NSF PV-Workshop

Critical Issues in Thin Film Si

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Module selling prices: German market 2009

German spot market price (Euro/W)

- Multi-Si
- CdTe
- a-Si

 Photon International 11/09 and 03/10
Attributes of a-Si based modules

- ~5% of total PV market in 2008
- High yield (kWhrs/kW) due to good performance at high temperature and low light condition
- Inherently and easily made as multijunction allowing more efficient utilization of spectrum (only thin film PV with MJ modules)

- Fundamental understanding of material properties, deposition parameters and large area equipment
  - 35 years R&D on single deposition method
  - strong non-PV industrial interest

- Minimal deposition steps: PECVD + back contact
- Either glass or flexible substrate demonstrated in manufacturing
Status of manufacturing of a-Si based technology
Status of Manufacturing

Several companies completing lines for tandem a-Si/nc-Si module with rated stabilized performance 9-10%:

- Kaneka, Mitsubishi Heavy Ind, Sharp Solar: 40-60 MW in 2008
- Sharp Solar: 10%, 160 MW now, 480 Mw by 2011
- United Solar Ovonic: >100 MW of BIPV laminate in 2009

Several companies selling turn-key fab lines:

- Applied Materials, Oerlikon Solar, Leybold Optics, Ulvac

Masdar Initiative (UAE) selected tandem a-Si/nc-Si technology for both manufacturing development and installation:

- Investor confidence with $2B support for joint Masdar PV group with MIT and Helmholtz-Zentrum Berlin as R&D partners
Critical issues: before and now
Critical Issues for a-Si based technology

- Steady improvements in efficiency over 20 years leveling off
- No further improvements in
  - Light induced degradation
  - Engineering low band gap

+ Nanocrystalline (nc-Si) materials solve these problems.
- Several groups have demonstrated stabilized eff >11% with aSi/nc-Si double or triple junction cells

- However, new issues with nc-Si arise
- Weaker absorption of nc-Si requires 5x thicker layer
  - Significant efforts to increase growth rate with high nc-Si quality
- Control of nc-Si properties over large area module
Issues with introduction of nc-Si
**Device structure: a-Si to a-Si/nc-Si**

Due to low absorption coeff. of nc-Si compared to a-Si

5 x thicker →
Technical barriers for PECVD grown nc-Si and thrust area of R&D

- Increase nc-Si deposition rate » Higher throughput » Reduce $/Wp
  - Pressure and plasma frequency
  - new concepts for gas feed, gas pumping
- Large area substrates » Higher throughput
  - Effect of frequency: high rate Vs homogeneity over large area
  - Effect of electrode design: homogeneous and high throughput
- Increase efficiency by improved light trapping concepts
  - Effect of plasmon, intermediate reflector, thin AR for light trapping: Current management » increase Jsc » higher efficiency
Issues with increase deposition rate of nc-Si
Selection of Frequency-Power-Pressure for High rate nc-Si Deposition

RF: 13.56 MHz
VHF: 27 MHz - 80 MHz
LPD: < 1 Torr
HPD: 3-10 Torr

Data collected from J. Appl Phys. Appl. Phys. Lett. Several PV groups
Effect of Frequency on plasma deposition process

![Graph showing the effect of frequency on electron energy, electron density, and quarter wavelength.](image)
Improved homogeneity
@ high dep rate with VHF
Concept of Linear Source Electrode: Homogeneity and Throughput issues

Planar electrode

Linear (rod) electrode

Dresden Univ. of Technology
Cost estimation for in-line production machine

- substrate width \( (y) \)
- substrate velocity \( (v) \)
- solar module efficiency \( (\eta) \)
- deposition rate \( (r) \).

Estimation done by:
Dresden Univ. of Technology and FAP GmbH, Germany
Improved light harvesting with new optical engineering
Index matching optical layers
Device design for a-Si/nc-Si thin film solar cell

glass/\text{SnO}_2/

\text{TiO}_2/

p-i(a-Si)-n/

n-SiO_x/

p-i(nc-Si)-n /

ZnO/Al

R. I. scale 1.0 1.5 1.9 2.5 3.5 2.1 3.5
$a$-Si/nc-Si cell with TiO$_2$ as anti-reflection layer
$a$-$Si/nc$-$Si$ cell with $SiOx$ as intermediate-reflector layer

![Graph showing quantum efficiency vs. wavelength with and without SiOx](image)
a-Si/nc-Si cell with both TiO2 and SiOx as index matching optical layers
Current management in a-Si/nc-Si cell

![Graph showing current management in a-Si/nc-Si cell](image-url)
Plasmonic absorption with nanoparticles
Light trapping by surface plasmons

Conventional design

Surface Plasmonic Patterning

Attwater et al./ Polman et al.
Surface Plasmonic Light Trapping

Metal nanoparticle surface coatings

Evaporation and annealing (ANU) Porous alumina template (CALTECH)

Substrate conformal imprint lithography (SCIL) - Philips

A. Polman et. al
Demonstration of Plasmonic Solar Cell Design

Amorphous Si thin-film solar cell fabrication steps

Verschuuren et al.
Schropp et al.
Improved Long-Wavelength response using plasmonic design

6% eff cell  Measured Spectral Response

51% increase in photocurrent from 600-800 nm

No decrease in response from 400-600 nm

Ferry et al.
Recommendations for strengthening U.S. thin Si industry: a-Si/nc-Si technology

Higher deposition rate ⇒ higher throughput
- new plasma electrode configurations (linear, ??)
- new plasma conditions in terms of pressure, power
- nc-Si material and device uniformity and interface control with diagnostic tools

Better light trapping ⇒ Higher Jsc ⇒ higher efficiency
- dielectric interlayers
- index matching front TCO
- plasmonic back reflector