Measurements and Characterization

Scope. The Measurements and Characterization (M&C) groups at the National Center for Photovoltaics of the National Renewable Energy Laboratory provide characterization support, collaborative research, and the development of new measurement techniques and diagnostics to advance the photovoltaic (PV) generation of energy. M&C researchers use state-of-the-art characterization tools to solve problems in all phases of material and device development. The result of these efforts is an increased understanding that drives improvements in the performance, reliability, price, and manufacturability of PV materials, devices, and systems.

The M&C area consists of four closely integrated core competency groups:

- Analytical Microscopy
- Electro-Optical Characterization
- Surface Analysis
- Cell and Module Performance

Each group uses a wide array of state-of-the-art measurements and characterization techniques and has highly trained staff with a combined total of more than 500 years of experience in PV materials and device characterization. This extensive PV experience base, coupled with the breadth of our capabilities and highly integrated approach, sets us apart from other organizations throughout the world. The M&C groups have a long history of working with the PV community to solve material, device, manufacturing, packaging, and reliability issues. We strive to develop a solid scientific foundation to help our customers advance their manufacturing process development, research, and reliability R&D to a higher level.

We enthusiastically welcome industry, manufacturing, university, and government enterprises to collaborate with us. We are motivated to share our expertise and knowledge base and to collaborate on research, problem-solving, and commercial product development.

Contact/Web

General information

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Analytical Microscopy Core Competencies and Capabilities. The Analytical Microscopy Group uses various high-resolution techniques to obtain information about materials on the nano or sub-nano scale. These tools are some of the most powerful tools available for understanding a material's basic structure, chemistry, morphology, and electrical behavior. We use two complementary types of analytical microscopy techniques—electron microscopy and scanning probe microscopy—together with a variety of state-of-the-art imaging and analytical tools to capture data about PV materials and devices. A brief summary of our capabilities is listed below.

- Scanning electron microscopy (SEM)
- Transmission electron microscopy (TEM/STEM)
- Cathodoluminescence (CL)
- Electron beam induced current (EBIC)
- Electron backscattered diffraction (EBSD)
- Focused ion beam (FIB) microscopy
- Electron probe microanalysis (EPMA)
- Scanning probe microscopy techniques:
  - Atomic force microscopy (AFM)
  - Scanning capacitance microscopy (SCM)
  - Scanning tunneling microscopy (STM)
  - Scanning Kelvin probe microscopy (SKPM)
  - Scanning spreading resistance microscopy (SSRM)

Contact/Web

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Electro-Optical Characterization Core Competencies and Capabilities. The Electro-Optical Characterization Group uses a powerful combination of optical spectroscopies, electrical device measurements, and sophisticated computer modeling to understand the complex relationships between material properties, device processing, and device performance. Our techniques apply to virtually all PV technologies, and we bring world-class expertise to measurement of critical parameters such as minority-carrier lifetime, dislocation density in silicon wafers, and the fundamental junction parameters in PV devices. Optical measurement techniques are inherently rapid and non-contact and well suited to the in-line manufacturing environment. We have a demonstrated track record of technology transfer and actively seek out industrial partners for collaborative R&D on the critical problems facing the PV industry. A brief summary of our capabilities is listed below.

- Photoluminescence spectroscopy (PL)
- Minority-carrier lifetime (TRPL, RC-PCD, and µW-PCD)
- Fourier transform infrared spectroscopy (FTIR)
- Spectroscopic ellipsometry (VASE/RTSE)
- Capacitance techniques (C-V, DLTS, AS, and DLCP)
- 2-D and 3-D computational device and measurement simulation modeling
- Imaging diagnostics and development
  - Dark lock-in thermography (DLIT)
  - Lock-in thermography (LIT)
  - Electroluminescence imaging (ELI)
  - Photoluminescence imaging (PLI)
  - Diffuse spectroscopic reflectometry
- Surface photovoltage (SPV)
- Laser beam induced current (LBIC)
- Conformal Raman and PL microscopy

Contact/Web

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Surface Analysis Core Competencies and Capabilities. The Surface Analysis Group uses techniques to determine the chemical, elemental, and molecular composition, and electronic structure of material surfaces and interfaces. This research is important because the properties of the surface and outer few micrometers of a material often control the electrical, chemical, or mechanical properties of that material. 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. A brief summary of our capabilities is listed below.

- Auger electron spectroscopy (AES)
- X-ray photoelectron spectroscopy (XPS)
- Ultraviolet photoelectron spectroscopy (UPS)
- Thermal desorption mass spectrometry (TDMS)
- Dynamic secondary ion mass spectrometry (SIMS)
- Time-of-flight static secondary ion mass spectrometry (TOF-SIMs)

Contact/Web

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Cell and Module Performance Core Competencies and Capabilities. The Cell and Module Performance Group is the premier U.S. Department of Energy research laboratory for testing performance of commercial, developmental, and research PV devices. We are one of only two laboratories in the world to hold an International Organization for Standardization (ISO) 17025 accreditation for primary reference cell and secondary module calibration, in addition to accreditation for secondary reference cell calibration under American Society for Testing Materials (ASTM), and International Electrotechnical Commission (IEC) standards. We are one of only four laboratories in the world certified in accordance with the IEC standard for calibrating terrestrial primary reference PV cells. We test cells and modules of any size, shape, or technology from around the world, putting all PV performance measurement "on the same page." A brief summary of our capabilities is listed below.

- Current versus Voltage (I-V) measurements
  - I-V @ 1-sun Standard Test Conditions
  - Cell I-V vs. concentration and temperature
  - Cell I-V vs. spectrum
  - Continuous and pulsed module simulators
  - Adjustable-tilt test bed for 1-sun outdoor module I-V
  - 2-axis tracker for up to 10 concentrator modules
- Spectral responsivity (SR/QE)
  - Single- or Multijunction vs. temperature, bias light, and voltage bias
- ISO 17025 accredited primary reference cell
  - Secondary reference cell and secondary module calibration

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
NREL/FS-5200-48346 • Revised June 2013