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nanosolar

High-Productivity Annealing for Thin-Film CIS PV

DOE Solar Energy Technologies Program Peer Review

Denver, Colorado
April 17-19, 2007

Project Basics

"High-Productivity Annealing for Thin-Film CIS PV"

NREL Subcontract No. ZXL-6-44205-15

Phase I: 3/9/06 – 3/8/07
Phase II: 3/9/07 – 3/8/08
Phase III: 3/9/08 – 3/8/09

Principal Investigator: Chris Eberspacher

Key Personnel: Craig Leidholm, Jeroen van Duren, Matthew Robinson

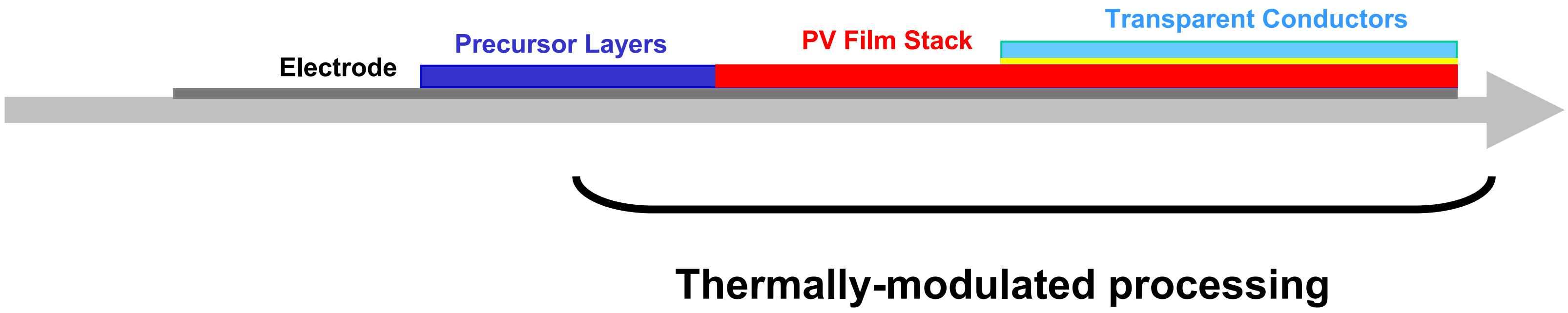
Business Contact: Brian Sager

Technology Waves

Technology Wave	I. Silicon Wafer Cells	II. Vacuum-based Thin Film	III. Nanosolar Roll-Printed Thin Film
Process	Silicon wafer processing	High vacuum (e.g. sputtering)	Roll-to-roll printing
Process Control	Fragile wafers	Narrow process windows	Built-in bottom-up reproducibility
Process Yield	Robust	Fragile	Robust
Materials Utilization	30%	30-60%	Over 97%
Energy Payback	3 years	1.7 years	< 1 month
Throughput/CapEx	1	2-5	10-25

RTP

Rapid Thermal Processing is an essential enabling technology for fabricating high-performance, flexible, low-cost PV



typical heating cycle ~ 60 minute dry / cure / fuse at 200-400 ºC

60 minutes x 3 m/min ~ 180 m processing length

10 m machine length x 2 machines / 3 m/min linear speed ~ 7 minute processing cycle

-> rapid thermal processing is essential

-> "High-Productivity Annealing" = HPA

Relevance/Objective

- **Relevance: high-through-put processing of thin-film PV using capital-efficient processes to make low-cost modules for cost-effective systems**

- **Nanosolar is developing roll-to-roll processes based on particulate material printing and rapid thermal processing**

- **Project Objective : demonstration of efficient CIS alloy cells fabricated using High-Productivity Annealing**

Activity Summary

Three Project Activities

1. design and fabricate HPA equipment
2. develop an HPA process yielding 10% 100 cm^2 CIS alloy solar cells
3. demonstrate high-through-put HPA

Thermal Processing

Batch furnaces

Slow, large batches

T(t), t ~ hours

RTP furnaces

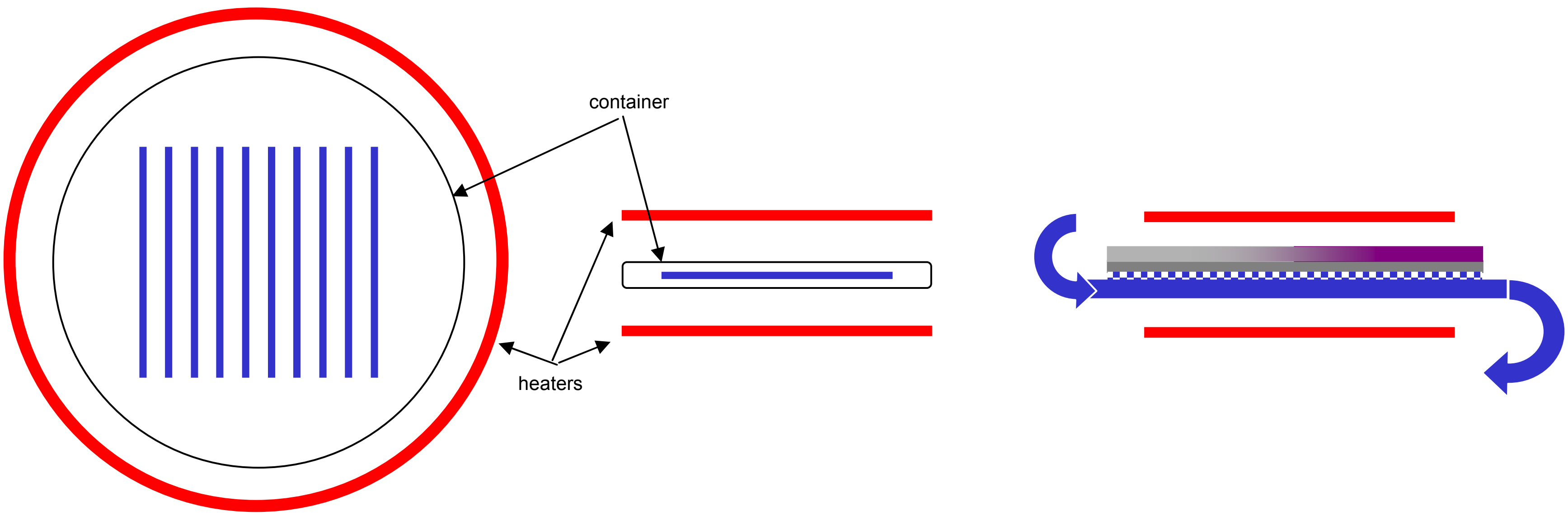
fast, single wafer

T(t), t ~ seconds

In-line furnaces

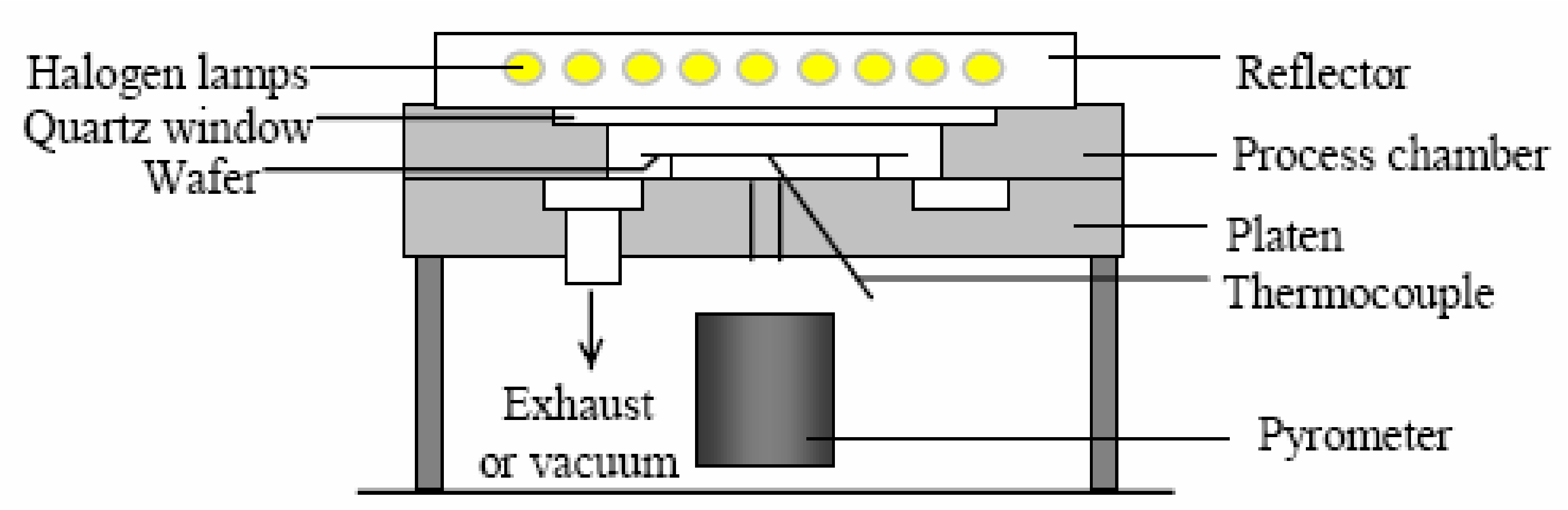
fast, continuous

T(x) <-> T(t)

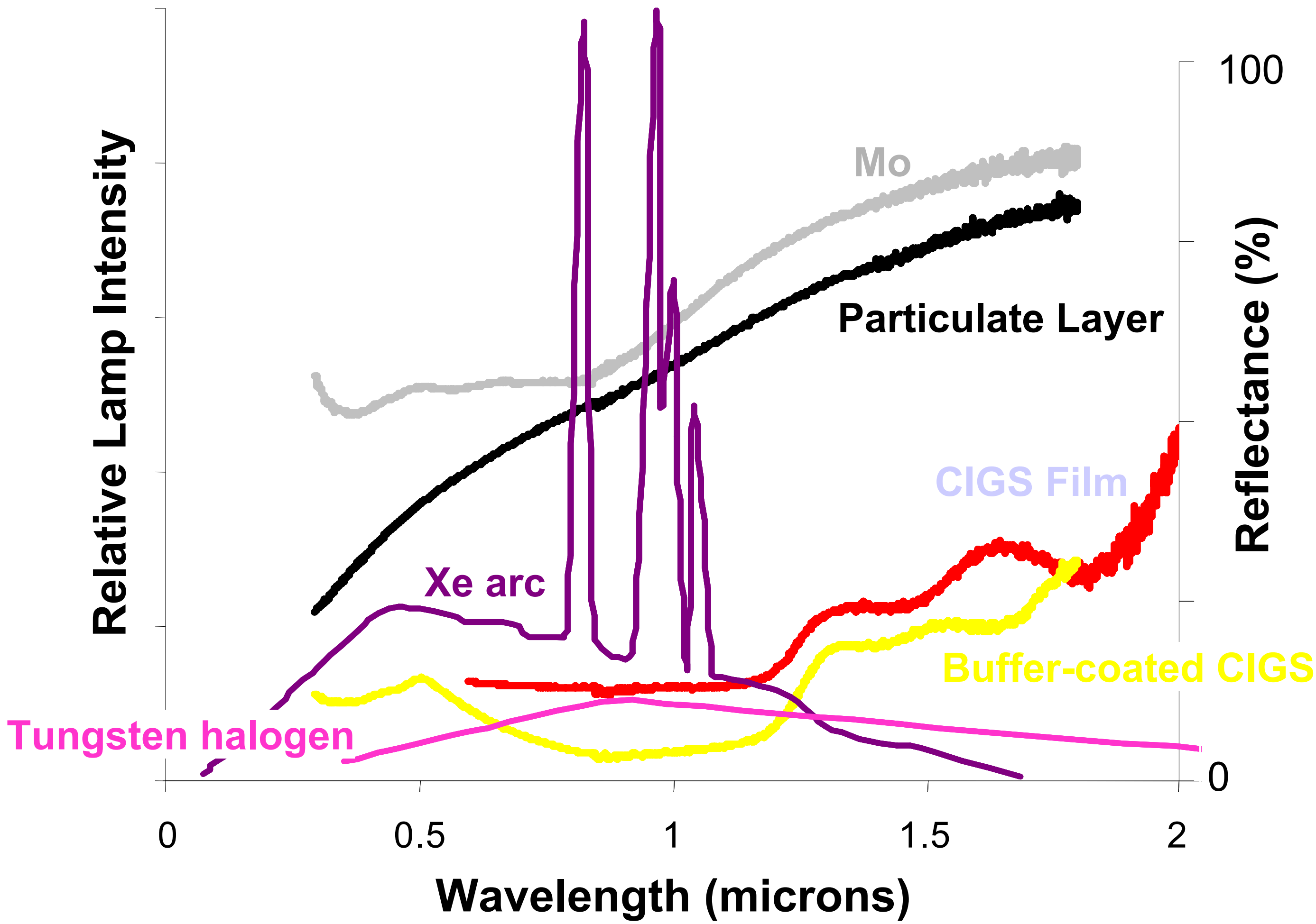


HPA Hardware

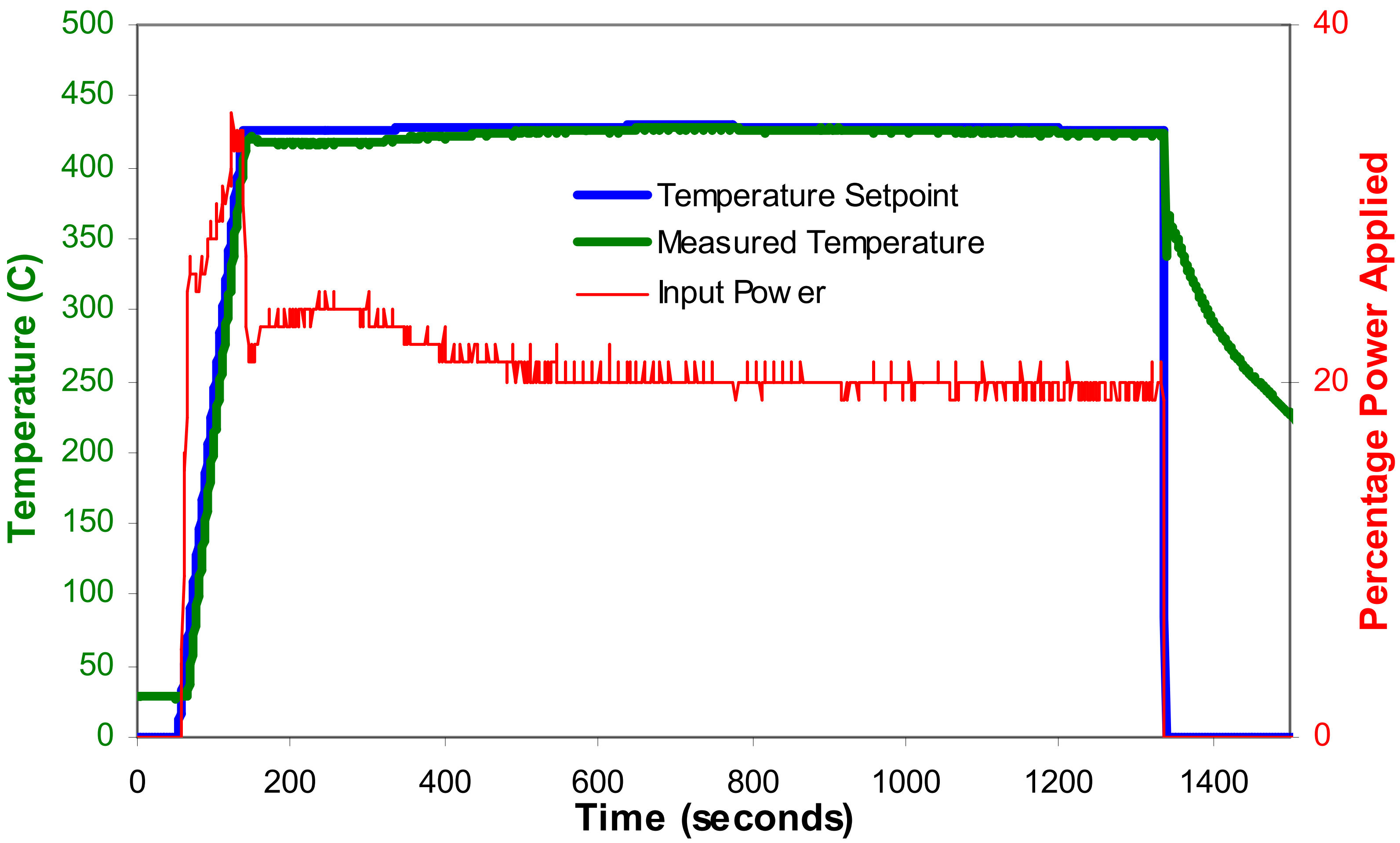
Lay-out of Jipelec JetFirst RTP system



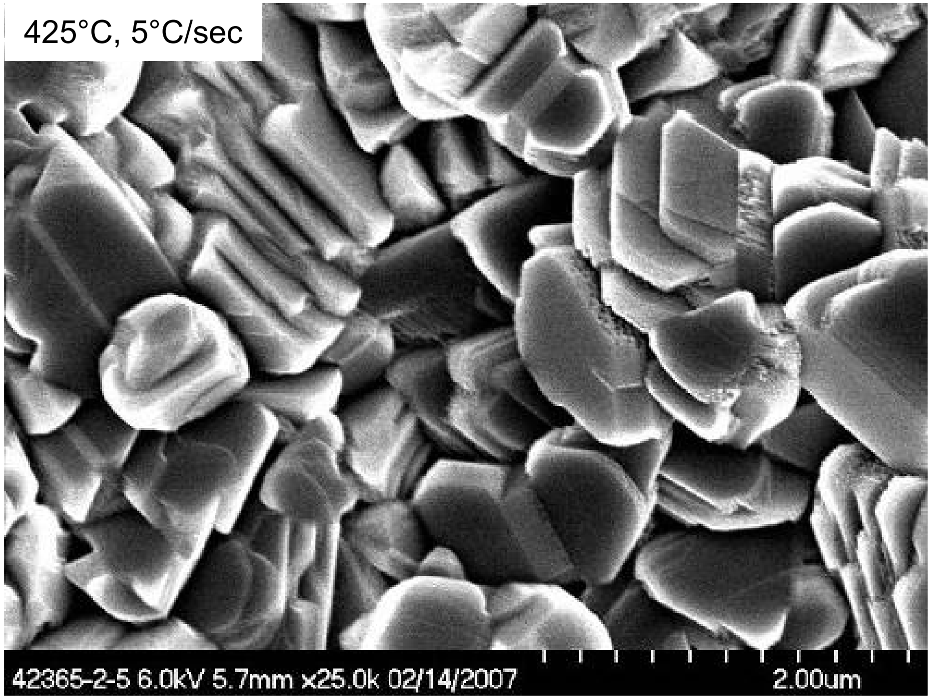
HPA Hardware Design

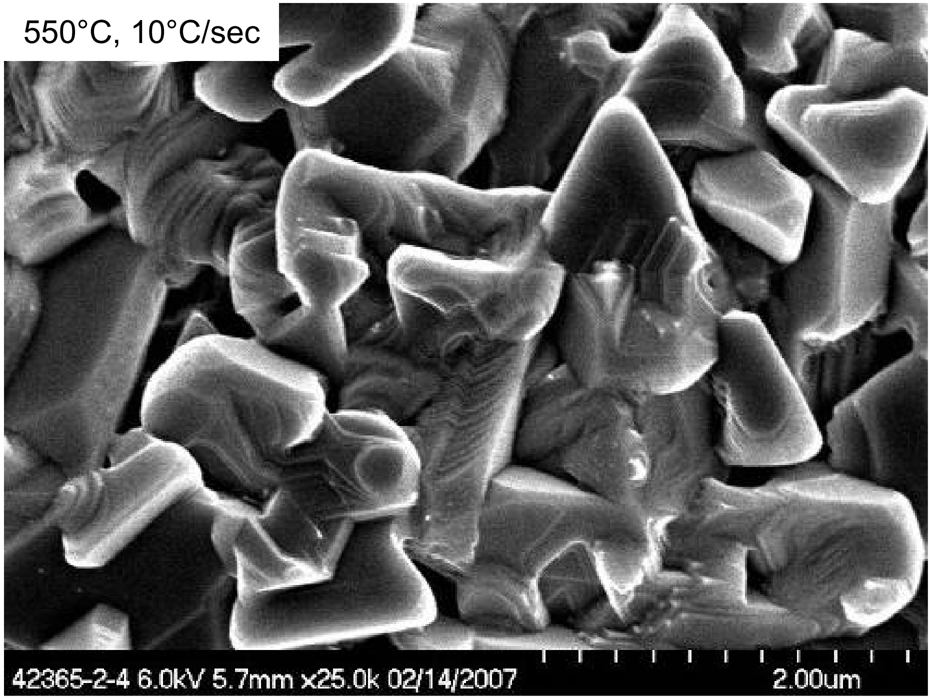


HPA Hardware Tests

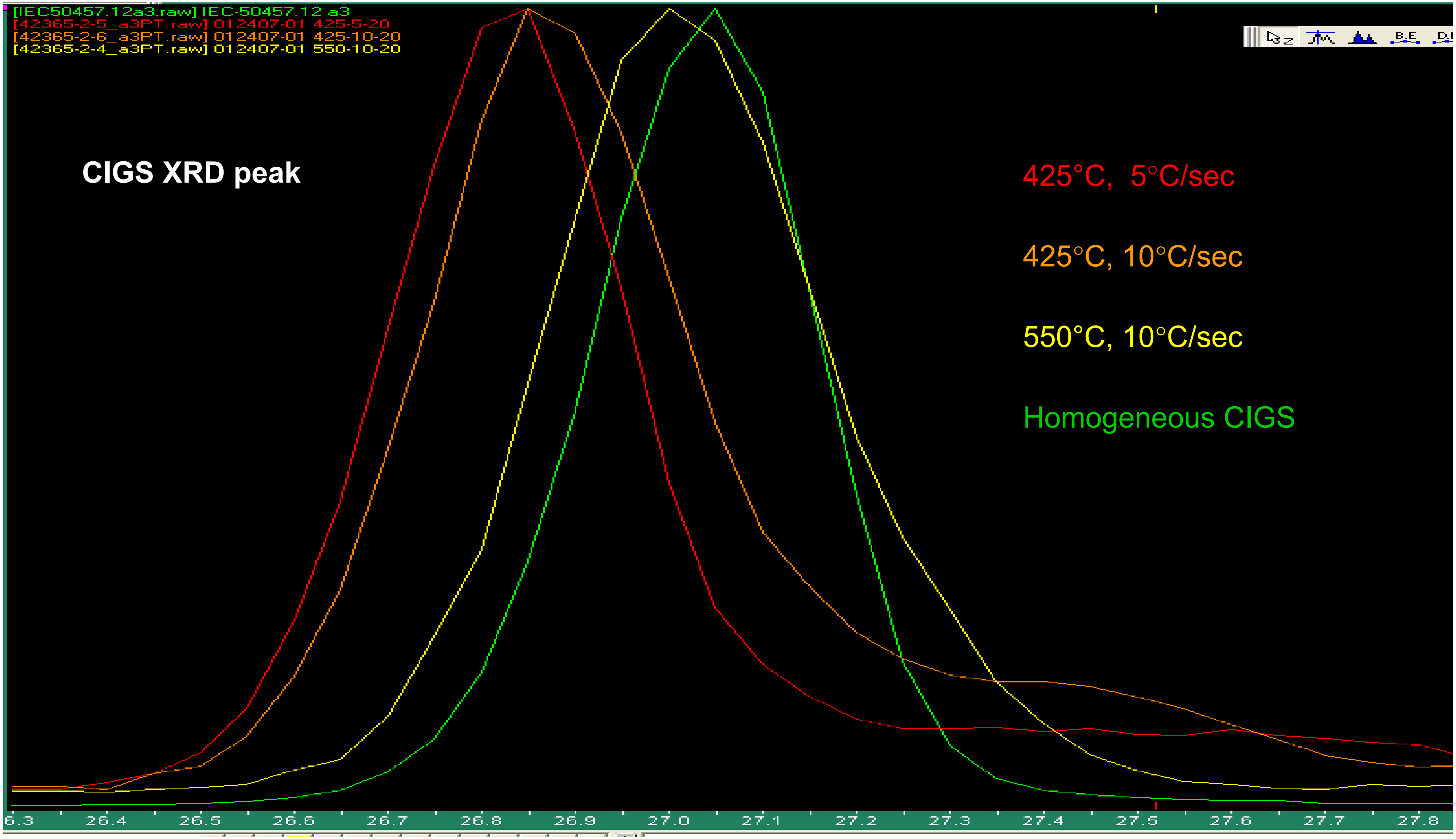


SEMs of HPA-processed particles-based CIGS films





HPA-processed CIGS



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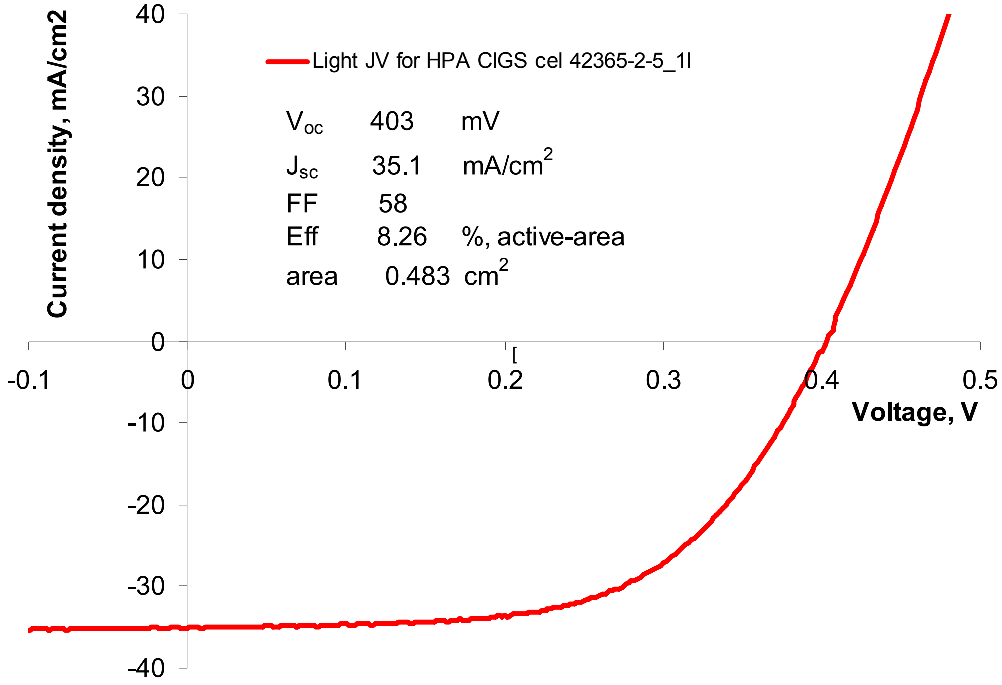
CIGS Solar Cells

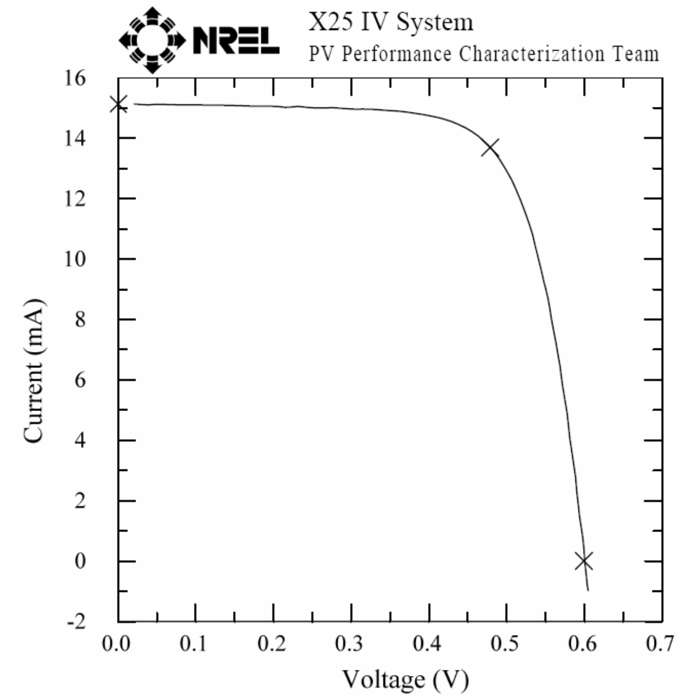
8% HPA-processed cell fulfilling Phase 1 goal



14% cell confirmed by NREL

Device ID: 26275-7-3 #5
Aug 10, 2006 14:24
Spectrum: AM1.5-G (IEC 60904)

Device Temperature: 25.0
Device Area: 0.470 cm^2
Irradiance: 1000.0 W/m^2



V_{oc} = 0.5993 V
I_{sc} = 15.131 mA
J_{sc} = 32.193 mA/cm^2
Fill Factor = 72.31 %

I_{max} = 13.693 mA
V_{max} = 0.4788 V
P_{max} = 6.5566 mW
Efficiency = 13.95 %

Project Milestones

Phase I: HPA Process and Equipment Testing

- ✓ Definition of baseline HPA process and equipment
- ✓ Evaluation of key HPA processing parameters
- ✓ 8% efficient HPA-processed CIS device (D1.7)
- ✓ Publication (D1.4)

Phase II: Film and Device Fabrication and Refinement

- Refinement to improve CIGS film properties
- HPA processing on 10x10 cm
- 9% efficient HPA-processed CIS device (D2.3)
- Publication (D2.4)

Phase III: 10% Efficiency and Fast Cycle Demonstration

- High-through-put HPA equipment
- 10% efficient HPA-processed CIS device (D3.7)
- Publication (D3.5)

Future Directions

- Internal milestones exceed original project pace
- Integration with systems-focused SAI activities
- Targeting high-volume, grid-parity PV
- Synergy with DOD programs

Budget History

Project Phase	NREL share	Nanosolar share
1, 3/06-3/07	$199,980	$ 11,080
2, 3/07-3/08	$202,542	$ 11,223
3, 3/08-3/09	$204,377	$ 11,324
Grand Total	$606,899	$ 33,627