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Exploring Diagnostic Capabilities for Application to New Photovoltaic Technologies

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Team Members

Sandia Solar Systems Department

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- Enrico C. Quintana, Member of Technical Staff
- Kyle Thompson, Member of Technical Staff
- Kevin Rolfe, Technologist

Advent Solar

- Peter Hacke, Scientist

Motivation for this work

- 2008 PV market growth was 110%! (MarketBuzz 2009 ™)
- Growth marked by:
  - Continued development of second (thin-films) and third generation PV (CPV and OPV)
  - Development and use of new materials and new component designs/geometries
  - Continued needs for failure analysis
  - Pressure to cut time-to-market development cycles
  - Pressure to increase throughput and yield
  - Pressure to develop and apply non-destructive diagnostics capable of rapid turnaround
- Continued development of Sandia's Computed Tomography capabilities

Non-Destructive Evaluation (NDE)

- NDE consists of a wide range of modalities to non-destructively inspect components
- Radiography – Traditionally use thru-transmission x-ray sources to create a 2D image (Similar to medical x-ray)
- Computed Tomography (CT) – Acquisition of a series of x-ray images that are reconstructed into a series of thin cross sectional slices of the component being inspected (CAT Scan)
- Ultrasound (UT) – Measurement of sound waves as they are passed through or reflected at interfaces between materials
- Electroluminescence (EL) – Light emission in a material when an electric current is applied; images are acquired with an IR sensitive camera

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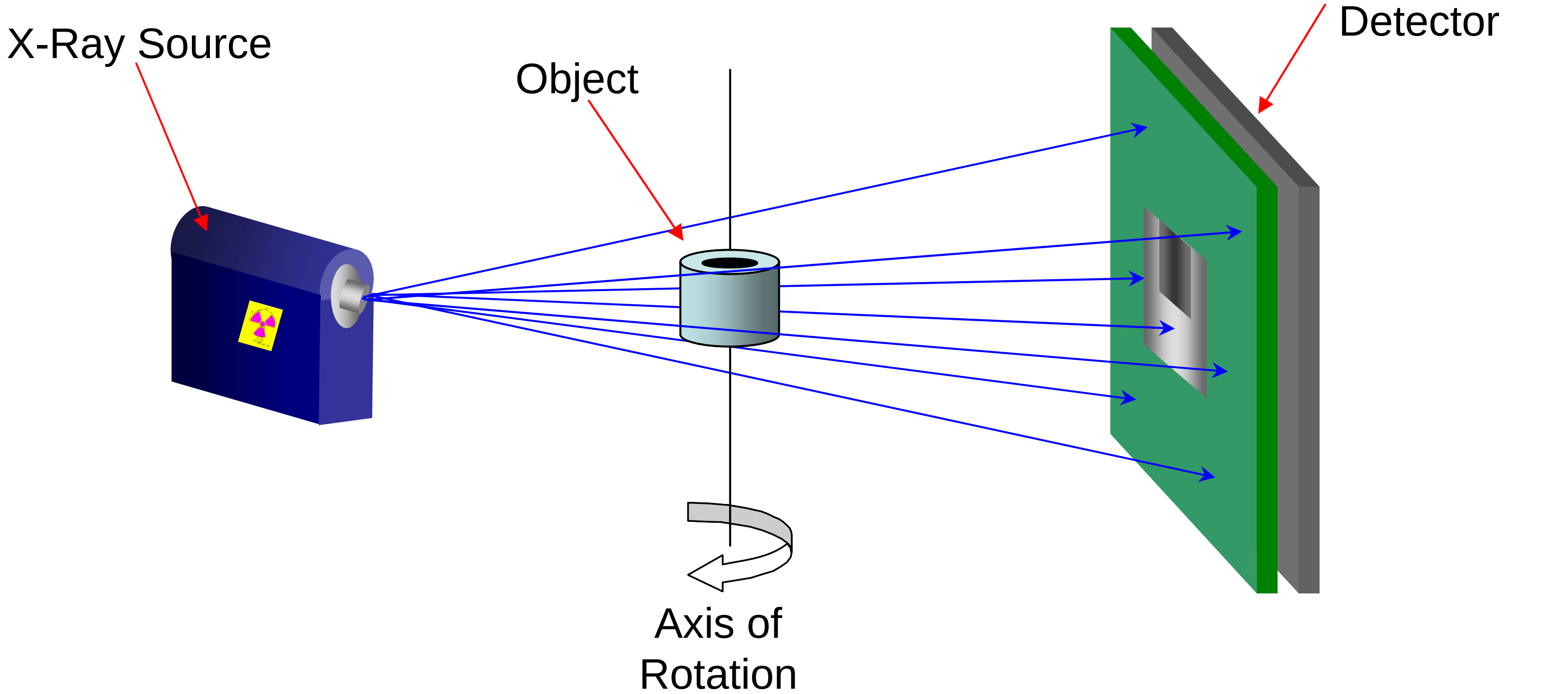
CT/Radiography is useful for PV R&D/Manufacturing

- Interface characterization
- Measure internal component dimensions
- Investigate internal component changes due to environmental testing
- Locate voids, cracks, and inclusions
- Verify internal structural integrity
- Provide qualitative material density characterization
- Internal diagnostics of dynamic tests
- Locate components of interest in a 3D reference frame
- Manufacturing process quality control

How does CT work?



Cone Beam Computed Tomography System Diagram

***Detector Spatial Resolution = 127µm**

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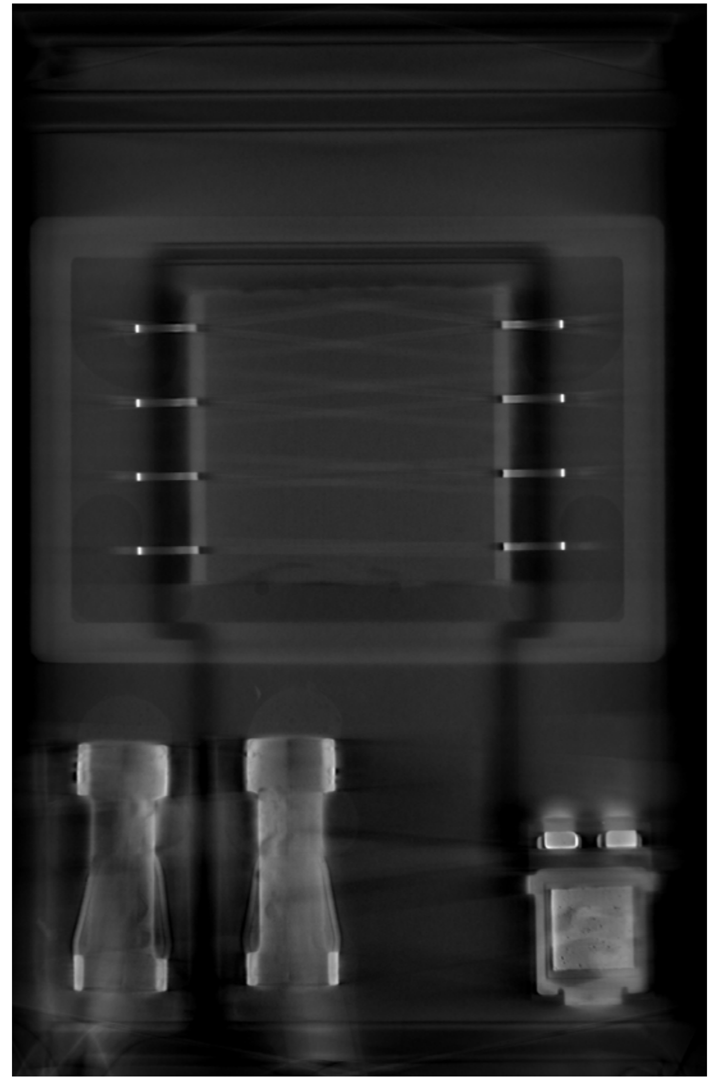
CT Application - CPV Cell Assembly

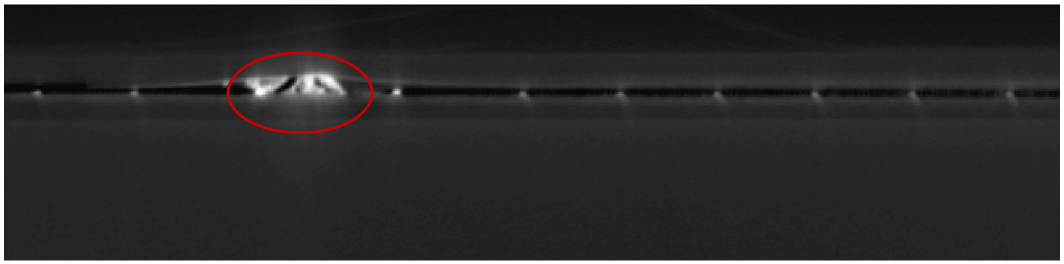
- Thermal management is critical for high concentration CPV
- Cell-to-substrate interface quality is key
- CT provided high resolution inspection of:
  - wire bonds
  - interfaces
- Cell-substrate interface study showed
  - slight geometry variation at perimeter
  - small voids in interface material

Optical image

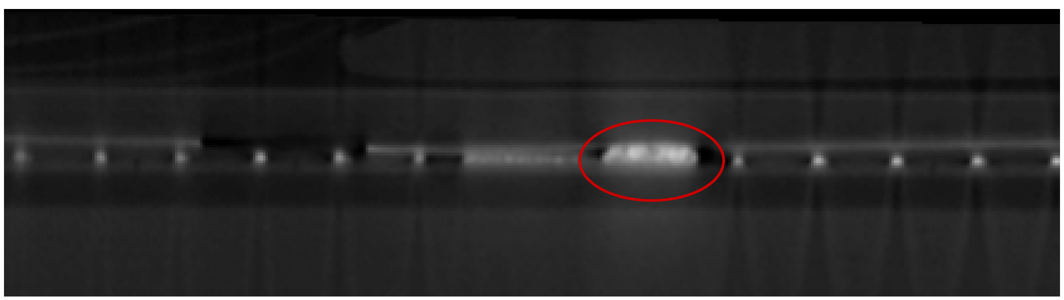


CT scan video

CT Application – Assessing Bond Integrity



Bond shows void and non-uniform geometry



Bond uniform throughout

Multiple bonds from sample

- Scanned with Phoenix Micro-Focus at 160 keV and 110 μA
- Varian 2520 panel with lanex regular screen
- Cone beam reconstruction
- ~4.3x magnification, 30 μm resolution
- Results fed back into R&D process

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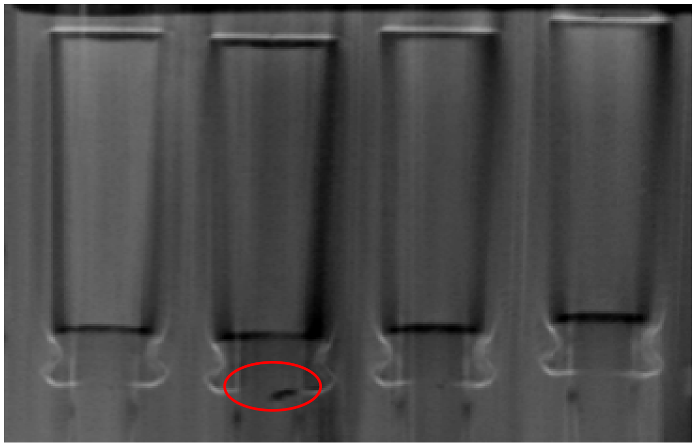
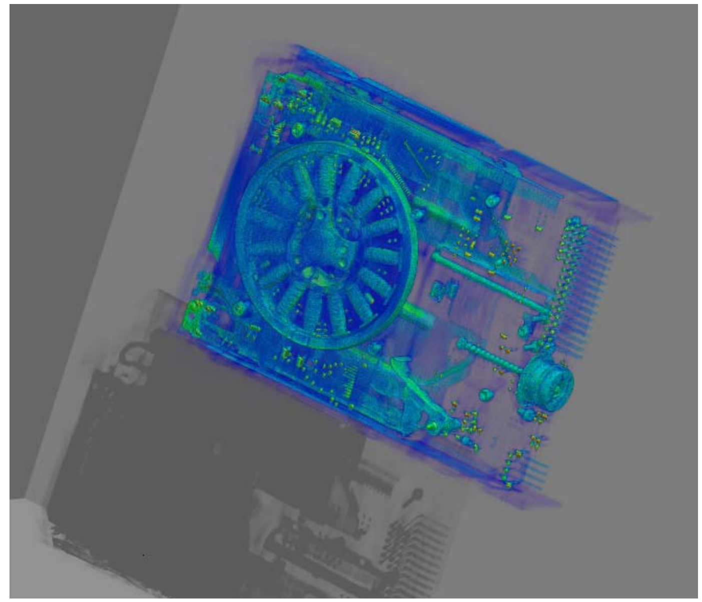
CT Application – PV Electronic Assemblies



- Capacitors in a potted electronic assembly
- Note the void between leads
- Moisture penetration into void will decrease distance between capacitor leads by 50%
- Vulnerability to failure increased



- 3D rendering of μPV array
- CT allowed us to check for any gross defects in the PV assembly
- Integrity of the adhesive bond between the cells and the substrate

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Case Study: Applying Multiple Diagnostics to Drive Successful R&D

Problem statement 1

- Advent Solar has developed its Ventura™ Technology
- A key feature is the innovative Monolithic Module™ Assembly (MMA)
- MMA module development process observed "shunt" like failure after damp heat tests
- Shunting behavior confirmed by IR tests but cause was unknown
- Advent consulted Sandia about non-destructive test approaches
- Advent also wanted information about the integrity of conductive bonds
  - Placement with in the laminate
  - Geometry and uniformity

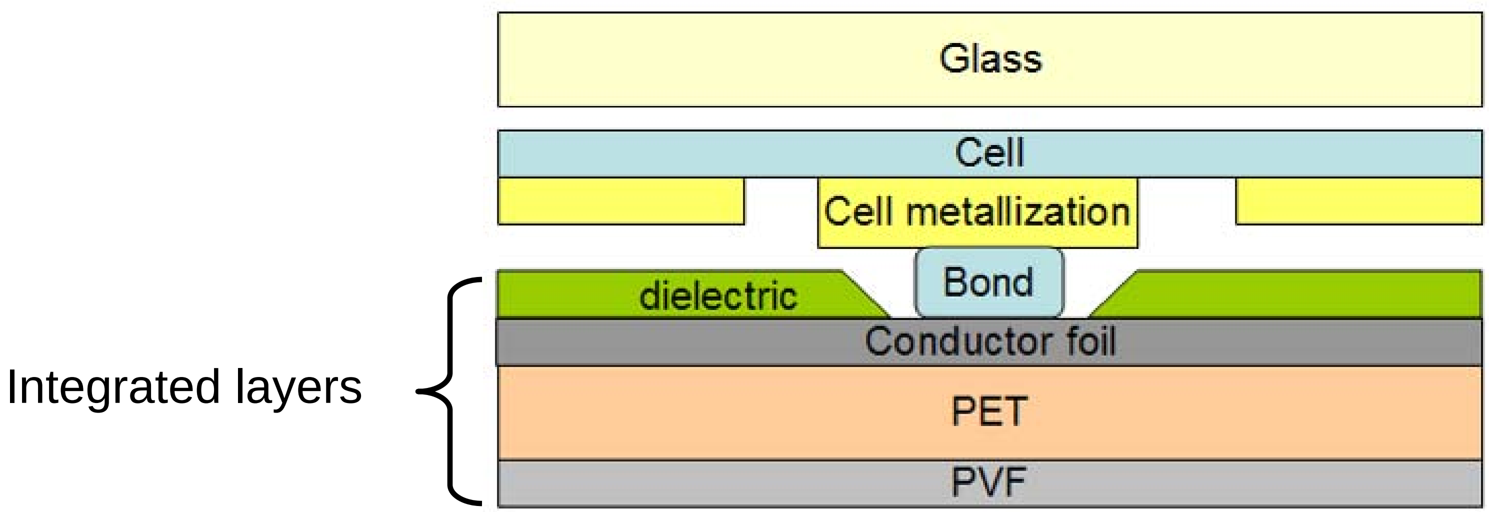
Innovative Module Assembly

Use of integrated backsheet layers

- Integrated foil conductor forms circuit
- Integrated dielectric layer
- PET/PVF backsheet

Integrated layer bonds directly to cell metallization on cells

- Cell-to-circuit bonding using solder or electrical conductive adhesive
- May eliminate cell stringing process



Cross-section of MMA

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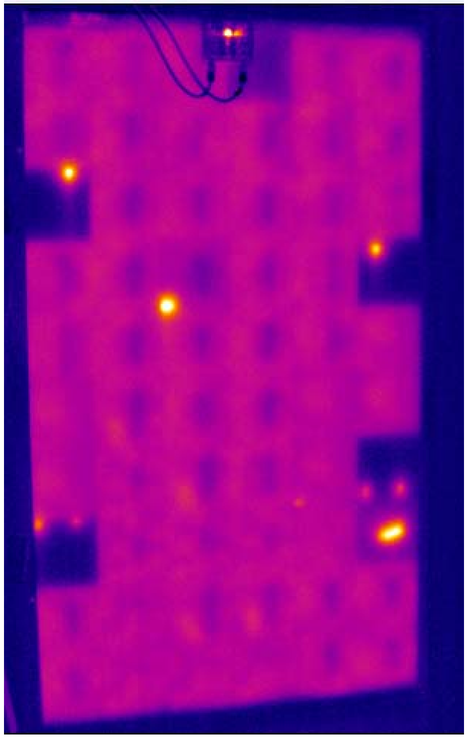
“Shunt-like” Behavior Seen in IR images

During development:

- Hotspots seen in forward bias, but not in reverse bias
- Same hotspots show up in reverse bias when a single cell is isolated with leads
- Destructive failure analysis revealed no apparent explanation for the shunts
- Significant effort without conclusive results can hamper development costs!



Shunts showed up after damp heat testing

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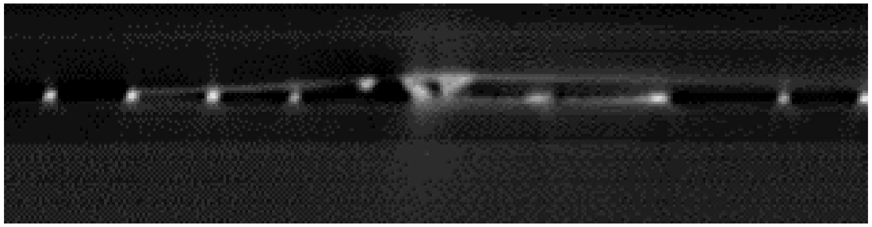
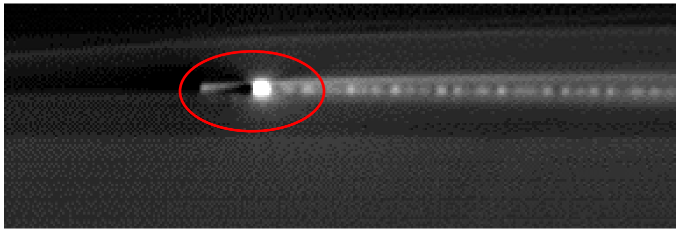
CT Identified Problem; Cross-sectioning Confirmed





- CT detected a pattern: single cell mini-modules shunting in the region where the n-busbar crosses the Cu etch line
- CT detected irregularities with copper foil-to-cell spacing throughout
- Cross-section revealed the Cu foil very close the top of the N-busbar on the edge of the cell
- Contact between the n-busbar on the cell and the P-polarity of the Cu foil would cause shunting--an edge pinch-off phenomena is confirmed

Problem Statement 2

Two minimodules:

- Experienced performance degradation during damp heat tests
- EL performed on samples
  - observed general darkening around cell edges
  - visual inspection did not reveal visible disconnects
  - based on EL interpretation knowledge, root cause of degradation was unclear
- Minimodules submitted to Sandia for ultrasound inspection

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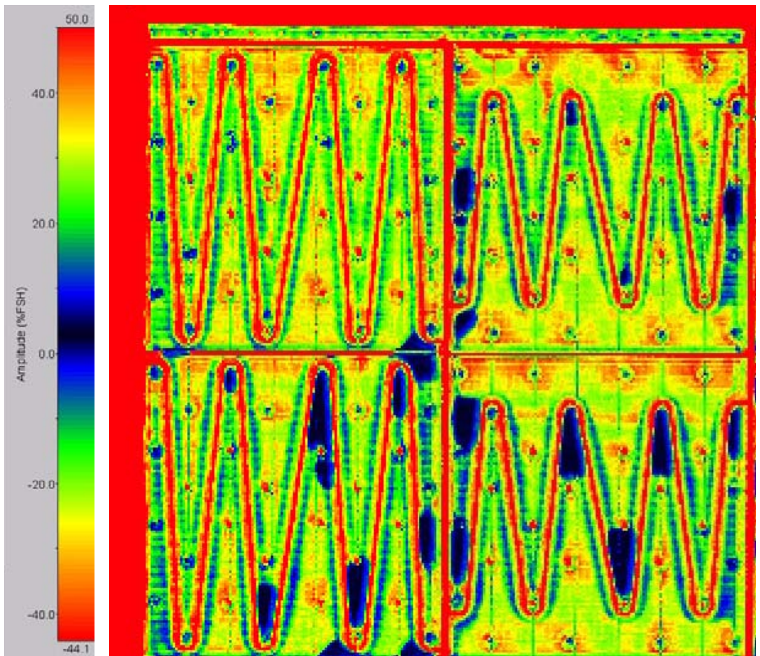
Ultrasound and Electroluminescence Results

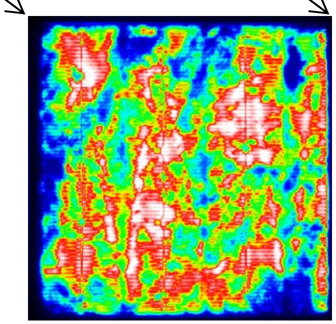
UT scan of 2x2 section of test sample



- EL indicated inactive regions (possibly high resistance) around cell perimeter
- Ultrasound applied to examine bonds within the laminate
  - through transmission technique
  - low acoustic transmission indicates unbonded regions
- UT clearly identifies electrical bonds/disbonds (including kissing disbonds)

➢ EL image of single cell from above sample

➢ Dark blue areas indicate inactive regions



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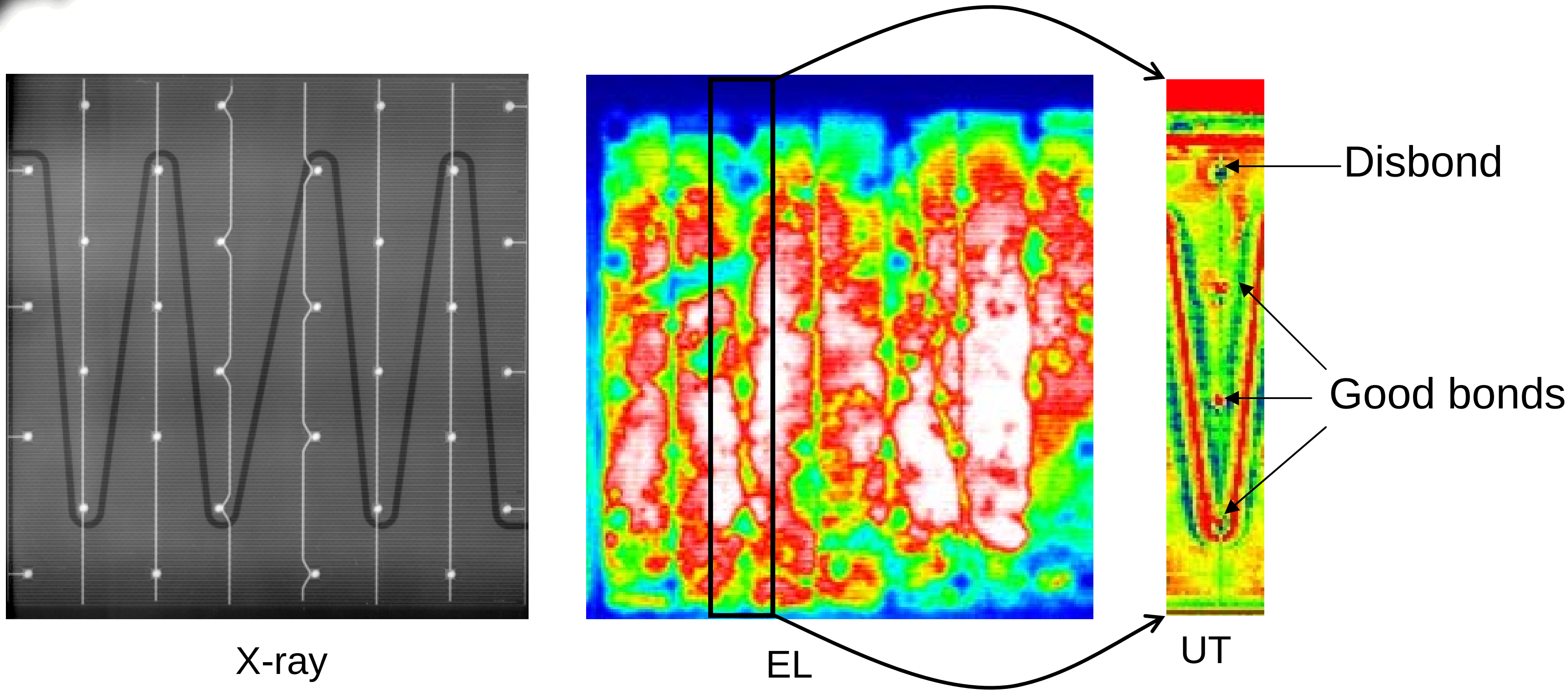
Correlation of UT and EL Images



- X-ray confirmed that bonds and bond locations were in place
- Disbonds in UT images correlated well with inactive regions on the perimeter on the EL image
- Good bonds in UT images correlated with active regions on EL

Conclusions

- Photovoltaics R&D efforts have benefited significantly from application of CT, digital x-ray, UT, and EL
- CT has produced positive results for CPV cell-assembly, c-Si module and BOS R&D efforts
- Future studies include:
  - µcrack detection in Si cells
  - j-box to thin-film interconnection characterization
  - possible study of glass-metal seals
- NDE modalities are complementary; UT can cover the shortcomings of X-ray/CT and vice versa
- Industrial 3D CT capabilities are improving
  - mm → µm
  - days → hours
  - $M → $k
- NDE systems are portable--your facility or ours!

Questions

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Sandia CT System Specifics

- Varian 2520 Amorphous Silicon Panels (Active area 25cm x 20cm)
  - Lanex Regular, Cesium Iodide, DRZ-High scintillators
- Detector native resolution - **127 µm**
  - Achieved **6 µm** resolution with microfocus CT
  - Resolution is size dependent
- Microfocus CT – Kevex and Phoenix x-ray Sources
- 1:1 CT – Phillips 450 keV x-ray source
- Imtec data acquisition and reconstruction software
- Image Pro-Plus and Volume Graphics VG Studio for image processing and 3D data manipulation