Photovoltaic Reliability and Failure Analysis: Enduring a Storm

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Introduction to Photovoltaics Failure Analysis

Introduction to solar technologies
- Silicon: Single crystal, polycrystalline and amorphous
- Thin film technologies: CdTe, Cu(In,Ga)Se and organic

Failure modes for photovoltaics
- Silicon: packaging, contacts
- Thin film: stability, oxidation, breakdown

Photovoltaic Failure Analysis
- Light emission (electroluminescence & photoluminescence)
- Thermal Imaging (infrared and thermal reflectance)
PV reliability: different than IC or LED

- PV panels sit outside
  - Extreme environment
  - -20 to 110 °C
  - 365 * 20 years of thermal cycles
  - 0-100% humidity + 1” hail
  - kW – MW of power
    - 1000V @ 10 amps

- PV Panels are big
  - Large environmental chambers
  - Low statistics

- PV panels are expensive
  - 100 part test = too expensive
Overview of Failure Analysis

- Failures result of two types of test
  - Qualification testing (e.g. IEC11646)
  - Field (weather) failures

- Photovoltaic Failures: ~1mm – 100 cm range
  - Packaging related
  - Localized degradation

- Efficiency optimization: 0.1 – 100 µm range
  - Improving materials properties
Solar cell efficiency improvements

Goal for next generation solar cells: high efficiency AND low cost

Multi-junction cells
- MBE growth
- > 40% efficient
- Expensive

Single crystal Si
- >20% efficient
- Expensive

Thin film cells
- >10% efficient
- Less expensive
- Toxic materials

Polymers
- <5% efficient

Cost
DOE Solar America Initiative Goals (funding = $160M current → $200M future)

**Primary goal:**
Low cost / watt

1.5x reduction:
Residential energy

3x reduction:
Utility generation

Cost:
~50% module
~50% installation

**Cost (LOC) = Capital / Lifetime → longer lifetime**
"Home Depot" cost of PV panel

Spot price for Si module: $1.79 / watt
Spot price for thin film module: $1.30 / watt
Utility price for PV panels: ~$1.00 / watt (First Solar)
Current generation silicon solar cells

- Single crystal silicon photovoltaic solar cells

**Advantages:**
- 10 - 20% power efficiency (commercial module)
- 20 – 24% champion cell efficiency (internal reflectors, multi-junctions, etc…)
- Very high reliability

**Disadvantages:**
- Theoretical limit of ~30% efficiency
- Expensive
- Use semiconductor waste (limited supply)
- Price goes up as production goes up
- High energy input for manufacturing: Production energy ~2 years of operation
Silicon Cells

- Alternate silicon solar cells

**Poly-crystal Si solar cells**
- 10 - 15% power efficiency (commercial)
- High temperature annealing (600°C – 800°C)
- High purity material still required
- Abundant substrates

**Amorphous Si:H**
- As deposited Si is amorphous
- High hydrogen content to passivate traps
- 6 – 10% power efficiency (commercial module)
- Weak Si-H bond ➔
  - Major stability / reliability problems
Alternate Thin Film Solar Cells

CIGS Solar Cells
(Miasole, Nanosolar)

• High efficiency (12 – 17% module efficiency)
• Lower temperature processing (~400°C)
• Metal foils for substrates

CdTe Solar Cells
(First Solar)

• High efficiency (12 – 17% module efficiency)
• Lower temperature processing (~400°C)
• Metal foils for substrates
Dye sensitized solar cells

- Nanostructured TiO2 electrode + liquid electrolyte
  - Light induced oxidation / reduction of electrolyte
  - > 10% conversion efficiency demonstrated in 1991
  - Liquid based processing (inexpensive)
  - High surface area electrode

Problem: Long term stability (reliability)
Organic Photovoltaics

- Nanostructured organic mixture (Konarka)
  - Organic Polymer + C60 as absorber
  - Co-polymer as electrode
### PV Reliability and Si: Packaging

**S. Kurtz, NREL**

#### Reliability Concerns Associated with Application of PV Technologies in Systems

<table>
<thead>
<tr>
<th>Known and Anticipated Failure Modes &amp; Degradation Mechanisms</th>
<th>Priority/Prob. of Success / Role for Labs (High-Med-Low)</th>
<th>Diagnostic Technique / Qual Test (e.g., chamber tests, HVTB)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion leading to loss of grounding</td>
<td>H/L/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quick connector reliability</td>
<td>H/L/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improper installation leading to loss of grounding</td>
<td>H/L/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delamination</td>
<td>H/M/M</td>
<td>This is especially a problem for flexible packages</td>
<td></td>
</tr>
<tr>
<td>Glass breakage</td>
<td>M/F/L</td>
<td>For products using glass</td>
<td></td>
</tr>
<tr>
<td>By-pass diode failure</td>
<td>M/H/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter reliability</td>
<td>M/H/M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor solder joints between string ribbons and wires</td>
<td>H/H/H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracked cells (caused by bending of conductors, strain</td>
<td>H/M/H</td>
<td>Electro-luminescence can detect cracks.¹</td>
<td></td>
</tr>
<tr>
<td>Increased series resistance from solder joint or gridline</td>
<td>H/M/M</td>
<td>This is not new, but continues to be a quality assurance issue</td>
<td></td>
</tr>
<tr>
<td>Reduced adhesion strength that increases corrosion</td>
<td>M/M/M</td>
<td></td>
<td></td>
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<tr>
<td>and/or delamination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow degradation of $I_{sc}$</td>
<td>M/M/M</td>
<td>Mechanisms are not fully understood</td>
<td></td>
</tr>
<tr>
<td>Fatigue of ribbon due to thermal cycling</td>
<td>H/L/L</td>
<td>Not new, but continues to be an issue</td>
<td></td>
</tr>
<tr>
<td>Junction box failure</td>
<td>H/M/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Busbar adhesion, electrical contact, etc.</td>
<td>M/M/M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass edge damage of frameless modules (installation,</td>
<td>M/M/L</td>
<td>Frameless construction is infrequently used today for Si.</td>
<td></td>
</tr>
<tr>
<td>handling, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light-induced cell degradation</td>
<td>M/M/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of glass on encapsulant durability</td>
<td>M/M/L</td>
<td>Problems may return because ofGeo being removed from the glass</td>
<td></td>
</tr>
<tr>
<td>Effect of glass on module performance</td>
<td>M/M/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front surface soiling</td>
<td>L/M/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress breakage in glass-glass laminates</td>
<td>L/H/L</td>
<td>Glass-glass laminates are almost never used because of added weight.</td>
<td></td>
</tr>
<tr>
<td>See items listed in “General” section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrochemical corrosion of SiO$_2$-F</td>
<td>M/M/L</td>
<td>Light soaking; Voltage biased damp heat²</td>
<td></td>
</tr>
<tr>
<td>Initial light degradation (a-Si)</td>
<td>L/L/L</td>
<td>Light soaking</td>
<td></td>
</tr>
</tbody>
</table>

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**For Si cells, materials and packaging**
### Thin film cells: Stability of thin film

**S. Kurtz, NREL, 2009**

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H/H</td>
<td>Cell layer integrity – backcontact stability</td>
<td>Voltage biased damp heat</td>
</tr>
<tr>
<td>L/M</td>
<td>Cell layer integrity – interlayer adhesion and delamination; Electrochemical corrosion of SnO2:F</td>
<td></td>
</tr>
<tr>
<td>H/M/H</td>
<td>Full-factor loss (increased series resistance and/or recombination)</td>
<td>Cell + Module Light soaking; Damp Heat</td>
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<td>H/H</td>
<td>Busbar failure - mechanical (adhesion) and electrical</td>
<td>IR Camera; Hot/humid vs. damp heat</td>
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<td>H/M</td>
<td>Shunt hot spots at scribe lines before and after stress</td>
<td>IR Camera; Hot/humid vs. damp heat</td>
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<td>H/M/H</td>
<td>Weak diodes, hot spots, nonuniformities before and after stress</td>
<td>IR Camera; Hot/humid vs. damp heat</td>
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<tr>
<td>H/H</td>
<td>Cell layer integrity – contact stability</td>
<td>Mo backcontact (all), the front contact is only a problem when the module is assembled from discrete cells</td>
</tr>
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<td>M/H/M</td>
<td>Cell layer integrity – interlayer adhesion</td>
<td></td>
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<td>Full-factor loss (increased series resistance and/or recombination)</td>
<td>Screen at cell initially, then module</td>
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<td>Notable sensitivity of TCO to moisture</td>
<td>Damp heat exposure</td>
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<td>H/M/H</td>
<td>Moisture ingress failure of package</td>
<td>Hot/humid vs. damp heat</td>
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<tr>
<td>H/M/H</td>
<td>Cell–to–cell interconnect (discrete cells)</td>
<td>IR Camera; Hot/humid vs. damp heat</td>
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<td>Notable sensitivity of TCO to moisture; need to pass damp heat test (non-shingle specific)</td>
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<td>M/H/M</td>
<td>Edge shunting</td>
<td>Discrete Cell – Flexible roofing products</td>
</tr>
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</table>

**For thin film (nanostructured) PV's: Degradation is Localized**
Large area device non-uniformities

Most large area devices will have intrinsic non-uniformities
Exception, a-Si on glass, Single crystal cells
Example of Thin Film PV

- Cu(In,Ga)Se thin film photovoltaic
  - Significant grain structure / surface morphology
"Hot Spot" degradation of solar modules

Partial shading of module can lead to degradation of modules
Module vs. Cell

- Cells (5”): fit in SEM, minimal encapsulation
- Module = large area: does not fit in SEM, encapsulated
- FAILURES are at module level

Cell vs. thin film

- Thin film technologies: cells fabricated in parallel
- Cells have ~10mm x 1000mm size

Glass substrate (CdTe) vs. superstrate (Si cells)

- Some technologies fabricated on glass / TCO
- Inspection through glass required

Materials

- Plastics and nanostructured materials
Multi-Cell Fabrication: Si and thin films

- **Cell Assembly**
  - Fabricate cells (5” standard)
  - 1 cell = 1 watt / 0.5V / 2A
- **Glue cells to glass**
  - EVA polymer encapsulant
- **Cell interconnects applied**
- **Plastic back-coating applied**
- **Sealed in frame**
  - Edge seal critical for moisture
  - High voltage applied to edge
Thin film fabrication on glass substrate

- Deposit TCO on glass
  - TCO = transparent electrode
  - Pattern TCO layer (P1)

- Deposit absorber
  - a-Si, CdTe
  - 400 – 600 °C
  - Pattern absorber (P2)
  - Laser leaves TCO

- Deposit metal contact
  - PVD and / or paste
  - Pattern metal contact (P3)

- Glue to glass backplate
Roll-roll processing (organic PVs)
(M. Kreger, Konarka)

- High speed and low temperature processing
- Bulk Heterojunction Technology
- Intertwining of phases of each of components
- Morphology contributes significantly to module performance
Degradation tends to be localized

- **Shunts**
  - Local shorting within PV material

- **Weak Diodes**
  - Large local series resistance

- **Hot spots**
  - Excessive recombination current

- **Cold spots**
  - Spots with no current

- **Poor contact**
  - Local degradation of metal or transparent conductor

- **Leakage**
  - Moisture induced leakage and corrosion

- **Localized defects impact yield and efficiency**
Detection of Failed Cells

Infrared imaging of modules:
Shunted cells

Infrared Imaging: industry standard for PV analysis

www.movitherm.com
Partial Shading and Differential Analysis

Shade one Cell by 50%

Current (A)

Voltage (V)

Shunt resistance of shaded cell
- 40 ohms
- 16 ohms
- 8 ohms
- 4 ohms
- No Shading

Peak in dV/dI ~ shunt resistance

Differential Resistance dV/dI (ohm)

Resistance Maximum

Current (A)
Extraction of Shunt Resistance: Better Statistics

| 20 | 2.1 | 5.9 | 7.1 | 0.6 | 1.1 |
| 21 | 63  | 45  | 25  | 1.4 | 1.3 |
| 18 | 43  | 26  | 16  | 1.4 | 1.2 |
| 15 | 55  | 11  | 38  | 1.4 | 1.7 |
| 14 | 5.1 | 5.3 | 1.8 | 1.8 | 2.2 |
| 11 | 2.0 | 2.3 | 6.3 | 2.4 | 3.5 |
| 2.8 | 43 | 53 | 2.1 | 2.3 | 2.5 |
| 4.8 | 15 | 3.3 | 7.9 | 2.3 | 3.4 |
| 3.7 | 8.5 | 2.8 | 10  | 6.6 | 3.3 |
| 2.8 | 18 | 17 | 20  | 8.0 | 2.5 |
| 4.7 | 2.5 | 15.2 | 4.4 | 3.3 | 3.1 |
| 1.5 | 58 | 1.5 | 1.5 | 7.5 | 1.5 |
Comparison to EL

Low Shunt Resistance ~ Dark Cells

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<th>20</th>
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<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>
1) Automatically cycle through shading each cell
2) Automatically collect module IV
3) Use shaded IV curve to extract cell parameters
   Shunt Resistance
   Cell Power Contribution

Example scan of 18 cell panel from Kyocera
Time: ~15s / cell
Shunt resistance from shaded dV/dI curve
Also applicable to hot spot testing
Localized Heating IR imaging

- Dominate imaging technique is IR imaging
  - Identify regions with <0.2°C temperature increase
  - Poor spatial and time resolution

![ILIT Amplitude Image of a Si solar cell](image1.png)
![DLIT Amplitude Image of a thin layer module](image2.png)
Core Sample Removal

Full size module (~4’ x 5’)

2” core sample

Remove small core sample for detailed SEM and AFM image
Common Photovoltaic Failure Analysis

- **Induced current probes**
  - LBIC / EBIC / XBIC (light / electron / x-ray beam induced current)
  - Spatial mapping of quantum efficiency
  - Local mapping of carrier lifetime
  - Shunt / series resistance mapping

- **Emission Spectroscopy**
  - Information depends on emission energy
    - Electroluminescence (visible – near infrared)
    - Photoluminescence (near infrared)
    - Thermal imaging (far infrared)
  - Local mapping of current density
  - Local mapping of carrier lifetime
  - Shunt / series resistance mapping
Optical Emission from Si (EI and PL)

Different energy emission = different mechanism

Breakdown radiation
Band-to-band luminescence
300K thermal radiation
Dislocation luminescence

Detectors:
- InGaAs
- InSb
- HgCdTe

M. Kasemann et al., EU PV Sol. Energy Conf. (2008)
Pre-breakdown emission from Electroluminescence

Under reverse bias:
  localized EL spots visible (5-10V)
  Spectrum in visible

Energetic electrons with large reverse bias:
  “Avalanche” breakdown or “Zener” breakdown = broadband emission
  Correlation to metallic impurities
  Correlated to local heating

Band-Band Emission (Near-IR)

- Strongest EL and PL emission from band-band
  - CdTe = direct bandgap (strong), Si = indirect (weak)
- Weaker emission from impurity states (band-tail)

EL and PL emission from Cu-CdTe
DAP = Donor acceptor pair

EL emission from poly Si
Band to band and defect (band edge)
Dreckschmidt et al, EU PV energy Conf (2007)
EL emission proportional to local current
- Forward bias, image in NIR

Non-uniform EL emission of cell

Broken contact lines on cell

Electroluminescence intensity ~ current → Detect local breaks / cracks
Electroluminescence Applied to Modules

- EL emission has turn on voltage near Voc
  - Shunted cells = lower Voltage at given current relative to good cells
  - Cell-cell contrast will depend on bias current

0.75 A / 35V Bias

3 A / 45V Bias

Bad cells at low bias

Cells “OK” at high bias
Carrier lifetime mapping with EL and PL

- Forward bias cell
- Emission Intensity ~ lifetime
  - Intensity = G * τ
    (Generation rate * Carrier lifetime)
  - Fixed generation rate
    - Intensity ~ lifetime
- Quantitative lifetime
  - Not an absolute measurement
  - Calibration with known sample
  - Transient method for calibration
- Contrast depends on current
  - Diode current is non-linear
  - Saturated diodes = no contrast

Trupke et al., PVSC (2008)
Near IR EL: Series Resistance Mapping

Series resistance from EL

- EL sensitive to local current and voltage
  - Carrier diffusion length extraction
  - Diffusion depends on potential

- Quantitative series and shunt resistance
  - Difficult to determine why region is dark
  - Possible to extract voltage
  - Non-linear IV dependence → modeling

- Qualitative: Bias dependence
  - Current has turn-on voltage
  - Region always dark = High series R
  - Region dark at low current = Low shunt R

Trupke et al., Appl. Phys. Lett 90, 093506 (2007)
Laser Beam Induced Current (LBIC)

- Spatial resolution of current across solar cell
  - Maps quantum efficiency and carrier diffusion length across solar cell
  - Most sensitive near band edge -- choose wavelength carefully

Scanning local illumination of solar cell

Current output across solar cell

Commercial tools available (Semilabs)
Services available (analogous to OBRICH)

J. Sites et al., (www.physics.colostate.edu/groups/photovoltaic/PDFs/SitesLBIC.pdf)
Electron Beam Induced Current
Performed in SEM

- Spatial resolution of LBIC limited by spot size and carrier diffusion

- Internal quantum efficiency maps

- Greater carrier lifetime = greater efficiency

- Positive impact of passivation

Inject electrons directly into Si (>10keV)

Shorter lifetime = dark at grain boundaries

Higher resolution (<10nm spot size)

Grain boundaries Dislocations

Low temperatures required for best resolution

Passivated poly-xtal Si

Unpassivated poly-xtal Si

A. Zuschlag et al., EU PV Energy Conf. (2008)
Infrared imaging of modules:
Shunted cells

Infrared imaging of cells:
Local shunts / weak diodes

www.movitherm.com

Infrared Imaging: industry standard for PV analysis
### Electrical defects: Thermal Imaging

#### Thermal hot spots in chips: Electronics focus on resolution

<table>
<thead>
<tr>
<th>Method</th>
<th>Principle</th>
<th>Spatial (μm)</th>
<th>Temperature (K)</th>
<th>Response time (s)</th>
<th>Imaging?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microthermocouple</td>
<td>Seebeck effect</td>
<td>50</td>
<td>0.01</td>
<td>5 m</td>
<td>No</td>
</tr>
<tr>
<td>Infrared thermography</td>
<td>Planck blackbody emission</td>
<td>3–10</td>
<td>0.02 (if blackbody)</td>
<td>10 μm (single point)</td>
<td>Yes</td>
</tr>
<tr>
<td>Liquid crystal thermography</td>
<td>Crystal phase transitions (change color)</td>
<td>2–5</td>
<td>0.5</td>
<td>3 m</td>
<td>Yes</td>
</tr>
<tr>
<td>Thermoreflectance</td>
<td>Temperature dependence of reflection</td>
<td>0.3–0.5</td>
<td>0.01</td>
<td>0.006–0.1 μm</td>
<td>Yes</td>
</tr>
<tr>
<td>Scanning thermal microscopy (SThM)</td>
<td>Atomic force microscope with thermocouple or Pt thermistor tip (surface morphology)</td>
<td>0.05</td>
<td>0.1</td>
<td>10–100 μm</td>
<td>Scan</td>
</tr>
<tr>
<td>Fluorescence thermography</td>
<td>Temperature dependence of quantum efficiency</td>
<td>0.3</td>
<td>0.01</td>
<td>200 μm</td>
<td>Scan</td>
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<tr>
<td>Optical interferometry</td>
<td>Thermal expansion, Michelson type</td>
<td>0.5</td>
<td>0.0001 (1 fm)</td>
<td>0.006–0.1 μm</td>
<td>Scan</td>
</tr>
<tr>
<td>Micro-Raman</td>
<td>Shift in Raman frequency or ratio of Stokes/anti-Stokes amplitudes</td>
<td>0.5</td>
<td>1</td>
<td>1 μm</td>
<td>Scan</td>
</tr>
<tr>
<td>Near field probe (NSOM)</td>
<td>Use near field to improve optical resolution</td>
<td>0.05</td>
<td>0.1–1 (S/N dependent)</td>
<td>0.1–10 μm</td>
<td>Scan</td>
</tr>
<tr>
<td>Built-in temperature sensors</td>
<td>Fabricate a thermal sensor integrated into the device</td>
<td>100s</td>
<td>0.0002–0.01</td>
<td>1 μm</td>
<td>No</td>
</tr>
</tbody>
</table>
Shunts and weak diodes

- Non-uniform current = local heating = IR emission
  - Forward bias: Hot spots and shunts
  - Reverse bias: Weak diodes and Shunts
  - Shunts = heating in forward and reverse bias

Forward bias heating at weak diode

Weak diode removed

1225 h at Voc at 100 °C

4.5 - 6 %

9 %
Solar Panel Failure Analysis

Thermal Image of failed Si PV panel
Apply bias to module:
light spots = hot, dark = cold

Photovoltaic panels degrade through localized defects
Lock-in Thermography

- Static IR images: Thermal Spreading
  - Temperature wants to be uniform = low resolution

- Lock-in thermography: pulses
  - Uses high speed infrared CCD cameras
  - <1mK thermal resolution
  - Spatial resolution =
    - Thermal Diffusion / frequency ~ 3mm

- Very quantitative (variables scale out)
  - Shunt current, shunt IV

\[
I_{shunt} = \frac{I_{cell} \left( \frac{T_{shunt} - 90}{T_{hom} - 90} \right) A_{shunt}}{A_{cell}}
\]

Series of Dark images (D)
Series of Bright images (B)
Image = \( \Sigma_i [B_i - D_i] \)
Constraints of IR imaging

- Thermal Spreading and imaging through glass

(a) far-IR imaging of local hot spots in PV module

(b) Thermal reflection (TR) imaging of hot spot in PV module

AC modulated reflection signal from hot spot

Incident light near absorption edge

Heating of glass above shunt

Current induced heating of local shunt or weak diode

AC Current induced heating of local shunt or weak diode

far-IR thermal emission from glass
Infrared Limitations

Thermalreflectance imaging in visible

Silicon with 230nm oxide 800nm nitride

Reflectance change / temperature

\[ 10^4 \times \Delta R / (R \Delta T) \]

Wavelength(\(\lambda\)) in nm
High Resolution Thermal Imaging to study defect growth

Microscope based Thermo-reflectance

Far-Infrared (NREL)

TR image (UCSC/ASL)

Image in visible Through glass substrate

High resolution thermal Imaging to study defect growth
 Thermal imaging in visible
  • Glass is transparent
  • Combined images
    – brightfield
    – electroluminescence
    – thermal
  • Silicon camera
    – high pixel count
    – inexpensive

 Example for poly-Si

 Available as tool or service
Pulsed EL/Thermal Images

- **Thermal response time**
  - ~5μs
- **EL response time**
  - <1ns
- **Short pulses**
  - Detect EL defects
  - Before thermal runaway
  - Thermal runaway → breakdown
Solar Energy: Power through absorbing light

Optical absorption: Critical for solar materials

Optical Absorption with Resolution of $1 \times 10^6 \text{ cm}^{-1}$ to $1 \text{ cm}^{-1}$
Nanoparticle based solar cells (CdTe, 5% efficient)

Lower trap density in nanoparticle state!!
PDS and Trap States

Long term exposure to UV

- Unsintered Nanoparticles
  - Large increase in trap density
  - Destruction of ligands

- Sintered Nanoparticle Film
  - Higher trap density
  - Stable to UV light
Instabilities in Electrical Performance

Example of commercial CdTe modules (CIGS shows same phenomena) Data from J. DelCuesto, NREL

Instabilities
- Efficiency changes with light exposure
- aSi – degrades (si-H bonds)
  - Stabler Wronski Effect
- CdTe, CIGS - improvement
  - Efficiency Improvement up to 2%
  - Larger change in “aged” modules

Mechanism
- Copper diffusion?
- Trap states?

Dark Storage
After light exposure

Depletion length longer with long term light exposure
Photovoltaic Failure Analysis

- **Module level (cm range)**
  - Thermal (IR imaging)
  - IV analysis
  - Packaging related failures

- **Cell level (µm range)**
  - Material non-uniformities (shunts)
  - Traps (Stabler-Wronski effect)
  - Ionic diffusion
Photovoltaic Industry is very diverse (unlike SEMI)
  • Many different technologies
  • Many different manufacturing methods

Failure analysis needs to be tuned to technology
  • Large Area Imaging
  • Imaging through glass

PV FA has a lot to learn from the Semi industry
  • Failures are primarily packaging related
  • Efficiency gains from micro-analysis
Joint facility between UCSC and NASA-Ames
Located in NASA-Moffet Field in Mountain View
Goal: Develop NASA/UCSC/Industry interactions
See: asl.ucsc.edu

Solar related Activities at ASL:
1) Solar panel reliability / defects
2) Organic Material Reliability testing (dyes)
3) Photovoltaic thermal imaging
4) Advanced solar cell fabrication

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