Thin-Film Silicon Technology and Manufacturing

- Recap of a-Si and a-Si cell technology
- Types of a-Si manufacturing systems
- a-Si cell and module manufacturing at Xunlight
- Xunlight products and installations

Aarohi Vijh,
Xunlight Corporation
avijh@xunlight.com
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About Xunlight

- Founded in 2002; spinoff from UT
- Makes flexible, lightweight BIPV/BAPV modules
- Triple-Junction a-Si
- Makes own manufacturing equipment
- Plants in Toledo, OH and Kunshan, China
- About 80 people, 25 MW nameplate capacity

Recap

Amorphous Silicon

- Inexpensive, abundant raw material
- End product non-toxic
- Strongly absorbing
- Low temperature coeff of power
- Low temperature processing possible
- Insensitive to water and oxygen
- Environmentally friendly process
- Substrate or superstrate configuration

Major Players

- Mitsubishi, Sharp, Kaneka
- Canon (until 2002), Xunlight, Unisolar
- Flexcell, Powerfilm, Fuji Electric
- Applied Materials (until last year)
- Oerlikon/Tokyo Electron
- Dozens of small players in Asia

Recap

Amorphous Silicon

- Behaves like a direct band-gap semiconductor
- Needs hydrogen for adequate electronic quality
- Low carrier mobility (especially in doped a-Si) means that p-i-n structures, rather than p-n structures must be used.
- Light enters through p-layer

Recap

Amorphous Silicon

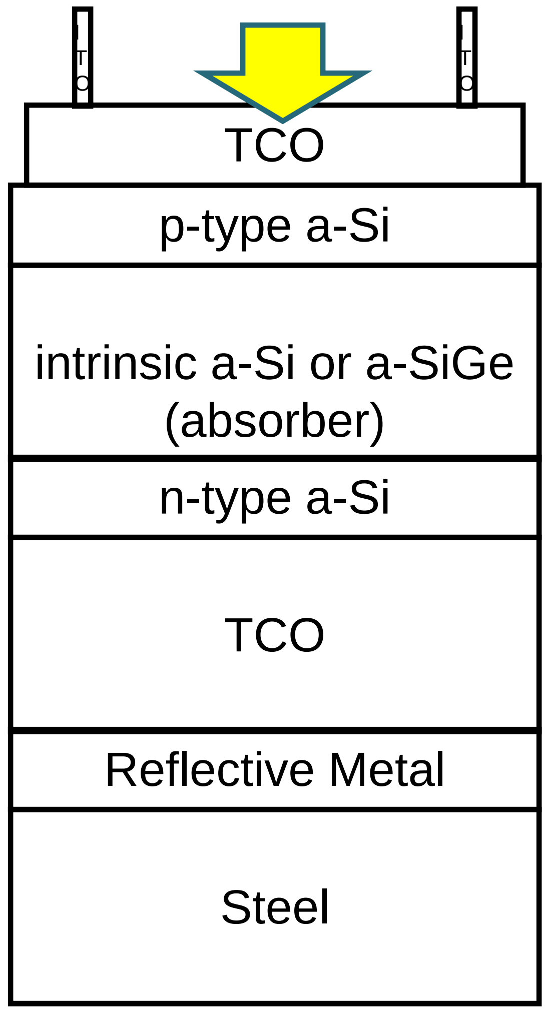
- Efficiency
  - around 7% for a-Si based structures
  - Around 10% for uc-Si based structures
- Light Induced Degradation
  - Can be managed by using multijunction structures
  - Can be greatly reduced by using uc-Si

Focus of Talk

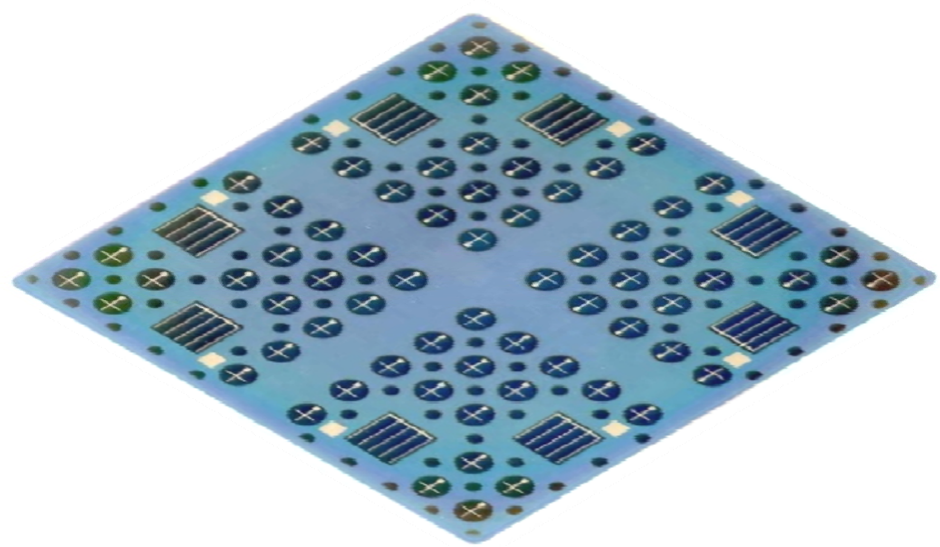
- Steel Substrate
- Roll-to-Roll Process
- Flexible Modules

Recap

Substrate-Style Amorphous Silicon Cell



- Sputtered TCOs and Metal
- Si by Plasma Enhanced CVD (SiH_4+H_2+dopants)
- Grid deposition by thin-film or thick-film processes



The i layer

- Function is to absorb light of specific wavelengths, and not lose too many of the photogenerated carriers
- Bandgap is controlled by Ge alloying
- Ge alloying creates more defects
- Bandgap grading and buffer layers are often used
- Microcrystalline Si is also used instead of Ge alloying.

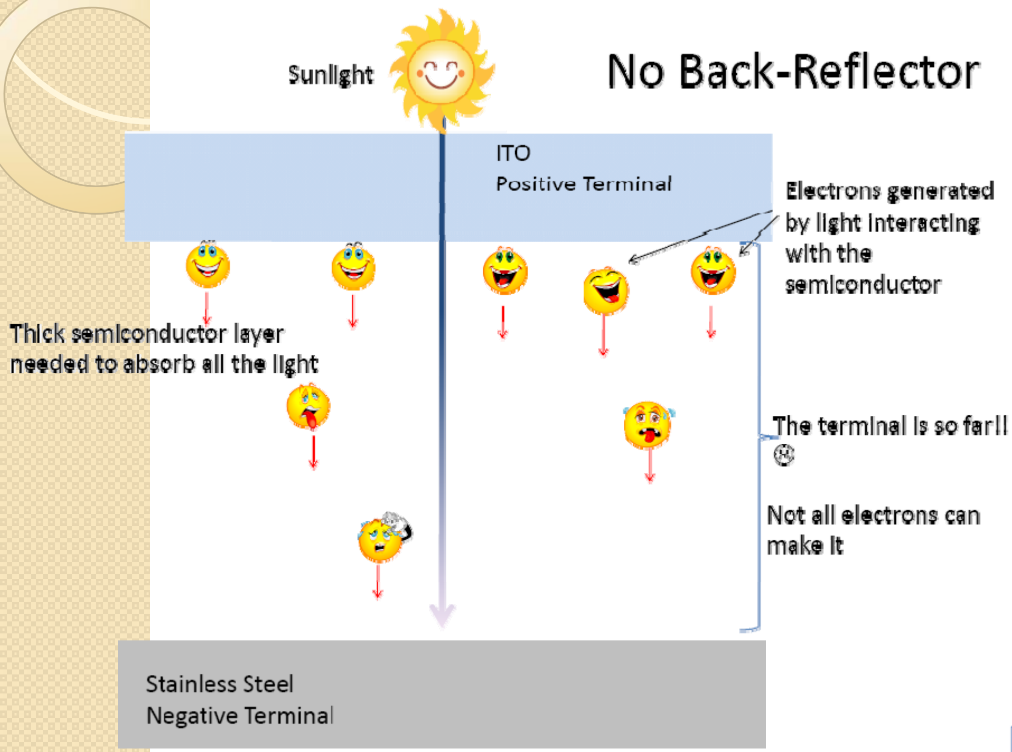
The n layer

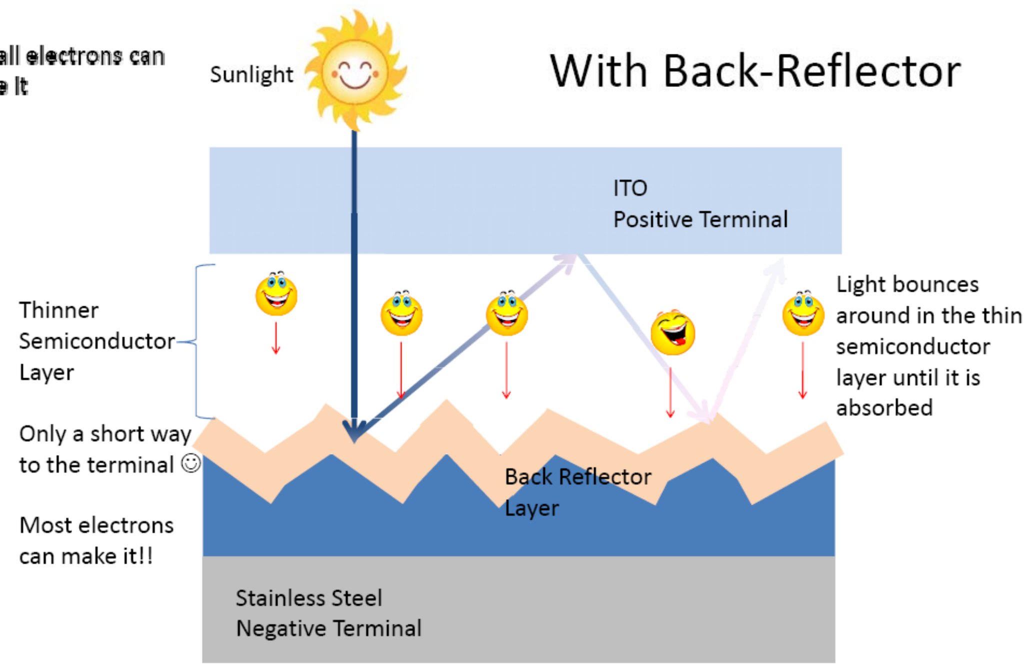
- Must have high optical transmission in wavelength range of interest
- Doped with PH3
- Generally not alloyed

The p layer

- Must have high optical transmission in the absorption wavelength range of the cell it is covering.
- Must form good junctions with ITO and with n-layer.
- Two major approaches
  - a-SiC:H (using $SiH_4+CH_4+BF_3$ or SiH_4+TMB)
  - a-Si:H based matrix with Si crystallites, with BF_3 doping.

The Back Reflector

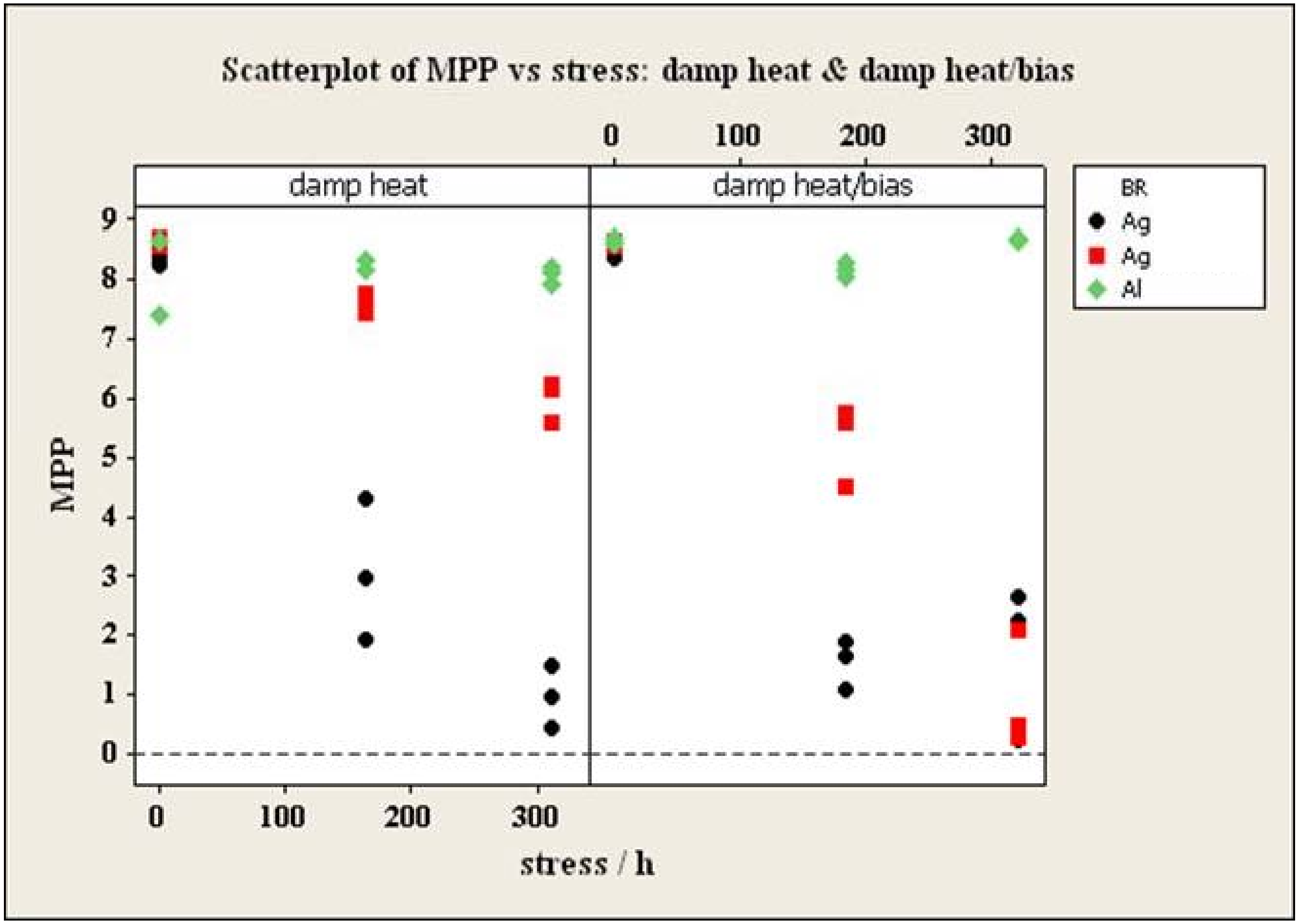




The Back-Reflector

- Allows thinner cells
  - Stronger electric field, less material usage, faster deposition
- Usually Ag/ZnO or Al/ZnO
- Ag gives better NIR reflectivity but can only be used where moisture is not an issue (without special and expensive techniques)
- Texture/diffuse reflection is generally desirable

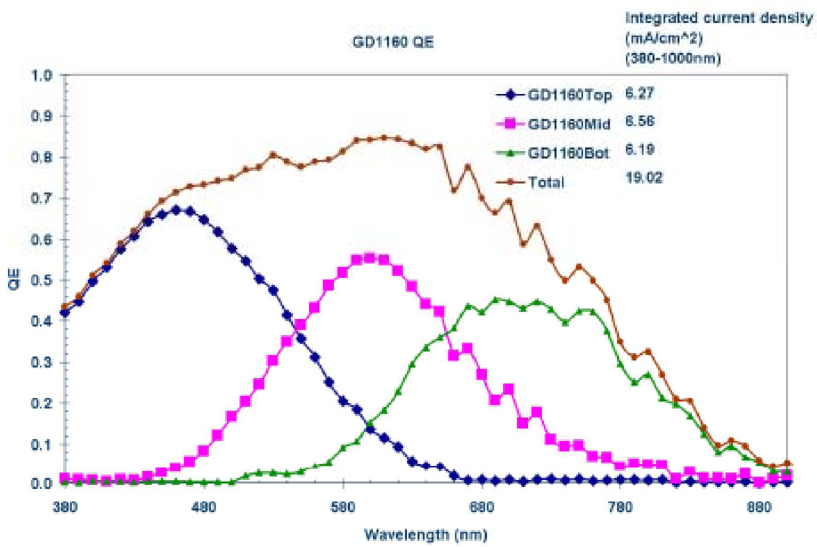
Design Consideration: Ag vs. Al in Moisture

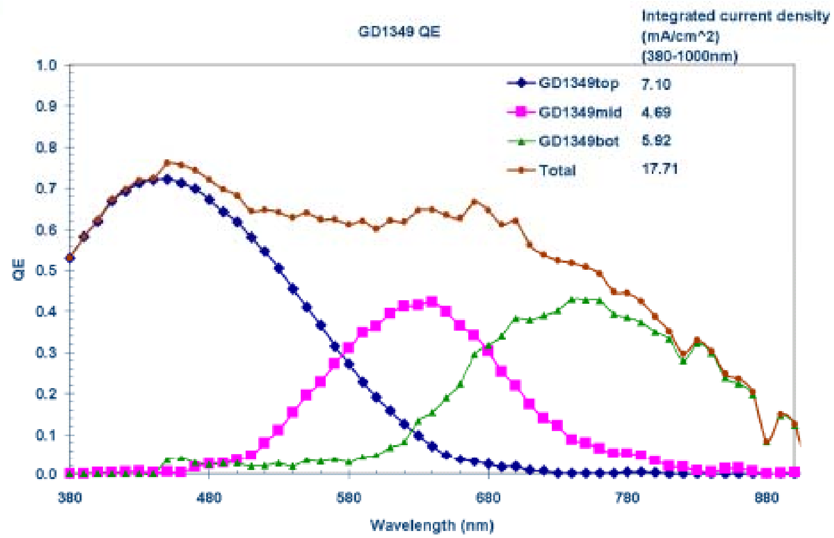


The Top TCO (Window)

- ¼ wavelength ITO (around 70 nm)to maximize green transmission
- Sheet resistances of around 100-150 ohms achievable in production

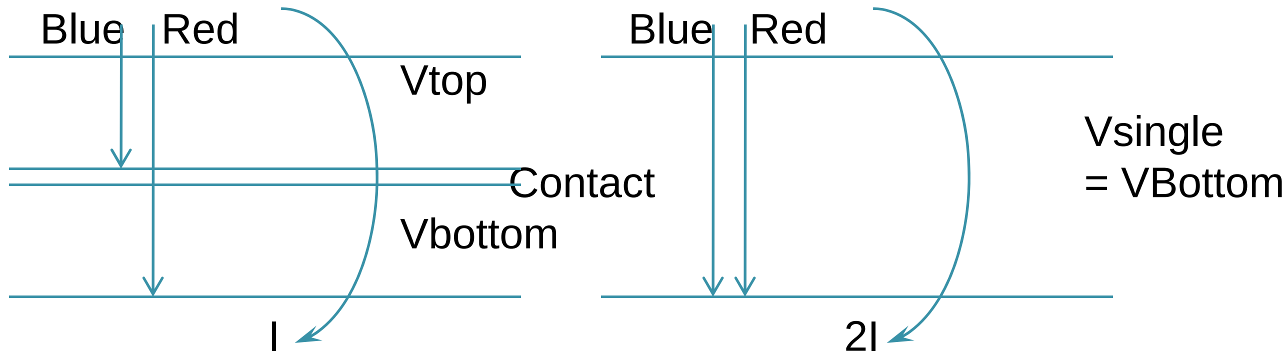
ITO Thickness vs. QE





Recap

Two-Terminal Multijunction Cell



Ptandem = I * (Vbottom + Vtop) > Psingle = 2I * Vsingle
because Vtop > Vbottom (and assuming contact loss is low).

- Current must be balanced
- Bandgap, thickness, reflectors are the usual knobs. Also AR.
- Contact/Junction loss must be low
- Thinner cells = stronger electric fields
- Many compromises in practice

Introduction

Amorphous Silicon – Triple Junction Cell

- Stack of 3 n-i-p cells
- i-layers have different Eg
- Lower light-induced degradation
- Voc ~ 2.2 V
- Jsc ~ 7-8 mA/cm^2
- Stable Efficiency >11% with μc-Si bottom cells

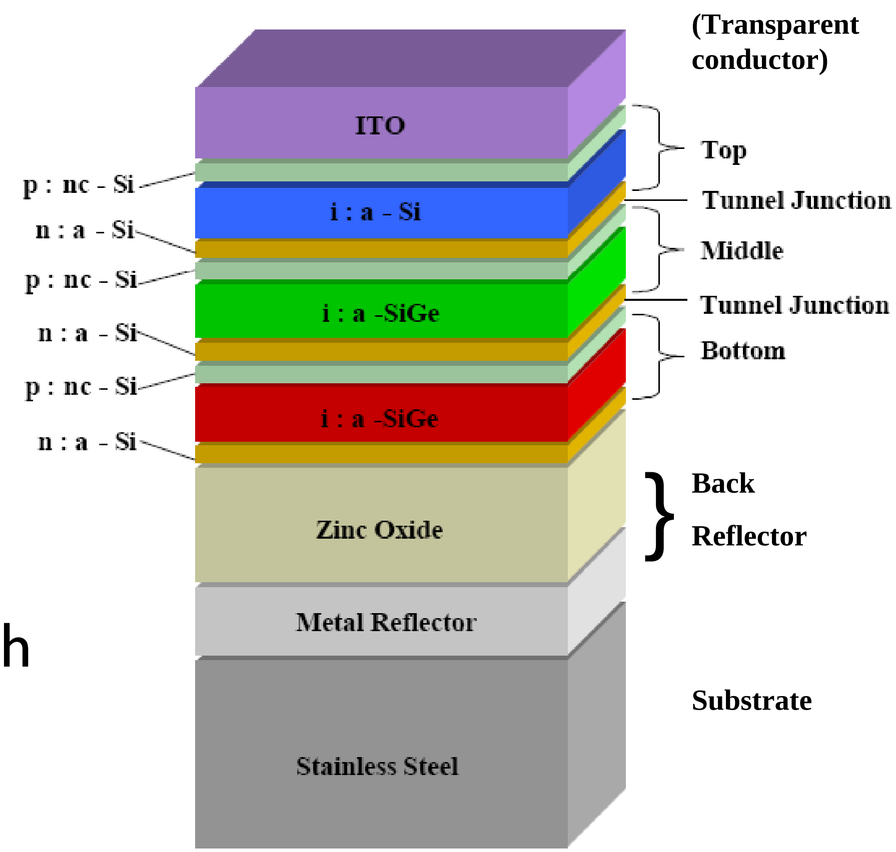
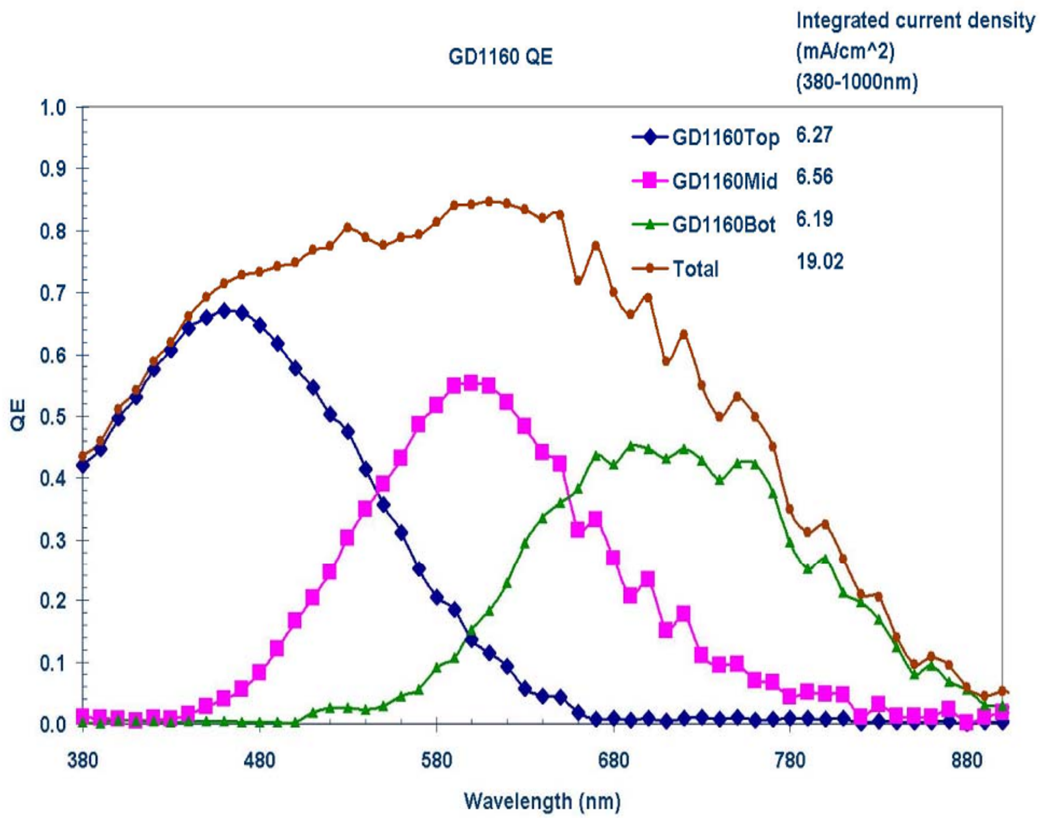
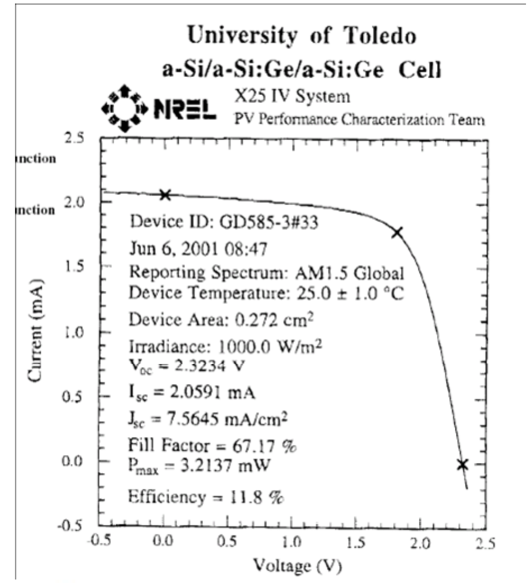
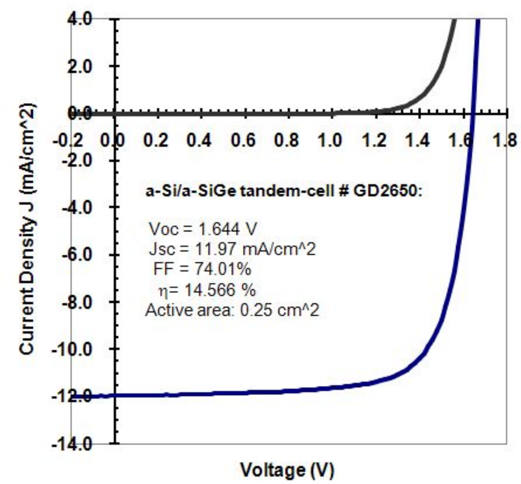


Figure from: X. Deng, A. Vijh, et al., "Optimization of a-SiGe based triple, tandem and single-junction solar cells", 31st IEEE Photovoltaic Specialist Conference, Orlando, Florida, January, 2005.

IV/QE







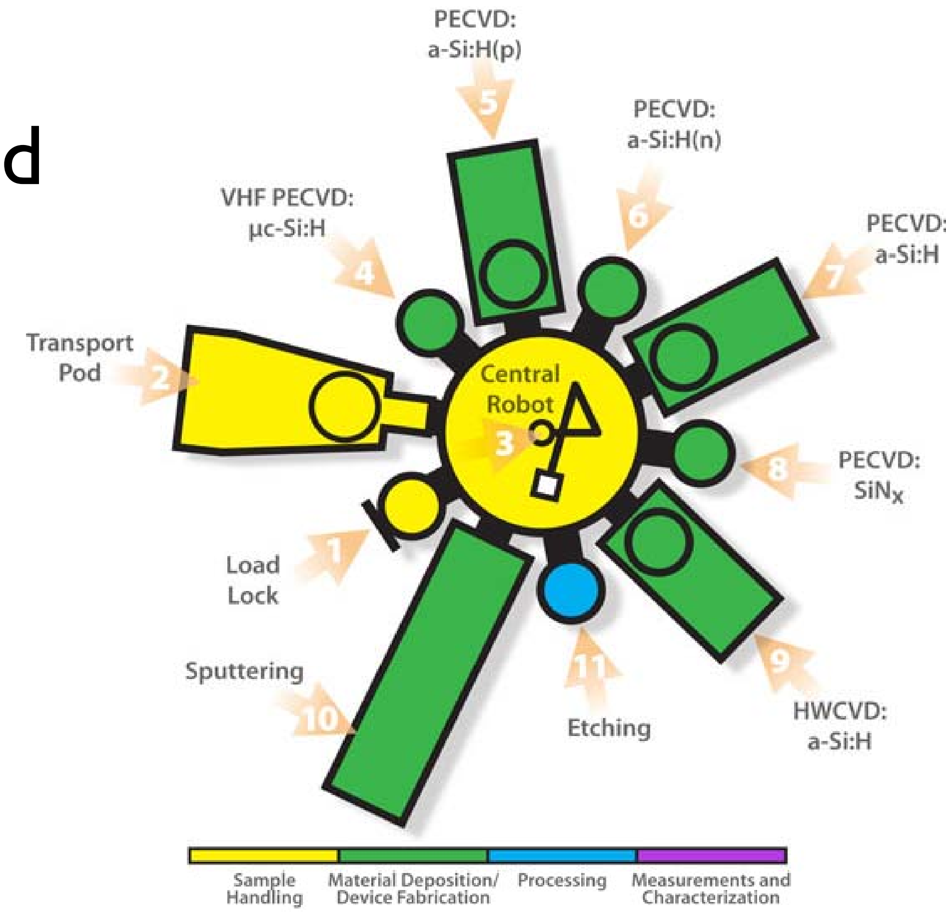
IVs: X. Deng, P. Agarwal and Q. Fan, University of Toledo

Types of Deposition Systems

- Cluster
- In-Line
- Single Piece/Batch
- Roll to Roll In-Line

Cluster

- Individual chambers served by a robot
- Max process flexibility




APPLIED MATERIALS
The Applied SunFab™ Thin Film Production Line
Tour the Line
Applied SunFab Automation
Applied SunFab Performance Service™
RESET
5 EXTERNAL WIRING AND PANEL POWER RATING
4 PANEL ENCAPSULATION
3 BACK CONTACT FORMATION
2 PHOTO CONVERSION LAYER FORMATION
1 FRONT CONTACT PREPARATION AND PATTERNING
Illustration only, actual configuration varies.

In-Line

- Substrate moves from chamber to chamber in sequence
- If one chamber fails, entire process stops


22 4:06PM

Batch

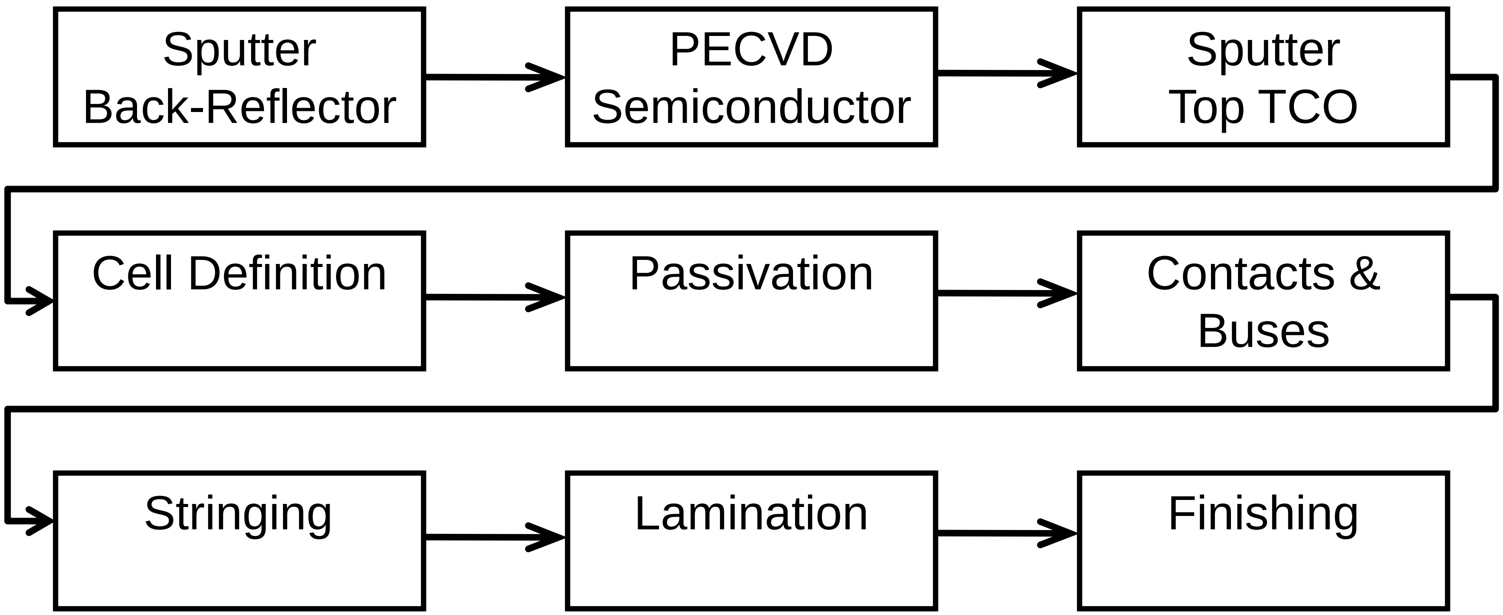
- Cluster Systems can be single or batch mode

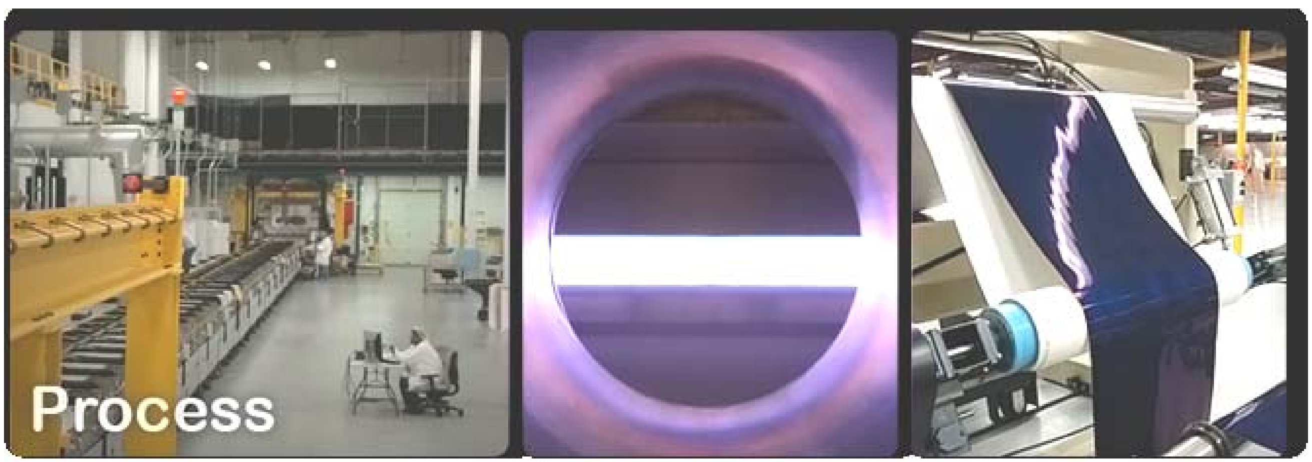
Roll to Roll Systems

Characteristics of Roll-to-Roll Processing

- Simplicity
- Steady operation
- Well suited to high volume production
- Speed must be the same in all zones
- Time is transformed to length
- Pressure must generally be the same
- No cleanroom needed
- Patterning is difficult
- Batch sizes are large

Flexible a-Si Manufacturing Process at Xunlight



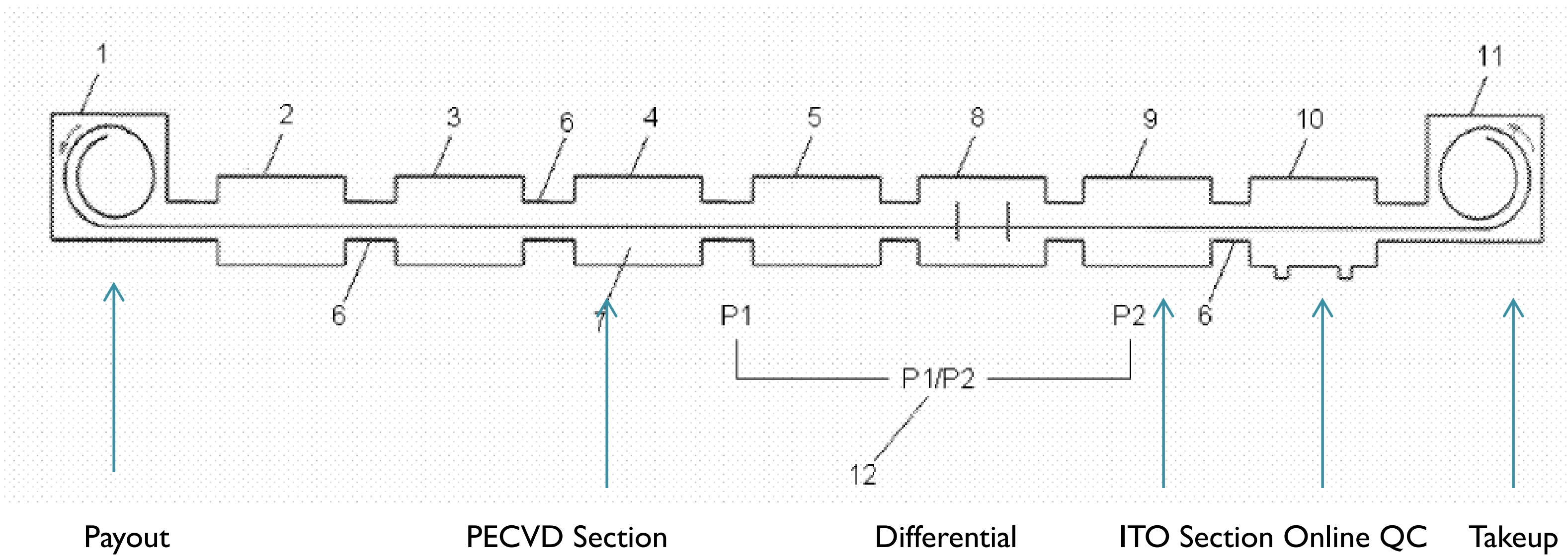


Xunlight 25MW PECVD/ITO Line

Xunlight 25MW PECVD/ITO Line

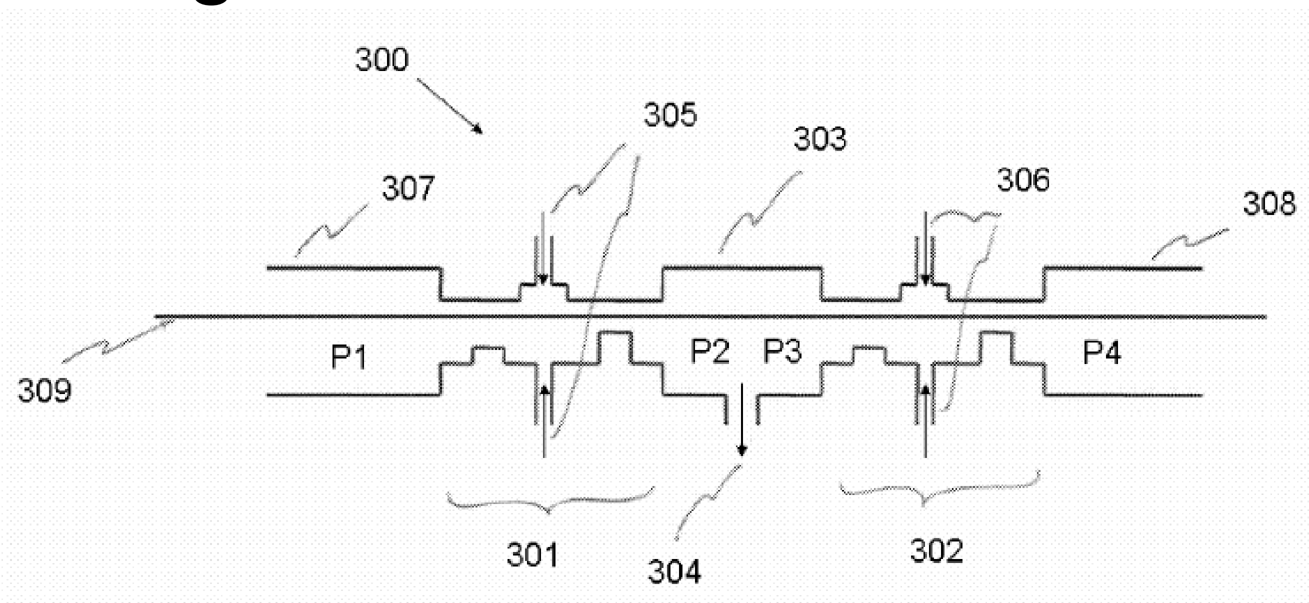
- 9 PECVD deposition zones (*nip-nip-nip*); each zone has single or multiple parallel plate electrodes, depending on deposition rates and thicknesses
- 1 sputter zone (ITO)
- Online QC capability
- 200 feet in length
- Capable of running lengths up to 8000 feet nonstop
- 36" wide substrate

Schematic of a Combined PECVD/ITO Roll to Roll Line



Differential Pressure Devices

- 1:1000 pressure ratios achievable while allowing web to move freely, and allowing no significant cross-contamination



Application number: 12/535,237
Publication number: US 2010/0029067 A1
Filing date: Aug 4, 2009

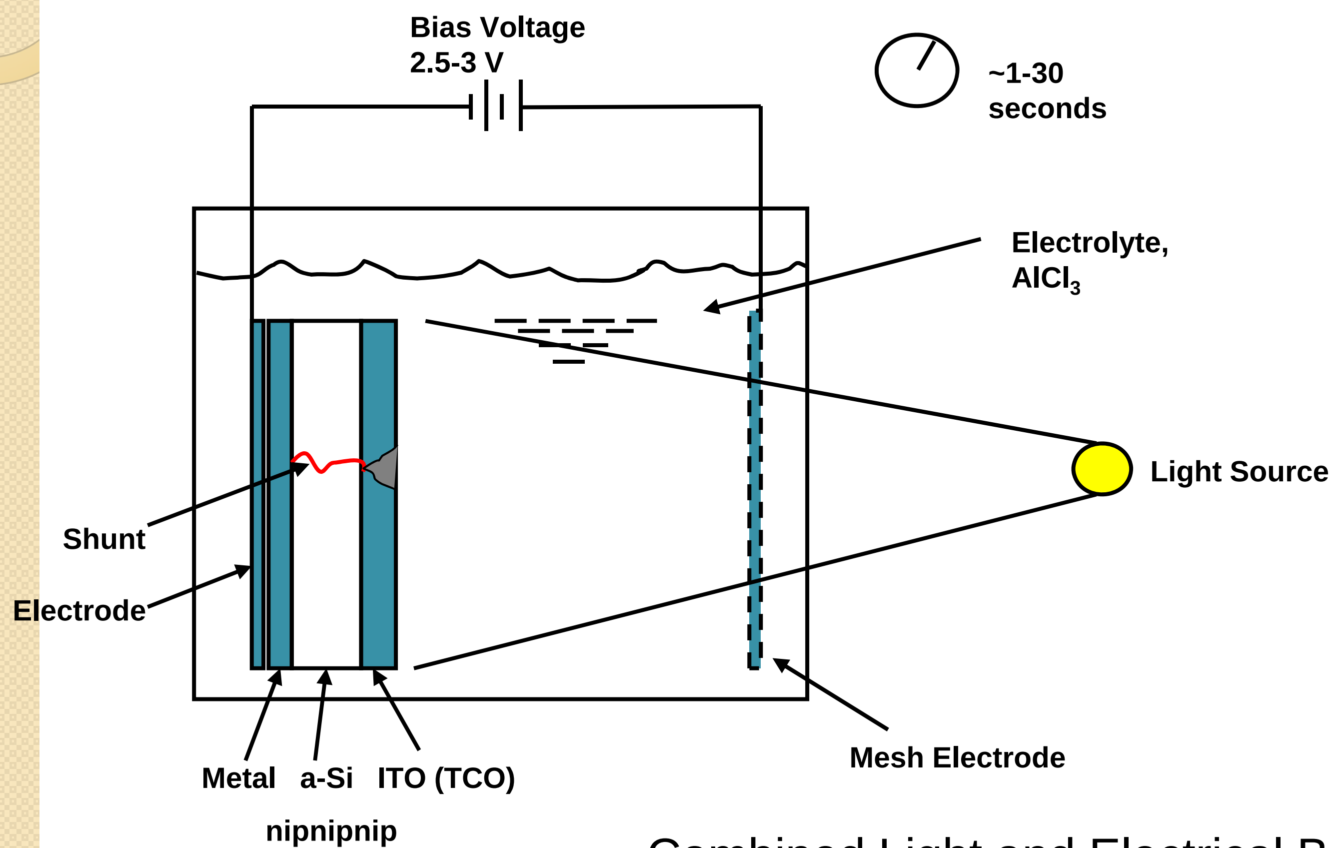
Photo of Coated Web

Back End I

- Singulation
- Edge Delete
- Shunt Passivation

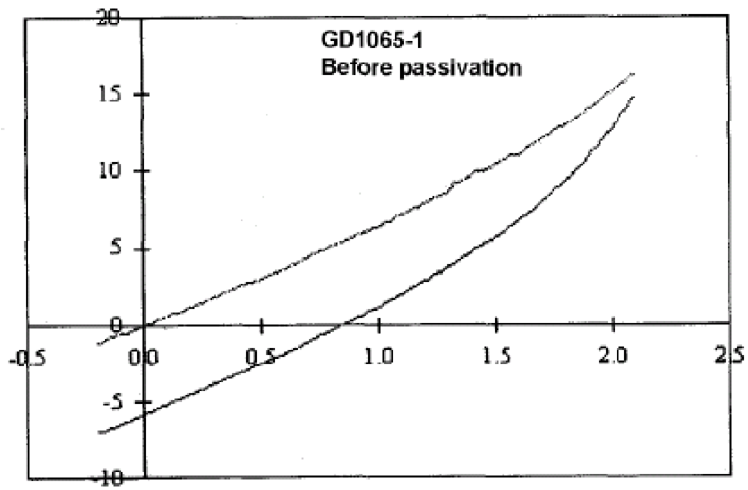
Shunt Passivation

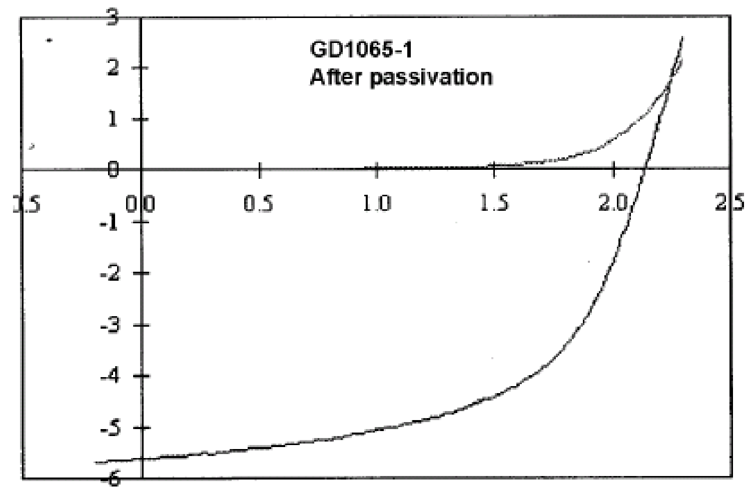
Apparatus for light-assisted shunt passivation



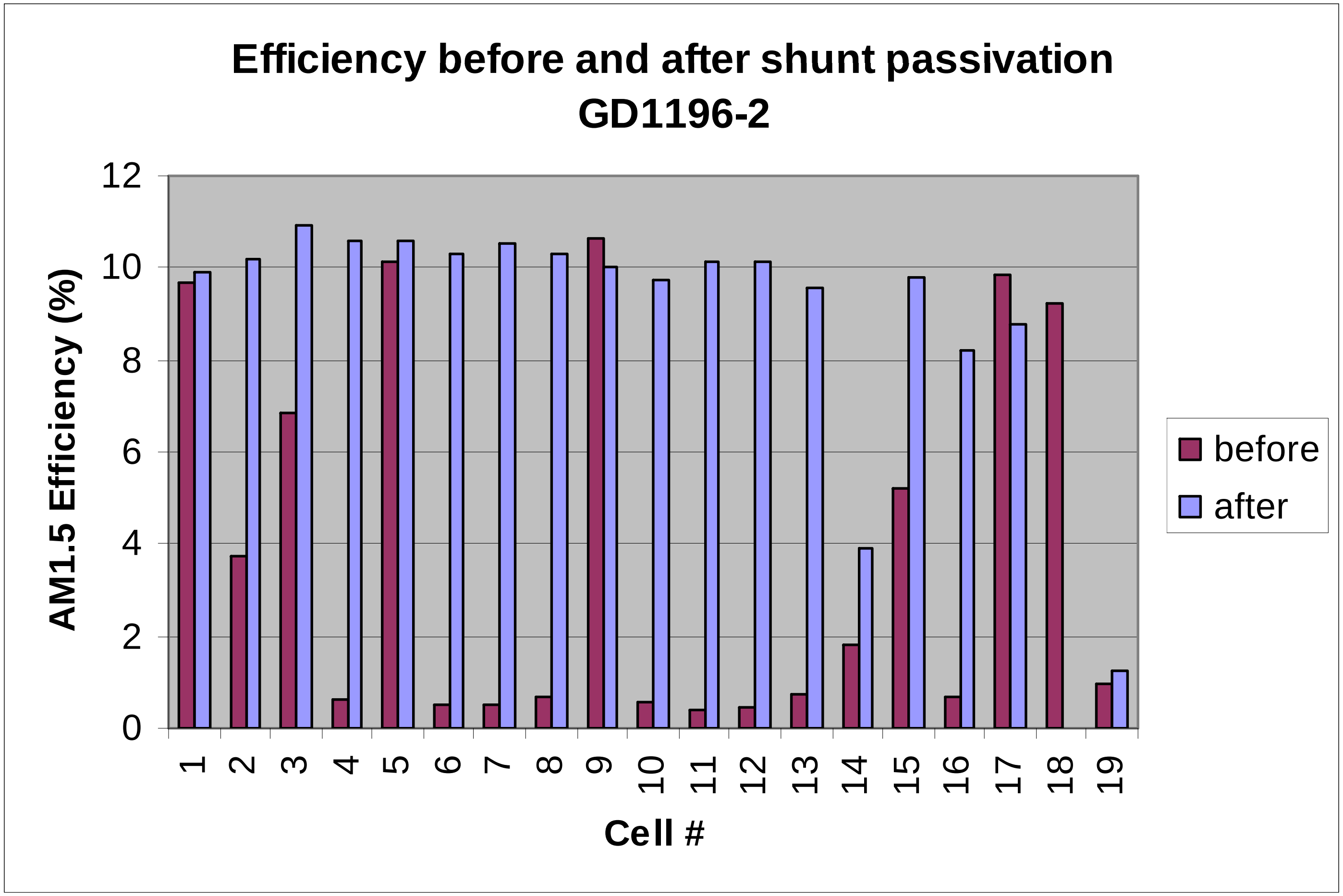
- Combined Light and Electrical Bias
- Reduces unwanted conversion of TCO
- Broadens process window

Shunt Passivation





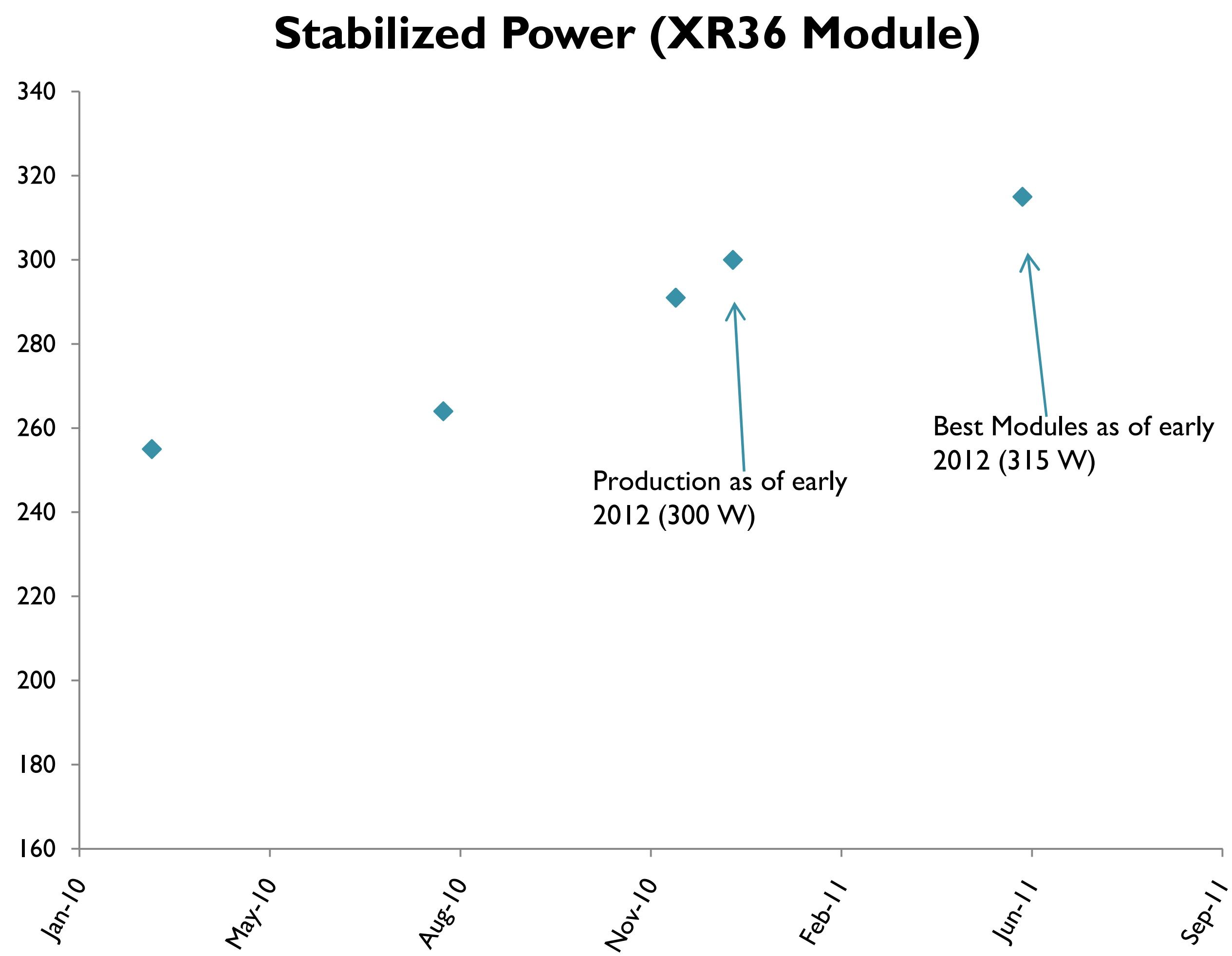
Shunt Passivation



Back End II

- Negative and Positive Buses
- Current Collection Grid
- Bypass Diodes
- Stringing
- Lamination
- Testing

Efficiency Improvement



Reliability Challenges

- Uncontrolled user environment
- Not serviceable
- Very long lifetime expectation with combination of sun, wind, water, high voltage, heat.

- Good part: No moving parts

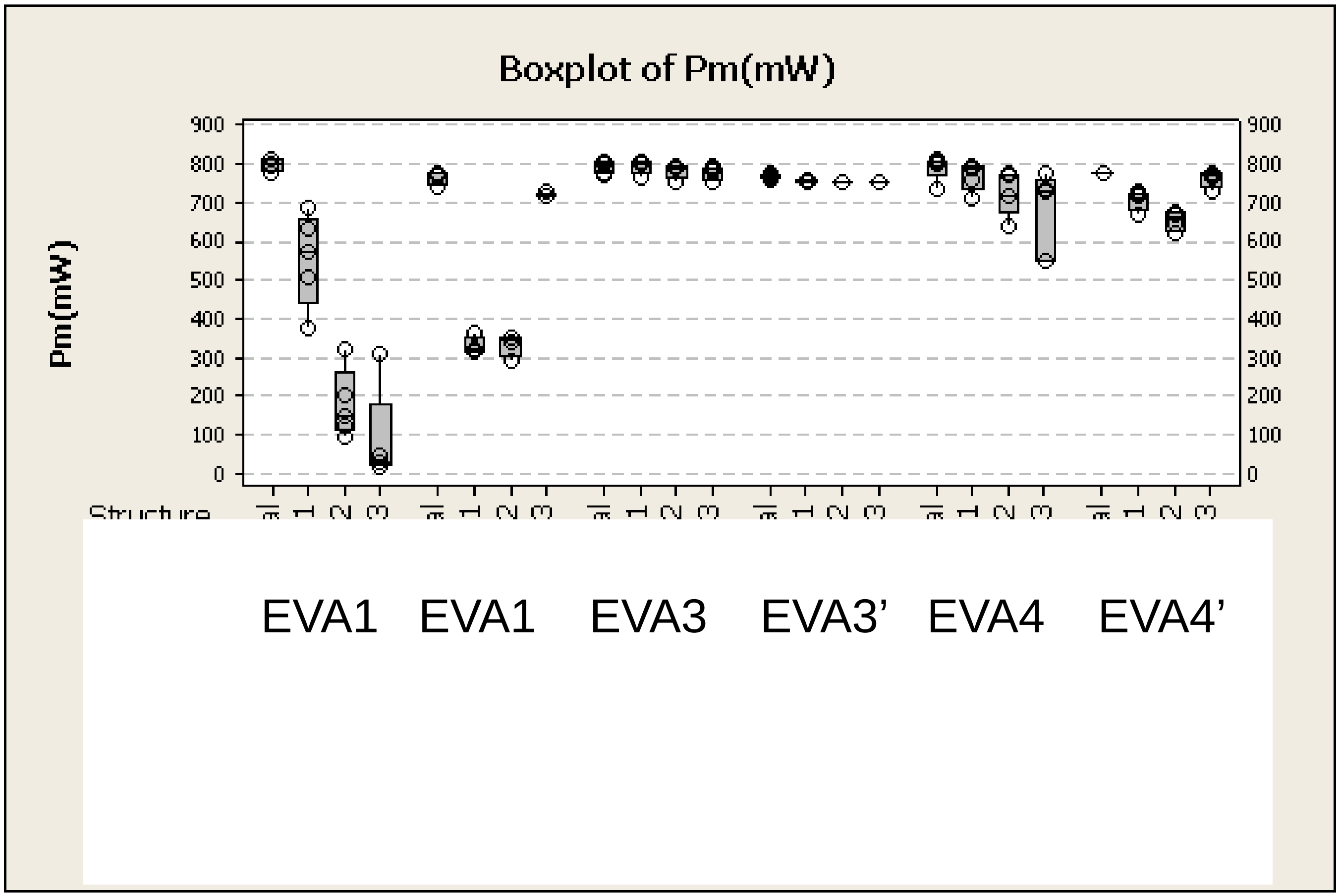
Functions of Package

- Let light through while protecting cells from environment (Light, UV, Heat, Water, Air, Mechanical).
- Be stable
- Provide electrical insulation: 1000 V continuous use.
- Be resistant to fire
- Provide a way to mount the module
- Be cheap
- Reliability is a big part of LCOE

Test Sequences for Compliance

- UL 1703
- IEC 61646
- IEC 61730-1 and -2

Package Considerations Example: UV Stability



References

- TUDelft OCW Web Site
  - http://ocw.tudelft.nl/courses/microelectronics/solar-cells/lectures/
- Handbook of Photovoltaic Science and Engineering, Chapter on a-Si by Deng and Schiff
- Images: AMAT/Voith/Hind High Vacuum/Google Image Search
- www.xunlight.com/products/installations/

Thank You.

Xunlight CORPORATION
Flexible • Lightweight • Powerful

XR Solar Laminate Series

Models: XR-12, XR-36, XRS-18

Basic Characteristics		XR12	XR36	XRS18
Power (±5%)	Pm (W)	97	291	146
Open Circuit Voltage	Voc (V)	26.50	79.50	39.75
Short Circuit Current	Isc (A)	6.35	6.35	6.35
Voltage at Max Power	Vm (V)	19.40	58.20	29.10
Current at Max Power	Im (A)	5.00	5.00	5.00
Length (±3 mm/0.12 in)	L (mm/in)	1801/70.91	5182/204.03	5220/205.53
Width (±3 mm/0.12 in)	W (mm/in)	911/35.88	911/35.88	476/18.75
Weight	M (kg/lbs)	4/9	12/26	6/13
Thickness	T (mm/in)	1.5/0.06	1.5/0.06	1.5/0.06

Characteristics for System Design *	
Max System Voltage	600 V (US/Canada), 1000 V (Europe)
Series Fuse	10 A (UL 1703/US NEC), 8A (Europe/IEC)
Temp Coefficient of Power	- 0.243 %/°C
Temp Coefficient of Voc	- 0.394 %/°C
Temp Coefficient of Isc	+0.136 %/°C
NOCT (Nominal Operating Cell Temp)	51.5°C
Classification	IEC Application Class A/Safety Class II
UL 1703 Fire Rating	Class A

* See manual or contact Xunlight for details.

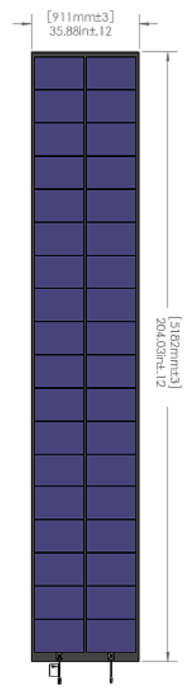
Certifications

Certified to the following standards: IEC 61646, EN 61730 and UL 1703.

Warranty

25 year limited power output warranty (90% of minimum power at 10 years, 80% of minimum power at 25 years)
5 year limited product warranty

All specifications subject to change without notice.



XR36 dimensions
See table for other models

TÜV InterCert CE ETL Safety Class II

 April 2011