NSF PV-Workshop

Critical Issues in Thin Film Si

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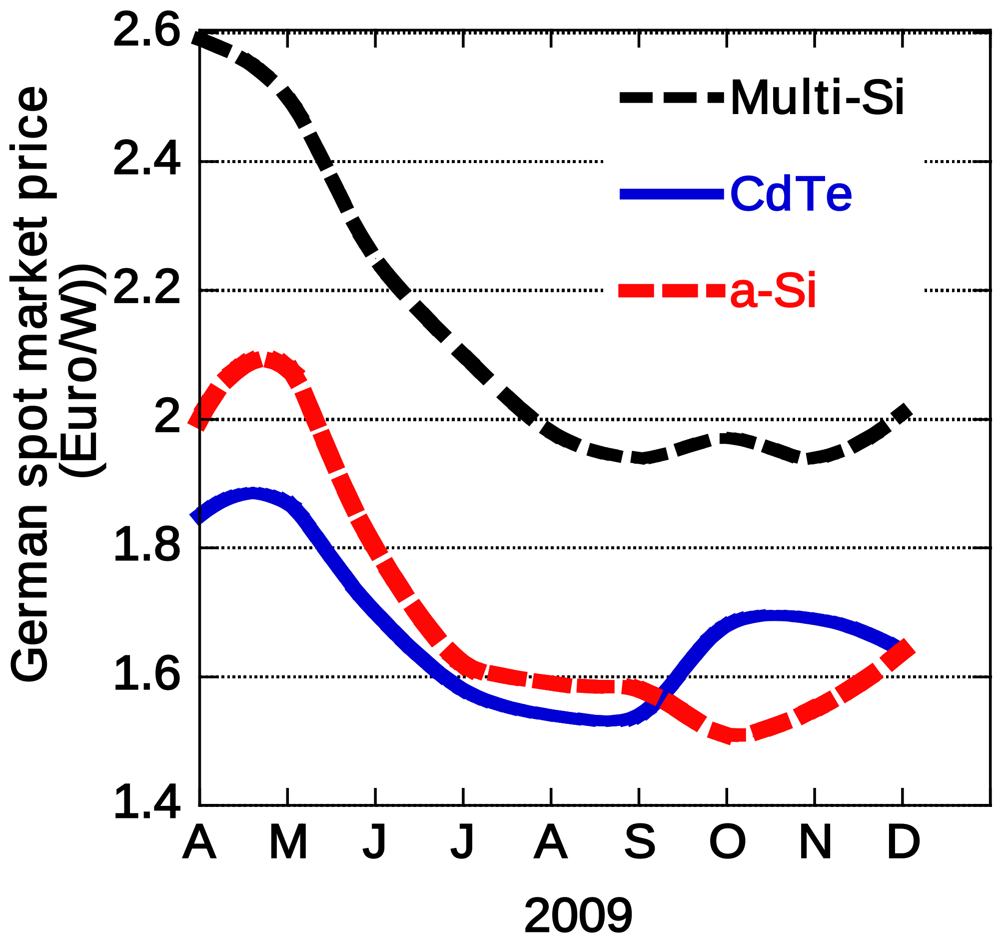
Module selling prices: German market 2009



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**

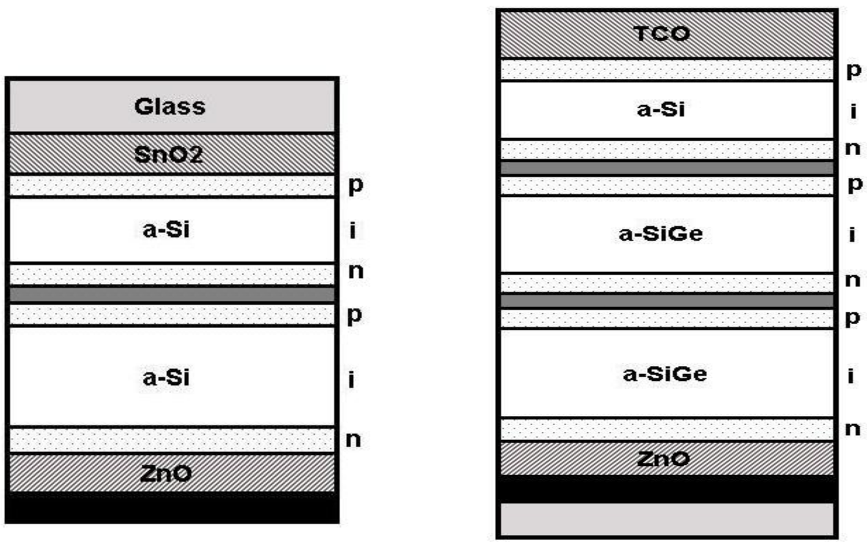
- However, new issues with nc-Si arise

- **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**

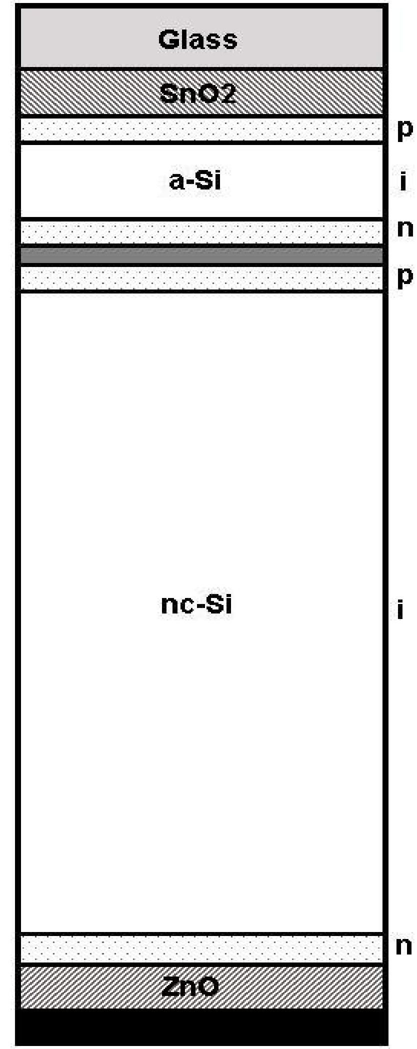
Issues with introduction of nc-Si

Device structure: a-Si to a-Si/nc-Si

Due to low absorption co-eff. of nc-Si compared to a-Si



5 x thicker >>

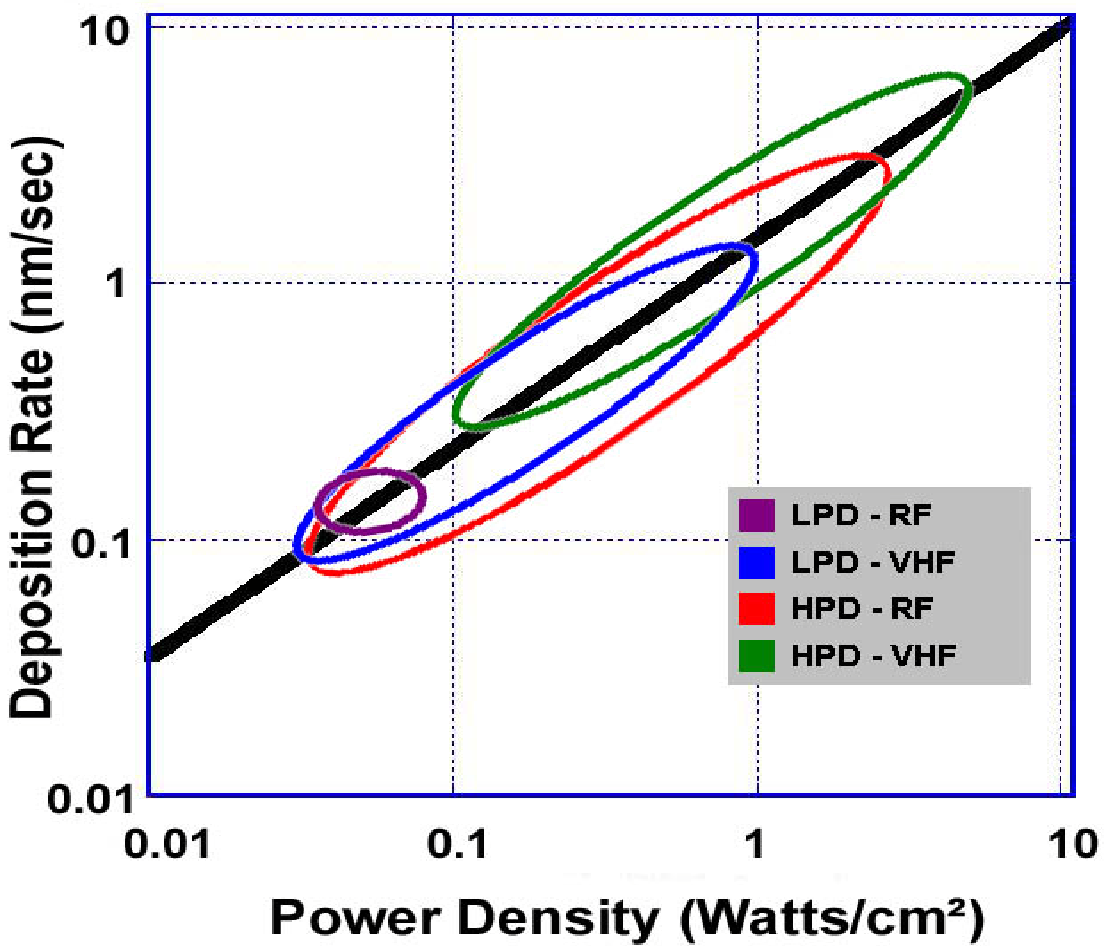


Technical barriers for PECVD grown nc-Si and thrust area of R&D

- **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



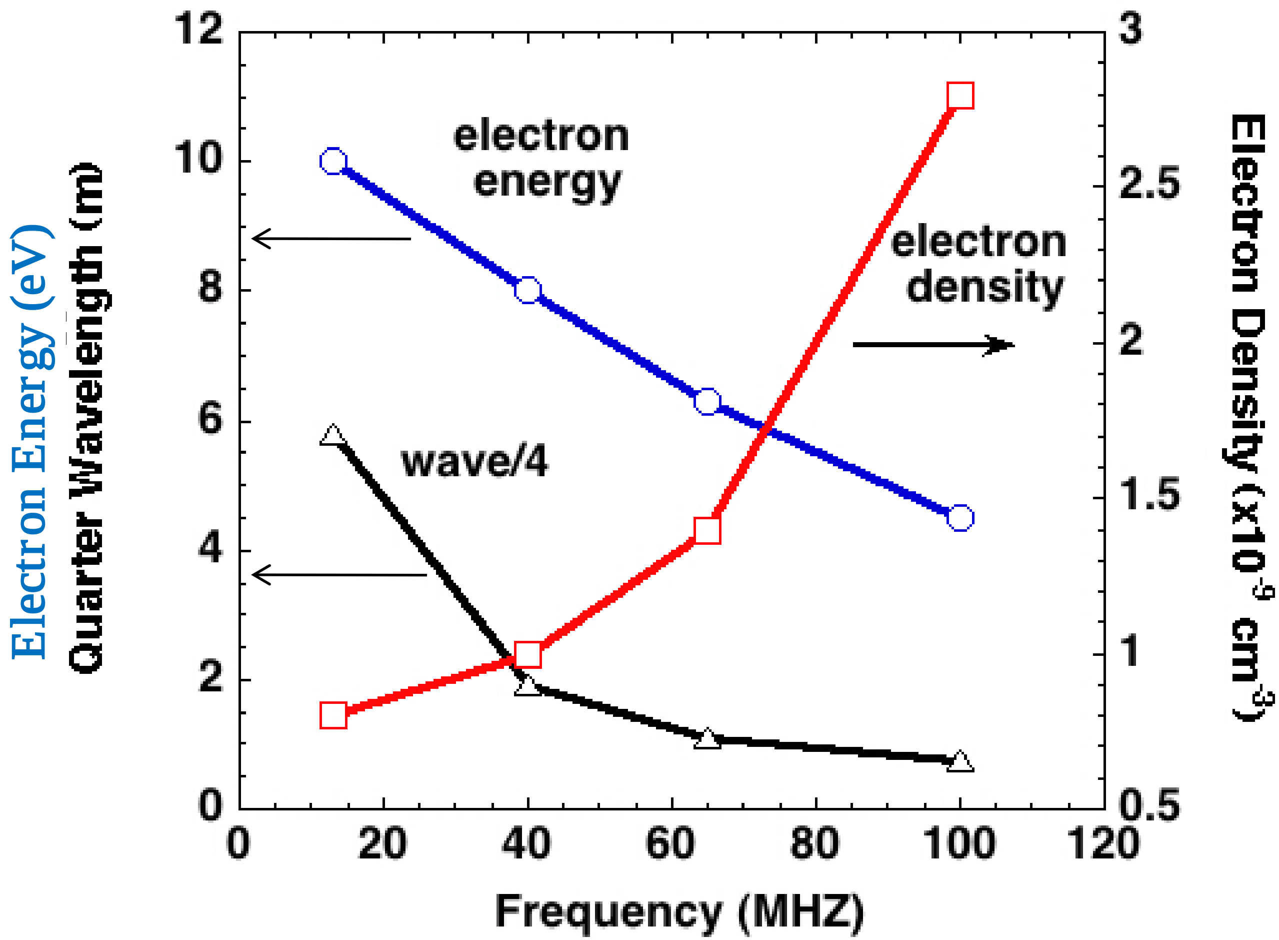
RF: 13.56 MHz

VHF:
27 MHZ -80 MHz

LPD: < 1 Torr
HPD: 3-10 Torr

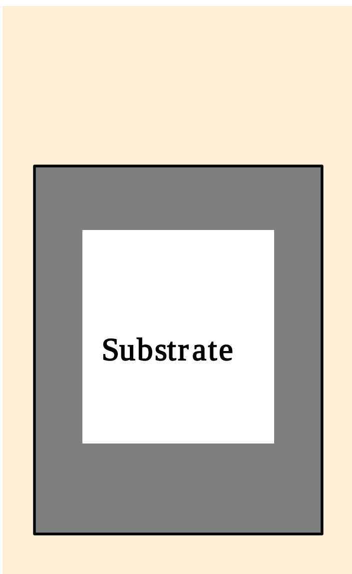
Data collected from
J. Appl Phys.
Appl. Phys. Lett.
Several PV groups

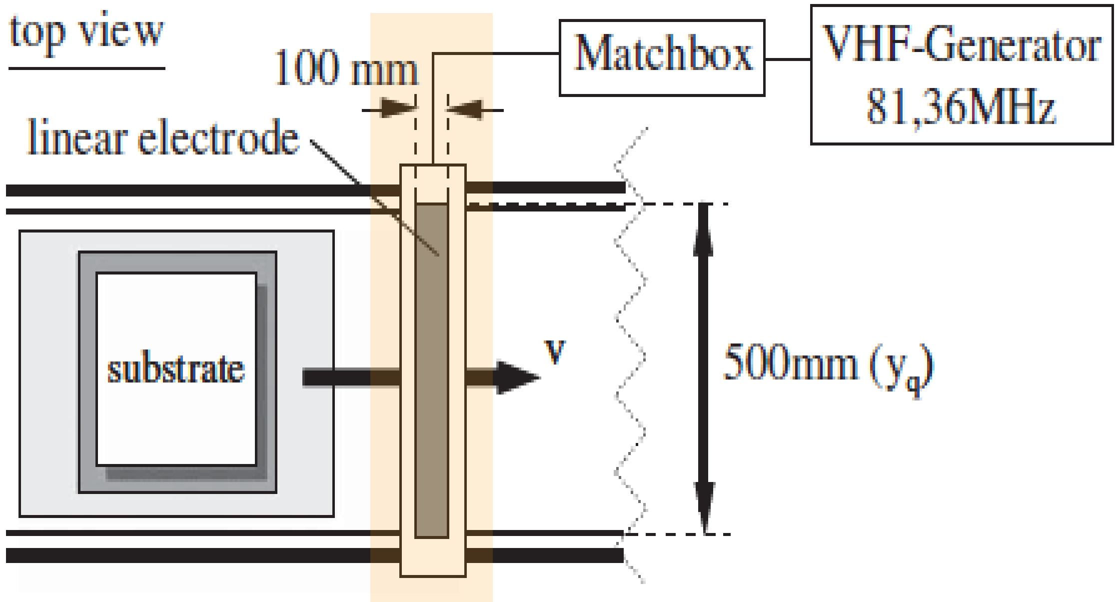
Effect of Frequency on plasma deposition process



Improved homogeneity @ high dep rate with VHF

Concept of Linear Source Electrode: Homogeneity and Throughput issues





Planar electrode

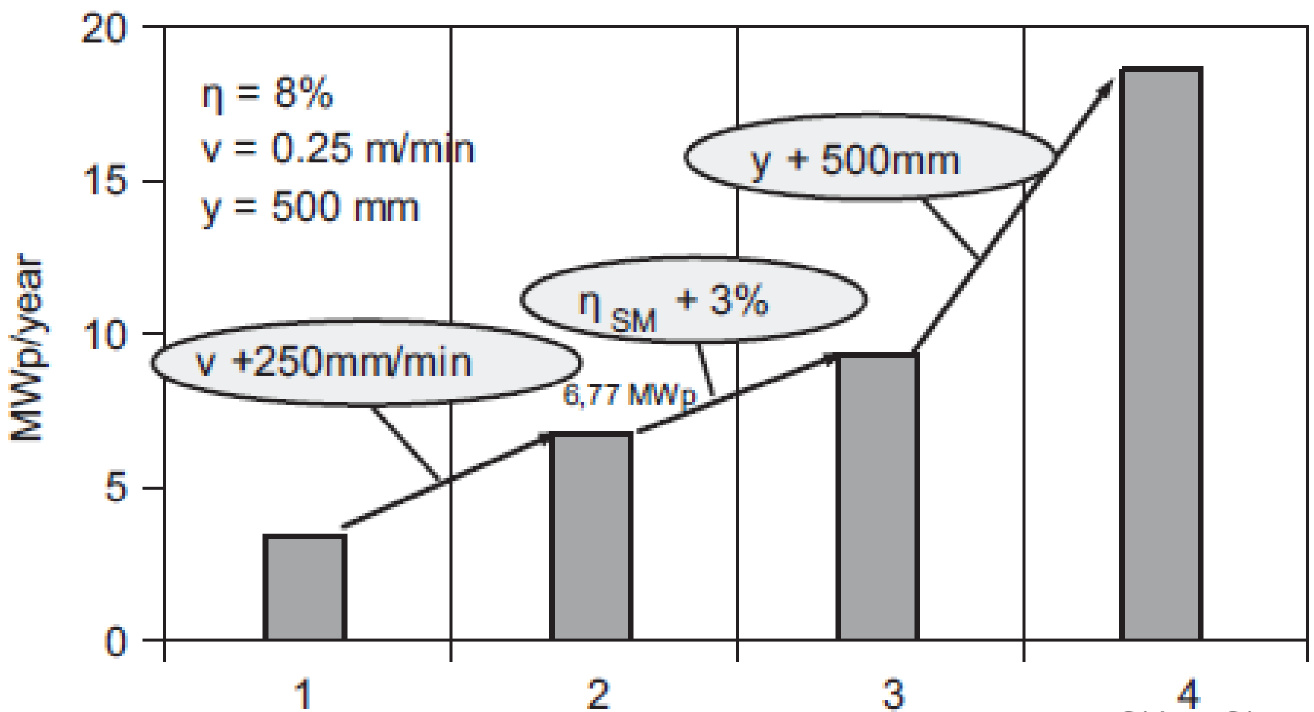
Linear (rod) electrode

Dresden Univ. of Technology

Cost estimation for in-line production machine

substrate width (y)
substrate velocity (v)
solar module efficiency (η)
deposition rate (r).

Estimation done by :
Dresden Univ. of Technology
and FAP GmbH, Germany

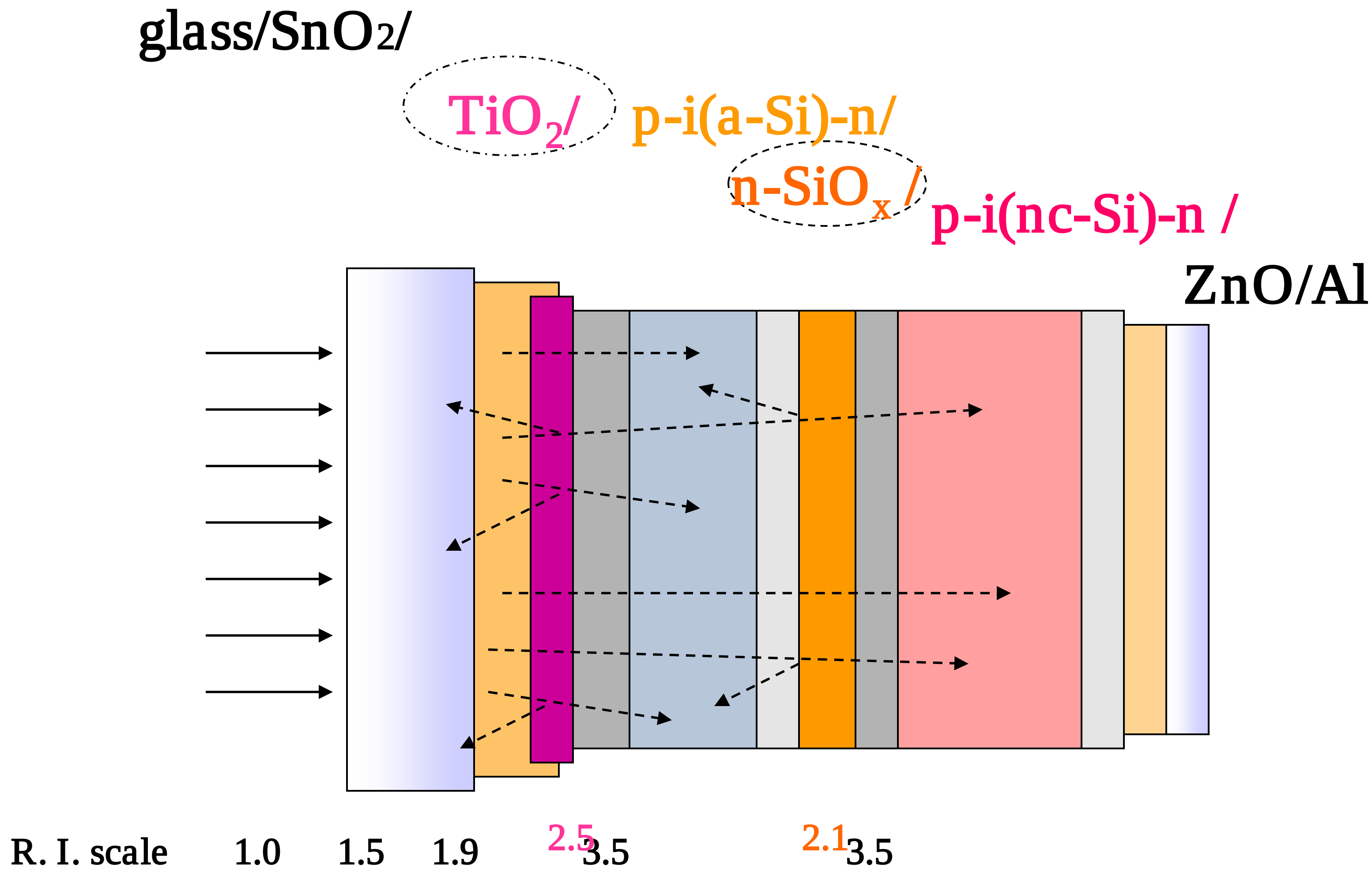


a-Si a-Si a-Si/nc-Si a-Si/nc-Si

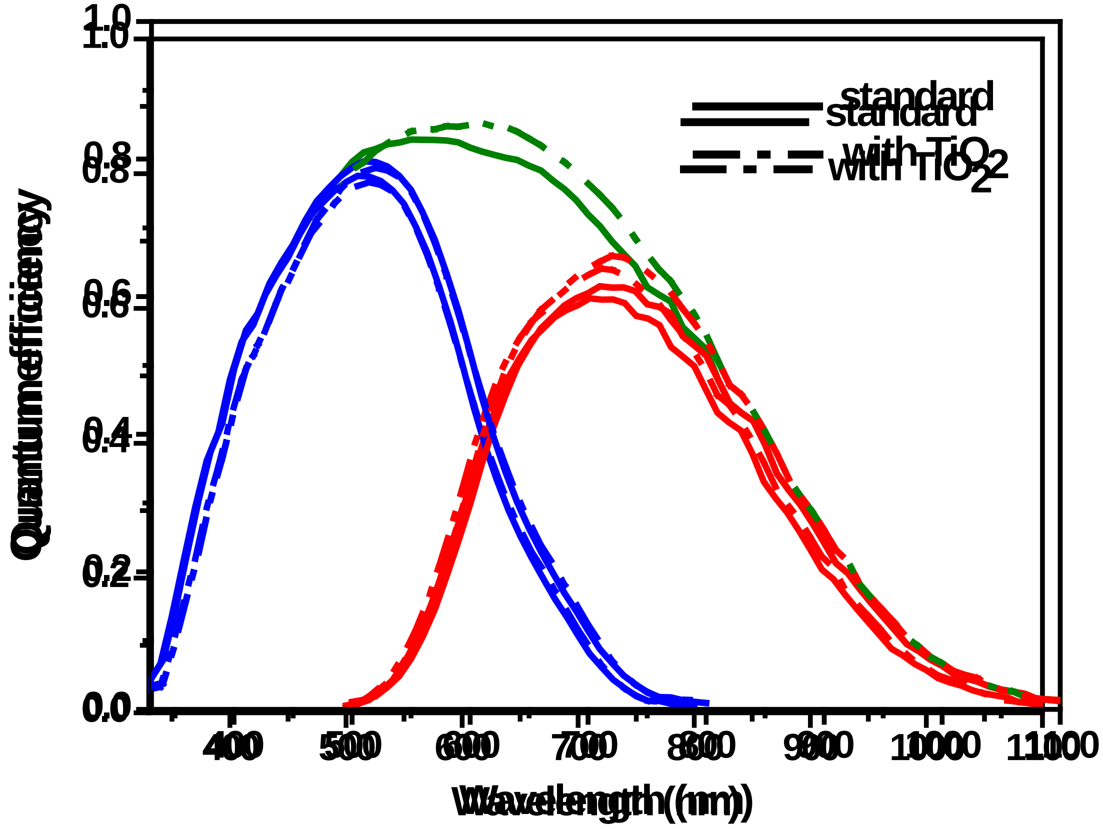
Improved light harvesting with new optical engineering

Index matching optical layers

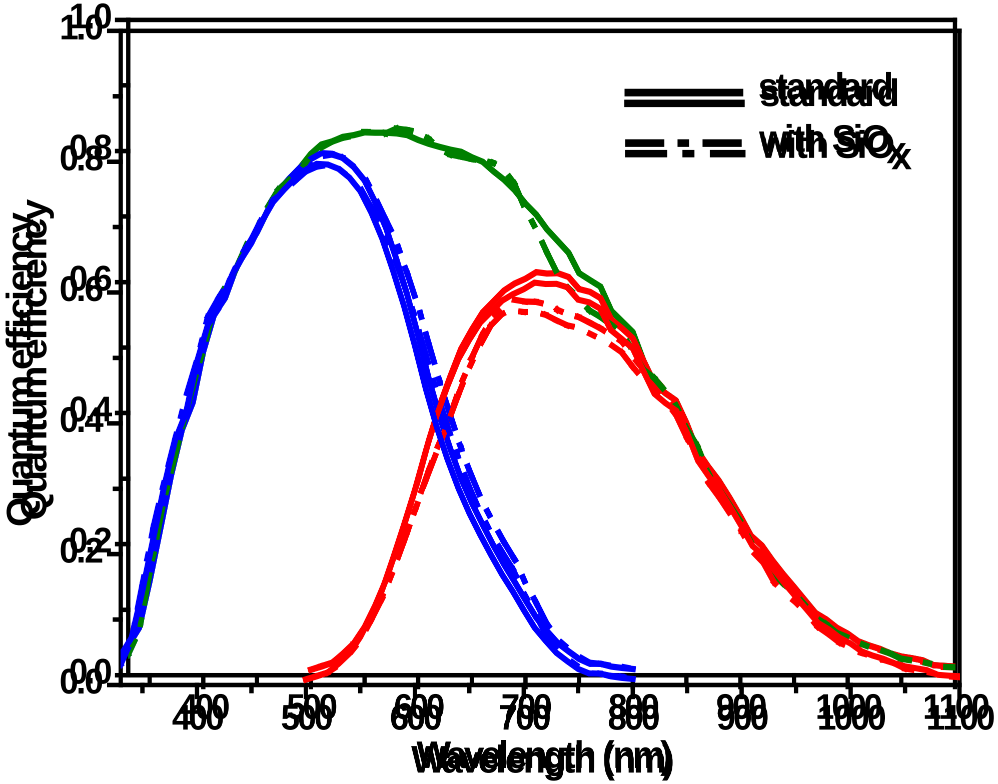
Device design for a-Si/nc-Si thin film solar cell



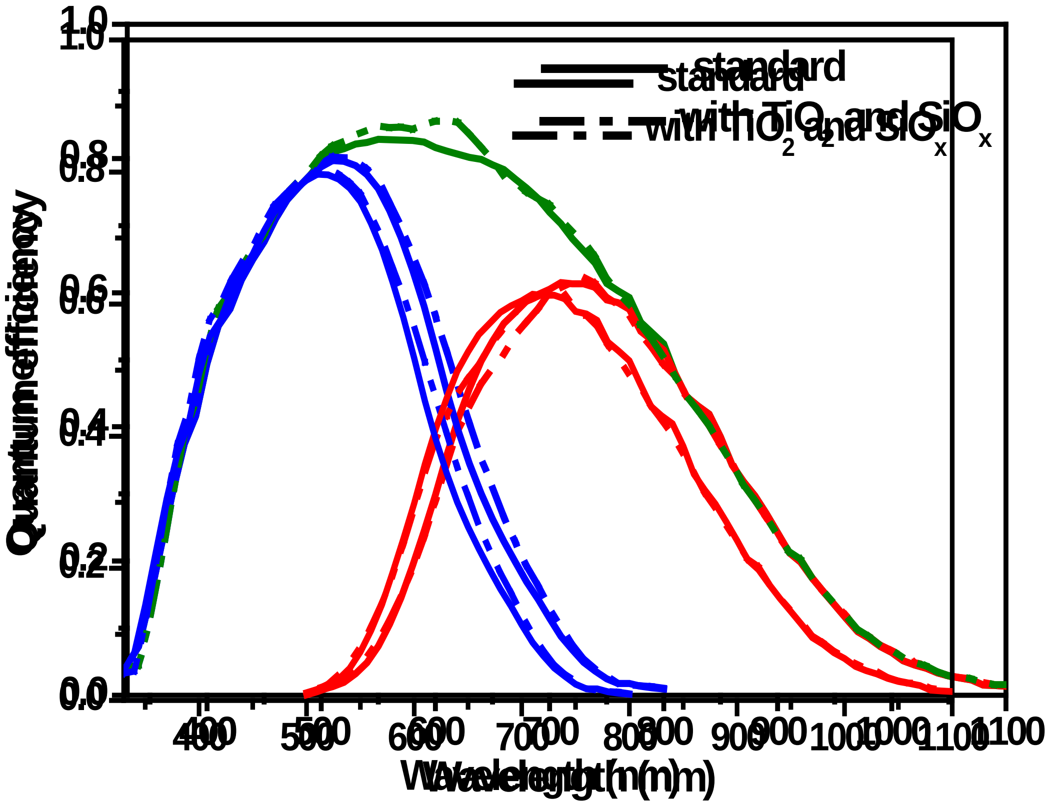
a-Si/nc-Si cell with TiO_2 as anti-reflection layer



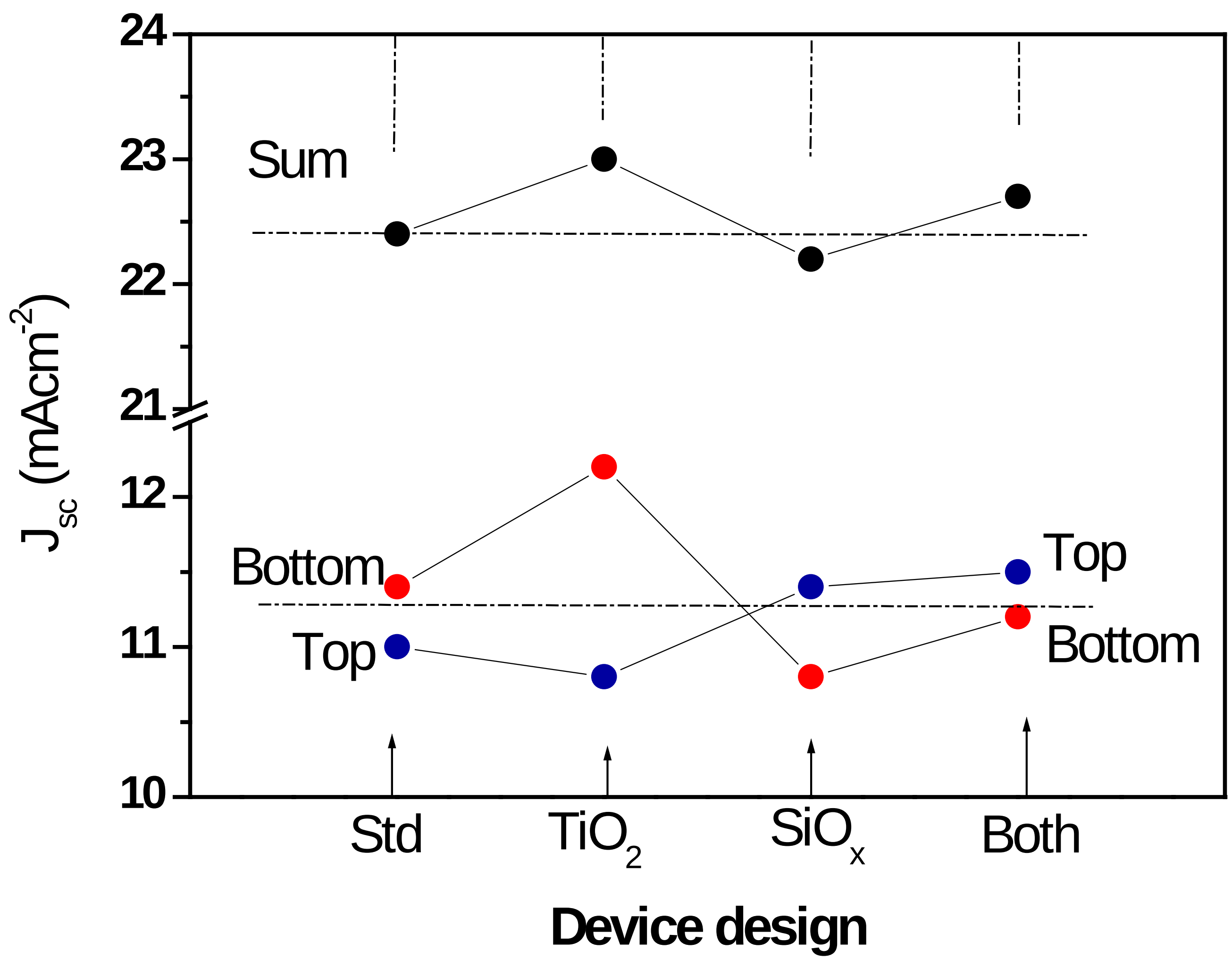
a-Si/nc-Si cell with SiOx as intermediate-refletor layer



a-Si/nc-Si cell with both TiO2 and SiOx as index matching optical layers



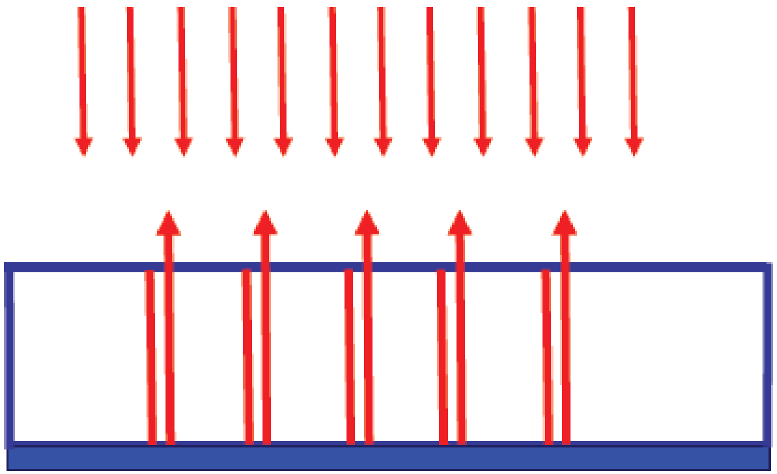
Current management in a-Si/nc-Si cell



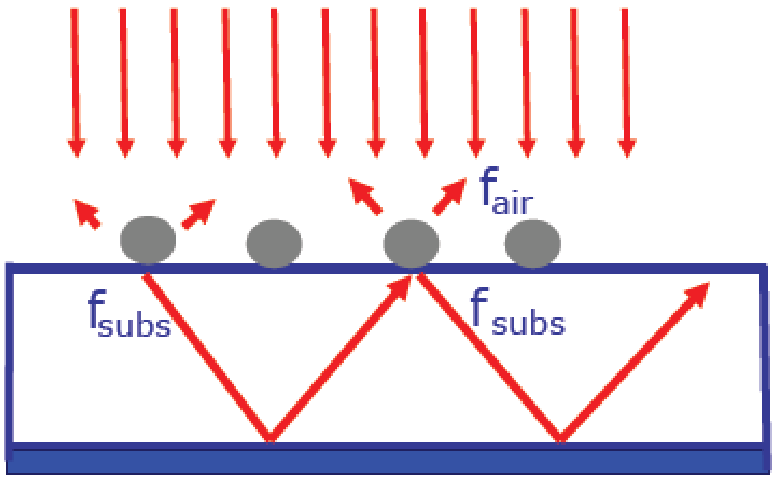
a-Si Top
nc-Si Bottom

Plasmonic absorption with nanoparticles

Light trapping by surface plasmons



Conventional design

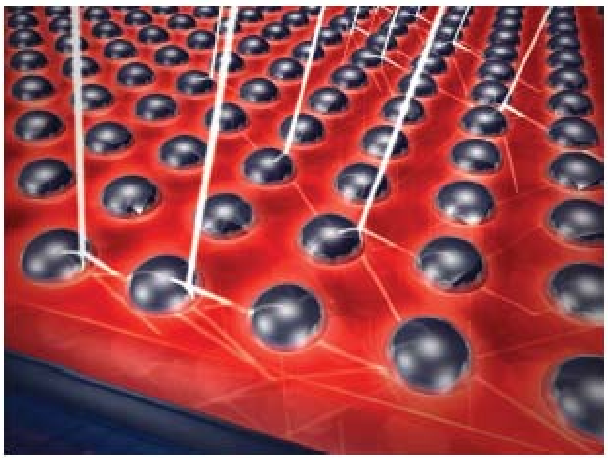


Surface Plasmonic Patterning

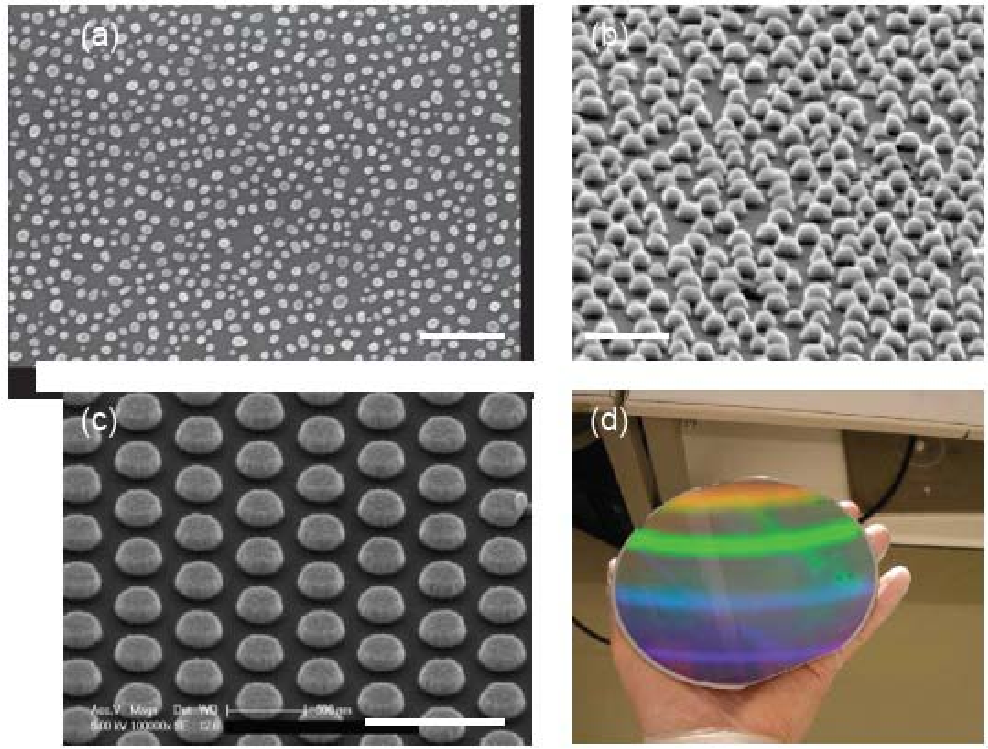
Attwater et al./ Polman et al.

Surface Plasmonic Light Trapping

Metal nanoparticle
surface coatings



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

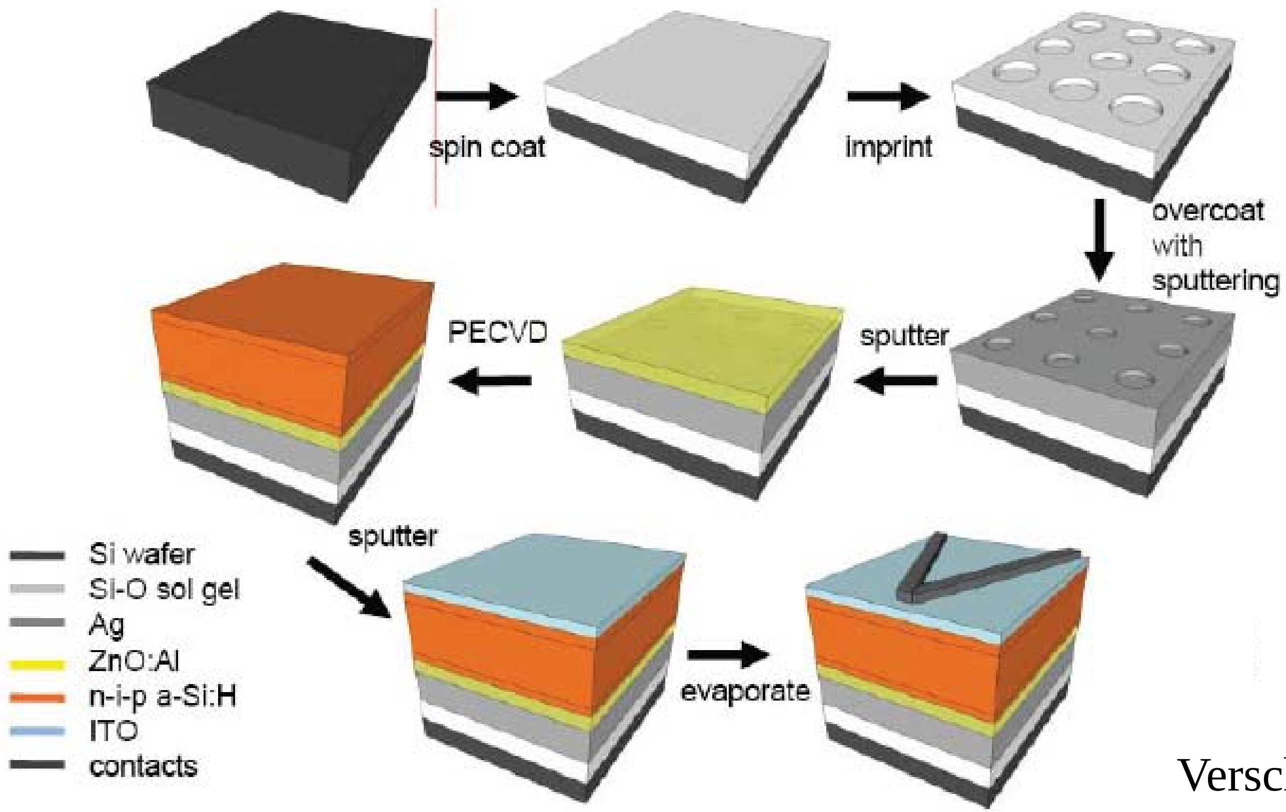


Substrate conformal imprint lithography (SCIL) - Philips

A. Polman et. al

Demonstration of Plasmonic Solar Cell Design

Amorphous Si thin-film solar cell fabrication steps

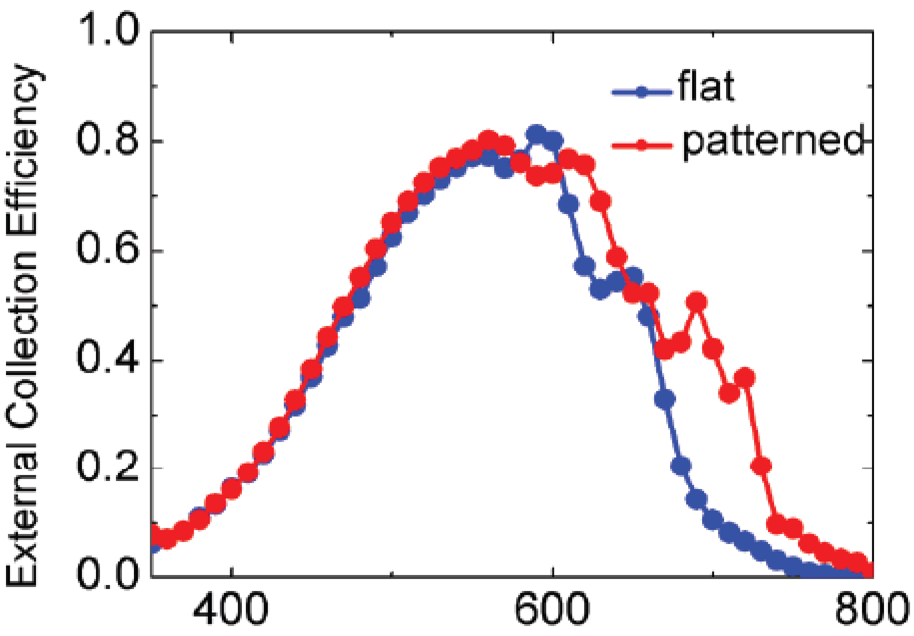


Verschuuren et al.
Schropp et al

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