Perspectives on Thin Film PV Reliability and Initial Product Introduction

Accelerated Aging and
Reliability in PV Workshop
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Overview of Discussion

- **Introduction to AVA Solar Inc. / Technology Description**
- **Importance of reliability**
- **Components of reliability**
- **Best practices / Challenges**
- **Advancements / Opportunities**
- **Summary**

AVA Solar Inc.

Technology	• **CdTe thin film photovoltaics**
Mission	• **Produce solar energy at costs competitive with conventional electricity**
Product	• **120x60 cm modules (~10% efficiency)**
Market focus	• **Utility and commercial scale applications**
History	• **15 years in development** • **Spun out of CSU 15 months ago**
Location	• **Headquartered in Fort Collins, CO**

Time to market is a major business driver

Technology description: Thin film CdTe

One-step semiconductor manufacturing

- Single tool (modest vacuum)
- Thin film CdTe semiconductor
- Semi process is dry, in-line, continuous, and automated
- High throughput: glass in device out

Technology description: Package

Key package characteristics:

- Glass/glass package
- Semiconductors on “superstrate”
- Leads out hole in back glass
- CdTe PV: increased moisture sensitivity compared to c-Si
- Frameless

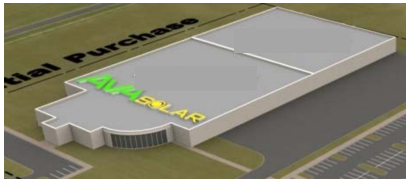
Glass into a PV device
Glass/Glass package

Scale-up roadmap
Importance of reliability in rapid growth environment

Pilot line

2008
Single PV line with all value-added processes

Initial factory



>100 MW
2009
Multi-line, fully automated facility

Large scale complex

Toward 1 GW
Integrated glass and PV factory complex

Aggressive production volume expansion
Rapid product introduction

Product reliability and qualification testing is critical

Target Market: Customer Expectations

Go-to-market strategy focused on grid-tie applications, market determines reliability expectations

Initial markets:

Utility-scale solar power plants

(1-100+ megawatts)

Commercial installations

(~100 kilowatts to 1+ megawatt)

Customers help drive reliability requirements

Importance of Reliability for AVA Solar

- **Utility and Commercial PV Customer Expectations**

  One of the largest thin film PV integrators: “We build PV power plants, modules should produce energy and that’s it.”
  - Cost of energy produced: dominate
  - Predicable, stable energy production needed for economic analysis
    - Warranty
    - Certifications
    - Reliability data

- **Manage Risk: New Company Growth**
  - Reputation: New company / new technology
  - Cost: Limited capacity for recalls/warranties

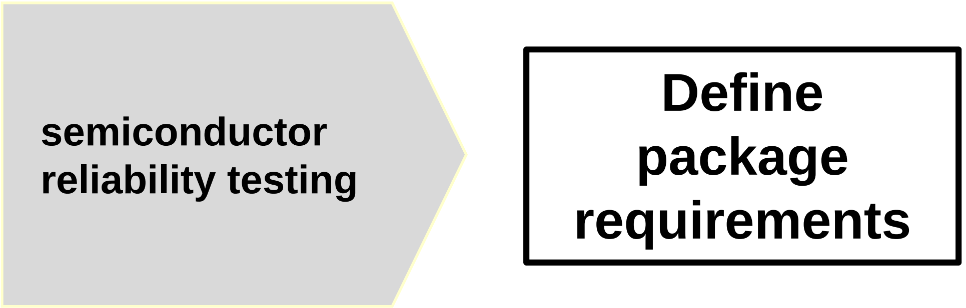
- **Investor**
  - Reliability key for access to capital

AVA Solar’s Approach to Reliability

- **For Development: Semiconductor <u>and</u> Package**

  The semiconductor and package were considered individually

- **Initial Emphasis: Semiconductor Device Reliability**
  - Device is fundamental to module
  - Reliability of the device difficult to separate from full module
  - Device reliability is tied to processing,



semiconductor reliability testing

Define package requirements

AVA Solar was formed <u>after</u> demonstration of semiconductor device reliblitiy

Best Approaches: Insuring Semiconductor Device Reliability

- **Highly Accelerated Stress Testing**
  - > 500 devices tested stress performance
  - “Indoor” controlled conditions
  - Higher temperatures studied: indications of mechanism shift

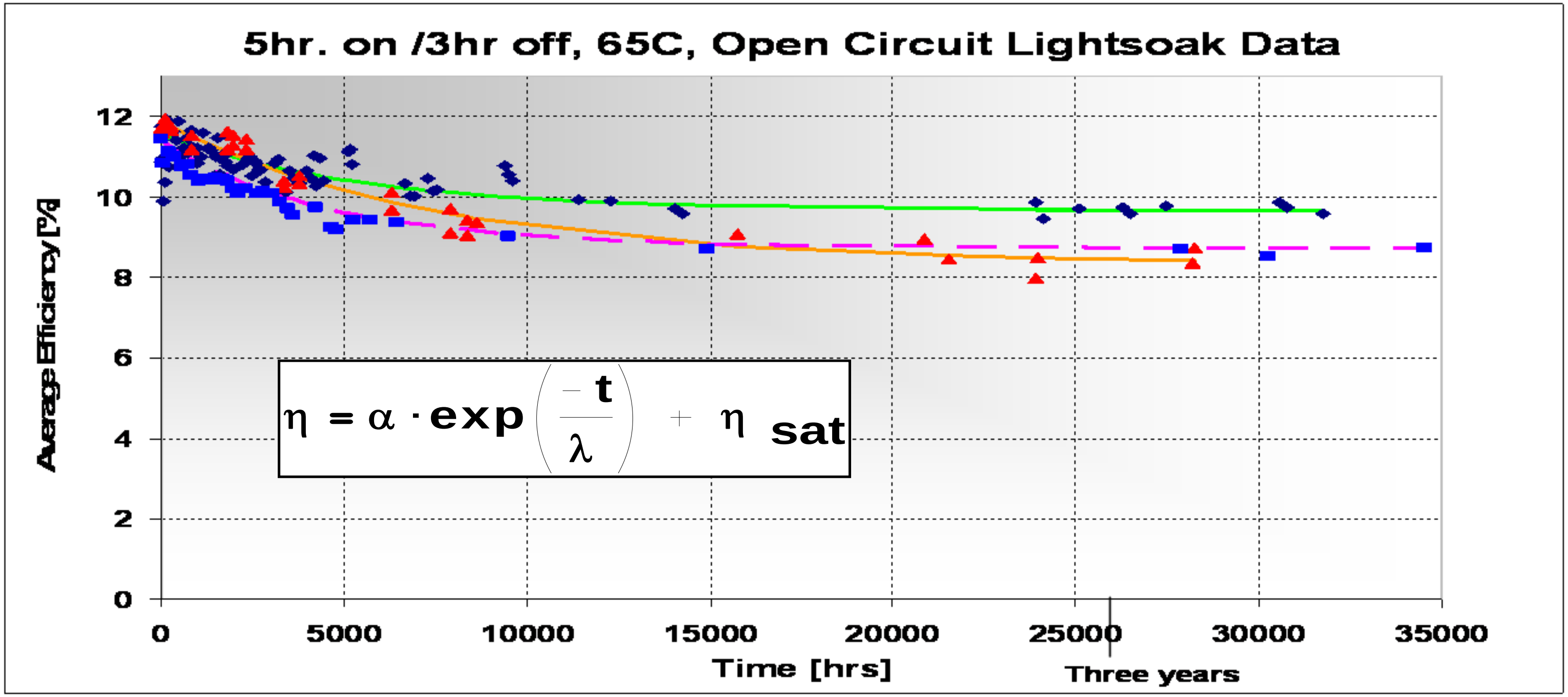
Conditions:
- 65 ° C closed loop controlled
- One sun illumination
- 5/8 hr. cycled illumination
- Desiccated air
- Open Circuit

- **Accelerated “Outdoor” Stress Testing**
  - Fixture exposes un-encapsulated devices to field temp. illumination without package
  - Bias applies significant stress

Conditions:
- Ambient temperature
- Ambient illumination
- Desiccated air
- Open Circuit

,* Hitner and J. Sites., NCPV PV Program, AIP 1999, p. 170

Very Long Term Accelerated Stress Testing



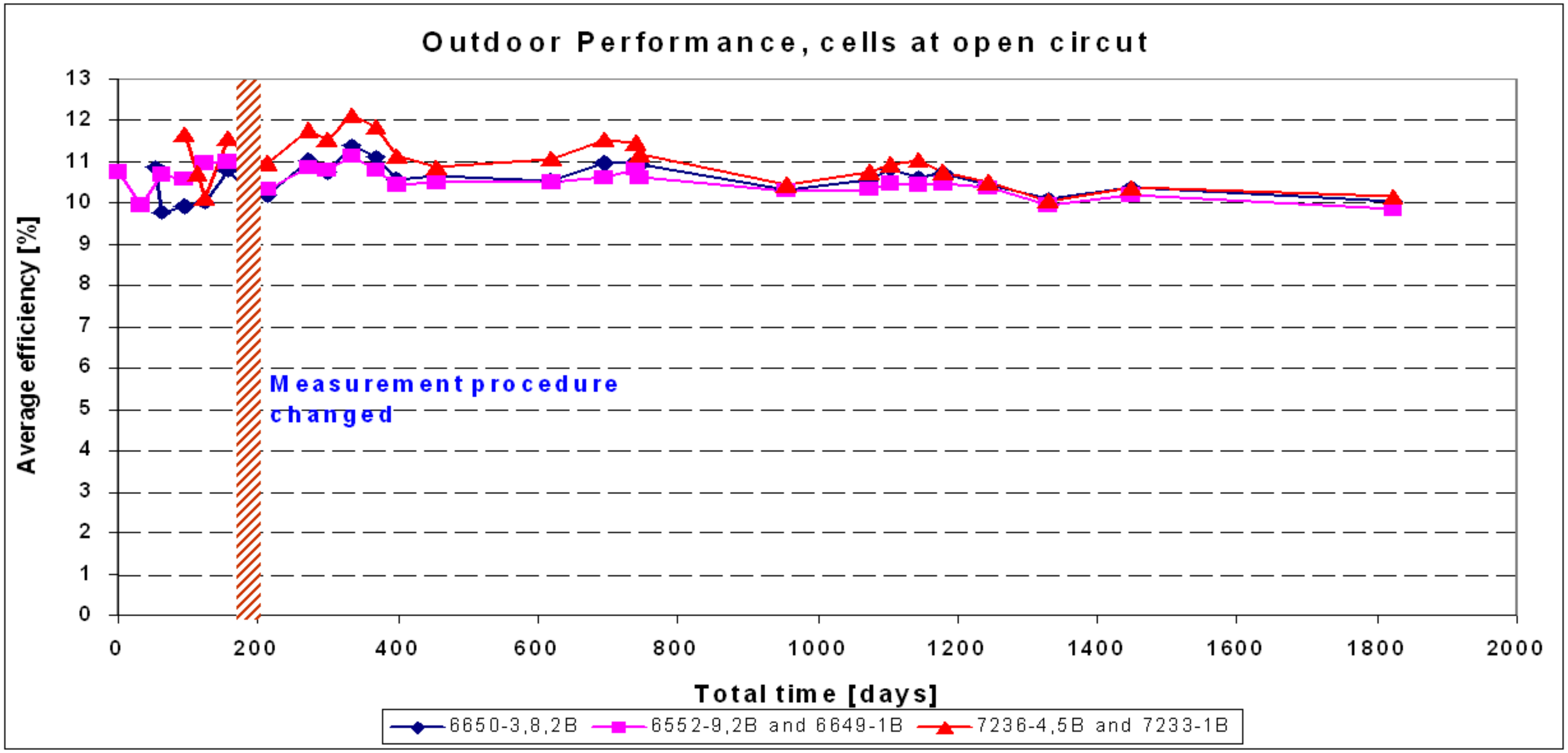
$$\eta = \alpha \cdot \exp\left(\frac{-t}{\lambda}\right) + \eta_{sat}$$

- Extremely long term testing under stressful temperature and bias *
- Process conditions ($CdCl_2$ anneal) influence the rate and ultimate leveling efficiency

Process dependant even using same hardware

,* Enzenroth et. al. 19th European Photovoltaic Solar Energy Conference, 7-11, June 2004 Paris, France.

Long Term Outdoor Accelerated Stress Testing



- Minor change on average, seasonal variation
- Many X acceleration for open circuit compared to max power *

Differences in indoor and outdoor behavior significant: >20 + life

,* Hitner and J. Sites., NCPV PV Program, AIP 1999, p. 170

Semiconductor Device Reliability Challenges

- **Stress Testing Challenges**
  - Time, time and .... **time**
  - Accelerating with temperature: Risk
    - Max module temp < 100 C
    - Mechanism shift at higher temp

Faster method required

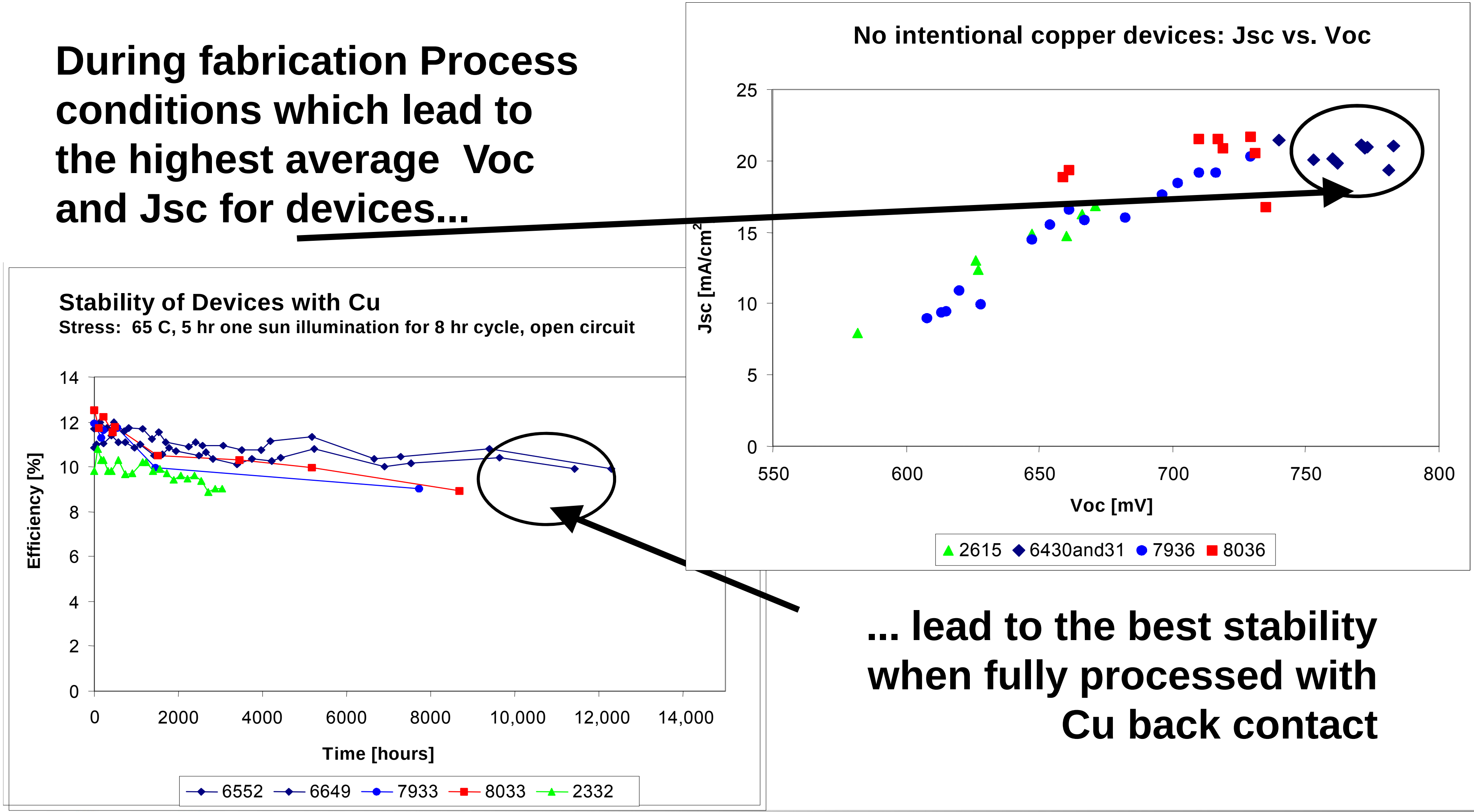
Metric to Ensure Consistent Stability

A relationship between unstressed device performance and long-term stability developed

The stability of devices with intentional Cu can be predicted from the light JV data of identically processed devices without intentional Cu

Stability Metric

During fabrication Process conditions which lead to the highest average Voc and Jsc for devices...



No intentional copper devices: Jsc vs. Voc

Stability of Devices with Cu

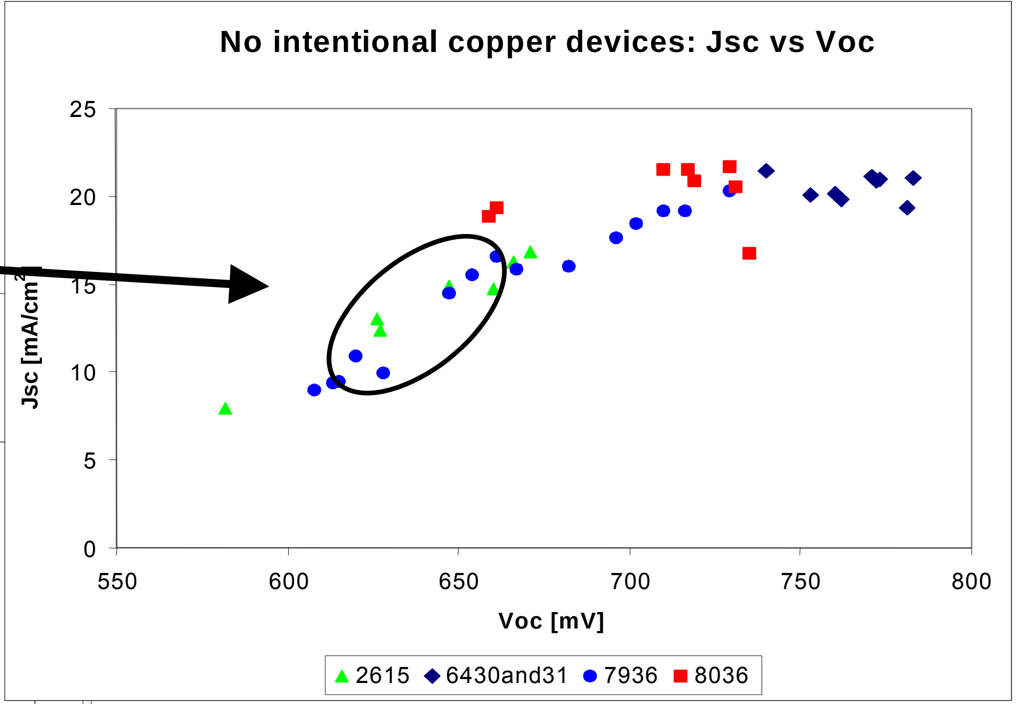
Stress: 65 C, 5 hr one sun illumination for 8 hr cycle, open circuit

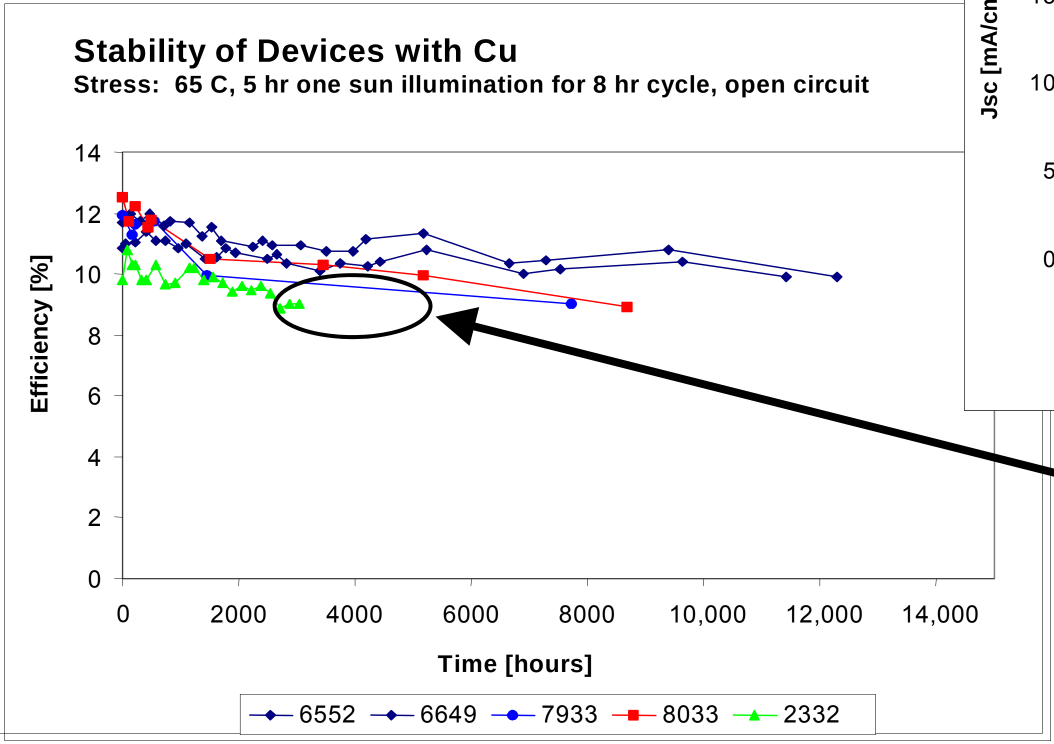
... lead to the best stability when fully processed with Cu back contact

, Source: Barth et. al. 31 IEEE PVSC

Stability Metric

Process conditions with lower average Voc and Jsc for devices without the Cu back contact processing...


No intentional copper devices: Jsc vs Voc


Stability of Devices with Cu

Stress: 65 C, 5 hr one sun illumination for 8 hr cycle, open circuit

... Have reduced stability when fully processed with the Cu back contact

, Source: Barth et. al. 31 IEEE PVSC

Package Reliability: Requirements

- **Package Requirements**
  - Performance: IEC 61646
  - Safety: IEC 61730, UL
  - 20+ years of warrantable life
    - Requires testing beyond certification

Customer driven

- **Product Requirements**
  - Low cost
  - Fast time to market

Business environment driven

Objective: Extremely reliable, low cost product

Package Reliability: Challenges

- **Identify Key Challenges**
  - Internal testing
  - Internal Modeling
  - Literature review
  - NREL, Consultants, Industry experts

- **Most Package Requirements**
  - Utilize existing best practices
  - Process development
  - Testing program

Process engineering needed, but solutions exist

- **Moisture Ingress: Key issue**
  - Significant failure in ASU-PTL tests
  - Internal testing shows moisture degrades device
  - Accelerated stress tests performed under desiccation

Package Reliability: Moisture Ingress

- **Develop moisture specification: level seen in accelerated testing**
  - Ambient moisture can hurt un-coated, non-encapsulated device
  - Moisture level during accelerated stress: Acceptable
    - Indoor and Outdoor
    - Controlled with desiccant

- **Package Design**
  - Maintain moisture levels below that seen in accelerated testing
    - Calculated field conditions
    - Qualification testing
    - Accelerated testing
  - EVA alone and other laminates: do not meet spec.
  - New designs being investigated
    - Glass/Glass seal
    - Back hole

Advancement Opportunities

- **Understanding Effects of Moisture**
  - CdS/CdTe films
    - Materials
    - Electronics
  - TCO and electrodes: expand current efforts
- **Materials Developments:** Encapsulation materials for “thin film”
  - UV performance
  - Low - MVTR
  - Transparency not needed for CdTe
- **Certification/Standards**
  - Streamline certification: Regional, UL, IEC,
  - Reduce certification lead time
  - Specifically recognize frameless modules
  - Correlate performance tests to field conditions
    - (85/85 Damp heat)

Summary

AVA Solar

- Rapid expansion requires proven reliability
- Time to market critical

Reliability requirements

- Risk reduction for company
- Customer, investors, access to capital

Approach / challenges: Semiconductor device

- Accelerated stress: stability, leveling
- Stability metric needed
- Determines package requirement

Approach / challenges: Package

- Engineering/best practices for design
- Moisture ingress critical: new design

Advancements opportunities

- Understand CdTe device / moisture interaction
- Thin film lamination / encapsulation materials
- Streamline, update certification process