2008 Solar Annual Review Meeting

Measurements & Characterization (M&C) Capabilities Overview

Peter Sheldon
Measurements and Characterization
NREL
1617 Cole Blvd.
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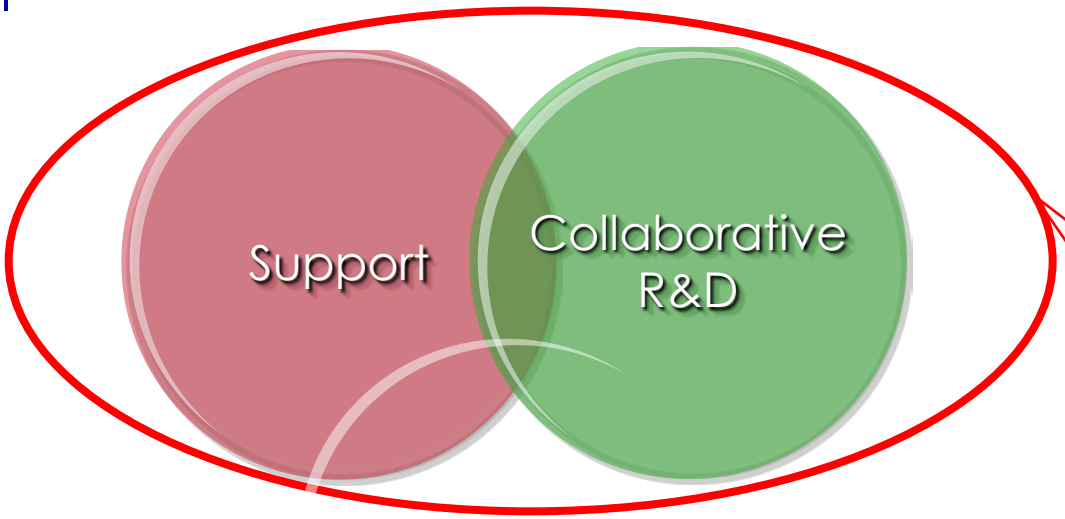
NREL/PR-520-43215
Presented at the Solar Energy Technologies Program (SETP) Annual Program Review Meeting held April 22-24, 2008 in Austin, Texas

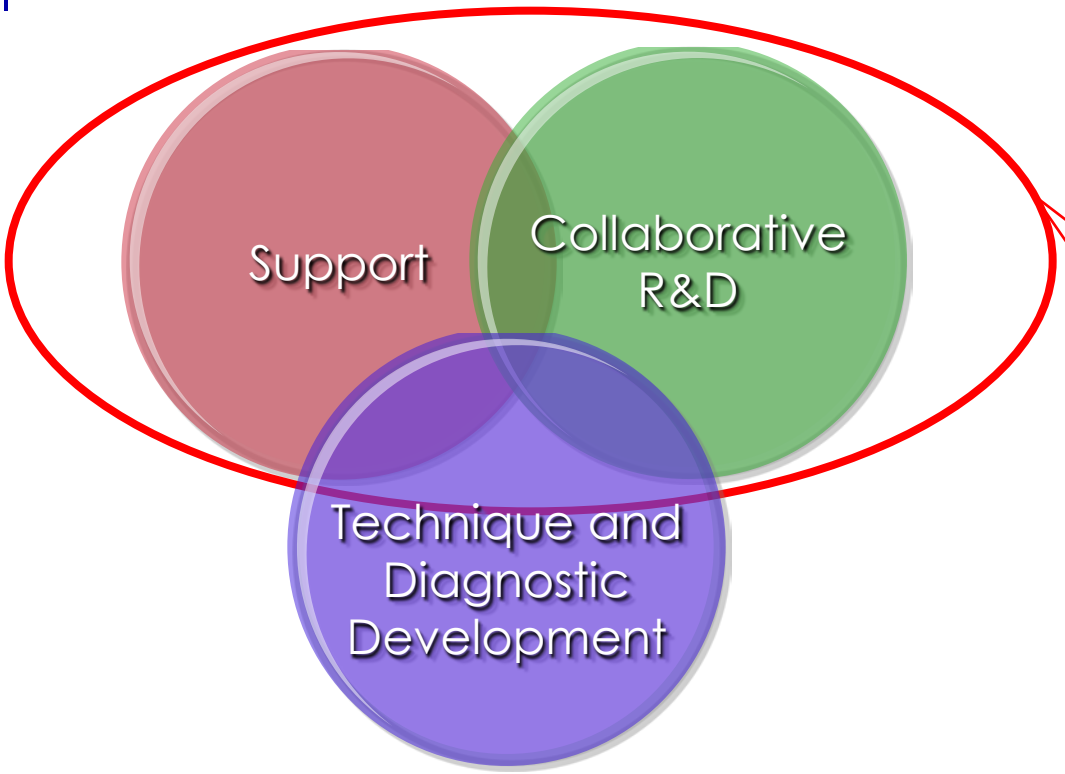
M&C Mission: Three Focus Areas

M&C Mission: Three Focus Areas



A key component of our mission is to work with SAI subcontractors and help them realize their goals

M&C Mission: Three Focus Areas



A key component of our mission is to work with SAI subcontractors and help them realize their goals

- Subcontract Stage-gate Review
- Test & Evaluation
- Process Development and Device R&D
- Cell/Module Failure Analysis R&D

SOLAR AMERICA INITIATIVE

M&C Supported Subcontracts

2008 Subcontractor Funding:	
Photovoltaic Systems R&D Technology Pathway Partnerships (TPPs)	~$51M
PV Technology Incubator	~18M
University Photovoltaic Product and Process Development	~$4M
Next Generation Photovoltaic Devices and Processes	~$7M
TOTAL	~$80M

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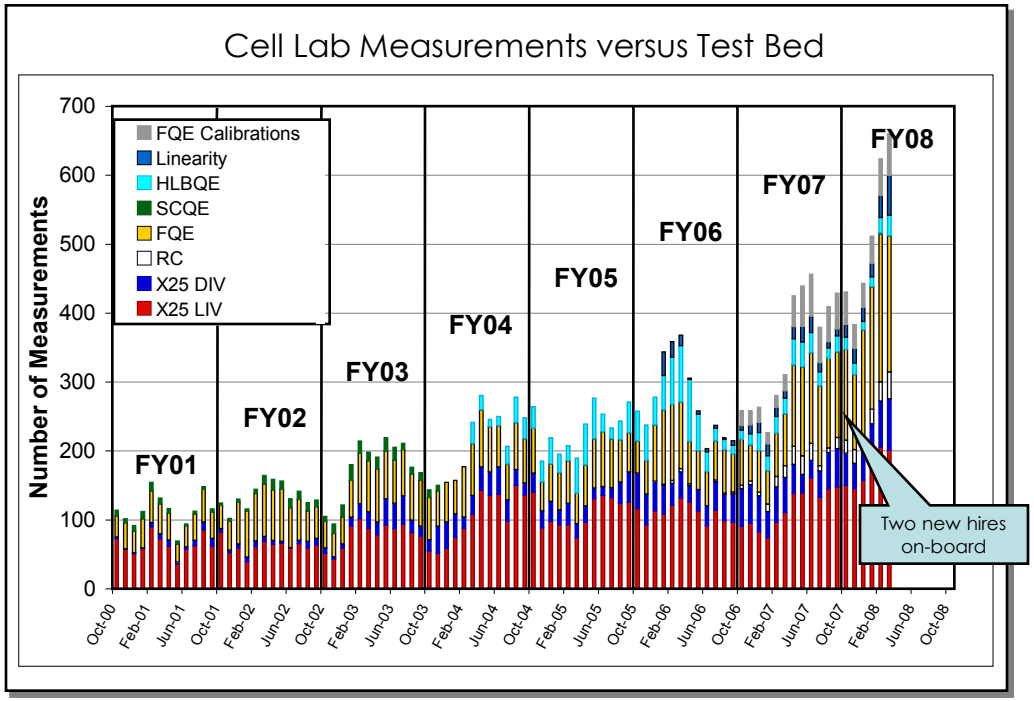

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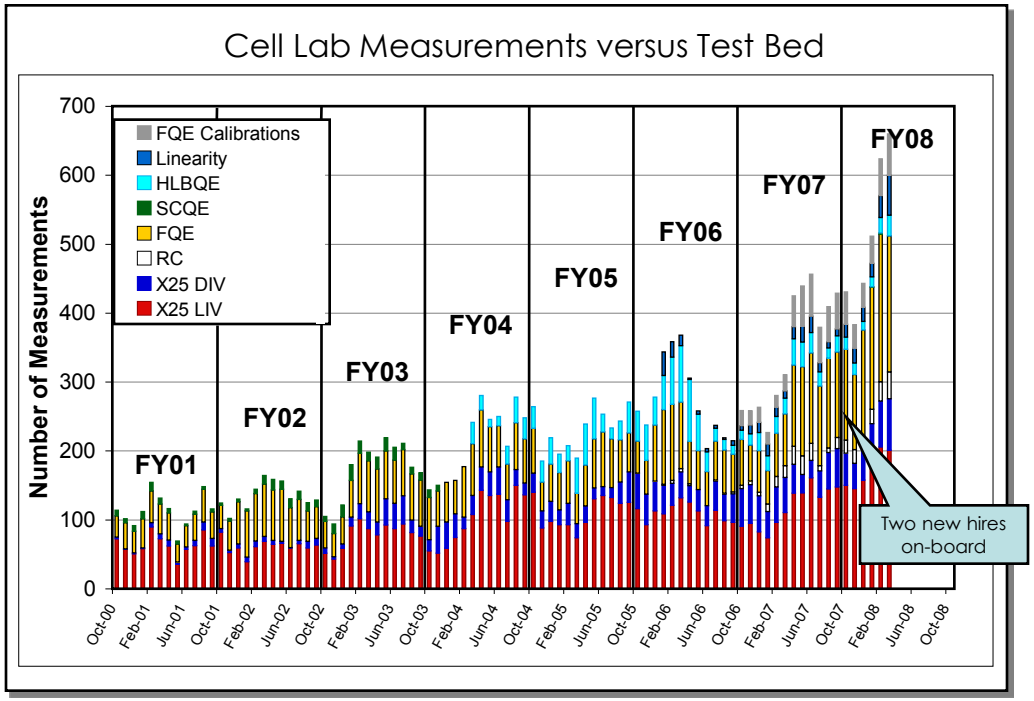

SOLAR AMERICA INITIATIVE

- Top priority/preferential treatment for SAI deliverables and stage gate reviews
- Support for all DOE-funded subcontracts on a first come first serve basis (no differentiation between TPP, Incubator, and pre-SAI subcontracts)
- Non-SAI funded PV industry requests

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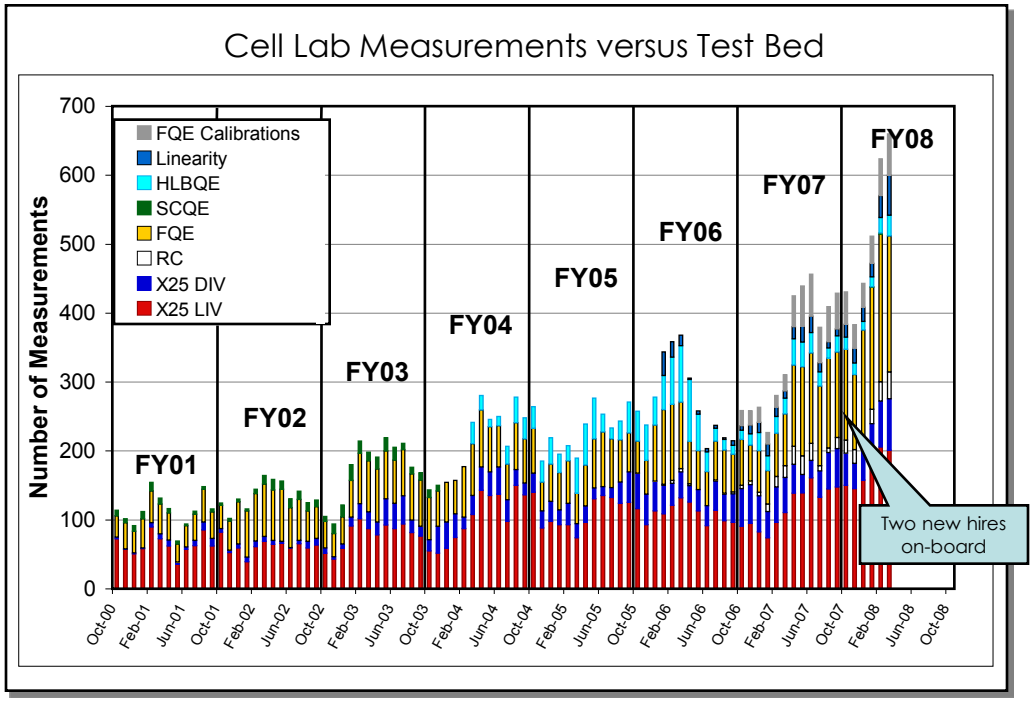

Increasing Priority Level

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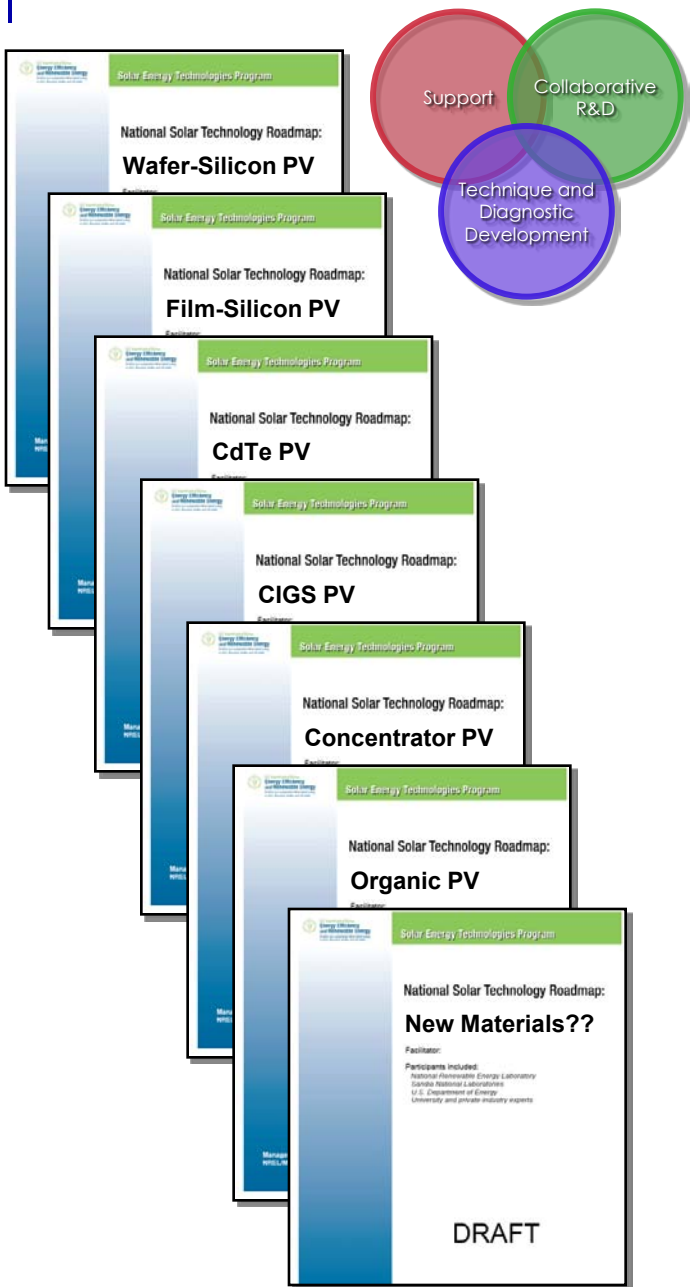
M&C Collaborations



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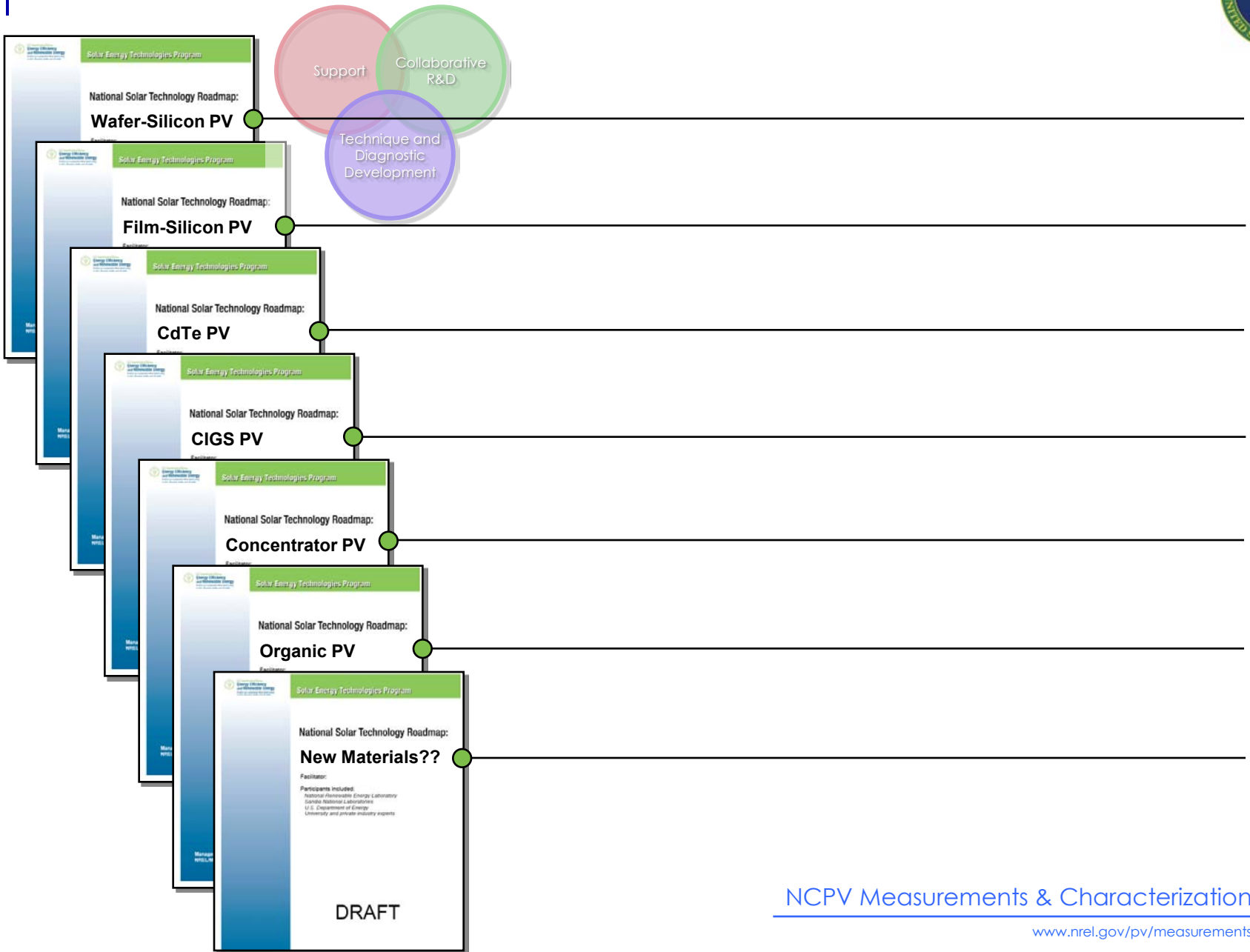

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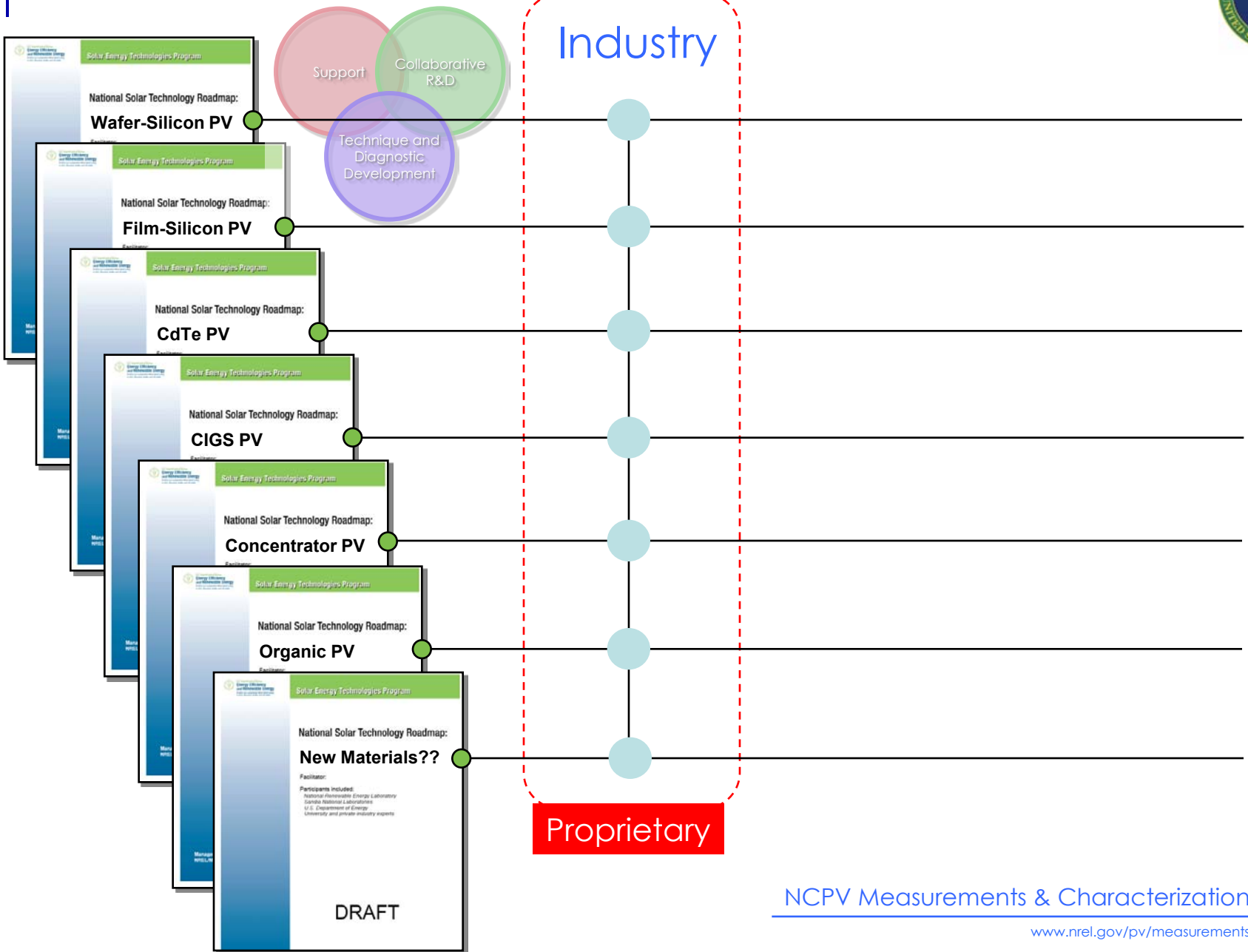

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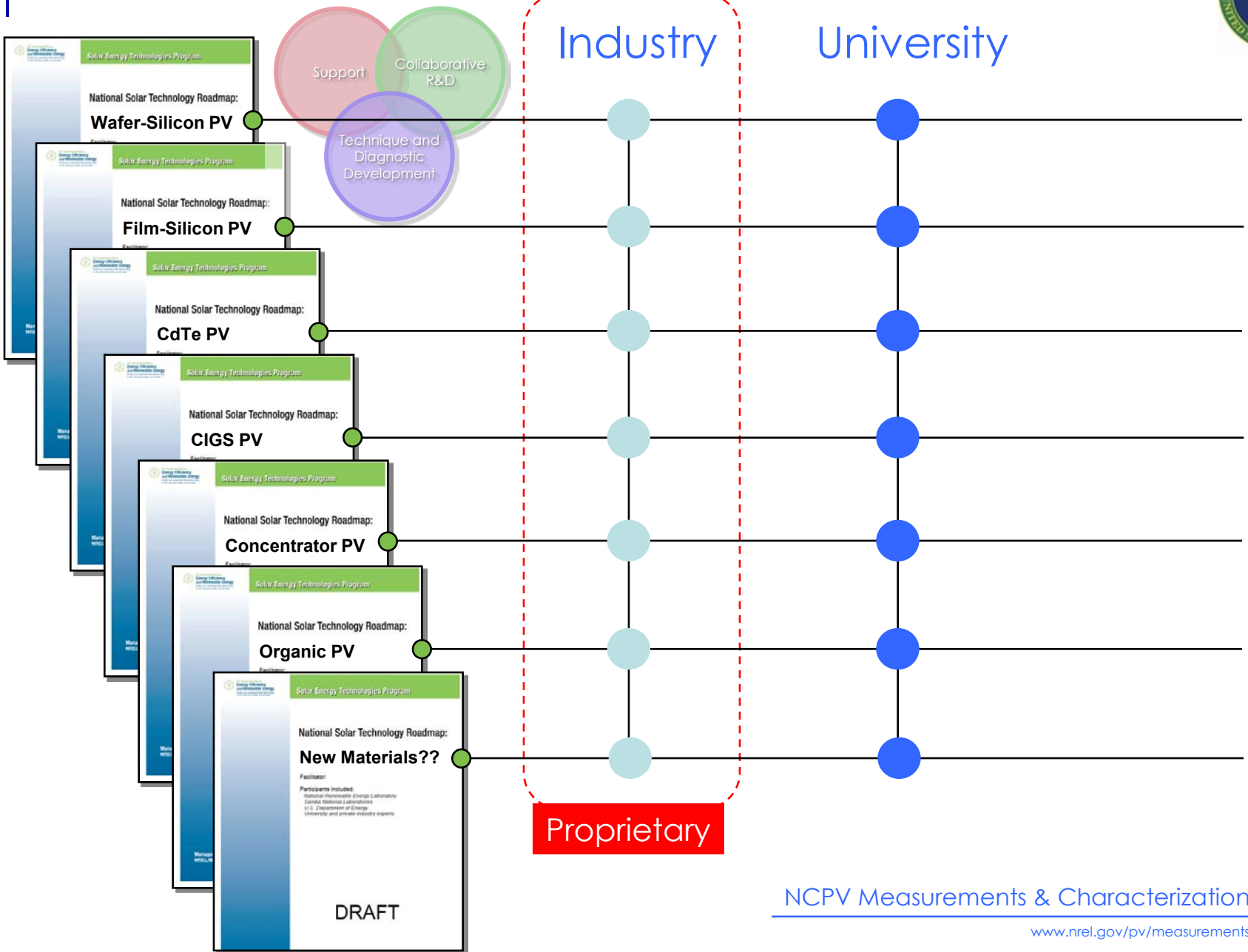

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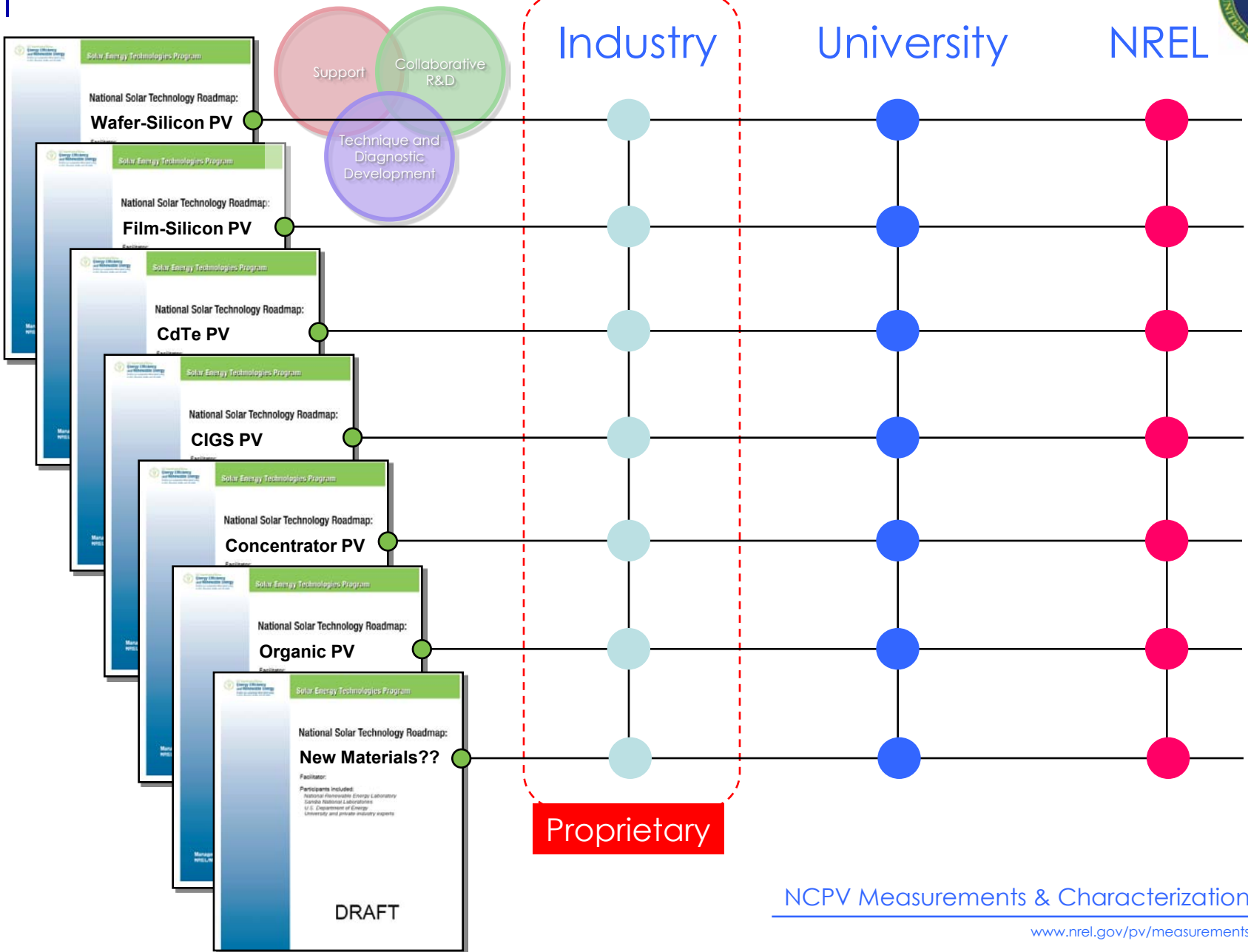
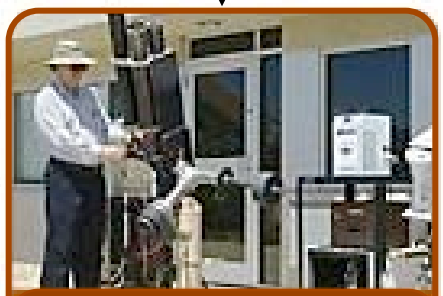


M&C Core Competency Areas

National Center for Photovoltaics (NCPV)

Measurements & Characterization

Peter Sheldon
peter_sheldon@nrel.gov

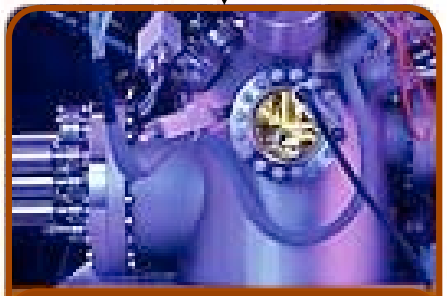


Device Performance

Keith Emery
keith_emery@nrel.gov

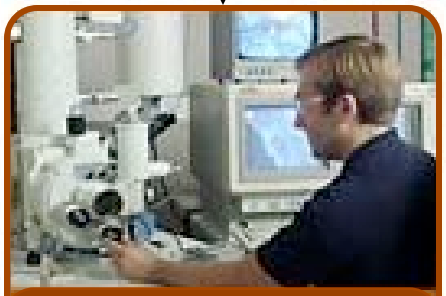
Electro-Optical Characterization

Dean Levi
dean_levi@nrel.gov



Surface Analysis

Sally Asher
sally_asher@nrel.gov



Analytical Microscopy

Mowafak Al-Jassim
mowafak_aljassim@nrel.gov

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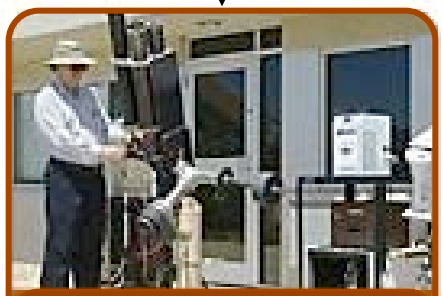

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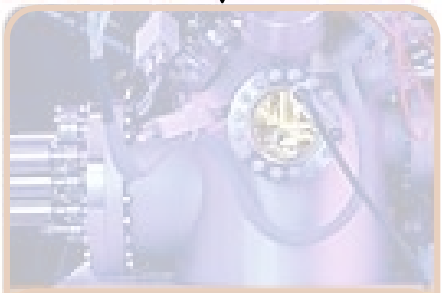

Surface Analysis

Analytical Microscopy

Cell and Module Performance Team

Device Performance

- *Independent facility for verifying device and module performance for the entire PV community*
- *ISO 17025 accredited for primary reference cell, secondary reference cell and secondary module calibrations*
- *Provide the U.S. PV industry with a calibration traceability path for peak-watt and efficiency measurements to reduce uncertainty in I-V measurements*
  - *Provide reference cell calibrations for the entire US terrsetrial community*
- *Develop hardware, software and procedures to accommodate new cell and module technologies. Assists industry in developing measurement system hardware and procedures*

ACCREDITED

Certificate Number 223601
ISO 17025 accredited for photovoltaic secondary cell, secondary module and primary reference cell calibration by the American Association for Laboratory Accreditation (A2LA)

NCPV Measurements & Characterization

www.nrel.gov/pv/measurements

Cell and Module Performance Team Capabilities

Application	Light Source	Test Bed
1-Sun Cells & Mini-Module		
Spectrolab X25	filtered 3 kW Xe Spectrolab X25 0.1 - 20 suns	30 cm x 30 cm
Concentrator Cells		
Continuous Illumination	1 kW Xenon or 3kW Tungsten 0.1 - 200 suns	1 cm diameter for Xe 5 cm x 10 cm for W
High Intensity Pulsed Solar Simulator (HIPSS)	Xe Flash Lamp 1 to 2000 suns	2 cm x 20 cm
Modules		
Spire 240A Solar Simulator	Xe flash lamp 0.1 to 1.2 suns	61 cm x 122 cm
Spire 4600 Solar Simulator *On Order*	Pulsed Light Source	137 cm x 200 cm
Spectrolab X200 Large-area Continuous Solar Simulator (LACSS)	Filtered 25 kW Xe 0.1 to 1 suns	122 cm x 152 cm
Standard Outdoor Measurement System (SOMS)	Sunlight	200 cm x 300 cm

- *2,300 gsf of new and reconfigured space*
- *Required to accommodate large-area solar simulator necessary to support the SAI*
- *A new Spire 4600 simulator will allow test of modules up to 137 cm x 200 cm (a 265% increase in size)*

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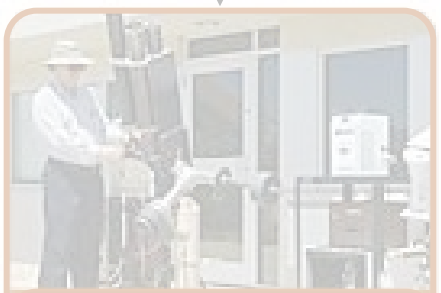

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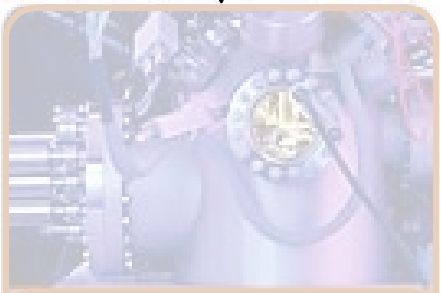
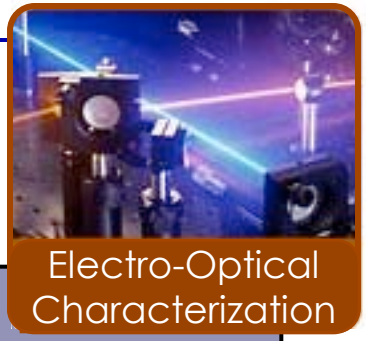


Surface Analysis

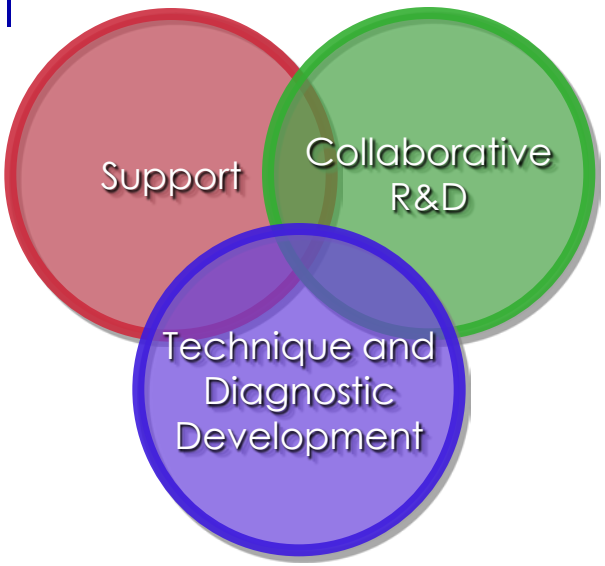
Analytical Microscopy

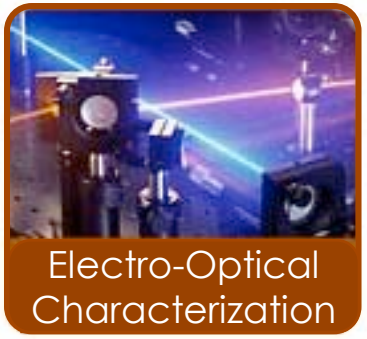
Electro-Optical Characterization Team Capabilities



Technique/Capability	***Typical Applications***
Photoluminescence Spectroscopy	*Measure bandgap and alloy composition; identify defects; provides a quick measure of material quality*
Minority Carrier Lifetime *TRPL, RC-PCD, and µW-PCD*	*Measure minority-carrier lifetime, material quality, surface/interface recombination and surface passivation; identify dominant recombination mechanisms*
Fourier Transform Infrared Spectroscopy	*Identify chemical composition, chemical bonding; analyze in-situ reactions and concentration of impurities; measure inhomogeneity*
Spectroscopic Ellipsometry *VASE and RTSE*	*Determine optical constants; layer thicknesses; surface/ interface roughness; as well as composition crystallinity, alloy composition, and growth dynamics of films*
Capacitance Techniques *C-V, DLTS, AS, and DLCP*	*Measure carrier concentration profiles, interface state densities, and deep-level properties*
Computational Modeling	*2-D solar cell modeling and simulation of measurement techniques (TRPL, RC-PCD, EBIC, QE, IV, CL, C-AFM)*
Diagnostic Development	*PVSCAN, PV Reflectometer, RC-PCD, PLI, and CDI*

Electro-Optical Diagnostic Development





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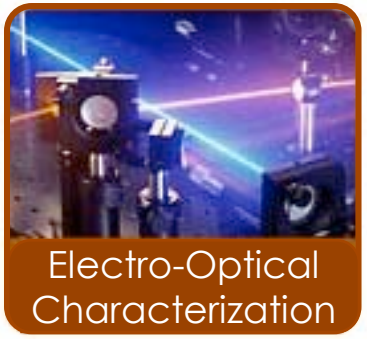
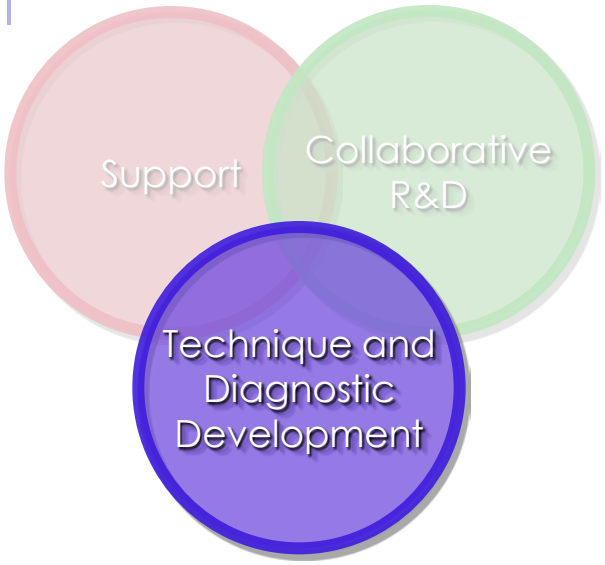
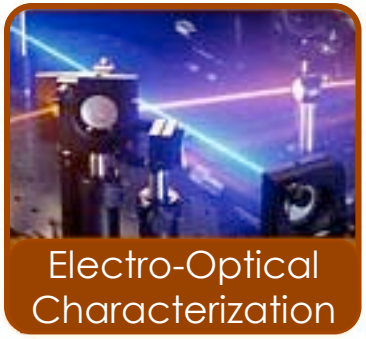


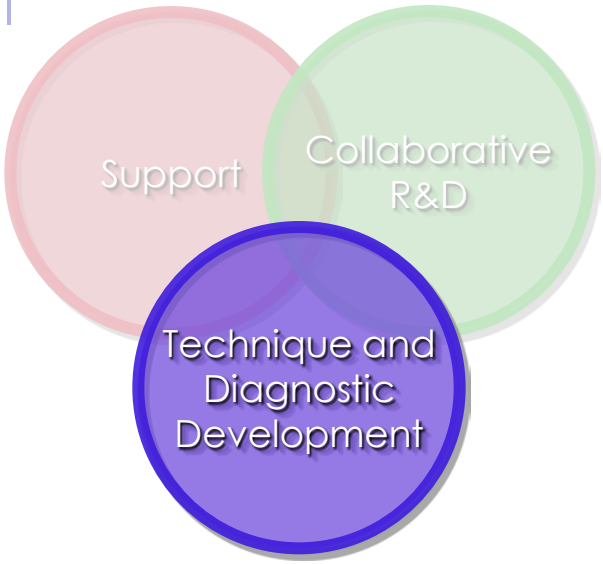


NREL Developed Diagnostics:

- ***PV Scan***..... *Licensed*
- ***PV Reflectometer***..... *Licensed*
- ***RC-PCD***..... *In- Process*

Electro-Optical Diagnostic Development





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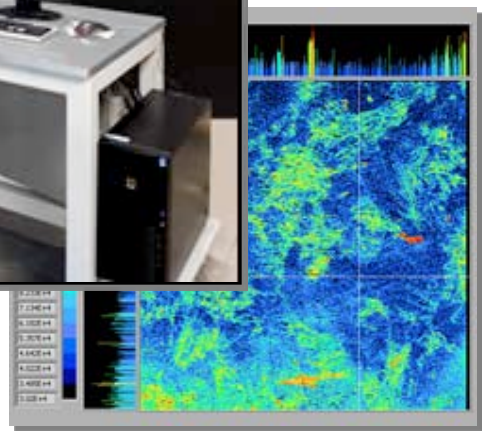
GT-PVSCAN 8000



- High-speed optical scanning system designed for characterization of PV materials and cells
  - Technology developed at NREL and licensed to GT Solar
  - 8' x 8" sample size
  - Measurement Modes:
    - Dislocation density
    - Reflectance
    - Light Beam Induced Current (LBIC)

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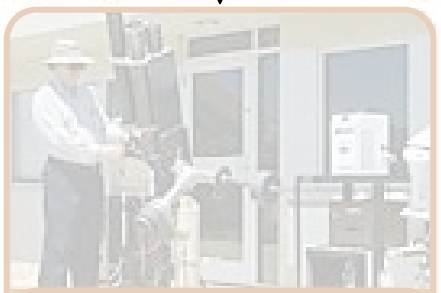

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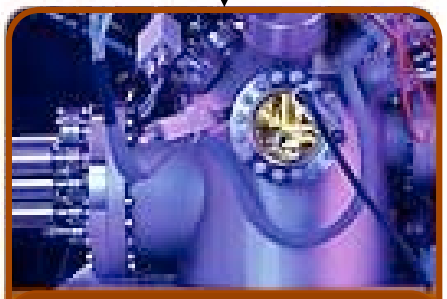
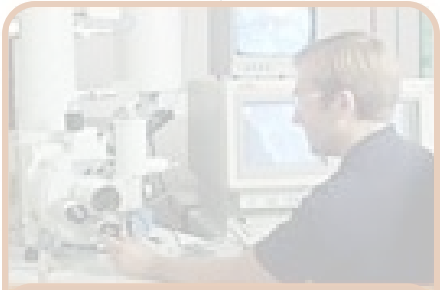


Surface Analysis



Analytical Microscopy

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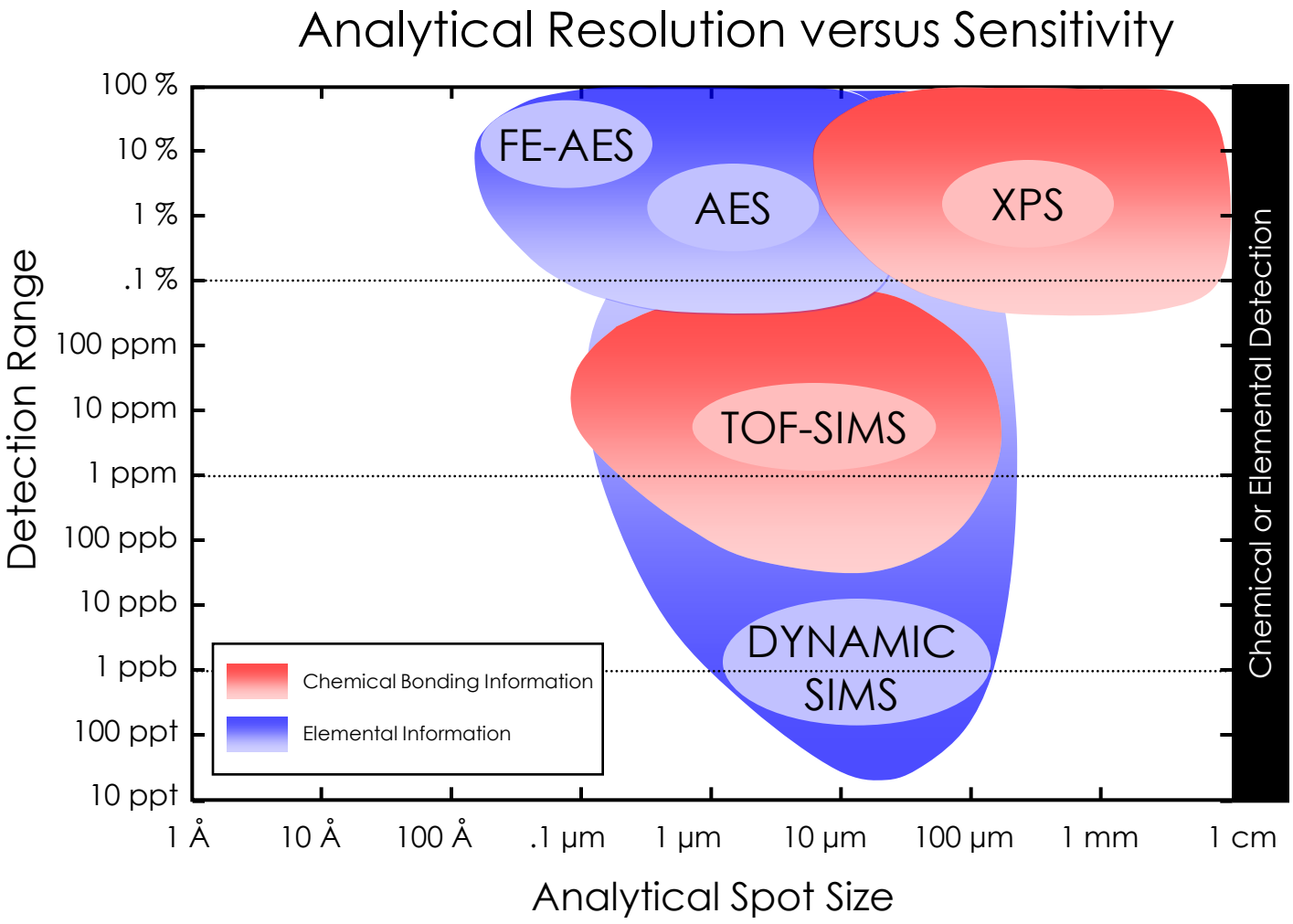
Surface Analysis Team Capabilities



AES

Auger Electron Spectroscopy

- Elemental information
- Detects Li - U
- 0-100Å depth resolution
- Depth profiling capable
- Imaging capability

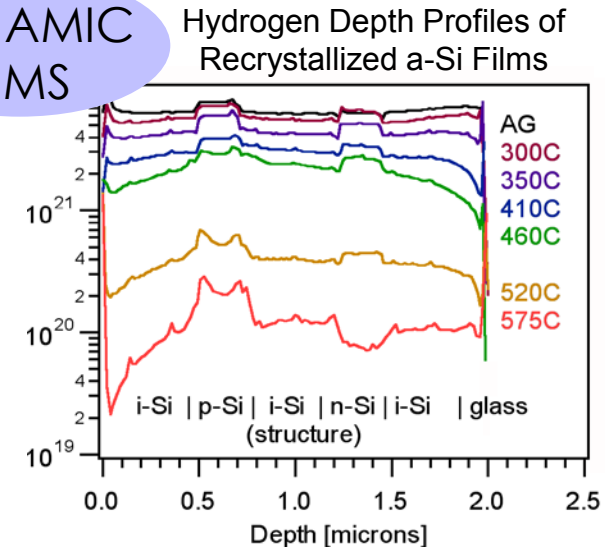
XPS

X-ray Photoelectron Spectroscopy

- Chemical Bonding Info.
- Detects Li - U
- 0-100Å depth resolution
- Depth profiling capable
- Imaging capability

Secondary Ion Mass Spectrometry (SIMS)
Time-of-Flight SIMS (TOF-SIMS)

DYNAMIC SIMS

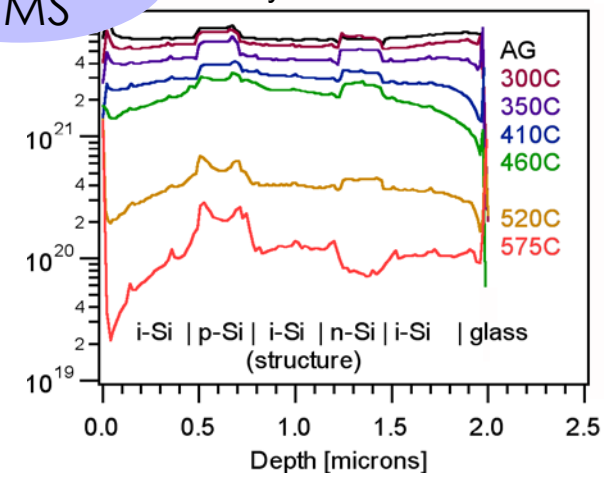


- Extremely sensitive - Detects fractions in the range of parts per million (ppm) to parts per billion (ppb)
- Elemental detection of species ranging from H to U and all isotopes
- Quantitative technique when used with standards
- Depth profiles with resolution of <10 nm - Excellent technique for analyzing interfaces

Secondary Ion Mass Spectrometry (SIMS)
Time-of-Flight SIMS (TOF-SIMS)

DYNAMIC SIMS

Hydrogen Depth Profiles of Recrystallized a-Si Films



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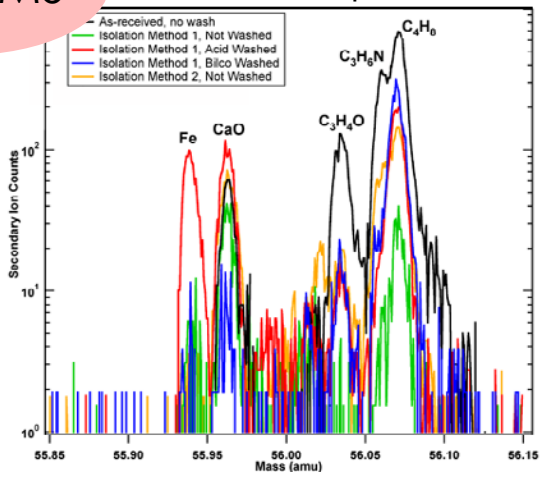
TOF-SIMS

SnO_2/Glass Cleaning Method Comparison



- Extremely sensitive - Detects fractions in the parts per million (ppm) range
- Elemental and molecular analysis- good for analyzing organics
- Surface sensitive technique - can study the top few monolayers of material
- Elemental detection of species ranging from H to U and all isotopes
- Depth profiles with resolution of <5 nm

M&C Core Competency Areas

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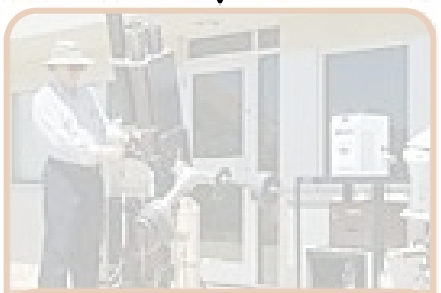
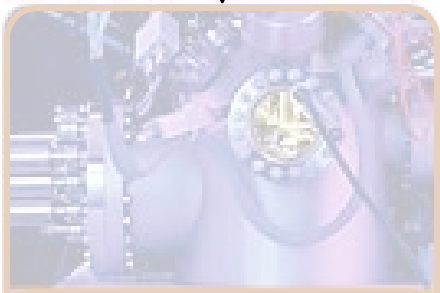
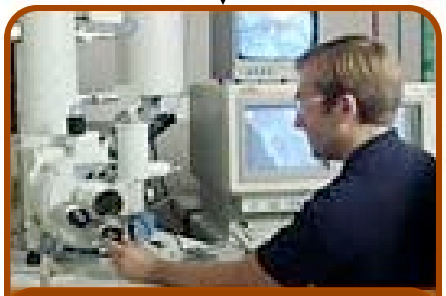


Device Performance

Electro-Optical Characterization



Surface Analysis



Analytical Microscopy

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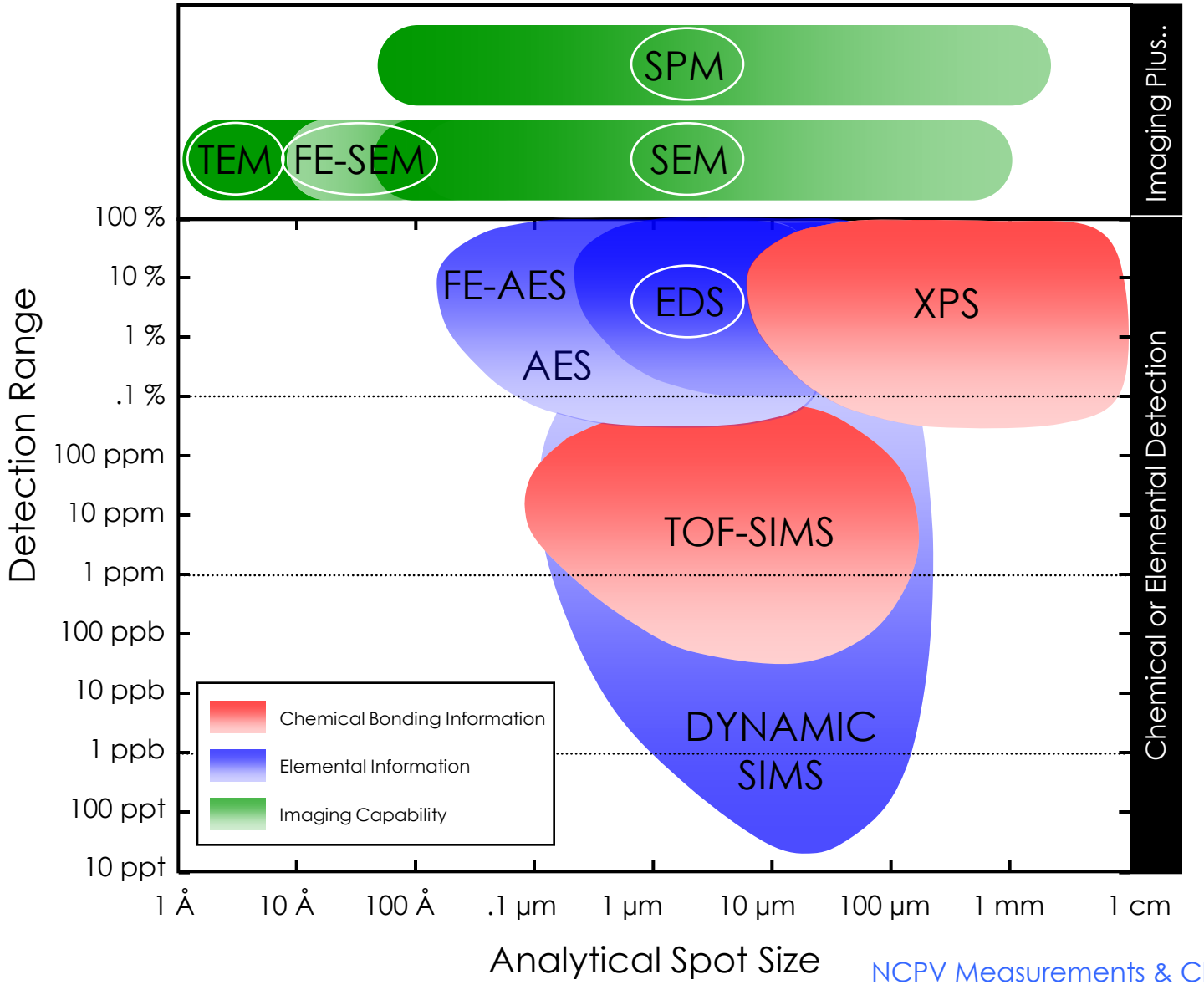
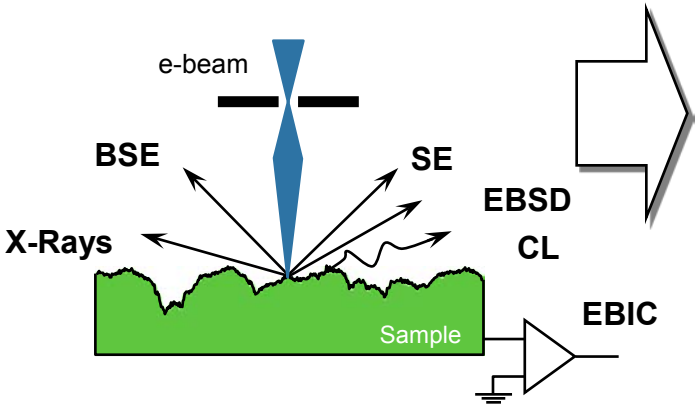
Analytical Microscopy Team Capabilities



SEM and SPM Capabilities

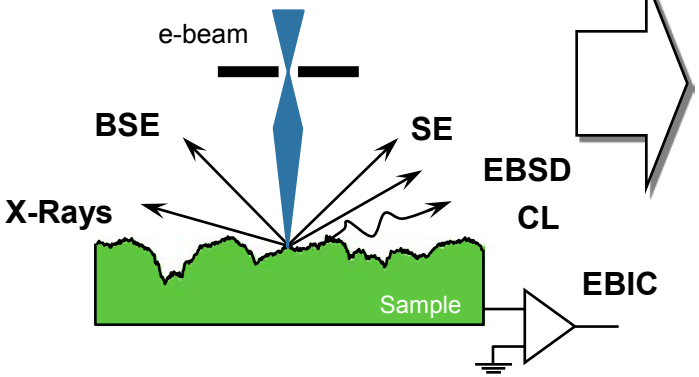
SEM Operational Modes



- Secondary Electron (SE) Imaging
- Back Scattered Electron (BSE) Imaging
- Cathodoluminescence (CL)
- Electron beam induced current (EBIC)
- Electron backscattered diffraction (EBSD)
- Energy dispersive x-ray spectroscopy (EDS)

SEM and SPM Capabilities

SEM Operational Modes



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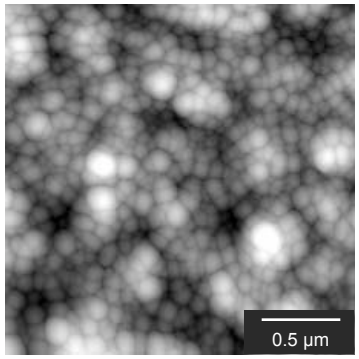
SPM Operational Modes

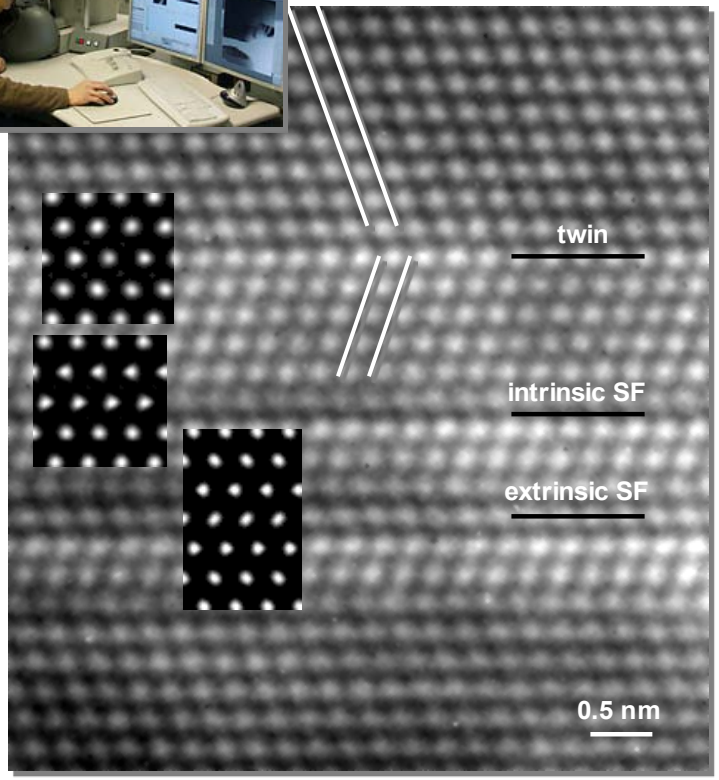


SEM-based

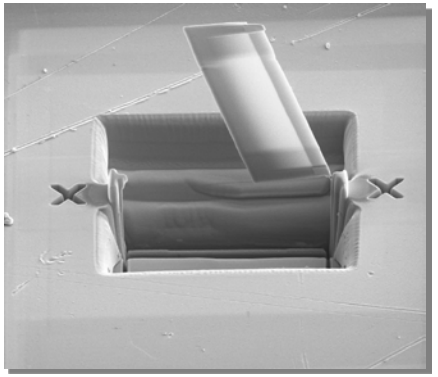
- Atomic Force Microscopy (AFM)
- Conductive AFM (C-AFM)
- Scanning Capacitance Microscopy (SCM)
- Scanning Kelvin Probe Microscopy (SKPM)
- Scanning Tunneling Luminescence (STL)
- Electroluminescence (EL) Mapping
- Near-field cathodoluminescence (NFCL)

Transmission Electron Microscopy (TEM)

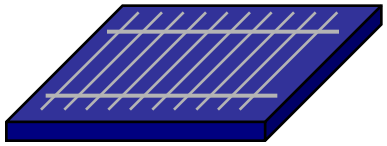
- ***High-Resolution Imaging*** - *Atomic resolution (1.4 Å)*
- ***Structural Analysis*** - *Electron diffraction and diffraction contrast analysis*



- ***Compositional Analysis*** - *Energy dispersive spectroscopy (B to U, ~0.5 at%)*
- ***Cross-Sectional Analysis -*** *New Focused Ion Beam (FIB) capability facilitates cross-sectional sample prep with pin-point accuracy.*

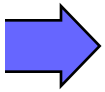


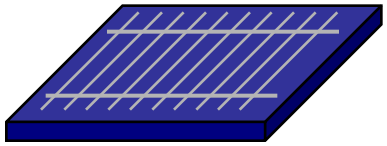
Combining Complementary Techniques



Combining Complementary Techniques

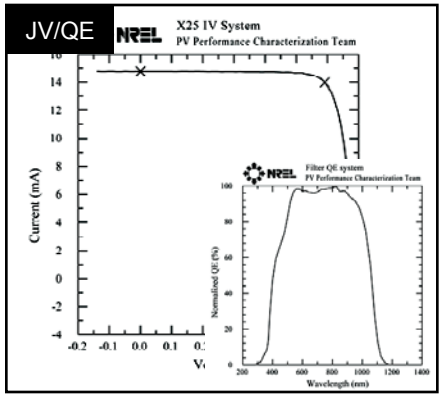
Process Knowledge



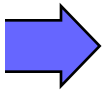


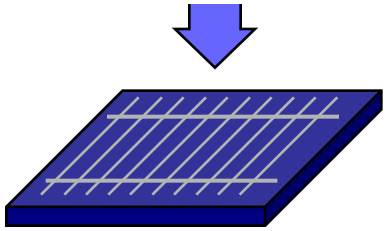
Combining Complementary Techniques

Device Performance



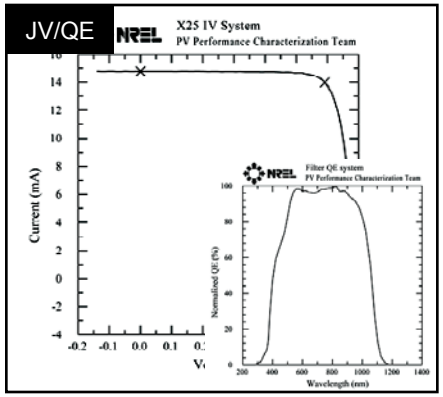
Process Knowledge



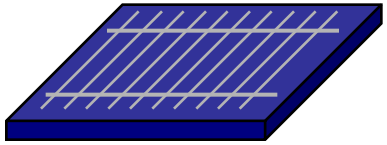


Combining Complementary Techniques

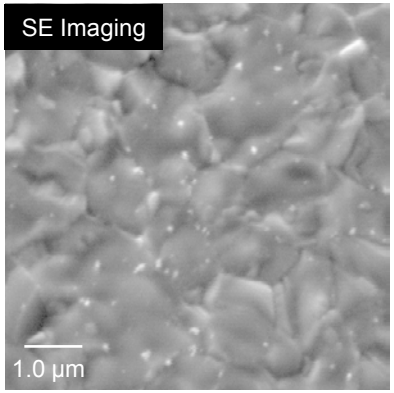
Device Performance



Process Knowledge

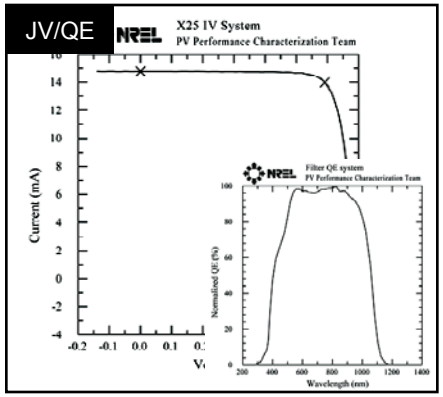


Topography

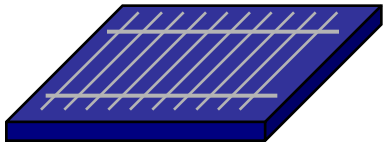


Combining Complementary Techniques

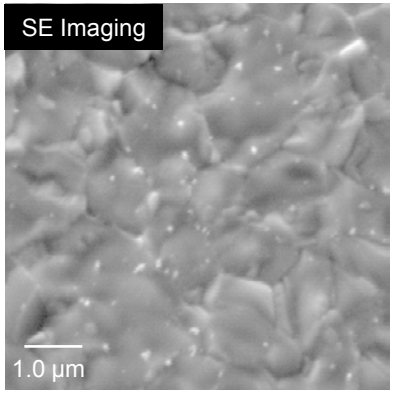
Device Performance



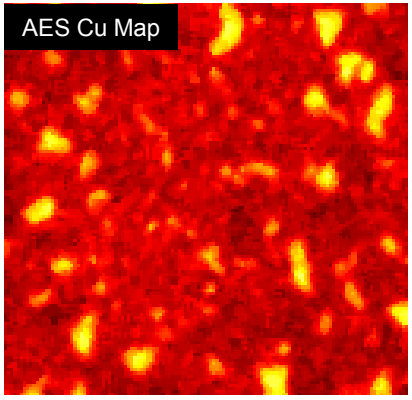
Process Knowledge

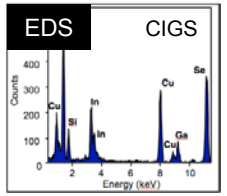


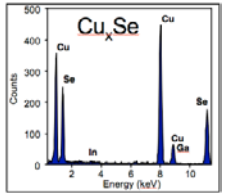
Topography



Compositional Characterization

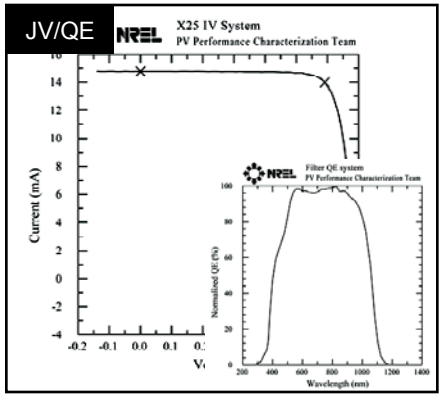




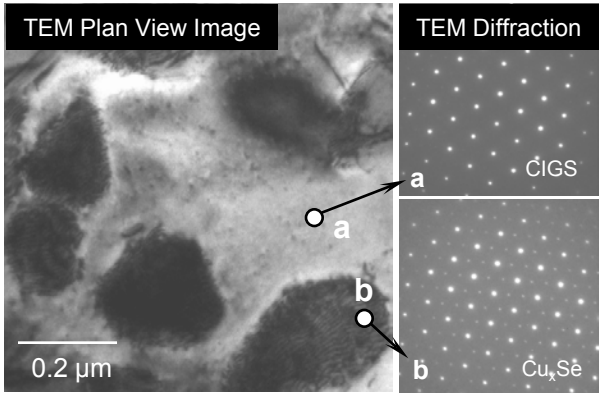


Combining Complementary Techniques

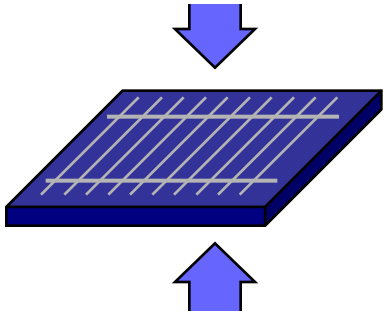
Device Performance



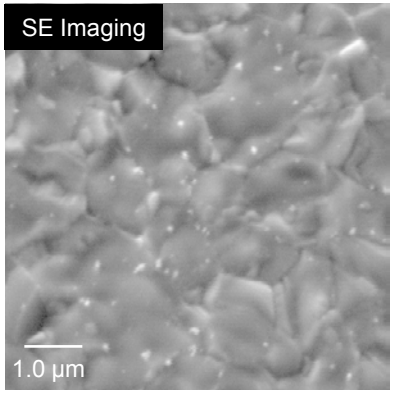
Structural Characterization



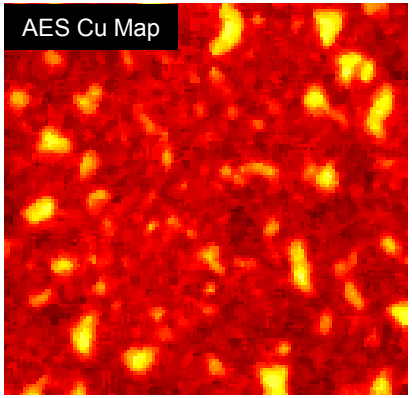
Process Knowledge

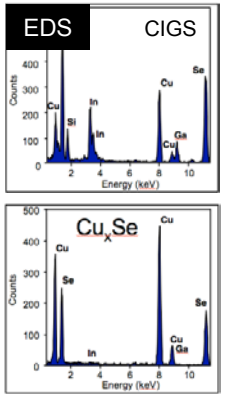


Topography



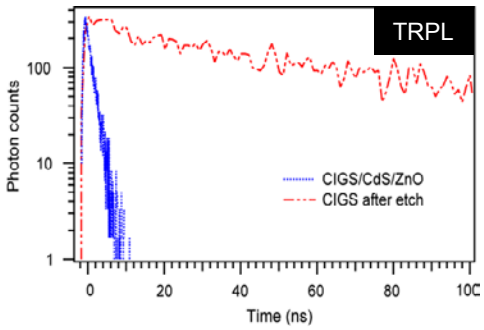
Compositional Characterization



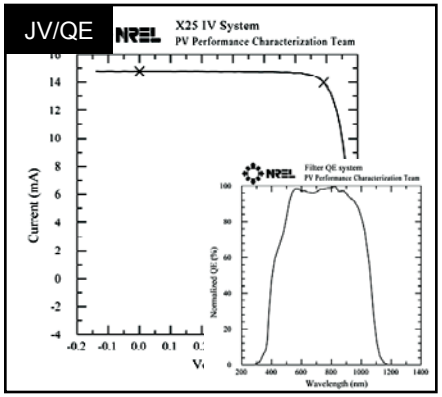


Combining Complementary Techniques

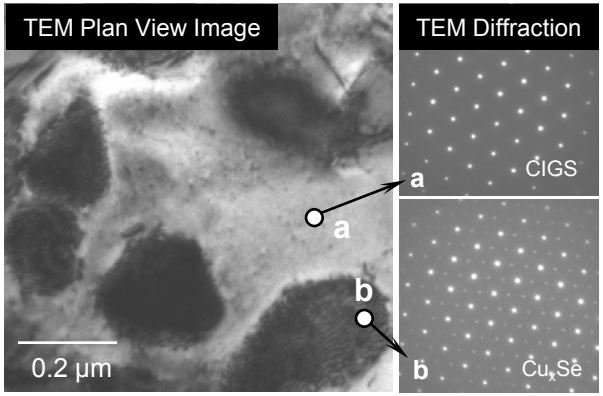
E-O Characterization



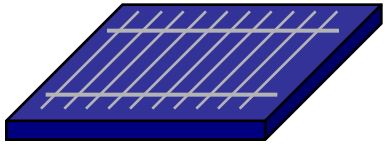
Device Performance



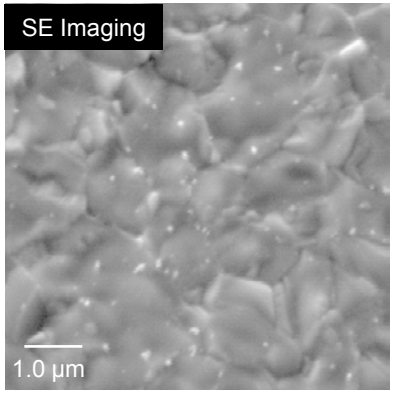
Structural Characterization



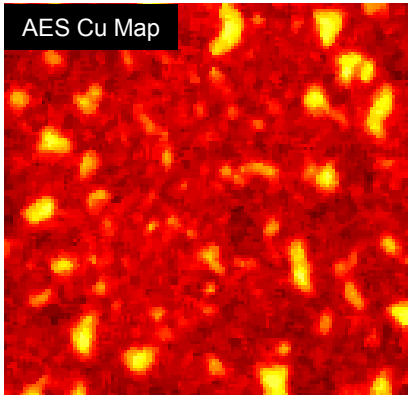
Process Knowledge

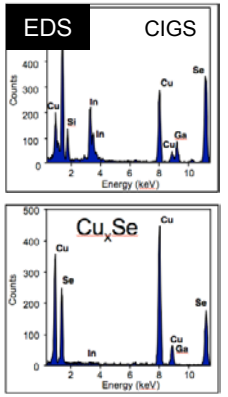


Topography



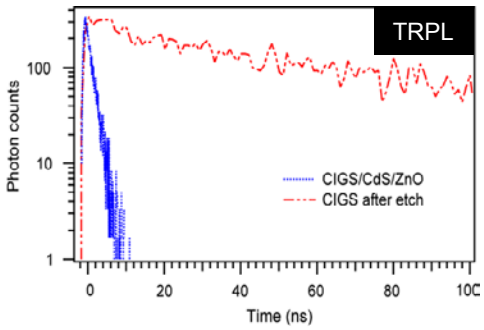
Compositional Characterization



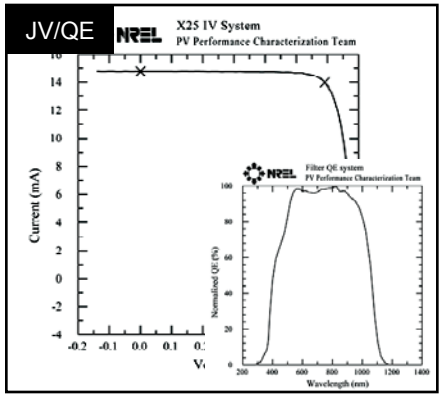


Combining Complementary Techniques

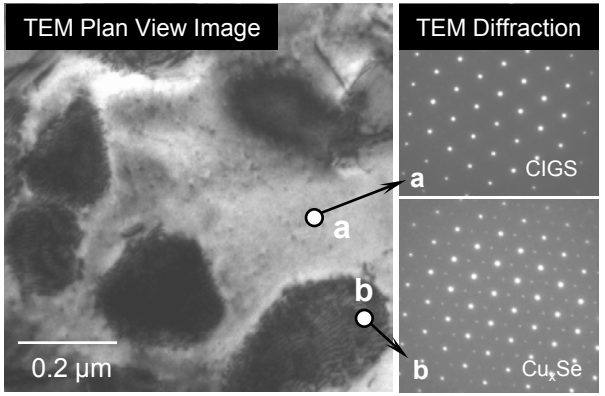
E-O Characterization



Device Performance

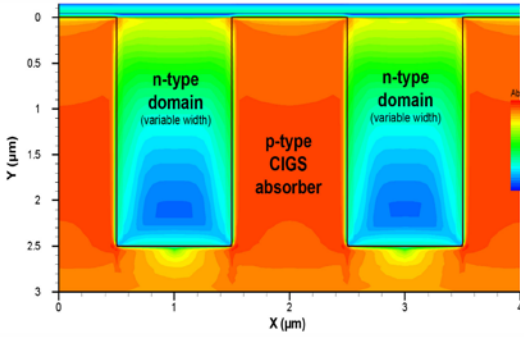


Structural Characterization

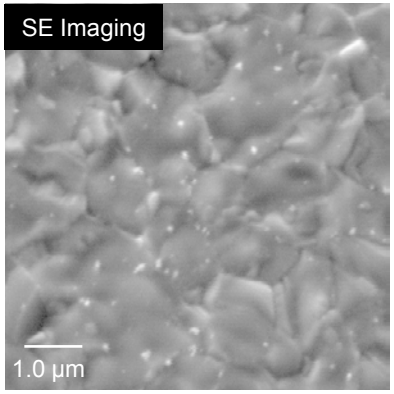


Process Knowledge

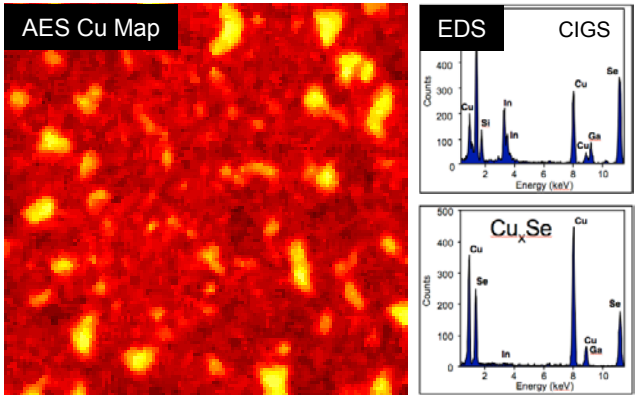
Device Modeling



Topography

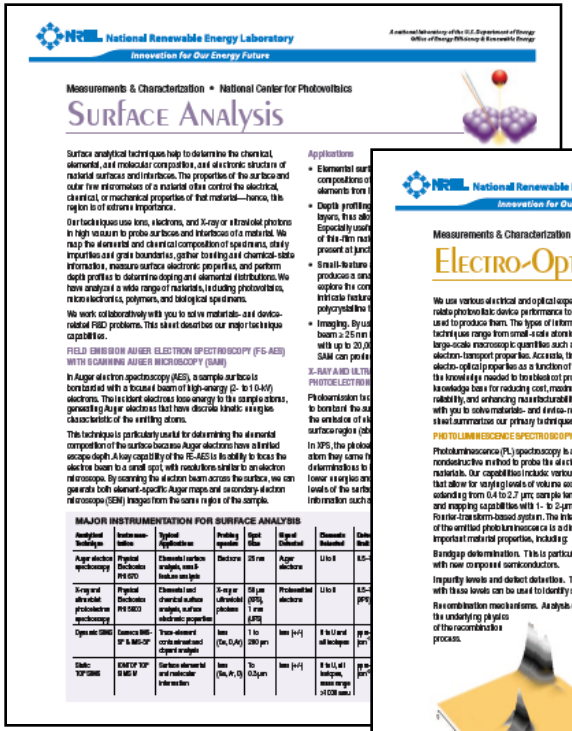


Compositional Characterization



M&C Capabilities

www.nrel.gov/pv/measurements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Measurements & Characterization • National Center for Photovoltaics
Surface Analysis


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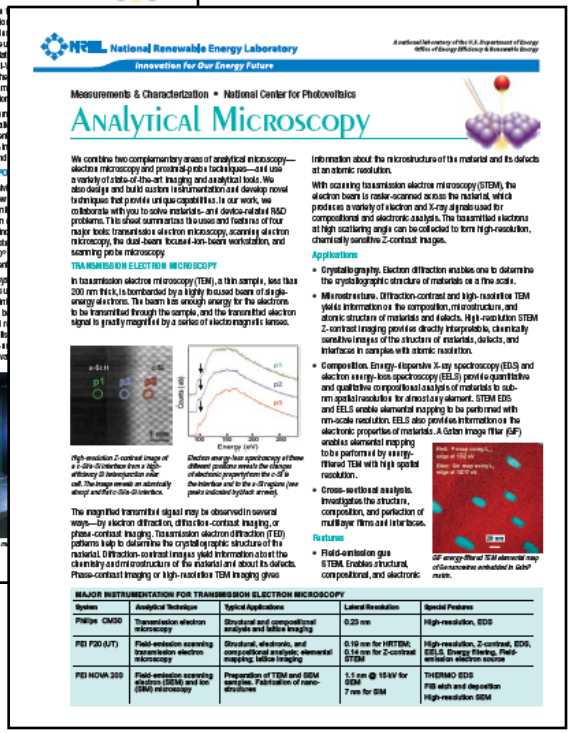
Measurements & Characterization • National Center for Photovoltaics
Electro-Optical Characterization


National Renewable Energy Laboratory
Innovation for Our Energy Future
Measurements & Characterization • National Center for Photovoltaics
Device Performance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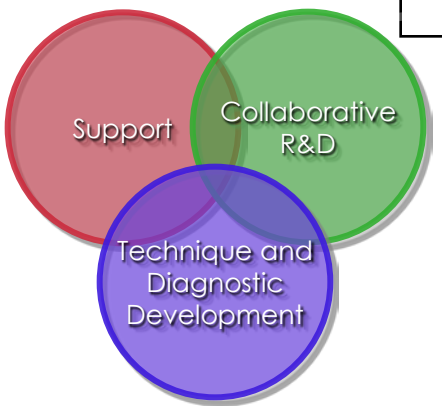
Measurements & Characterization • National Center for Photovoltaics
Analytical Microscopy



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