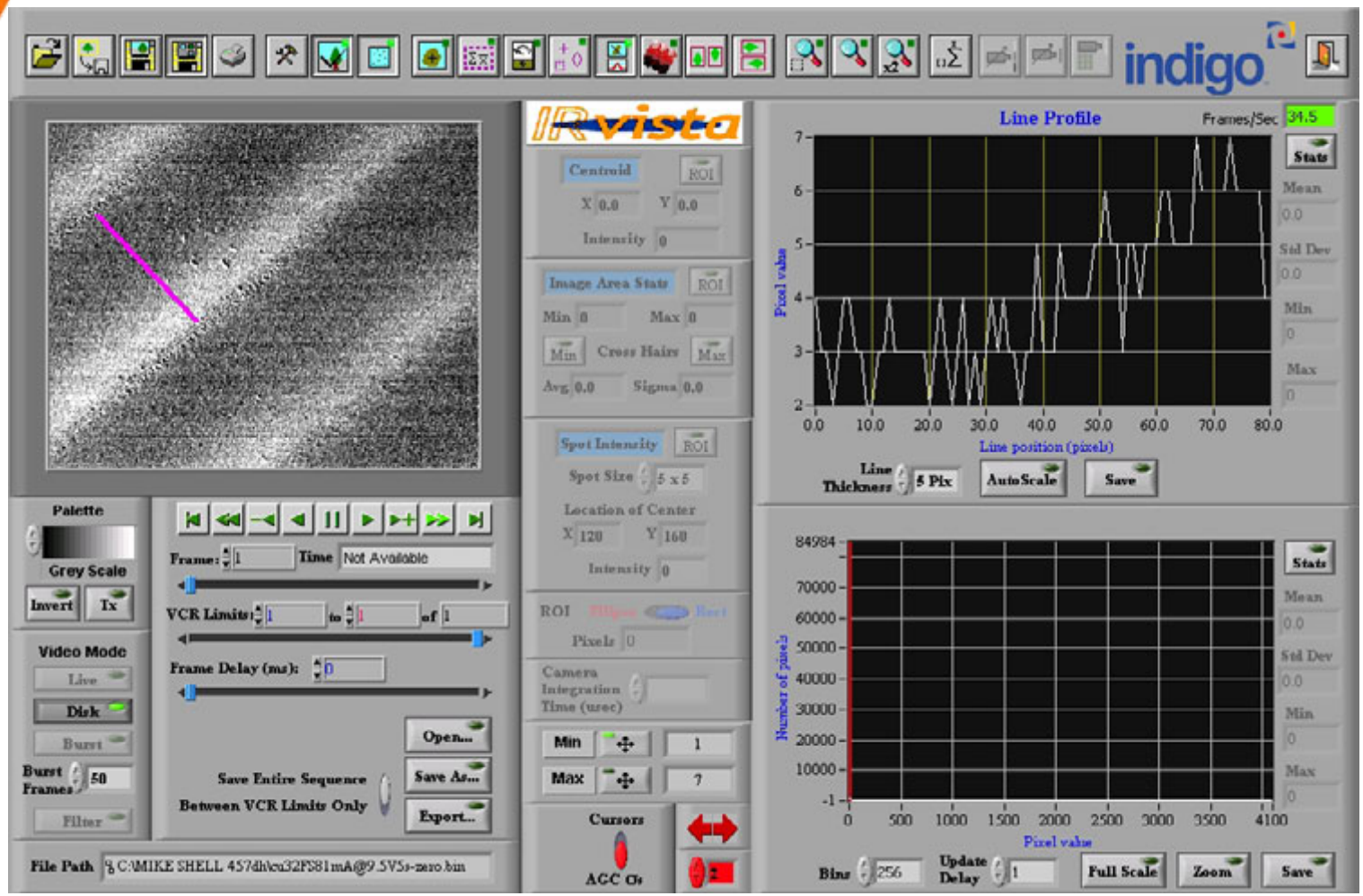
+81 mA



-0.24 mA

32FS 81mA@9.6V5s-zero

85%/85°C, 497h



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.