Advanced Metrology and Detailed Loss Analysis Throughout the PV Supply Chain

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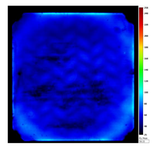
Material

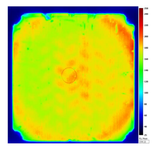
Sinton Instruments WCT-120	Effective carrier lifetime (τ_{eff}) vs. Δn; saturation current density (J_0); surface recombination velocity (S_{eff}); ideality factor
Jandel Four-Point Probe	Wafer resistivity; sheet resistance
BTi LIS-R1 PL System	Images of: τ_{eff}; J_0; S_{eff}; ideality factor
MDC *C-V* + *I-V* Characterization System	Interface defect density and fixed charge or dielectrics
JA Woollam M2000XI Spectroscopic Ellipsometer	Complex refractive index (n, k) vs. λ; mapping of n, k, and thickness
Zeiss ULTRA-55 FEG SEM	SEM imaging; EDS spectra
FEI 200 TEM FIB + Tecnai F30 TEM	TEM and HRTEM imaging; EFTEM imaging; EELS

Imaging of τ_{eff} via photoconductance calibrated PL

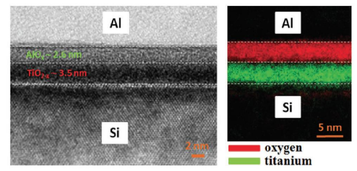
HF last SiN_x pass.

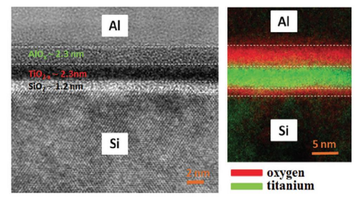


Oxide last SiN_x pass.



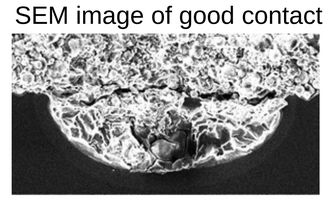
HRTEM and EFTEM imaging of passivated contacts



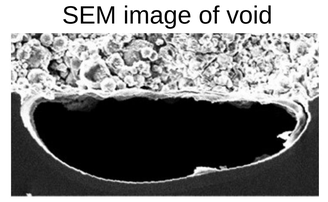


Studying voids in PERC cells

SEM image of good contact



SEM image of void



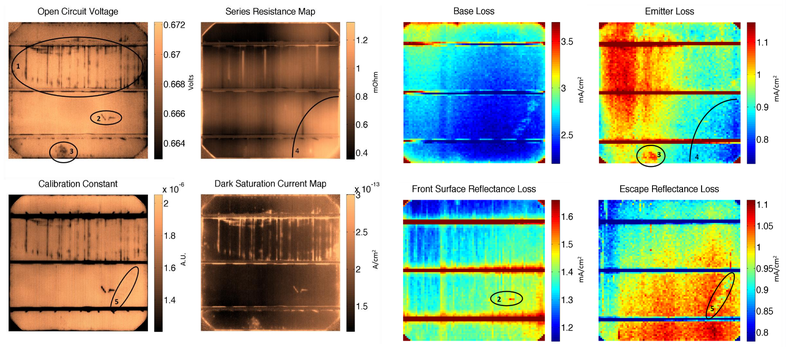
Cell

Newport Solar Simulator with Custom *I-V* Tracer	Efficiency; J_{SC}; V_{OC}; FF
Sinton Instruments Suns-V_{OC}	τ_{eff} vs. Δn; J_0; ideality factor; R_S; R_{SH}
BTi LIS-R1 PL System	Images of: efficiency; V_{OC}; J_0; ideality factor; R_S
Tau Science FlashQE with Integrating Sphere	Images of: J_{SC}; EQE vs. λ; reflectance vs. λ; IQE vs. λ; specific current losses
Tau Science Custom HR EL System (4MP DD Si CCD)	High resolution EL imaging and defect analysis
BrightSpot Automation ContactSpot	Contact resistivity; sheet resistance

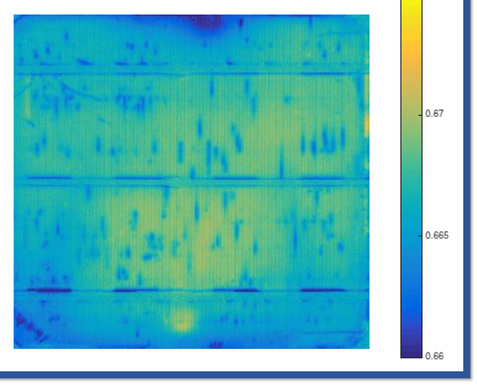
Spatially-resolved loss analysis

V_{OC}, R_S, J_0 imaging

J_{SC} imaging



V_{OC} image of PERC cell with many voids

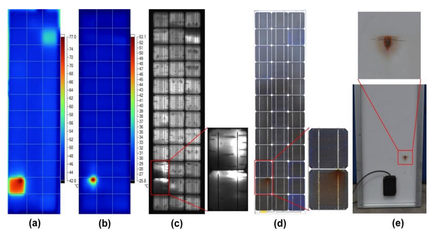


Module

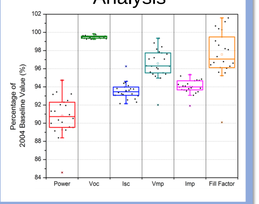
Spire 4600 SLP Solar Simulator	I-V measurements under standard test conditions
Sinton Instruments FMT 350	Multi-Irradiance Solar Simulator with Suns-V_{oc} analysis. Capable of accurately testing high efficiency modules
Electroluminescence (EL) Imaging System	High resolution imaging with advanced algorithms for quantitative assessments
BrightSpot Automation LoadSpot	Dynamic and static load application using high and low pressures to quantify performance loss due to load
Fluke TIR2 Infrared Camera	Thermal imaging of modules within the lab and while in the field.

Module Degradation Analysis

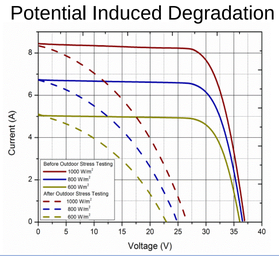
Interconnect Failure



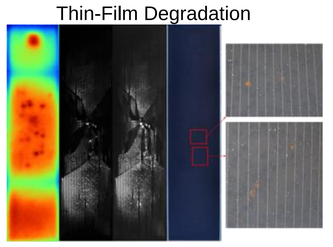
Statistical Performance Analysis



Potential Induced Degradation

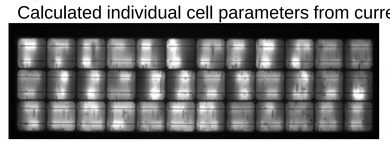


Thin-Film Degradation

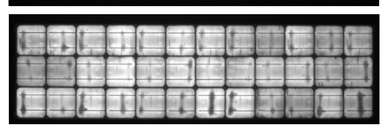


Quantitative Electroluminescence Analysis

Calculated individual cell parameters from current dependent images

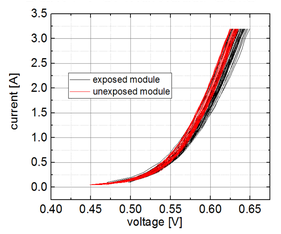


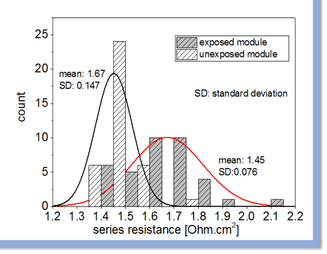
Exposed to hot and humid climate for 10 years



Stored indoor for 10 years

Dark I-V of Individual Cells

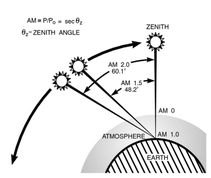


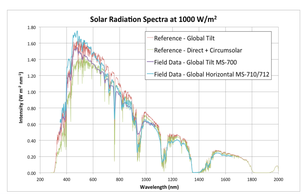


System

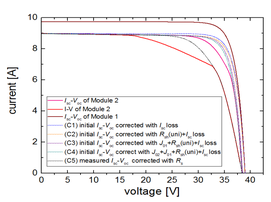
System Monitoring	Customized monitoring: DC/AC power measurements, string Inverters or micro-inverters, standard or bifacial modules
Atonometrics RDE300 Series	Module level I-V curve tracing with datalogging to Azure platform SQL database
EKO MS-710 and MS-712 Spectroradiometers	Plane of Array Spectral Irradiance Measurements: 350 nm to 1700 nm
Eppley pyranometers for Global, IR and UV irradiance along with PV reference cells	Meteorological station for correlating module/system performance to environmental conditions
Customized analysis	Power loss analysis at module level enables partitioning by Rs, Rshunt, Shading, Soiling, etc.

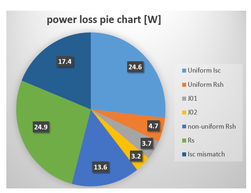
Spectral analysis using broadband spectroradiometer





Power loss analysis using in-situ I-V data





Regional Test Center – Hot and Humid Climate

PV system being validated at the FL RTC.

FSEC infrastructure supports the field testing of a wide range of technologies.
Single modules to 10 kW systems are supported.
High voltage configurations available

Racking being built for an RTC validation study

Representative inverter, disconnects, and monitoring equipment boxes at the FL RTC