A Different Approach - CIGS using All PVD

February 8th 2012
Outline

► MiaSolé Overview
► Cell and Module Design
► Production
► Development
► Summary
MiaSolé General Overview

► CIGS solar module manufacturer

► Located in Silicon Valley, California
  – Headquarters and Manufacturing

► Global Installations
  – 5 kW to 11.1 MW solar fields in operation
Some Installation Photos
Strategic Principals

► Product success is tied to LCOE
  – Maximize 1) Efficiency adjusted cost, 2) Energy Generation, 3) Durability

► Test to fail philosophy
  – Understand product breaking points

► Flexible module opportunities
  – Currently undergoing IEC certification
  – Uses the same solar cells as the Glass/Glass modules
MiaSolé CIGS Solar Cell Design

- 50 um Stainless Steel Substrate
  - High temperature
  - Flexible product

- Multiple layers to form the device
  - All layers deposited by PVD
  - All PVD performed in 1 Tool
  - Single pass
Production Process

• "Roll-to-Cell" process
• 1 Process tool deposits the entire film stack
• All films are deposited by sputtering
• Raw material to finished cell in 60 minutes
Production – All PVD CIGS Stack

- 1 Process tool deposits the entire film stack
- Minimizes tool cost
- Material utilization increased with rotary magnetrons

Planar Magnetron

Rotation through plasma race track erodes entire target surface

Limited erosion area

20-40% target utilization

>80% target utilization

Rotary Magnetron
MiaSolé Cell Interconnect

- Low resistance Collection Grid
- Redundant wires provide distributed interconnect between cells
- No solder joints, welding, or screen printing required

Cell interconnect provided by UltraWire™. Applied just like tape.
Module Design

- Glass/Glass package with liquid edge seal

- 2 rows of Cells with integrated interconnect
  - Parallel electrical circuits

- 1 Integrated Diode for every 2 cells
  - Automated application to the back
  - no solder or welds

- Corner Junction Boxes
  - Positive and Negative
Better Field or Rooftop Performance

- One ByPass Diode for every 3Watts vs 80W for Si Modules

**Shading Performance**

- **Long Edge**
  - MiaSole
  - 240W, mono Si

- **Short Edge**
  - MiaSole
  - 240W, mono Si

**Protection in Partial Shading**
Production Status

► Historical Production and Capacity

► Module Efficiency Distribution – January 2012
  – >15,000 modules
  – Tight distribution
Average Module Efficiency in Production

- Module efficiency = total area efficiency
- Modules produced in production
- Average efficiency of modules produced in reporting period

>30% Increase in Average Efficiency in One Year
Recent optimizations

1) Buffer layer optimization
2) Absorber optimization
3) Absorber optimization
4) Increased transmission

13.5% Product Leveraged Multiple Film Optimizations
Development Approach

► R&D laboratory
  – Feasibility studies
  – Device characterization

► Process Development
  – Uses production equipment
  – No production scale up needed
  – Fast cycles of learning
  – Define process space
  – Study film interactions
All PVD - Faster Cycles of Learning

- Single pass, well controlled vacuum environment
- Electrical data 60 minutes after processing
- Enables rapid learning of the Process Space
- Enables rapid testing of multi-film interactions
Web Efficiency Map

Contour Plot for Efficiency

- Every cell is flash tested
- Traceability in location and time
- Large statistical sampling for experimental data analysis
Development example – Optimizing sputtered CdS

1) Transparency Optimization

- Variable A
- Variable B
- Increasing

2) Thickness Optimization

- Variable A
- Variable C
- Decreasing

- No vacuum break between CIGS and CdS Buffer
- Repeatable sample conditions for multivariable test

Fast Development Cycle Resulted in Improved Buffer Layer
Development example – Defect reduction in CIGS

Contaminants in CIGS correlate with defects

- Identified sources of contaminants (stainless steel is one source)
- Co-optimized film stack to minimize impact of stainless steel

Integrated Tool Enables Multi-Film Optimization
Development 2012 – Cell and Module level

**Small Aperture**
- Efficiency **17.4%**
- FF 0.77
- $J_{sc}$ 35.3 mA/cm²
- $V_{oc}$ 0.641 V

**Cell**
- Efficiency **15.9%**
- FF 0.75
- $J_{sc}$ 32.4 mA/cm²
- $V_{oc}$ 0.650 V

**Module**
- Efficiency **14.3%**
- FF 0.73
- $I_{sc}$ 7.55A
- $V_{oc}$ 28.05 V

Opportunities in Voc, FF
- Reduce defect density in CIGS
- Improve junction

Higher light gathering
- Increased transmission
- Size optimization

Best module aperture efficiency **15.8%**

17.4% Film Performance Supports Higher Module Efficiency Roadmap
Driving Average Module Efficiency to >15% by 2013
Summary

• All PVD CIGS film stack in a single tool
• “Roll-to-Cell” process enables fast learning cycles
• Driving average module efficiency to >15% by 2013
• Data proofs guide toward advancements beyond 2013