2.626 Fundamentals of Photovoltaics
Fall 2008

Wafer Silicon-Based PV: From Wafers to Modules

Lecture 10 – 2.626

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General Announcements

- Quiz #1
- Class Projects

Si-based PV Production: From Sand to Systems

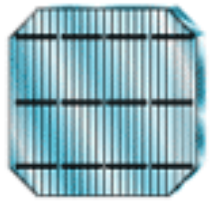
Image removed due to copyright restrictions. Please see http://freewebs.com/pinnaclegt/Polysilicon%20chunks.jpg.

Courtesy NASA and EERE.

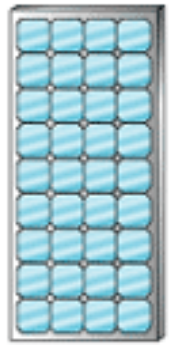
Raw Materials

Si Feedstock

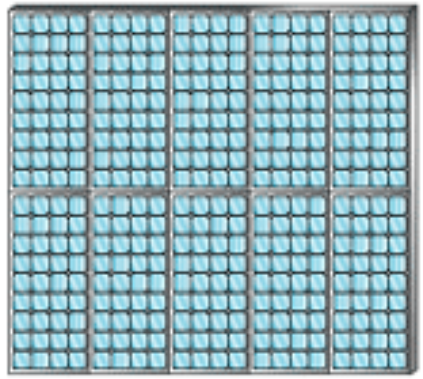
Wafer



Cell



Module



System

Cost breakdown

Graph of photovoltaic system cost breakdown removed due to copyright restrictions.

Source: H. Aulich, PV Crystalox Solar, 2007

Cell Processing

Image removed due to copyright restrictions. Please see
http://www.roth-rau.de/datenbanken/photovoltaic/Solland_Line.jpg

Cell Processing Today

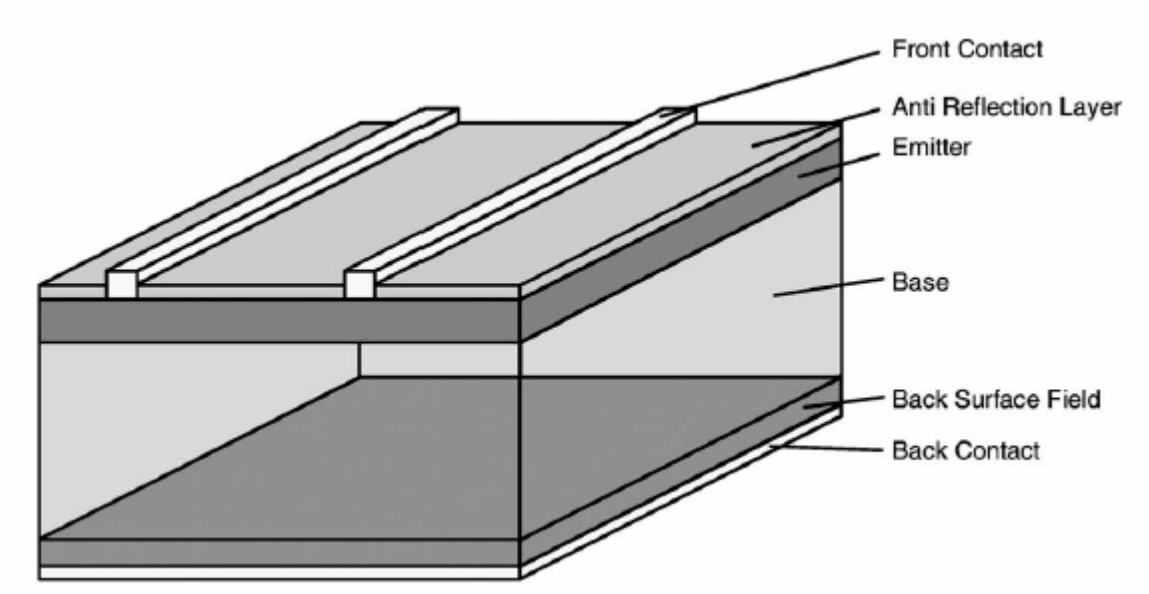
- Current fab capacity: 0.05–0.1 GW_p/yr.
  - > 13,000,000 – 26,000,000 cells/yr.
    - 1,400–2,900 cells/hr, 0.4–0.8 cells/sec)
    - *(15.6 cm^2 cells, 16.5% eff., 90+% yield)*

Image removed due to copyright restrictions. Please see
http://web.archive.org/web/20051210052417/www.centrotherm.de/Products/Photovoltaics/Page20155/Fab1.gif

Model 0.04GW_p fab
http://www.centrotherm.de/Products/Photovoltaics/Page20155/page20155.html

From silicon wafer to solar cell

- Saw damage removal etch
- Diffusion
- PSG Etch
- Edge Isolation
- Nitride
- Metallization
- Firing
- Test and Sort



Goetzberger et al, Material Science and Engineering R 40 (2003) 1-46

- Virtual factory tour at Q-Cells…

- Available as streaming video at:

http://www.q-cells.com/medien/solarenergie/herstellung/q-cells_ut_dsl.mp4

“How is a solar cell produced?”

In-line etch tools

http://www.rena.com/uploads/pics/F_223_0002_02_b_02.jpg

http://www.rena.com/typo3temp/pics/a12c4f60b7.jpg

http://www.pvmlphotovoltaics.com/images/man_edgeisloation.jpg

http://www.rena.com/index.php?id=40&L=1

Cell Processing Technology Evolution

Automated, High-Volume Batch Processing for Damage Etching, Diffusion ($POCl_3$), Antireflection Coating.

Image removed due to copyright restrictions. Please see
http://commons.wikimedia.org/wiki/File:Centrotherm_diffusion_furnace_at_LAAS_0493.jpg

http://www.centrotherm.de/Products/products.htm

In-line Diffusion

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http://www.btu.com/images/DiffusionFurnaceEntrance.jpg
http://www.sierratherm.com/images/1500.jpg

http://www.sierratherm.com/SolarCell.htm

www.btu.com

Cell Processing Technology Evolution

Silicon nitride antireflection coatings (ARC)
replace titanium oxide (and TiOx/MgFx)
Additional benefit of H2 passivation

http://www.roth-rau.de/datenbanken/photovoltaic/11728547651.jpg
http://www.roth-rau.de/datenbanken/photovoltaic/11728547652.jpg
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http://images.pennnet.com/articles/sst/thm/th_new%20inspection%2003.jpg

http://www.centrotherm.de/

http://www.roth-rau.de/index_engl.html

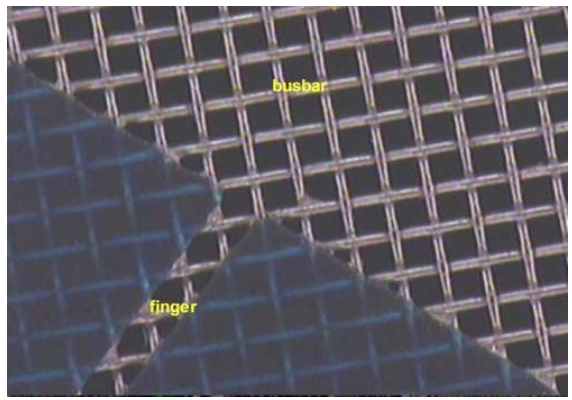
Cell Processing Technology Evolution

Screen printing for metallization developed, proven.

> Amazingly, it works, although front metal only contacts a tiny percentage of the emitter!

> Avoids galvanization, increases throughput.

http://www.sportop.com/images/screen-printing/automatic-screen-printing-press.jpg



Solar cell screen

http://www.udel.edu/igert/pvcdrom/MANUFACT/SCN_MESH.JPG

Courtesy Christiana Honsberg and Stuart Bowden. Used with permission.

Screen printing a shirt.

Image removed due to copyright restrictions.

http://www.polykomp.com/images/ESM500Unplated.gif

Close-up of screen printed metallization finger

Screen printing a solar cell.

http://www.sportop.com/screen-printing-services.cfm

Test and sort

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http://www.spirecorp.com/spire-solar/downloads/datasheets-april2009/Spi-Cell%20Sorter%20Rev%20B%2011-08.pdf
http://www.spirecorp.com/images/spire_solar/products/interconnect_solar_cells/SPI-ASSEMBLER_5000_animated.gif

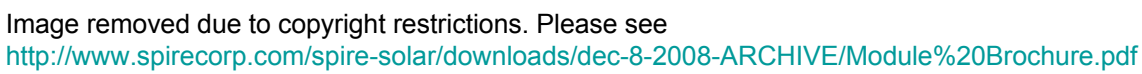
Image removed due to copyright restrictions. Please see
http://www.spirecorp.com/spire-solar/downloads/dec-8-2008-ARCHIVE/Module%20Brochure.pdf

Tabbing, Stringing and Layup

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http://www.spirecorp.com/minisite/Spire-Solar/files/images/spire_solar/product-images/600/Spi-Assembler-6000.jpg

Module Fabrication

Laminator

Trim and frame

http://www.spirecorp.com/minisite/Spire-Solar/files/images/spire_solar/product-images/600/Spi-Laminator.jpg
http://www.spirecorp.com/minisite/Spire-Solar/files/images/spire_solar/product-images/600/Spi-Frame-Press.jpg
http://www.spirecorp.com/images/spire_solar/2008/equipment/product/large/jboxer.jpg

Finish (J-box)

Technology Directions for c-Si

- Islands of automation cede to continuous in-line systems (diffusion, ARC, metallization).

Images removed due to copyright restrictions. Please see http://www.otb-solar.com/files/LINEx.pdf

Sample 8m cells/yr factory by OTB-Solar

Technology Directions for c-Si

- Low-throughput processes (bottlenecks) usurped.
- Higher-efficiency processes developed.

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http://pcdandf.com/cms/images/stories/mag/0602/0602woz1.jpg
http://www.ecn.nl/uploads/RTEmagicC_Celtechnologie2.jpg.jpg

Printing metallization (inkjet).
http://pcdandm.com/cms/content/view/2348/95/

Optimized (back contact?) metallization.
http://www.ecn.nl/en/zon/rd-programme/silicon-photovoltaics/crystalline-silicon-solar-cell-technology/

Technology Directions for c-Si

- Handling thin (~100 μm) wafers with high yield!

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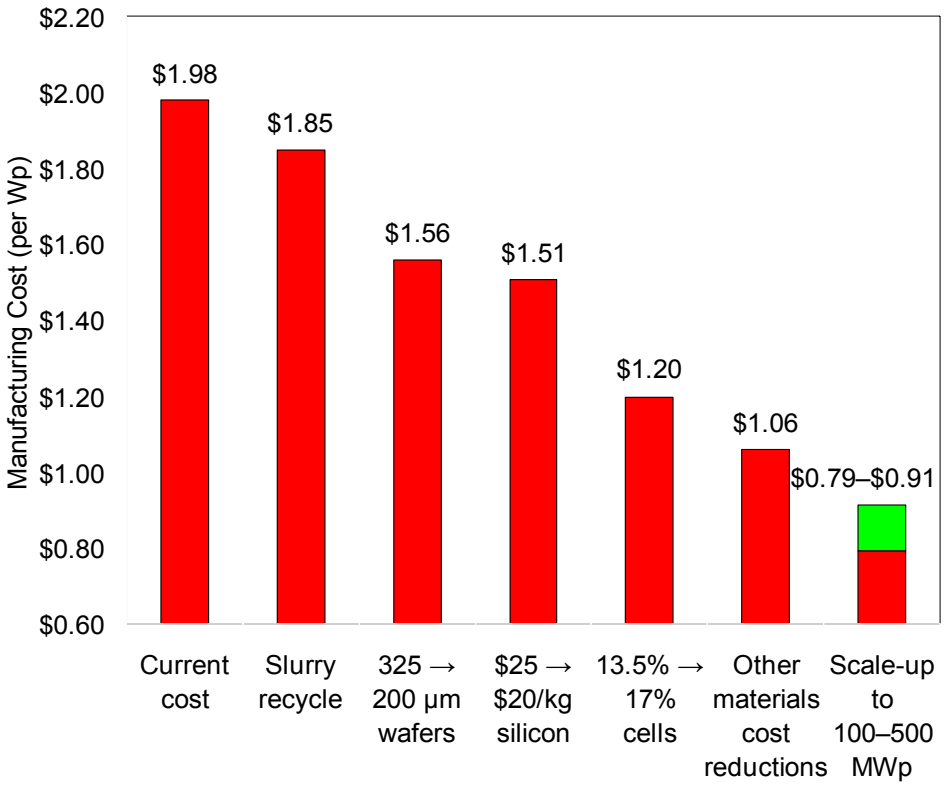
http://www.spirecorp.com/images/spire_solar/products/vac_660_pict_4.jpg
http://www.photovoltaik-zulieferer.de/fileadmin/user_upload/firmenbilder_2008/iBZPV_Jonas_Redemann_Bernou.jpg

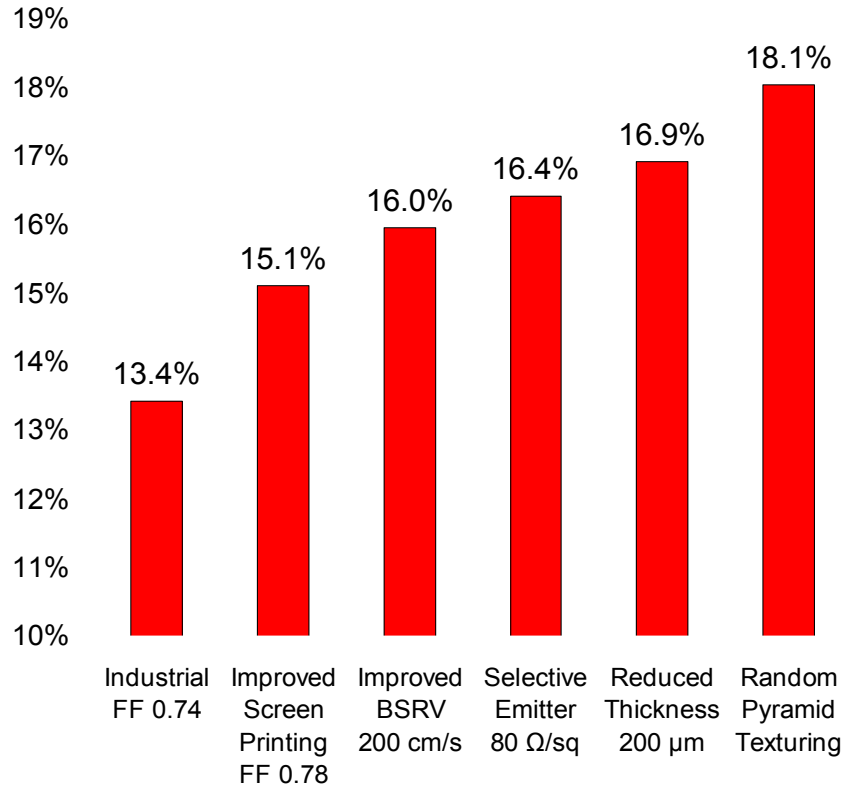
Suction cups.

Bernoulli grippers.

http://www.astec-halbleitertechnologie.de/docs/cc/download/PB_WTS-SC.pdf?PHPSESSID=83f7709a94d900a00e3dd1da5e056311

Economic and Technology Roadmaps for Producing PV Modules at ≤1 $/W





Courtesy of A. Rohatgi. Used with permission.

17-18%-efficient, 200 µm thick screen-printed solar cells with 500 MW annual production capacity can deliver ≤1 $/W PV modules

MIT and Local c-Si Companies

Map showing companies in the Northeast U.S. involved in crystalline silicon production removed due to copyright restrictions.