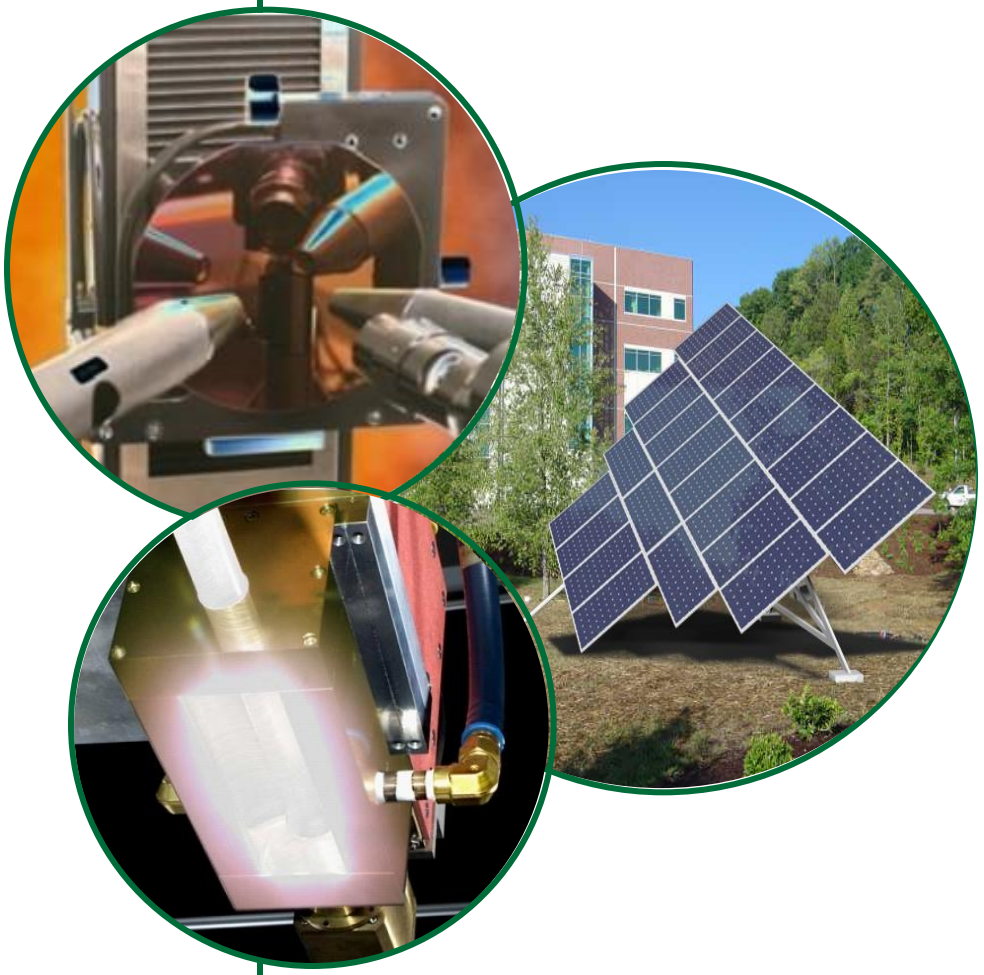
Solar Capabilities Overview

Gerald E. Jellison



ORNL User Week 2010

Solar Energy and Energy Storage: Answering the Energy Challenge

September 14, 2010

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

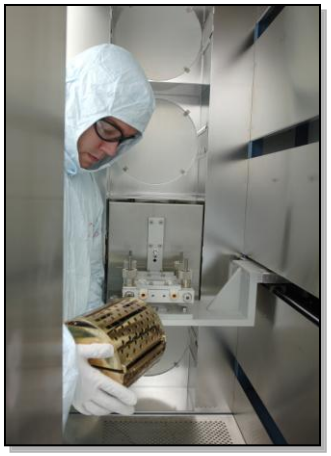
ORNL and PV

- ORNL was active in PV from late 1970's to 1987
- Principal emphasis: Laser Processing of emitters
- Primary findings of laser annealing for silicon solar cells:
  - Melting Model
  - Better incorporation of electrically active dopants (>solid solubility limit)
  - VERY low density of dislocation loops (better than thermal anneal)
  - Abrupt junctions
- Result: 19.5% cell in 1987 (R. F. Wood, R. D. Westbrook, and G. E. Jellison, "Excimer Laser-Processed Oxide-Passivated Silicon Solar Cells of 19.5% Efficiency," IEEE Electron Device Letters, EDL-8, (1987).).
- No significant PV work from 1987 to 2007.
- Since 2007, ORNL has been getting back into PV, since several of our past projects address similar issues as PV manufacturing.

ORNL Resources for Solar R&D

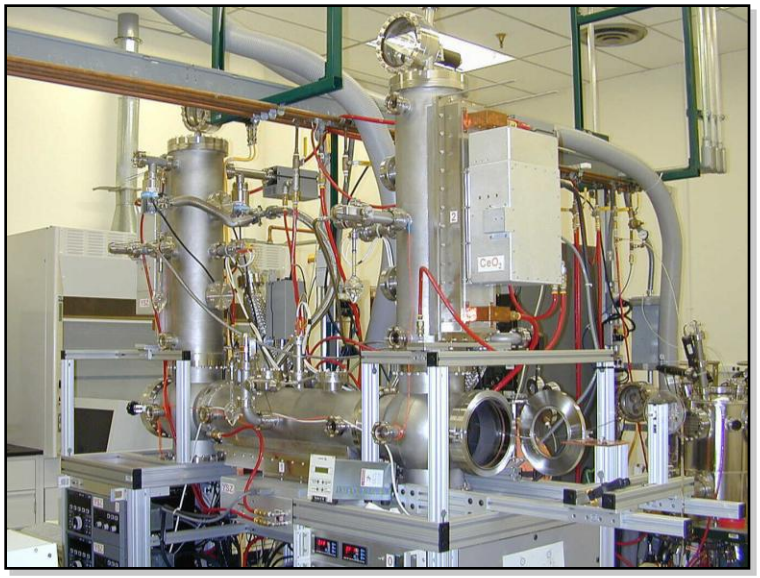
Fabrication	• Thin film deposition (LPCVD, PECVD, PLD, etc.) • Large area deposition (sputtering, slot die, inkjet) • Photolithography and etching • Oxide coatings and buffer layers
Characterization	• High Temperature Material Laboratory • Center for Advanced Thin-film Systems • Center for Nanophase Materials Sciences • Spallation Neutron Source
Processing	• Pulsed thermal processing • PulseForge photonic processing (Novacentrix) • Laser-assisted surface modification
Modeling	• First principles modeling of “materials by design” • DOE Leadership Computing Facility
Energy Frontier Research Centers	• Center for Defect Physics in Structural Materials • Fluid Interface Reactions, Structures and Transport (FIRST) Center

Advanced Materials Processing



Thin Film Deposition:

- LPCVD, PECVD, MOCVD
- Pulsed laser deposition
- E-beam evaporation
- RF & DC sputtering
- Slot die & ink jet coating
- Electrodeposition, CBD



Multi-layer *rf* sputtering

Photolithography:

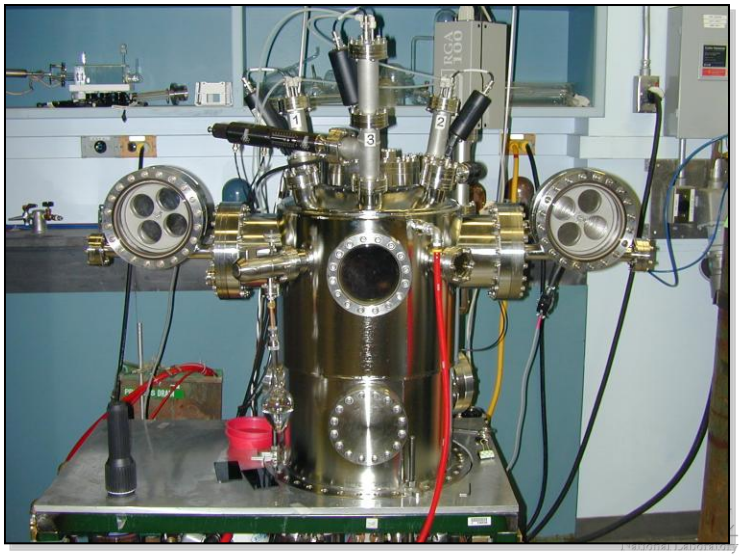
- 365 nm step & repeat system
- Karl Suss MA-6 contact lithography

Etching:

- Reactive ion plasma etching (Cl, F)
- Wet etch capability

Metrology:

- Hitachi S-4700 SEM, Auger spectroscopy
- Filmetrics F-40 thin film measurement
- Ultrafast Raman spectroscopy, EPR

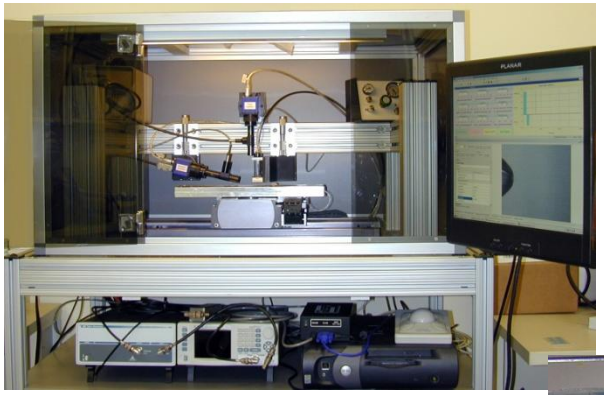


3-source e-beam coevaporation

Superconductive and Energy Efficient Materials Group

Expertise and capabilities in synthesis and characterization of multilayer coatings

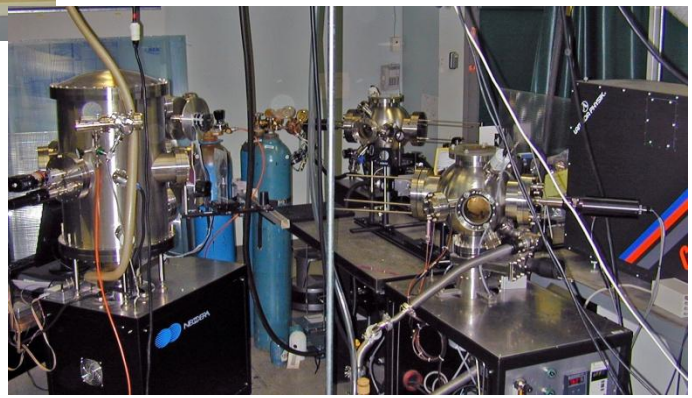
- Long-length thermo-mechanically crystalline metal templates for superconductor wires
- Multilayer coatings for buffer layers, oxide superconductors, and metal overlayers

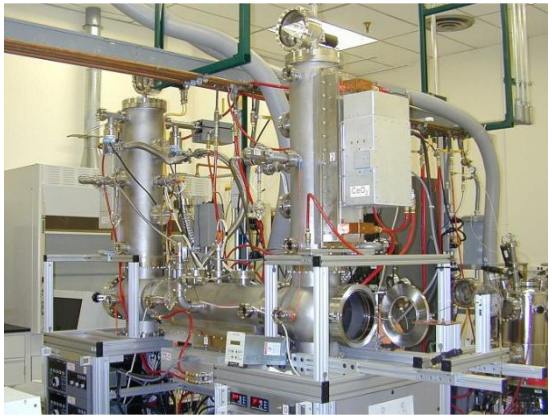


Solution coating
by inkjet printing

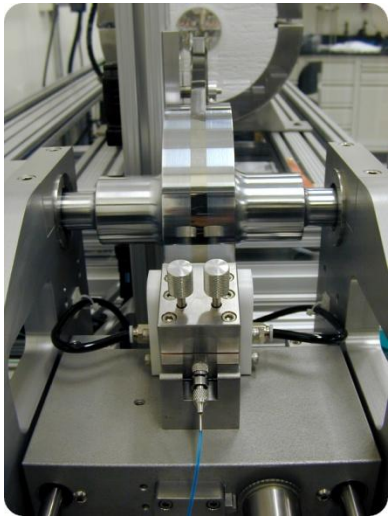
Coating Deposition

3-chamber
PLD system



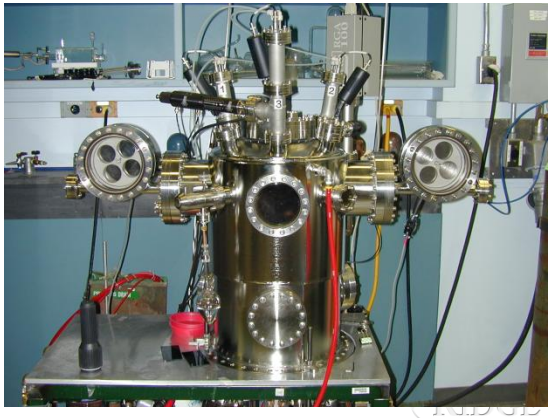


Multi-layer
rf sputtering
(3 systems)



Solution coating
by slot die (reel-to-reel)

3-source e-beam
co-evaporation
(2 systems)



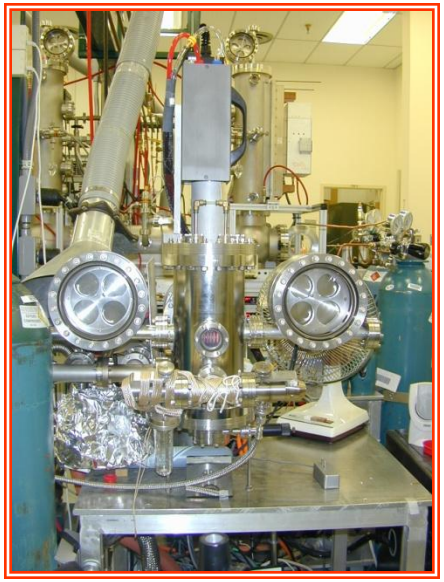
Superconductive and Energy Efficient Materials Group

Materials Processing and Characterization

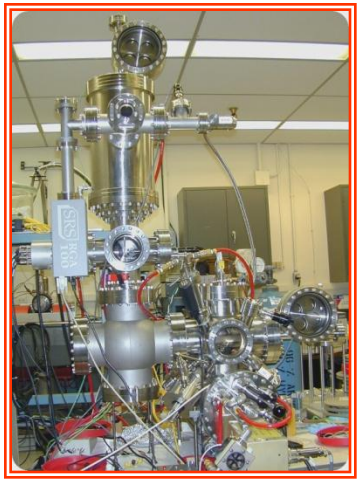
Class 1000, 4-High
Rolling Mill

Magnetic-field electrical properties systems (3 total)

Laser scriber
(sample patterning)



1500°C vacuum
thermal processing

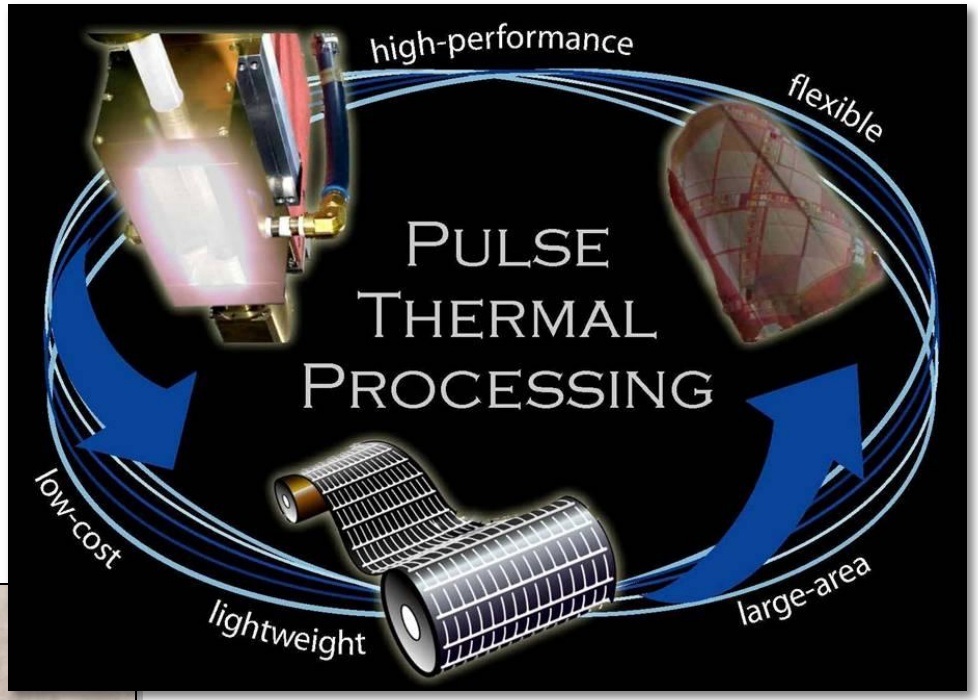


Auger spectroscopy
for surface composition

SQUID-based
Magnetometer with
7 Tesla Field

Pulse Thermal Processing / PulseForge

A new technology for high-speed drying, curing, sintering, or annealing of high-temperature materials on plastic and paper substrates.

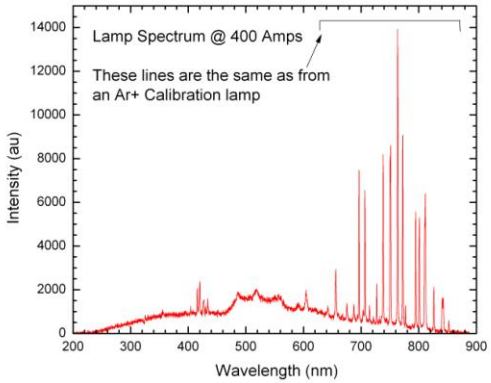


Characteristics:

- Energy Flux in excess of 20 kW/cm^2
- Heating Rates up to 600,000°C/s
- Exposure Time on (ms) and (µs) scale

R&D 100

2009 Winner



OAK RIDGE National Laboratory

Thin Film Solar Research at ORNL

Collaborative Projects with Industry Partners

Crystallize Amorphous Silicon on Metal Foil Substrate

UNI-SOLAR
United Solar Ovonic

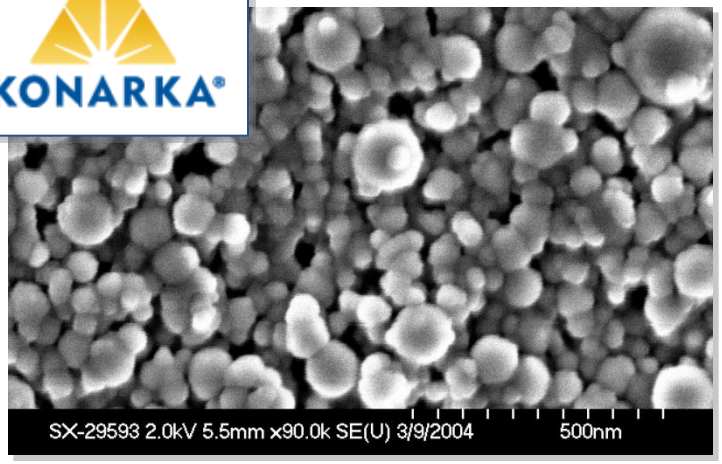
Low Cost Polycrystalline CdTe on Kapton Substrate

GENERAL ATOMICS

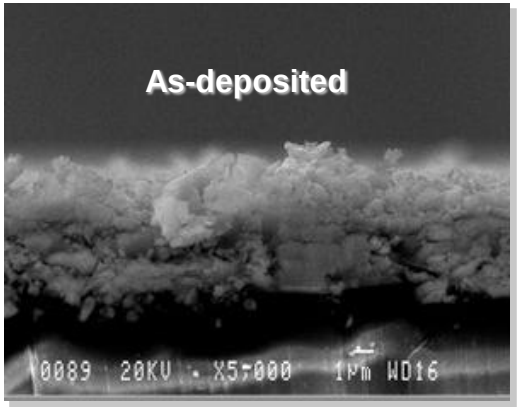
Texturing of CIGS Nanocrystals on Polymer

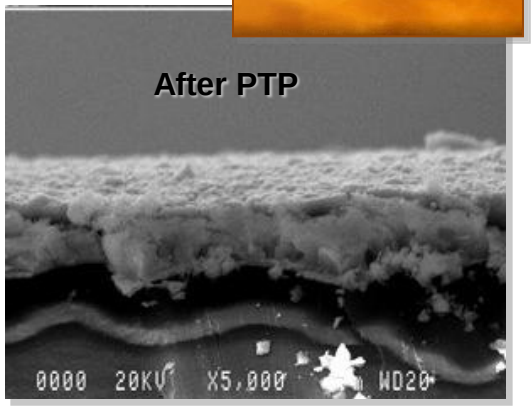
Ascent SOLAR

KONARKA



Sintered TiO_2 Nanoparticles on Polymer





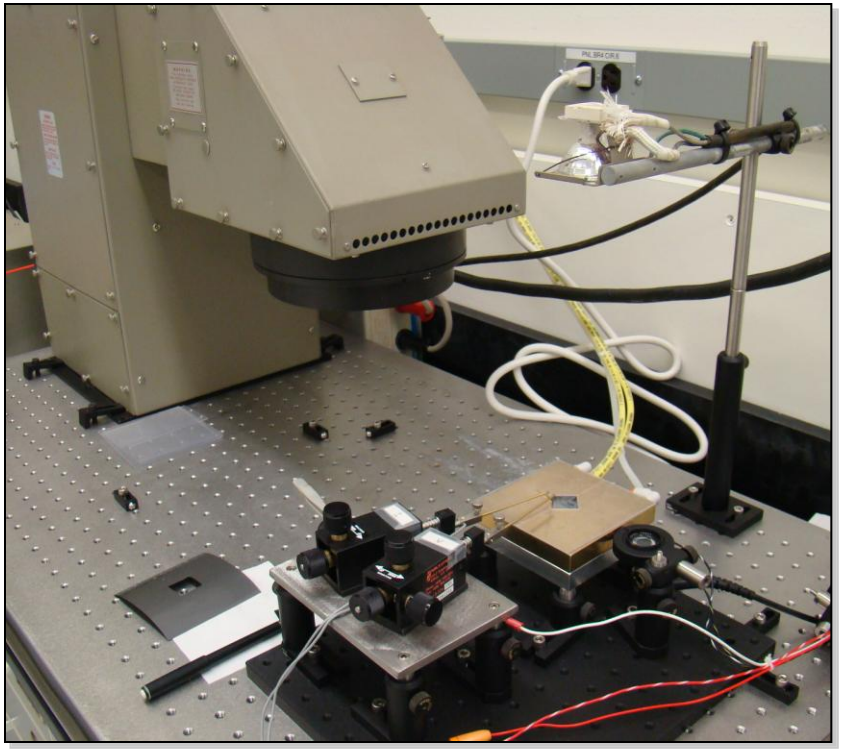
Grain Boundary Refinement Increased CIGS Thin Film Efficiency by 50%

Solar Cell Performance
Center for Advanced Thin-film Systems (CATS)

Solar Illuminated IV Curve

Measures **electrical behavior** of the solar cell until “normal sun” (or AM 1.5 light) conditions.

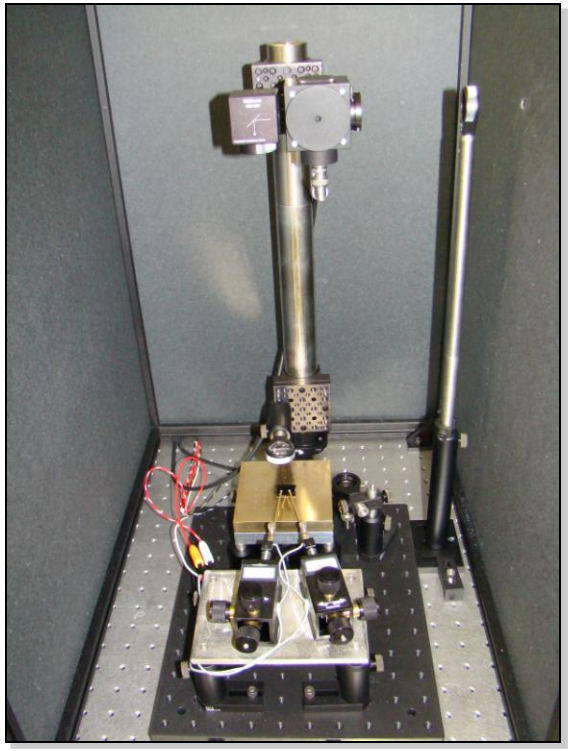
[efficiency, Voc, Isc, Pmax, Fill Factor]



Spectral Quantum Efficiency

Measures **ratio** of collected electron-hole pairs to photons of a given energy shining on the solar cell.

[quantum efficiency as f(λ)]

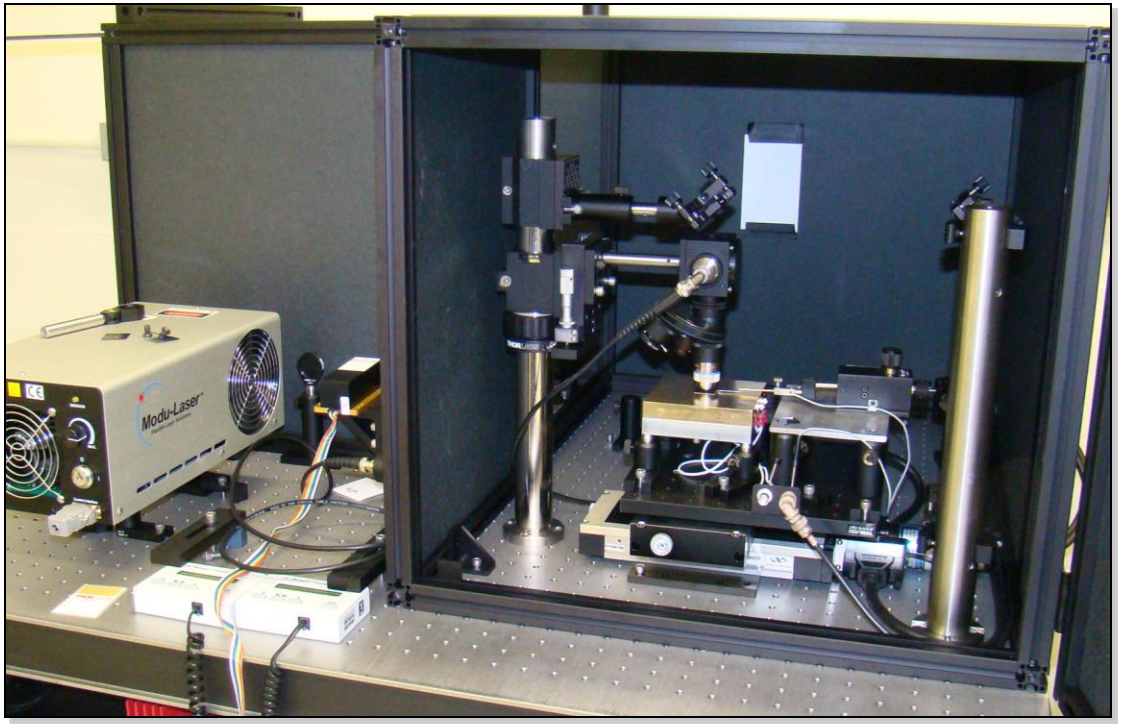


Solar Cell Performance
Center for Advanced Thin-film Systems (CATS)

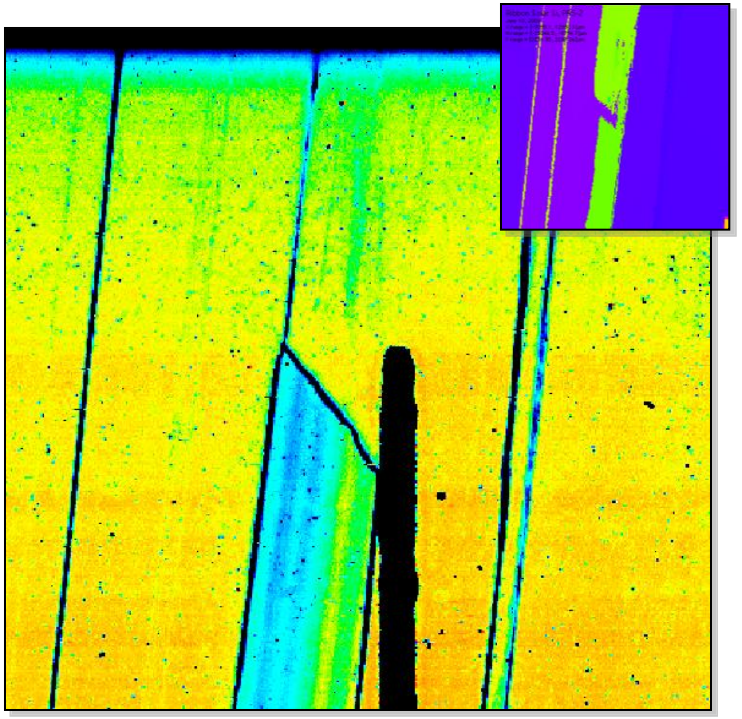
Light Beam Induced Current (LBIC)

Measures performance of solar cell at specific wavelengths of light illumination at high resolution (3 μm).

[2-D map of cell performance]



Synchrotron X-ray



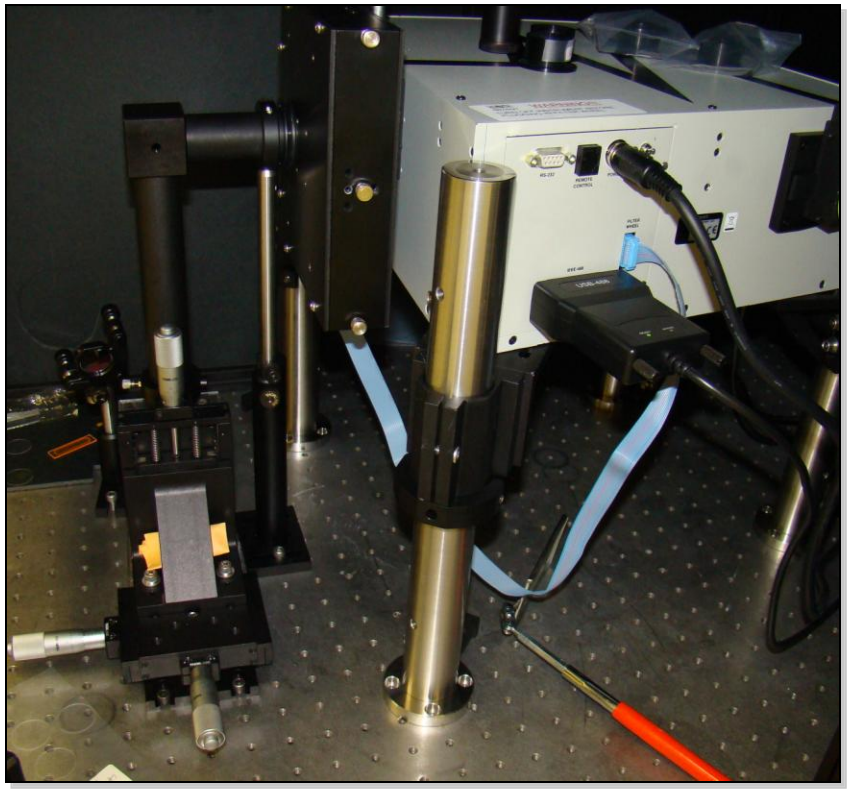
Compare with microstructural analysis to differentiate between defects that impact performance and those that do not.

Optical Characteristics
Center for Advanced Thin-film Systems (CATS)

Photoluminescence (PL)

Produces spectrum of light emissions after excitation at specific wavelength.

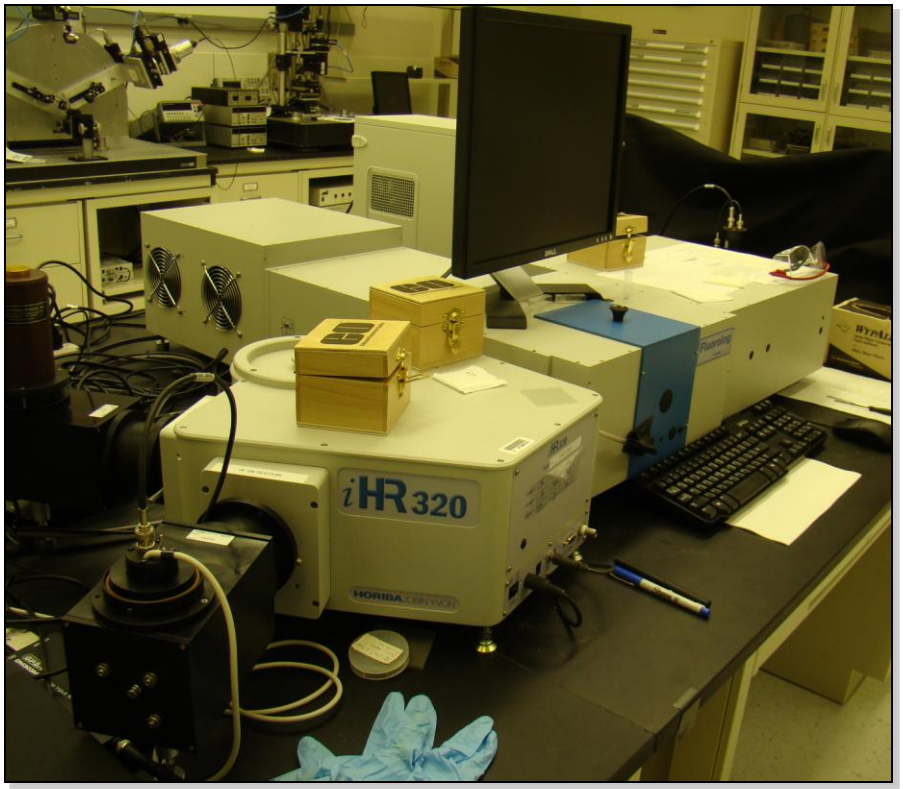
[band gap information, defect levels]



Horiba Jobin-Yvon Fluorimeter

Emission vs. excitation 3D maps that identify fluorescence spectrum from phosphors.

[band gap information]



Optical Characteristics
Center for Advanced Thin-film Systems (CATS)

Spectrophotometry

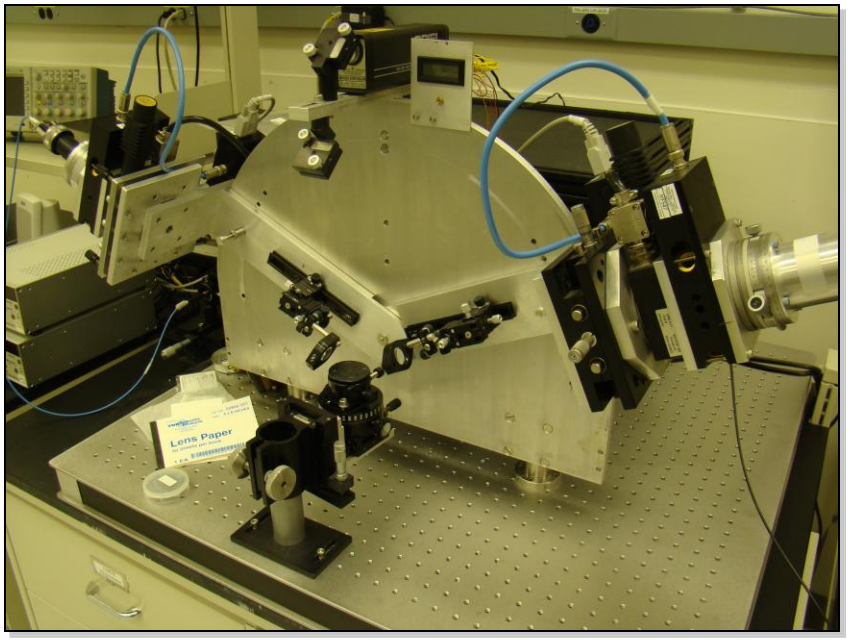
Measures relative amount of light that is transmitted, reflected, or absorbed. Useful for non-specular surfaces

[transmittance, absorption as f(λ)]

Generalized Ellipsometry

Uses polarized light to measure optical properties of thin films as well as film thickness and roughness.

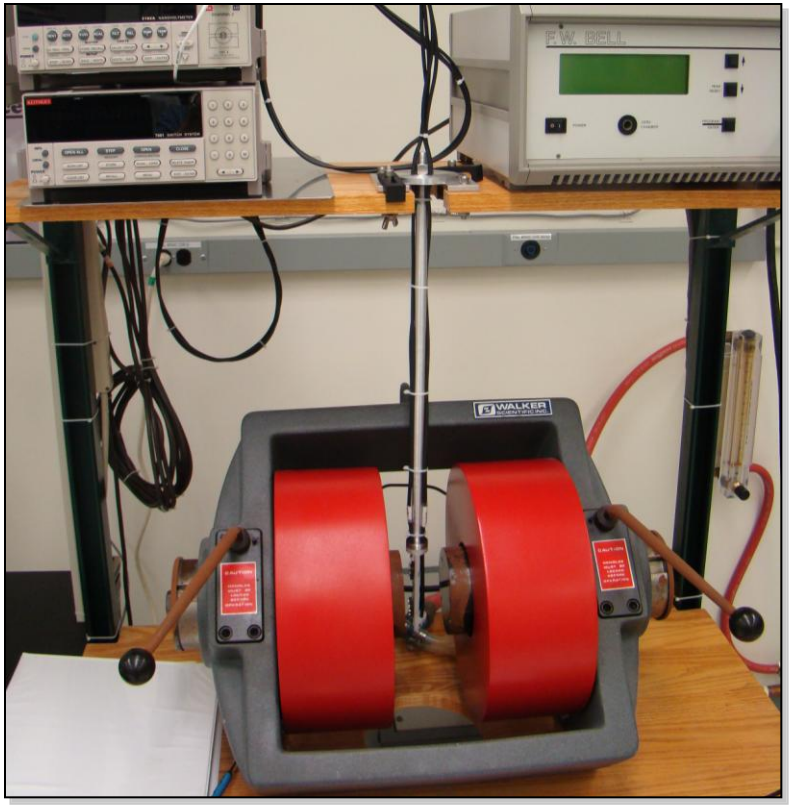
[absorption coefficient, refractive index]



Electrical Characteristics
Center for Advanced Thin-film Systems (CATS)

Hall Effect

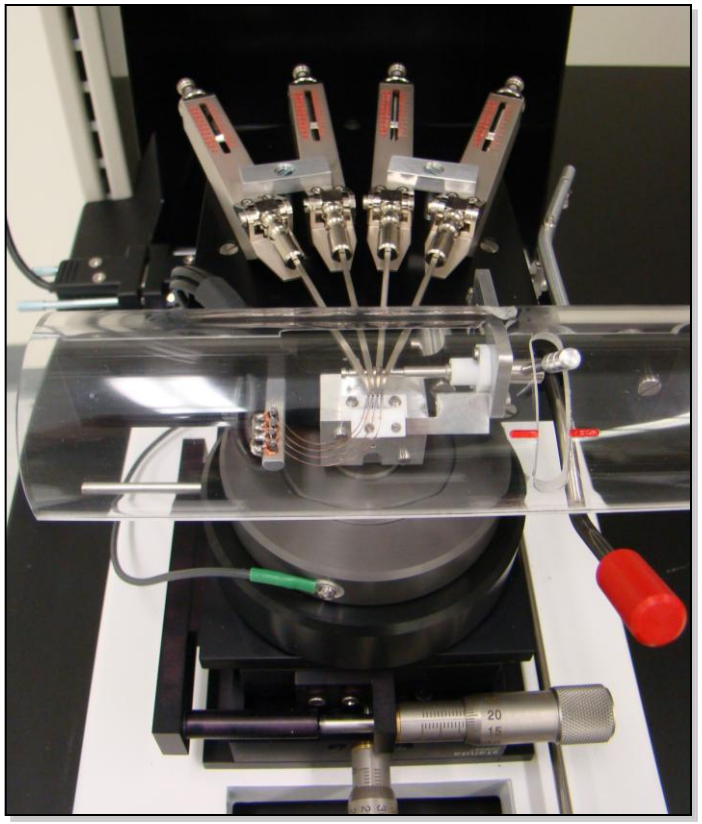
I-V measurements in a permanent magnetic field
[resistivity, carrier mobility and concentration]



4 – Point Probe Resistivity

A simpler measure of resistivity/conductivity of bulk materials and some thin films.

[conductivity/resistivity]



Water Vapor Transmission Rate Test System (Aquatran Model 1; Mocon)

ORNL has established a Barrier Coating Testing Facility

Accurately measures water vapor transmission rates up to 5 x 10^{-4} g/m^2-day

Research Collaborations