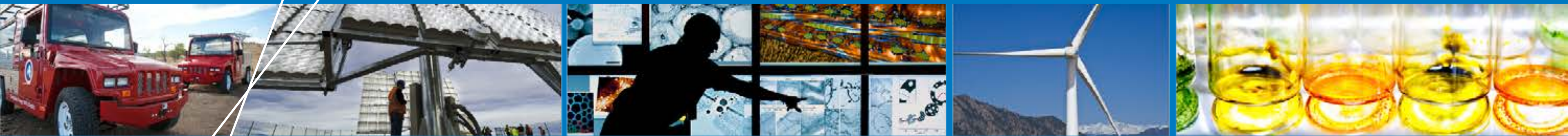
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EERE QC Workshop: Overview of Quality Control Techniques

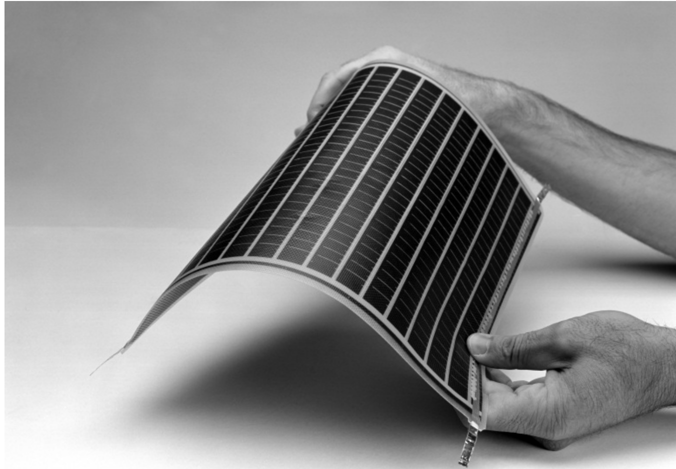


Michael Ulsh, NREL

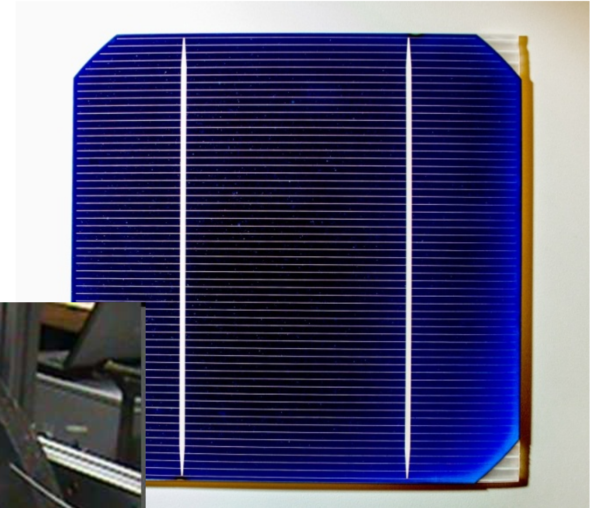
December 9, 2013

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.

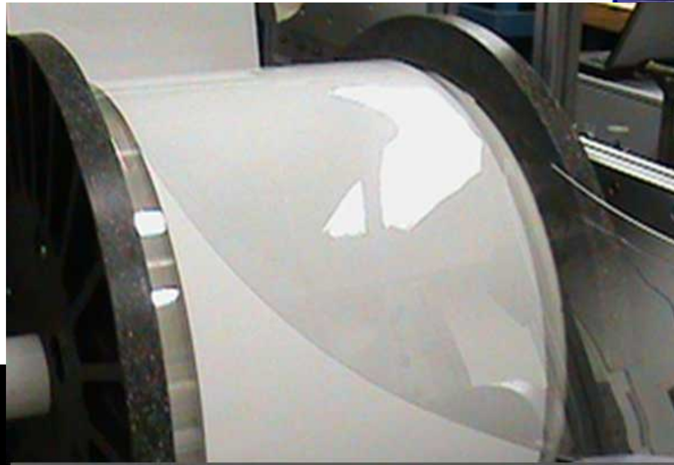
Materials



NREL Image Gallery #03541



NREL Image Gallery #27981



Corning, Inc. Courtesy of Sean Garner

NREL Image Gallery #18745

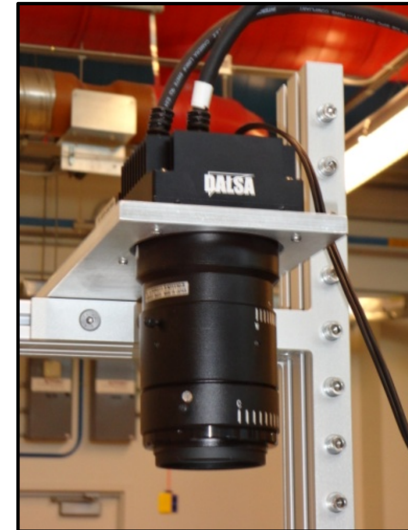
J. Morgan, “Reduction in Fabrication Costs of Gas Diffusion Layers,” DOE Hydrogen Program Annual Merit Review, May, 2011.

Outline

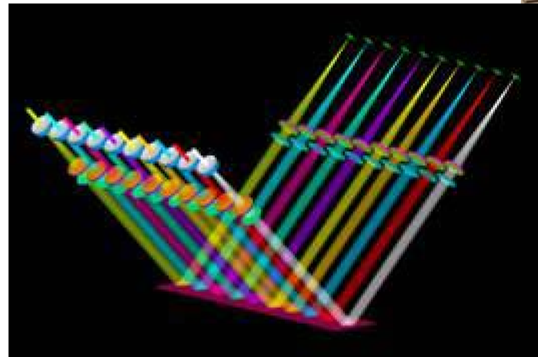
- Schemes for in-line inspection of sheets/surfaces
- Types of measurements
- Point measurements
- Line/area measurements

Schemes for in-line inspection

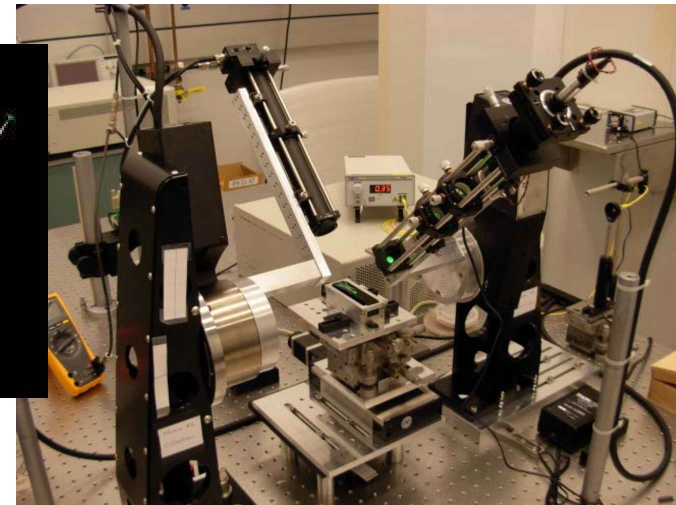
- Single/multiple point, stationary
- Single point, raster
- Line detector
- Areal detector



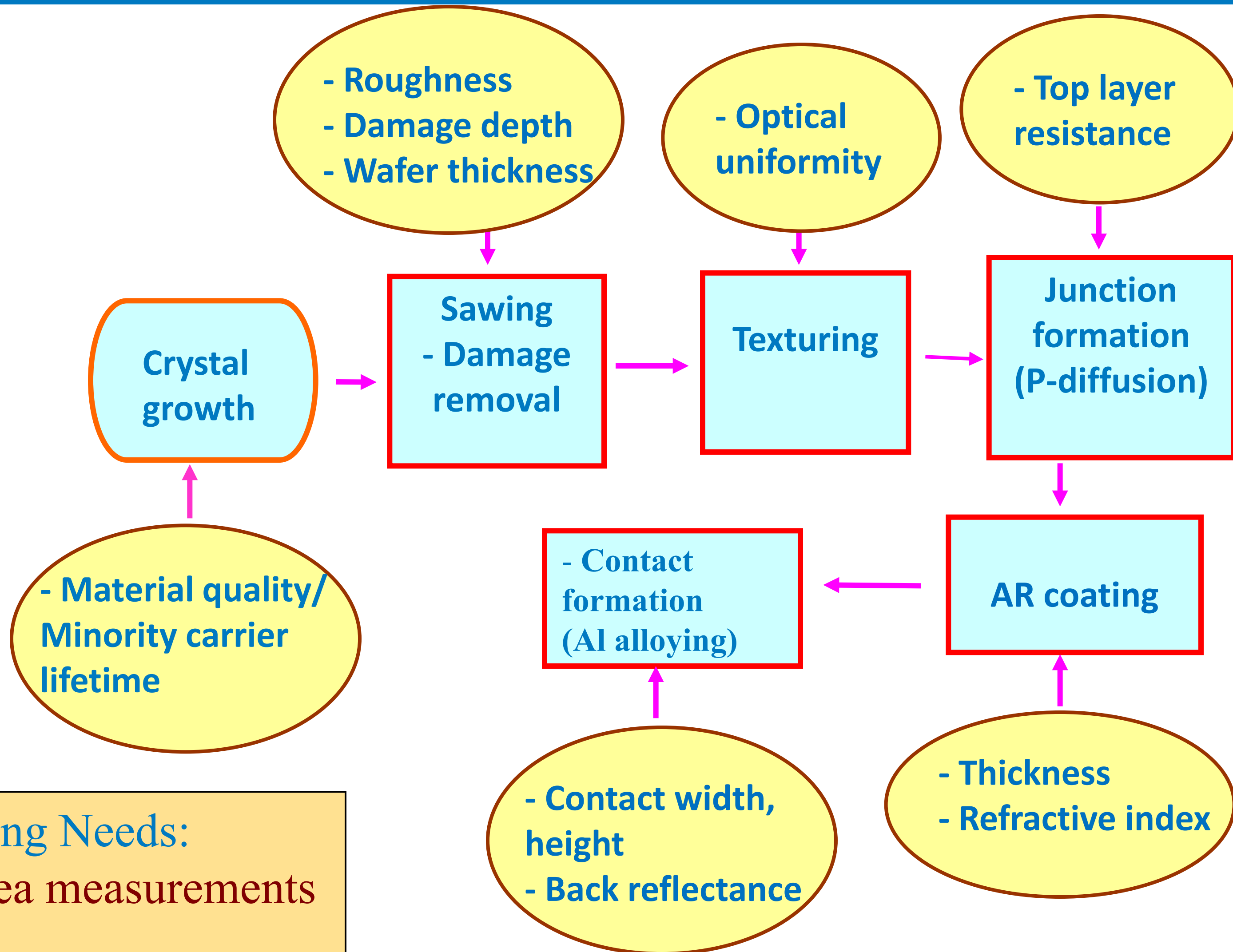
http://www.ndcinfrared.com/NDC/



M. Stocker, "Metrology for Fuel Cell Manufacturing," DOE Hydrogen Program Annual Merit Review, May, 2013.



PV inspection



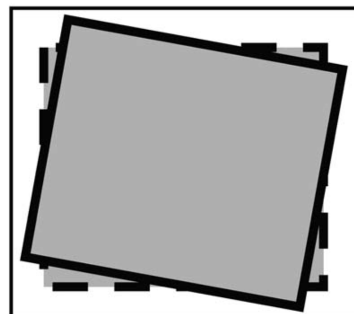
PV monitoring Needs:

- Large-area measurements
- Fast
- Low-cost equipment

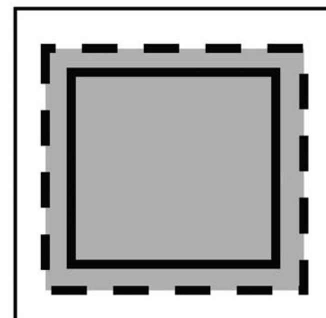
Types of measurements

Keyence, personal communication, 2012..

- **Dimension/location**
  - Thickness
  - Coated width
  - Edge location
  - Registration



(a) Uncontrolled catalyst layer overlap

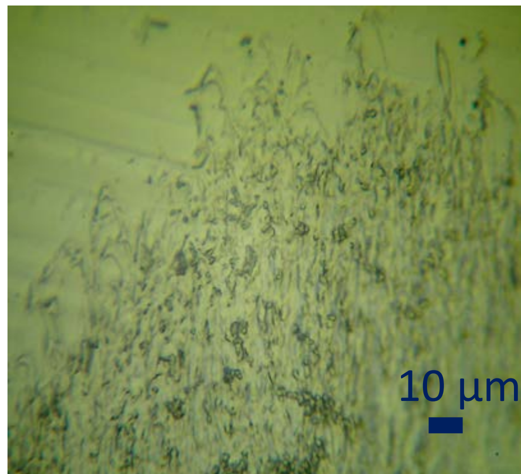


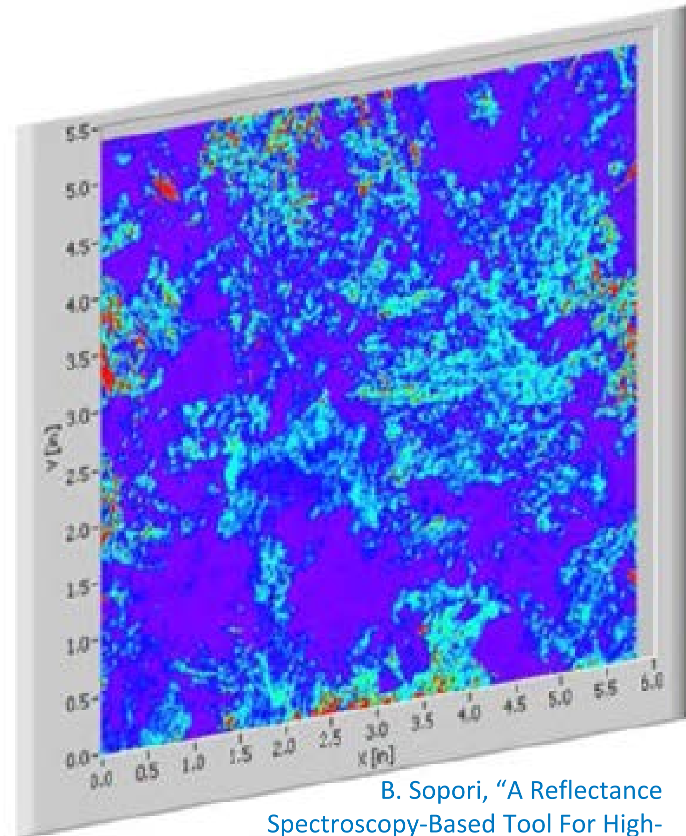
(b) Anode overlap control

B. Sompalli, "Membrane Degradation at Catalyst Layer Edges in PEMFC MEAs," *J. Electrochem. Soc.*, **154** (12) B1349-B1357, 2007.

Types of measurements

- **Non-uniformity/defects**
  - Thickness variation
    - Voids
  - Areal affects
    - Cutting and processing effects
    - “Orange peel,” “mottle”

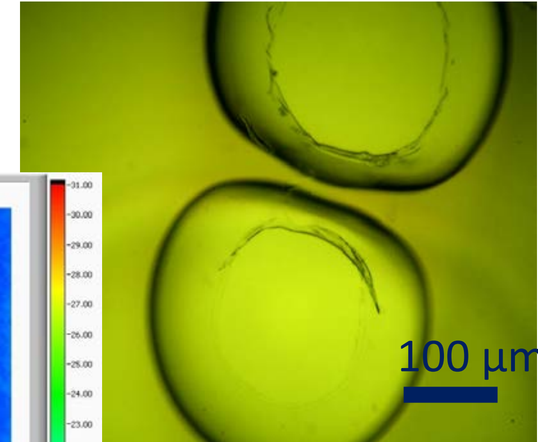


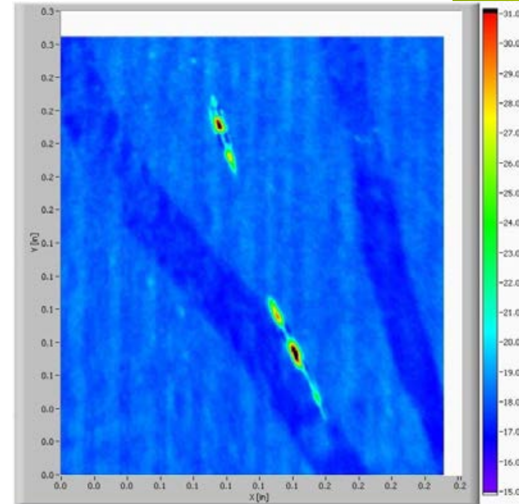


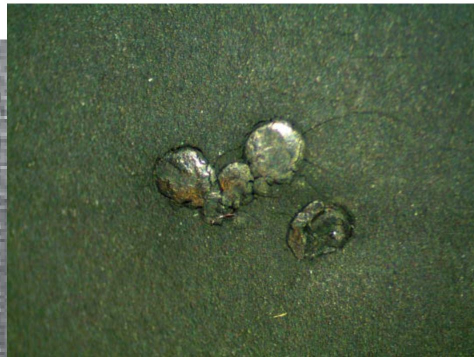
B. Sopori, “A Reflectance Spectroscopy-Based Tool For High-Speed Characterization of Silicon Wafers and Solar Cells in Commercial Production,” IEEE, 2010.

Types of measurements

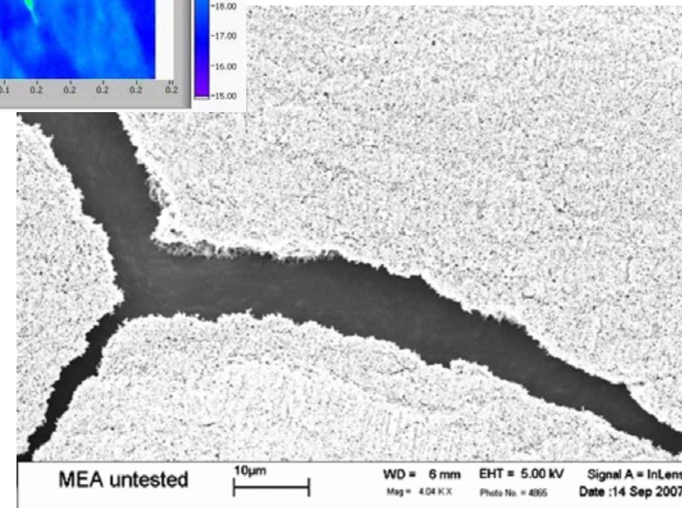
- **Non-uniformity/defects**
  - Discrete defects
    - Pinholes
    - Agglomerates
  - Systemic affects
    - Die lines







E. DeCastro, “High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies, Hydrogen Program Annual Merit Review, June, 2010.

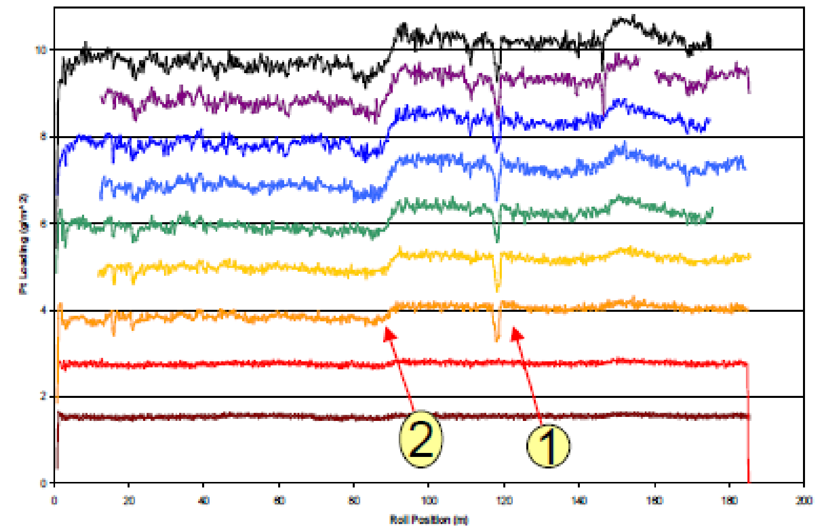


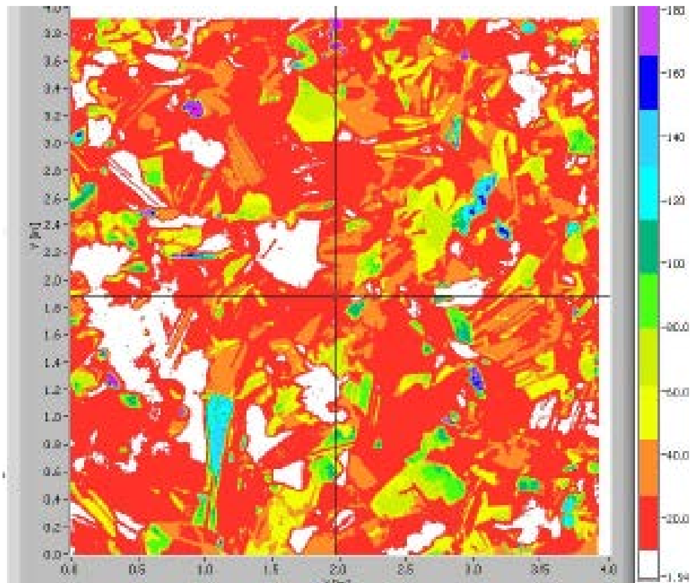
Pestrak, *J. Fuel Cell Sci & Tech,* **7** 041009-1 – 041009-10 (2010).

Types of measurements

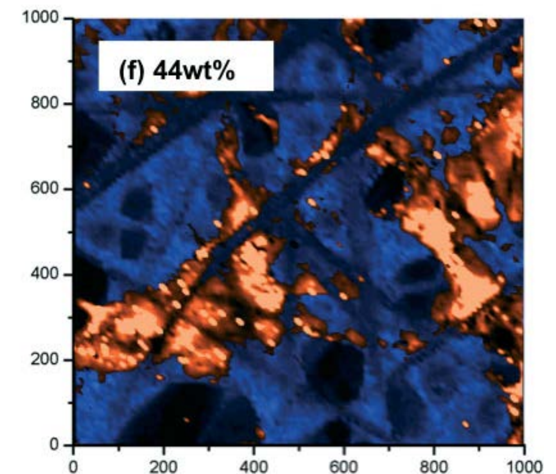
- **Function/property**
  - Chemical composition
  - Mechanical properties
  - Grain boundaries and orientation

E. DeCastro, "High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies," DOE Hydrogen Program Annual Merit Review, June, 2010.





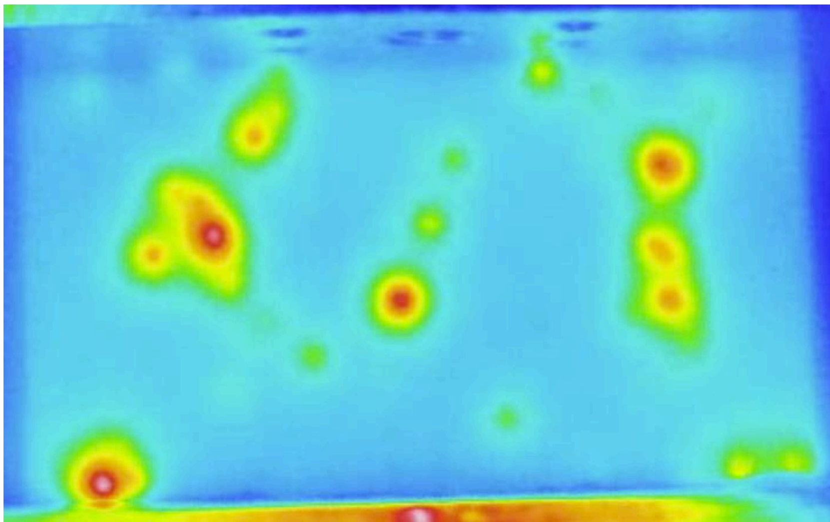
B. Sopori, "A Reflectance Spectroscopy-Based Tool For High-Speed Characterization of Silicon Wafers and Solar Cells in Commercial Production," IEEE, 2010.



A. Mendoza, "Raman Spectroscopic Mapping of the Carbon and PTFE Distribution in Gas Diffusion Layers," *Fuel Cells*, **11** (2) 248-254, 2011.

Types of measurements

- **Function/property**
  - Resistance/ conductance
    - Shorting
  - Optical properties



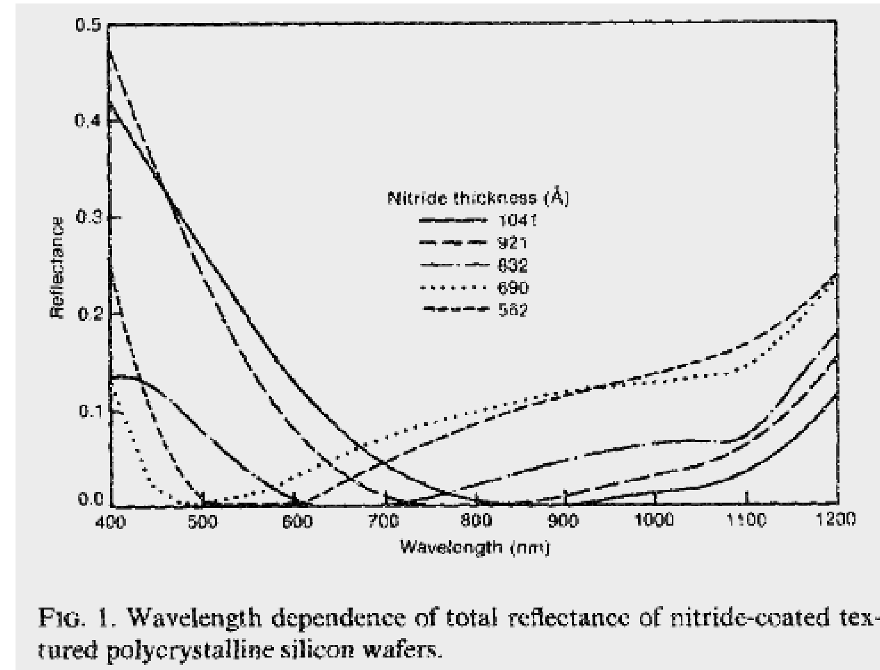
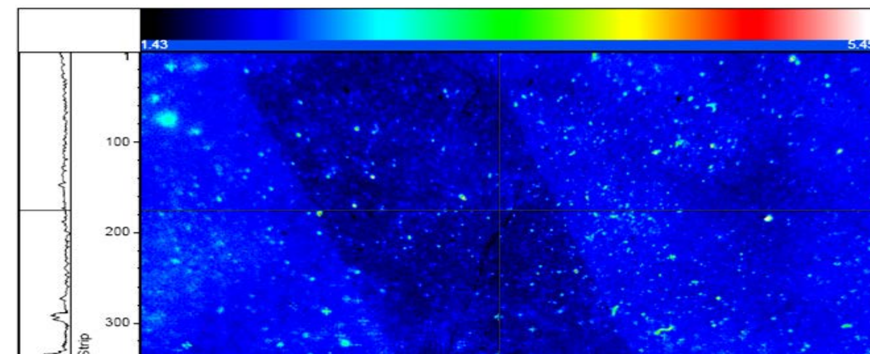


FIG. 1. Wavelength dependence of total reflectance of nitride-coated textured polycrystalline silicon wafers.

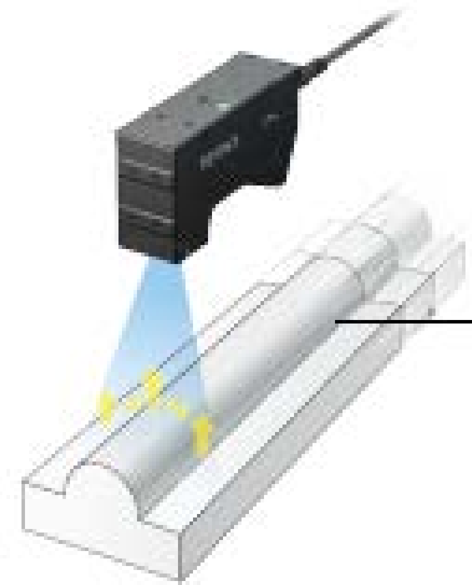
B. Sopori, "Principle of a new reflectometer for measuring dielectric film thickness on substrates of arbitrary surface characteristics," Rev. Sci. Instrum., **59**, 725, 1988.



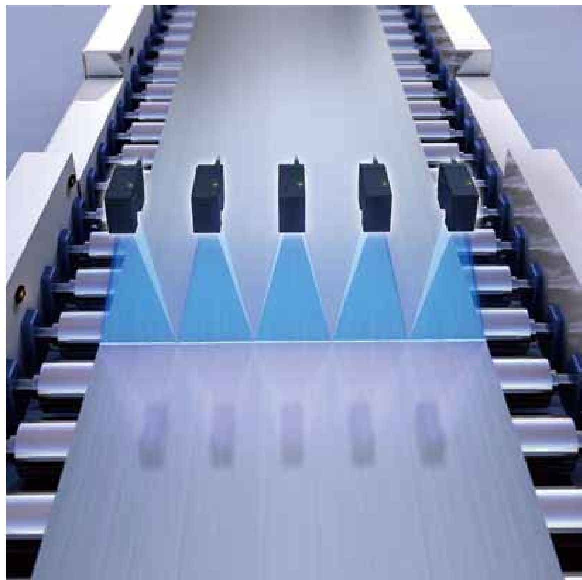
Point measurements

- **Laser**
  - Pulsed laser
  - Triangulation
  - Sheet

Keyence, LJ-V7000 Series brochure, 2012.



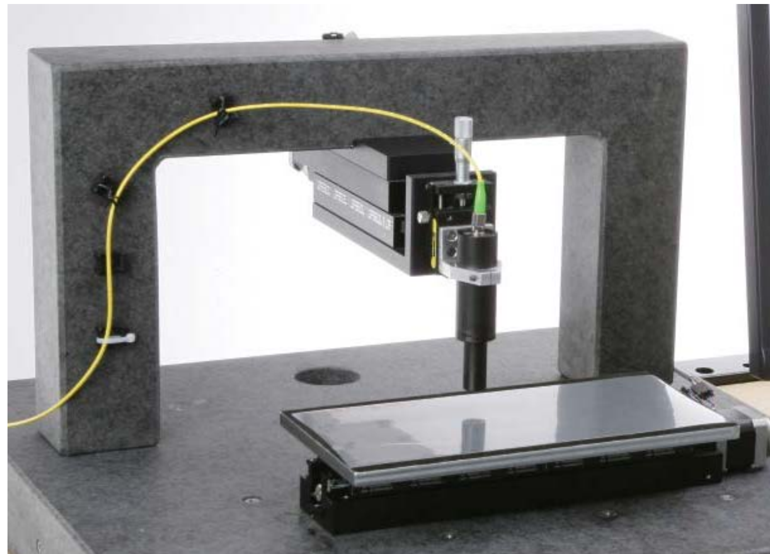
Keyence, LJ-V7000 series brochure, 2012.

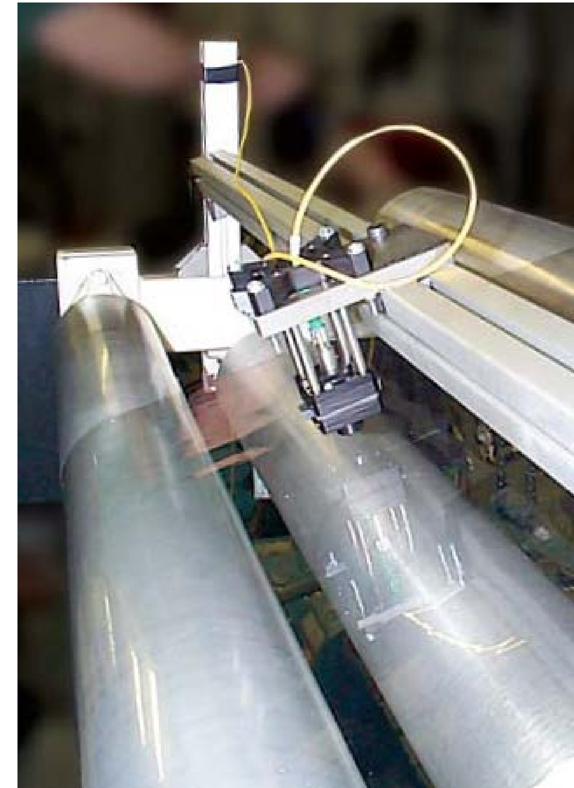


E. Stanfield, “Metrology for Fuel Cell Manufacturing,” Hydrogen Program Annual Merit Review, June, 2010.

Point measurements

- **Optical**
  - Interferometric
  - Spectroscopic
    - Raman
    - FTIR





Lumetrics, OptiGauge brochure, 2007.

Point measurements

- **Nuclear sources**
  - Beta/gamma
  - Coat weight

http://www.ndcinfrared.com/NDC/

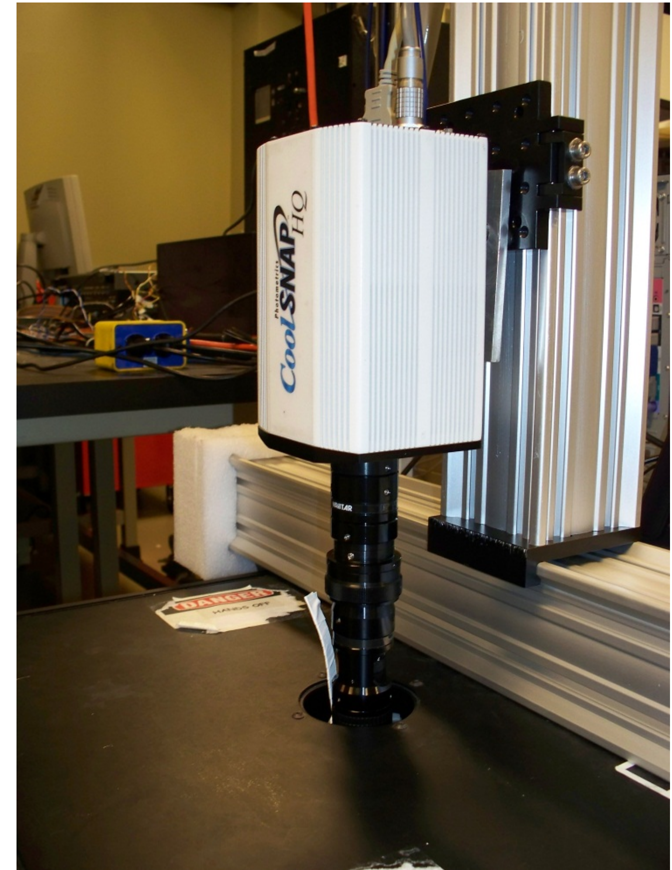
Point measurements

- **X-ray sources**
  - X-ray Fluorescence

E. DeCastro, "High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies, Hydrogen Program Annual Merit Review, June, 2010.

Line/area measurements

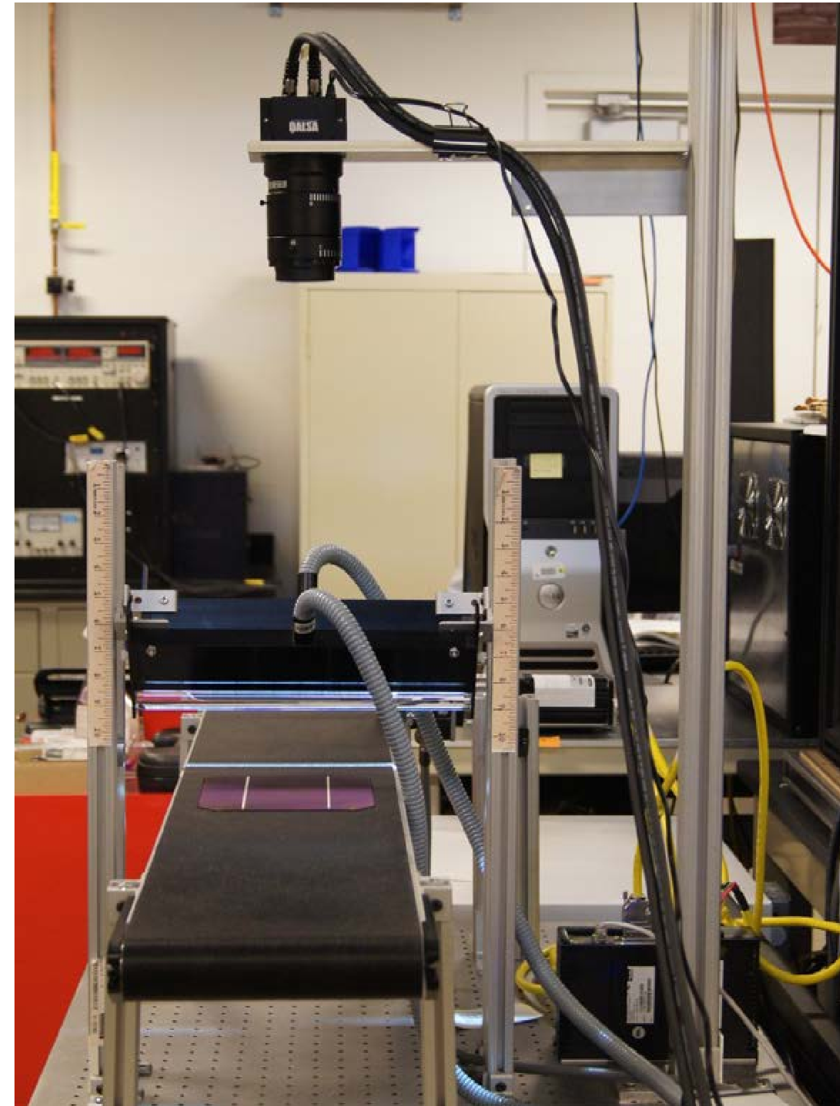
- **Detectors**
  - Visual (“machine vision”)
  - Reflectance/transmission/ absorption
  - Other wavelengths
    - UV
    - IR
    - X-ray



Keyence, CV Series Vision Systems brochure, 2008.

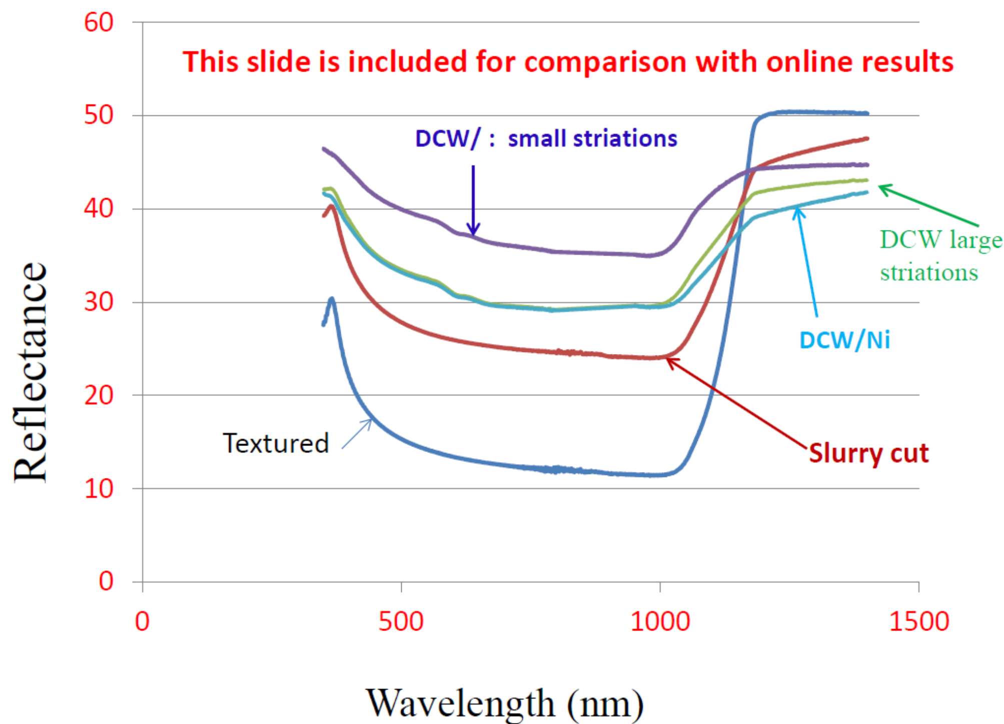
Line/area measurements

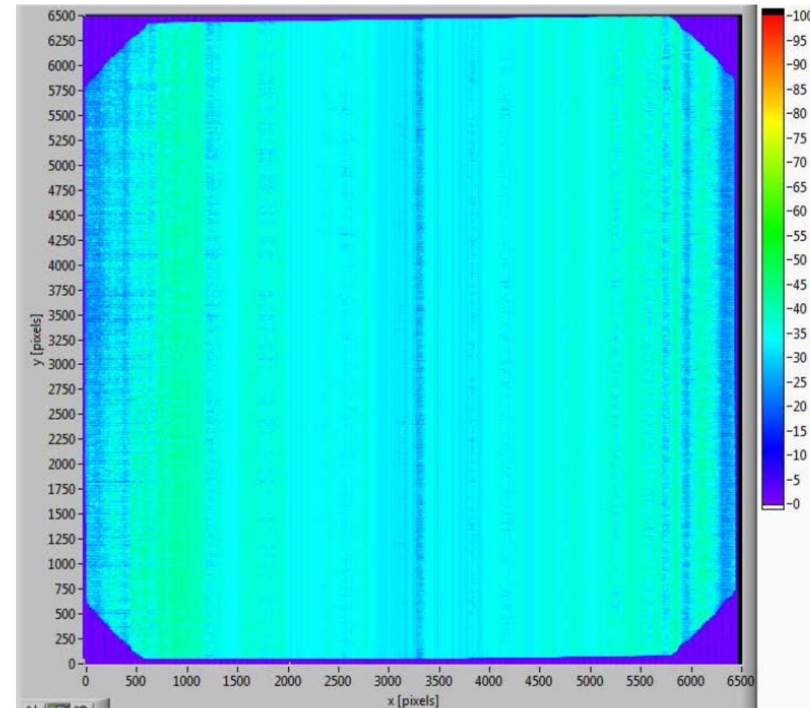
- **Reflectance-based wafer monitoring system**
  - Sawing irregularities
  - Texture uniformity
  - Grain orientation, size mapping
  - AR coating thickness
  - Metallization
  - Dislocation density



Line/area measurements

- **Sawing irregularities**

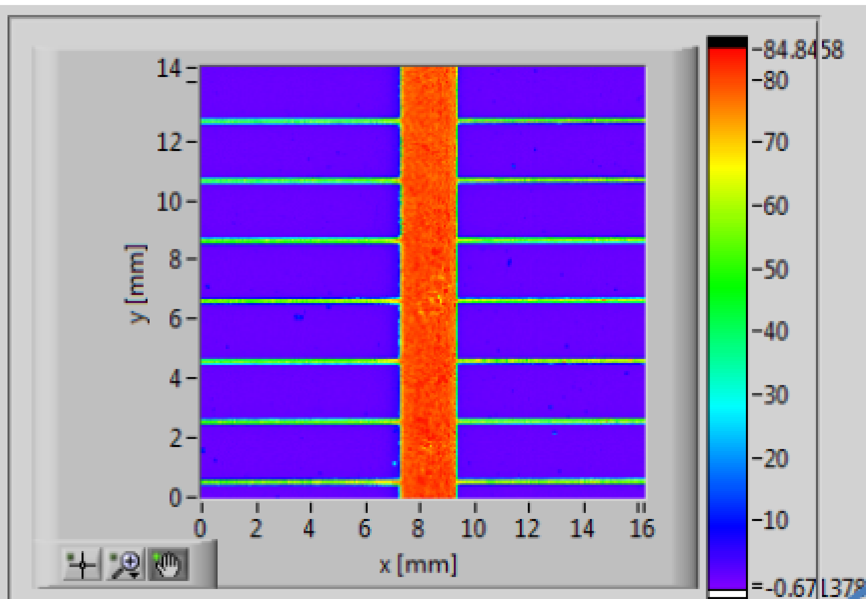


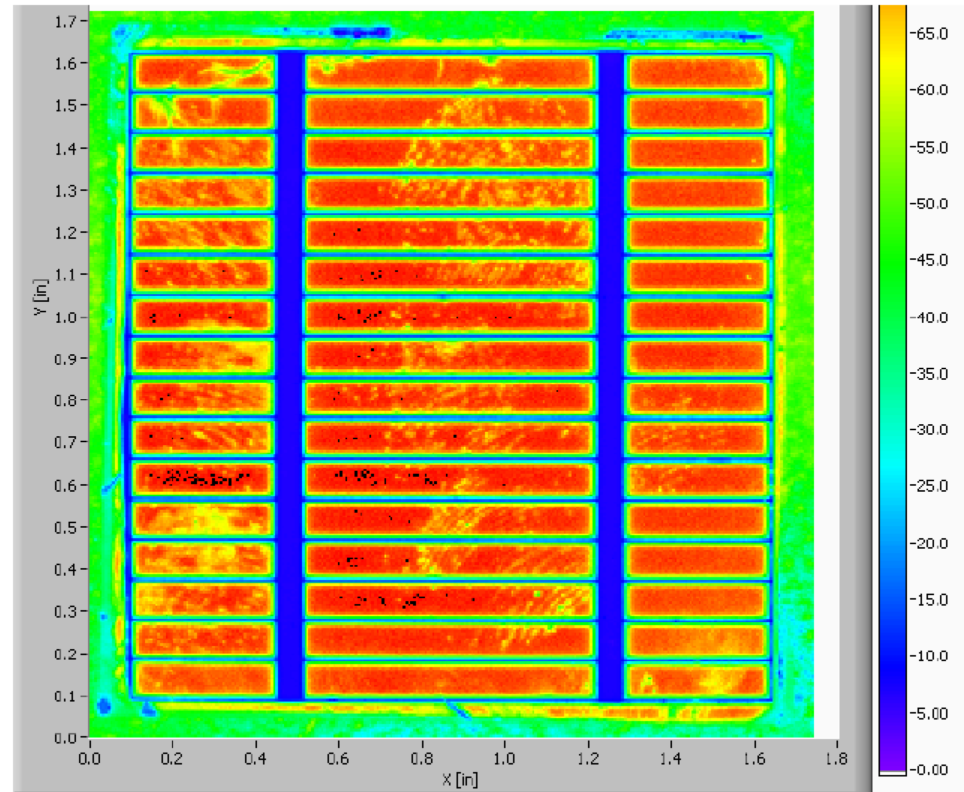


Line/area measurements

- **AR coating thickness and metallization parameters**

Bus bar width

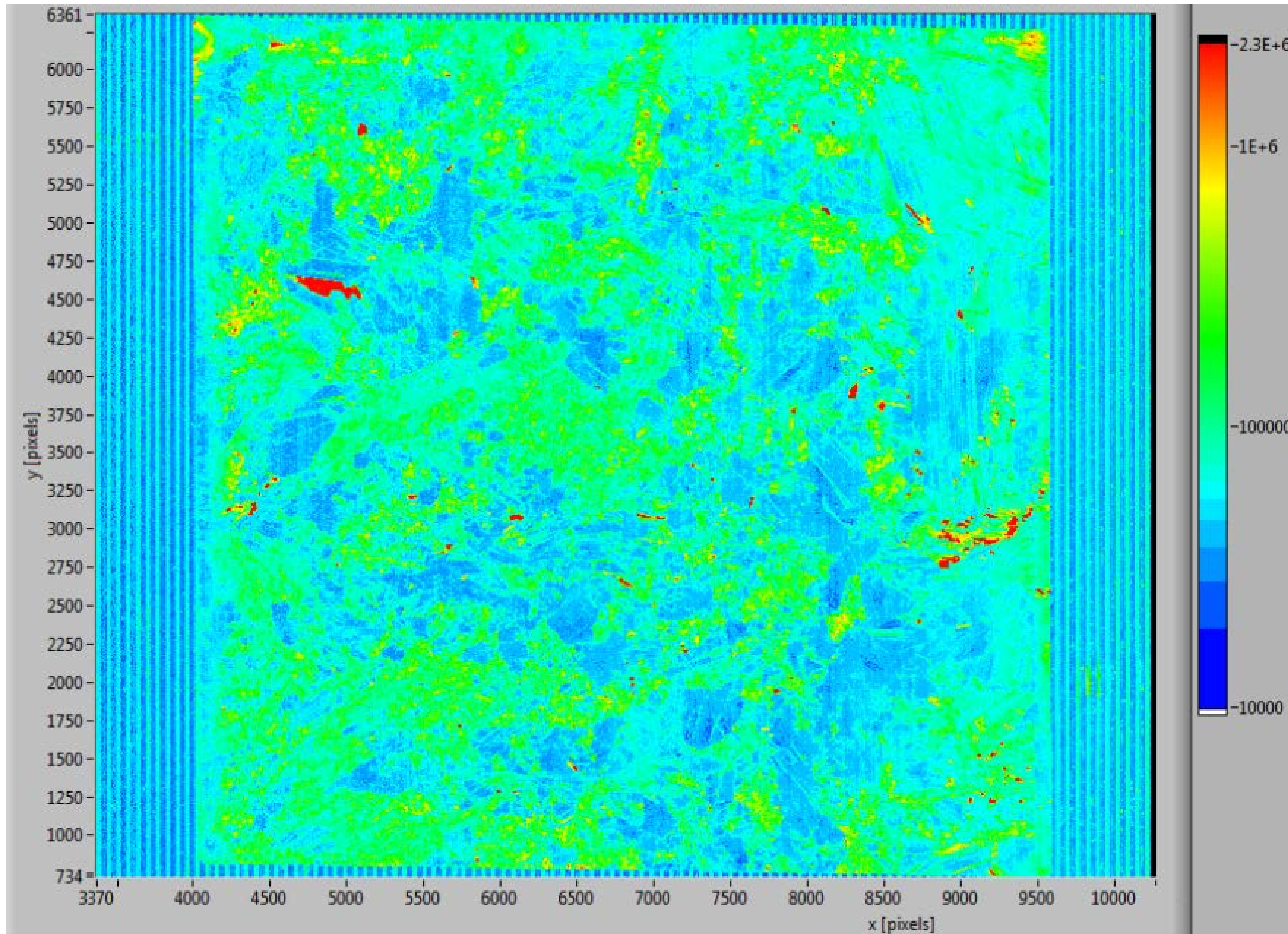




AR coating thickness

Line/area measurements

- **Dislocation density**



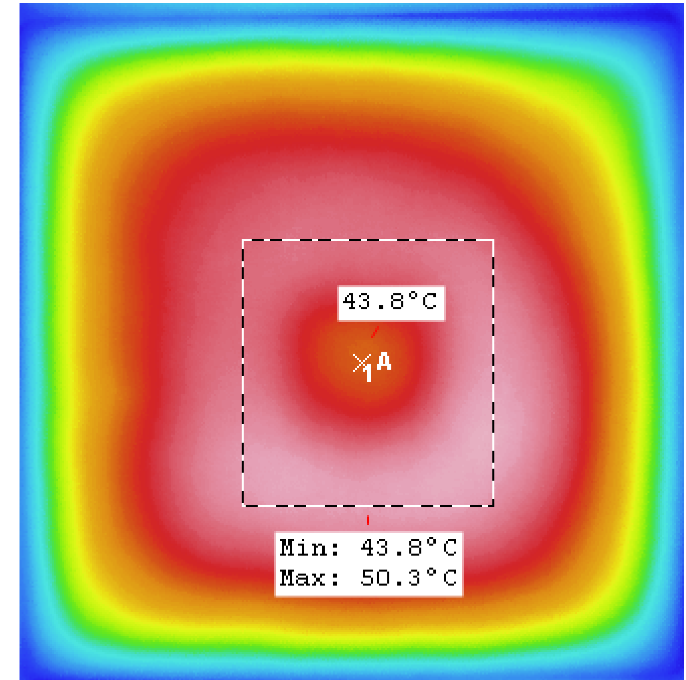
156x156mm mc-Si wafer

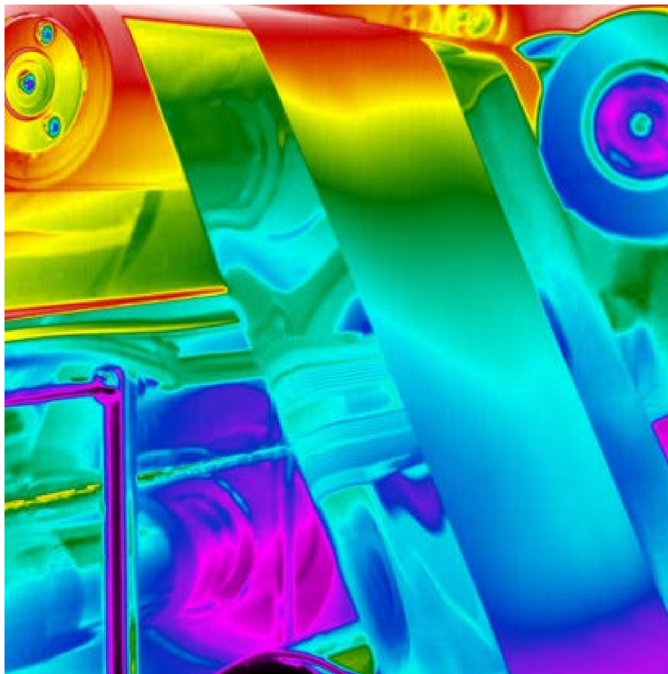
Line/area measurements

- **Excitation**
  - Light/EM
  - Electronic

Line/area measurements

- **Excitation**
  - Thermal
  - Reactive





D. Wood, "Advanced Materials Processing for Lithium Ion Batteries," ECS PRiME 2012, October, 2012.