Exploring a material's chemical composition via dispersive X-ray spectroscopy using a scanning transmission electron microscope. *Photo by Dennis Schroeder, NREL 36026*

Multiscale Materials Characterization

The National Renewable Energy Laboratory (NREL) is advancing the state of the art in multiscale characterization to solve critical issues in materials science. Of special interest are materials for energy storage, photovoltaics, and fuel cell applications, as well as lightweight alloys, glasses, composites, ceramics, membranes, and geologic materials.

Recent decades have seen tremendous advances in the imaging of material structure—using 3-D tomography, as well as high-resolution electron microscopy and scanning probe microscopy at the atomic scale. *In situ* surface science tools and mapping of chemical composition have yielded improved understanding of material properties. But future impact lies in correlating structure and composition with properties and performance.

NREL is at the forefront of these advances, providing access to state-of-the-art multiscale characterization across some 10 orders of magnitude. Our experienced research scientists collaborate with industry partners to solve materials problems, using these diverse tools to understand critical phenomena at relevant length scales.

We enthusiastically welcome industry, manufacturing, university, and government enterprises to partner with us on design integration that ranges from materials selection to manufacturing to reliability.

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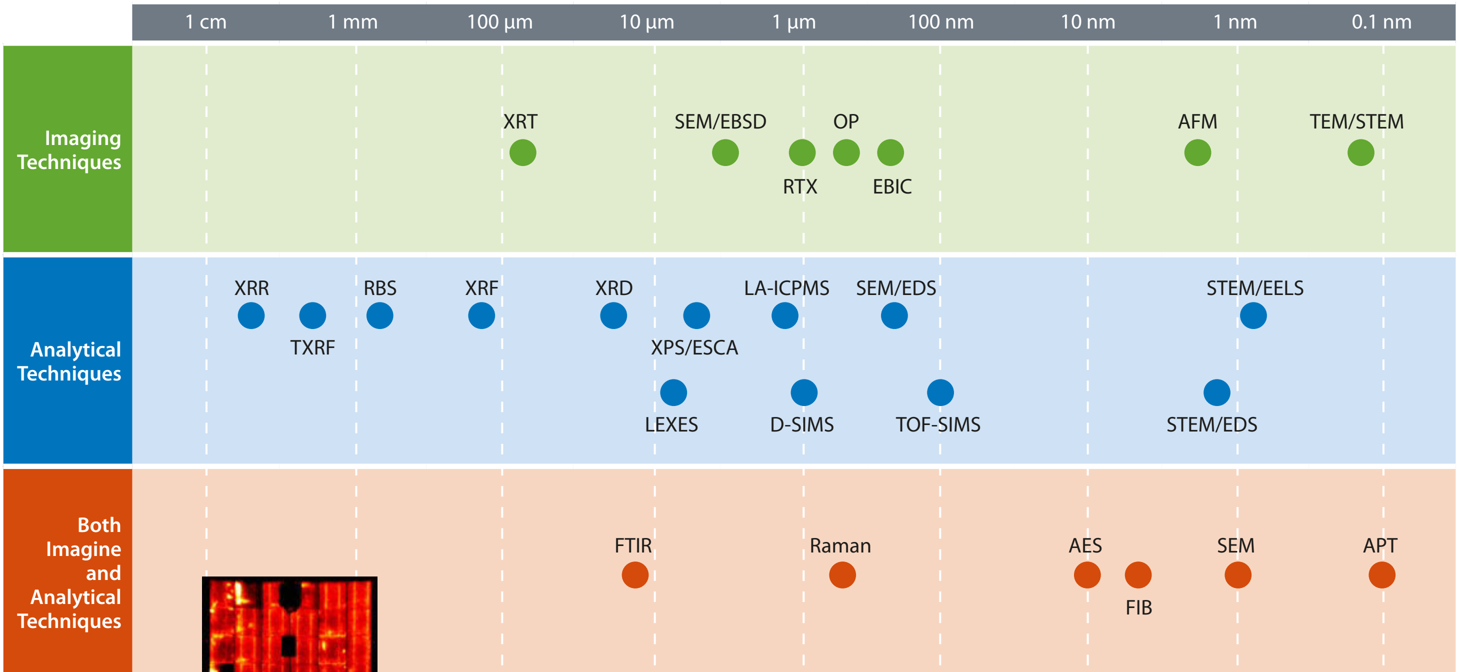
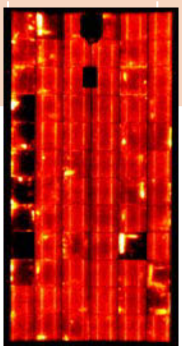
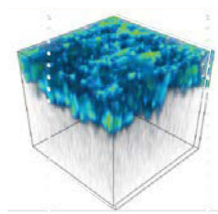
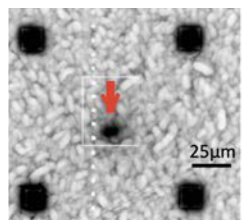




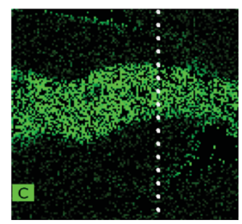
Thermography image of a PV module showing degradation.



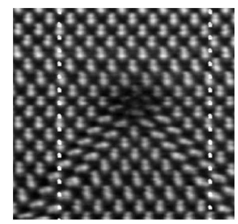
ToF-SIMS 3-D mapping of Cu in fuel cells



Electron-beam-induced image of a shunt in a Si solar cell



STEM-EDS elemental map of a fuel cell



Atomic resolution STEM image of structural defects

Glossary of Acronyms

AES Auger electron spectroscopy

AFM atomic force microscopy

APT atom probe tomography

CL cathodoluminescence

DLIT dark lock-in thermography

D-SIMS dynamic secondary ion mass spectrometry

EBIC electron-beam-induced current

EBSD electron backscatter diffraction

EDS energy-dispersive X-ray spectroscopy

EELS electron energy-loss spectroscopy

EL electroluminescence

ESCA electron spectroscopy for chemical analysis

FESEM field-emission scanning electron microscopy

FIB focused ion beam

FTIR Fourier transform infrared s pectroscopy

KPFM Kelvin probe force microscopy

LA-ICPMS laser ablation-inductively coupled plasma mass spectrometry

LEXES low-energy electron-induced X-ray emission spectroscopy

OP optical profilometry

PL photoluminescence

Raman Raman spectroscopy

RBS Rutherford backscattering spectrometry

RTX real-time X-ray

SCM scanning capacitance microscopy

SEM scanning electron microscopy

SSRM scanning spreading resistance microscopy

STEM scanning transmission electron microscopy

TEM transmission electron microscopy

TOF-SIMS time-of-flight secondary ion mass spectrometry

TXRF total reflection X-ray fluorescence

XPS X-ray photoelectron spectroscopy

XRD X-ray diffraction

XRF X-ray fluorescence

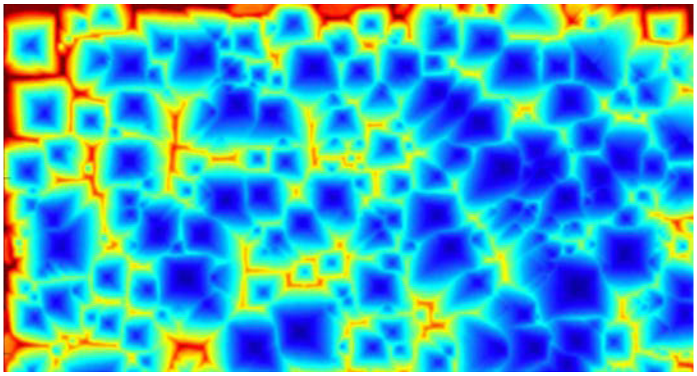
XRR X-ray reflectivity

XRT X-ray diffraction tomography

Analytical Microscopy and Imaging Science

Core Competencies and Capabilities

We use various microscopy, spectroscopy, and imaging techniques to obtain information about materials on a length scale from meters to Angstroms. These tools are some of the most powerful available for understanding the basic structure, chemistry, morphology, and electrical and optical properties of materials. We use two complementary types of analytical microscopy—electron microscopy and scanning probe microscopy—along with a variety of state-of-the-art imaging and analytical tools to capture data about materials.



Electron-beam-induced current map of a pyramid-textured poly-Si/SiO2 passivated-contact cell. *Image by Harvey Guthrey, NREL*

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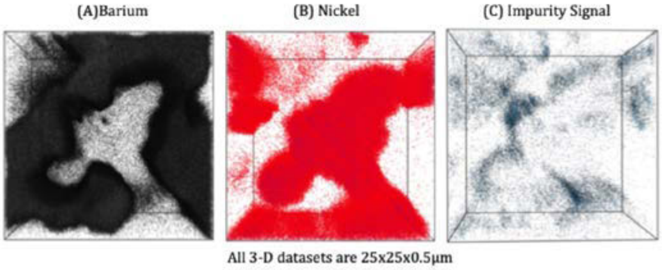
www.nrel.gov/materials-science/analytical-microscopy-imaging-science.html

Interfacial and Surface Science

Core Competencies and Capabilities

We use a complementary array of techniques to determine the chemical, elemental, and molecular composition as well as the electronic structure of material surfaces and interfaces, which play critical roles in many renewable energy technologies.

Using ions, electrons, and X-ray or ultraviolet photons in high vacuum, we probe surfaces and interfaces of a material or device to: map the elemental and chemical composition of specimens; study impurities and grain boundaries; gather bonding and chemical-state information; measure surface electronic properties; and perform depth profiles to determine doping and elemental distributions.



Time-of-flight secondary ion mass spectrometry 3-D tomography elucidates distribution of impurities in BaZrCeYO/Ni 2-phase composite material: (A) barium, (B) nickel, and (C) impurity signals. *Images by Steve Harvey, NREL*

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www.nrel.gov/materials-science/interfacial-surface-science.html

NREL Transforming ENERGY

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