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Kerf-less Silicon Technologies for PV

Dr. Andreas Bentzen

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About Beacon

- Bentzen Consulting was established as a sole proprietorship in 2012
- Serving primarily the photovoltaics and semiconductor industries, Beacon offers consulting services on:
  - Process and product development
  - Technology strategy and roadmap development
  - Technology assessment and benchmarking
  - Facilitation of improvement processes and failure modes and effects analysis (FMEA)
  - Market penetration for novel technologies

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Outline

- What is "kerf" and "kerf-less"?
- Why kerf-less?
- Si PV competitiveness – Why is Si PV so expensive?
- Some kerf-less Si technologies and their advantages (and disadvantages)
- Requirements and obstacles for kerf-less Si PV

What Is Kerf, and What Is Kerf-less?

- In wafer based Si PV, significant material losses are associated with the ingot-to-wafer process
- The "kerf", i.e. the material lost between the wafers, are roughly equal to the wire diameter plus twice the SiC slurry particle size
  - Wire: 120 – 140 µm
  - SiC: ~ 6 – 8 µm (F800)
  - Kerf: ~ 130 – 160 µm
- In addition to the kerf losses, significant Si material is lost due to edge exclusion and bottom / top cut-off
- Kerf-less silicon PV refers to silicon solar cells made such that **no or very little "absorber quality" material is wasted due to the wafering/layering process**

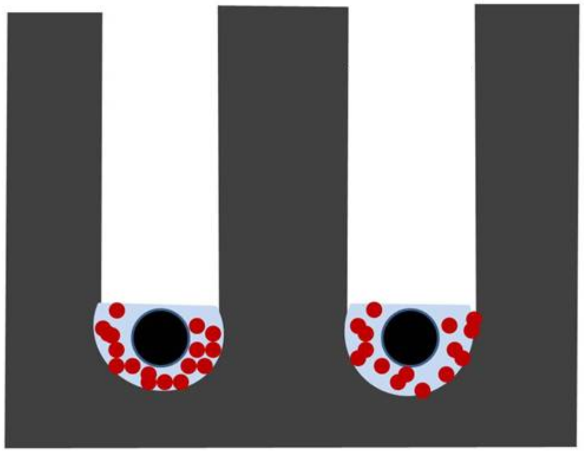

Image source: ISR [1]

Image source: BP Solar [2]

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Why Kerf-less Matters

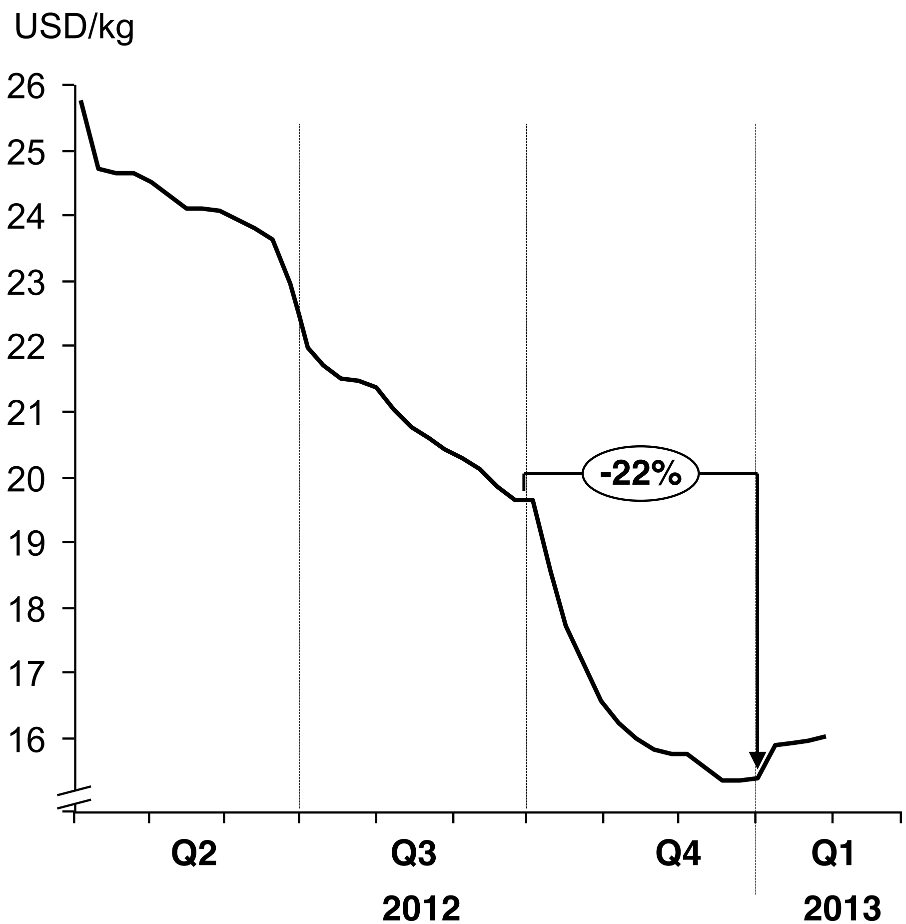

Image Source: REC [3]

- Polysilicon spot prices have declined rapidly the past ~ 2 years, reaching a current spot price of ~ 16-18 USD/kg
- "Best in class" polysilicon costs are currently about 20 USD/kg with a cash cost of ~ 12 USD/kg
- State-of-the-art silicon consumption for mc-Si PV is now 4 – 4.5 g/Wp, amounting to about 15-20% of the PV module variable costs at today's market prices
- In a well-balanced sustainable market, the polysilicon price "must" increase as non-competitive capacity is terminated and new investments are needed (25 – 35 USD/kg seems reasonable due to the high CAPEX for polysilicon)

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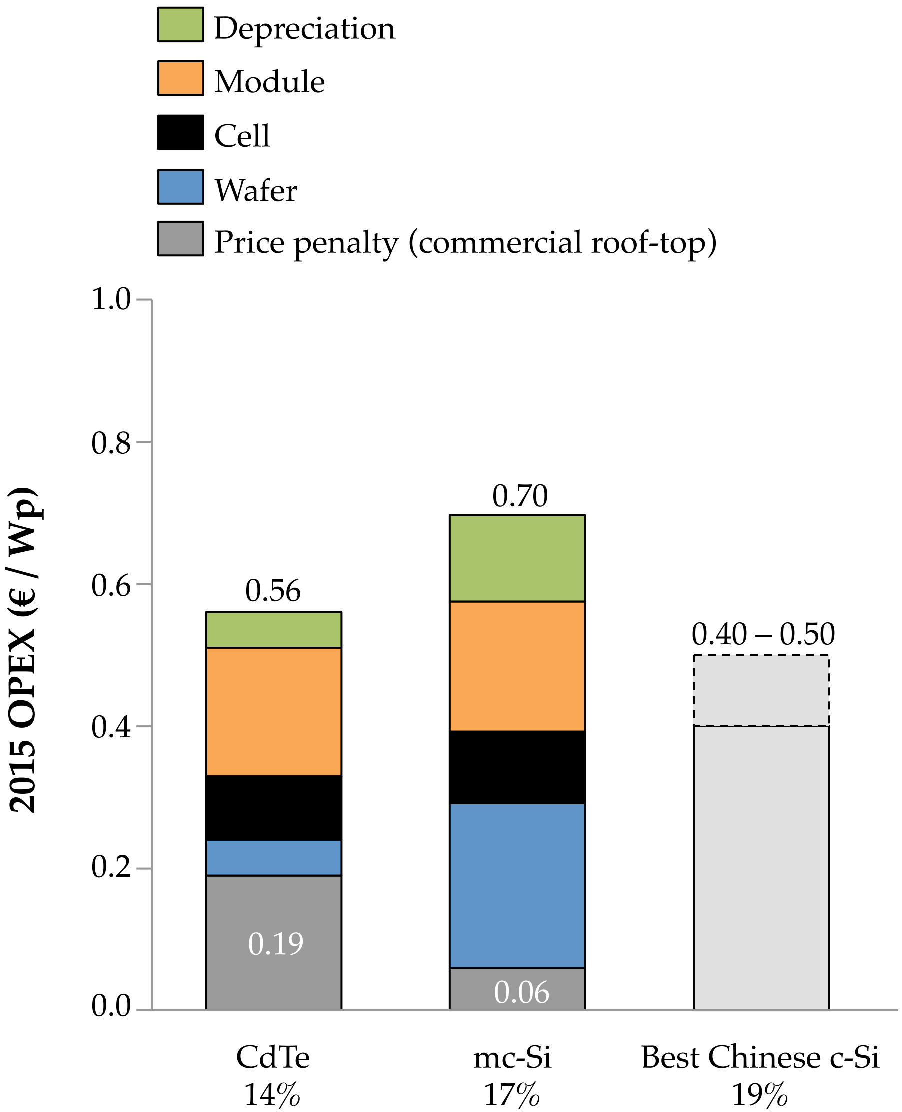
Si PV Competitiveness – OPEX (2015)



NOTE: Efficiency numbers refer to full module area efficiency

- Compared to CdTe, mc-Si has a variable cost about 60% higher **primarily due to the high wafer cost** as well as significantly higher depreciation cost
- The cost benefit of CdTe is not fully offset by the handicap of lower efficiency (and size) for utility scale or large commercial roof-top systems
- Considering best chinese c-Si players, Si PV is highly competitive particularly in the roof-top market segment(s)

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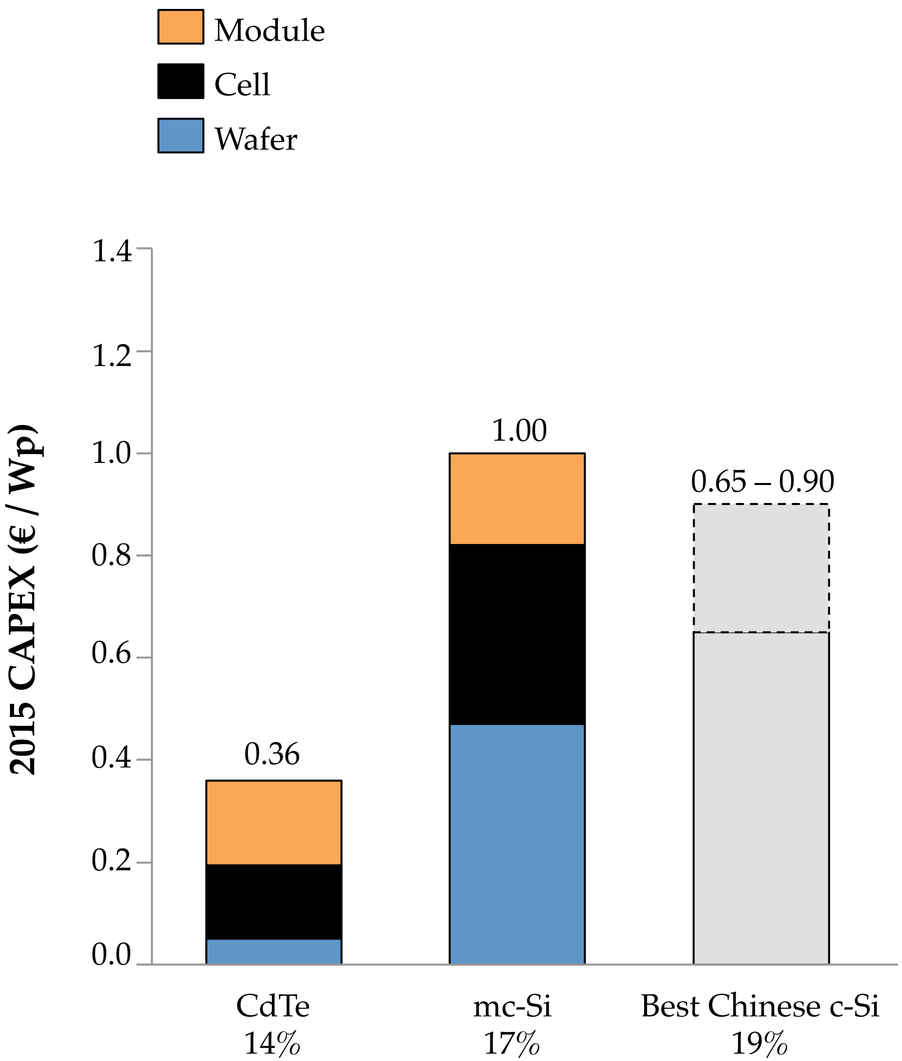
Si PV Competitiveness – CAPEX (2015)



NOTE: Efficiency numbers refer to full module area efficiency

- CAPEX cost comparison exhibits one of the major disadvantages of Si PV compared to thin film alternatives, i.e. the significant capital requirements for capacity expansion
- Again, **the largest contributor to the CAPEX disadvantage for Si PV is the wafer** (including feedstock)

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Why Is Si Wafer Based PV So Expensive?

Si wafer based PV is cost driven primarily by consumption of raw materials, cost of wafering and high capital cost of particularly feedstock and wafer manufacturing

In other words, the wafer is the limiting factor in terms of cost competitiveness for Si PV

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Kerf-less Si technologies

- Kerf-less wafering
  - Proton implantation and cleave
- Individual wafer deposition / growth
  - Direct wafer growth
  - Ribbon Si (EFG, STR, RGS). Not considered further in this presentation.
  - Epitaxial layer growth and cleave
  - Absorber deposition on permanent substrate

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Proton Implantation & Cleave

- Proton implantation at pre-determined depth creates damage layer (EOR)
- Post-implantation mechanical cleave, large range of wafer thickness possible (~ 20 – 120 µm)
- Pros:
  - High quality layers
  - Medium/low Si feedstock consumption
  - Technology applicable for regular wafer thicknesses
- Cons:
  - Throughput requirements limit usability to low wafer thickness (< 50 µm)
  - Key properties of wafer requires special care in cell manufacturing
  - Thinnest wafers requires a different approach to cell manufacturing
  - Value chain disruption

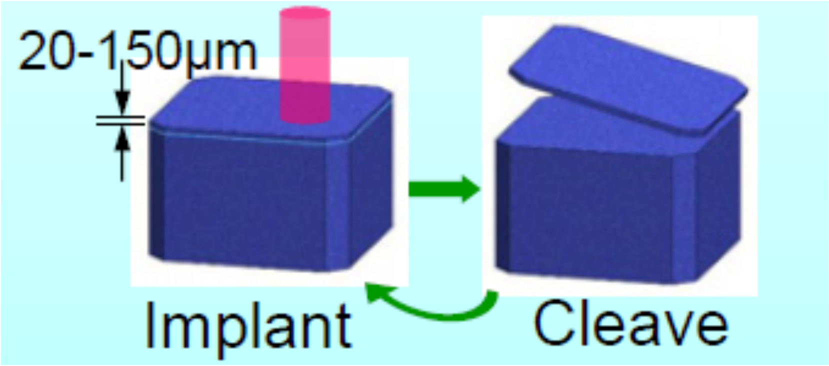

Image source: SiGen

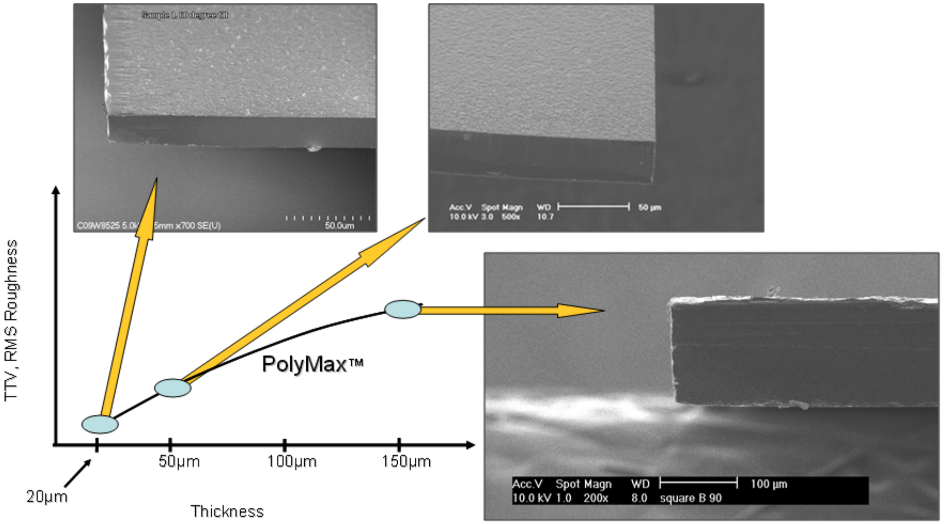

Image source: SiGen

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Direct Wafers

- Individual growth of wafers
  - Directional solidification in unit moulds (mini crucibles)
  - Individual wafer picking from melt
- Pros:
  - Zero kerf losses
  - Regular thickness wafers possible
  - Potential for swap-in usage in existing cell/module manufacturing
  - Little or no wafer-to-wafer and intra-wafer quality variations
- Cons:
  - Certain wafer properties requires special care in cell manufacturing
  - Limited material quality
  - Only wafer thickness > 120 µm?

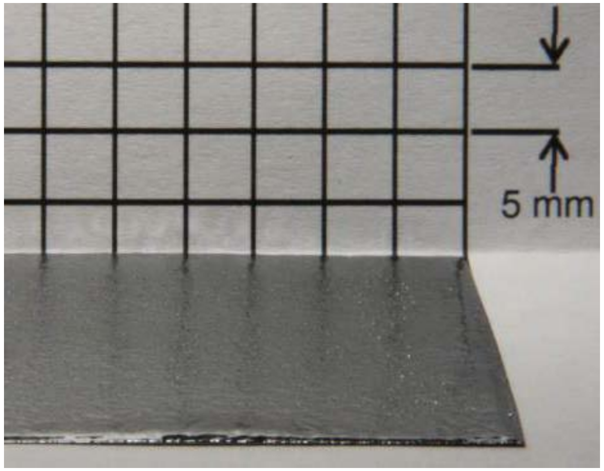

Image source: 1366 Technologies [4]

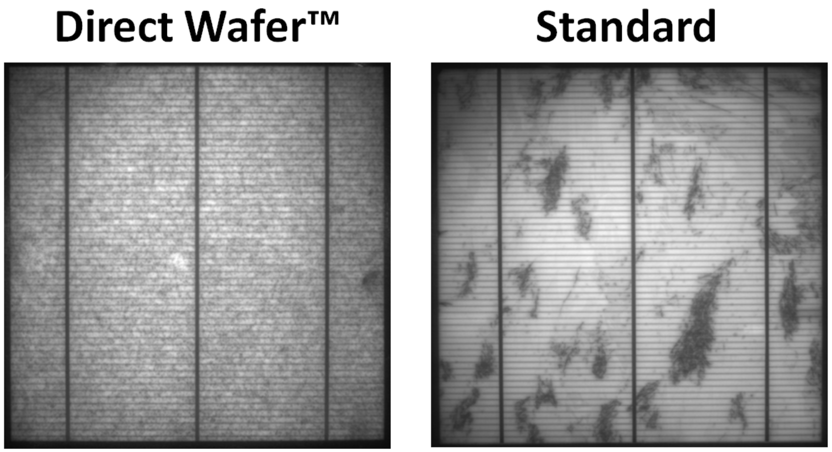

Image source: 1366 Technologies [5]

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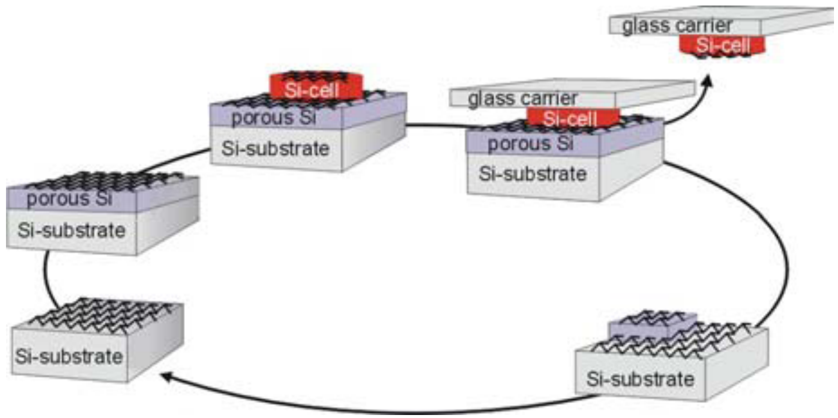
Epitaxial Layer Growth & Cleave

- Use of a porousified high-quality Si donor wafer as substrate for epitaxial layer growth
- Post-epitaxy detachment of layers, typically ~ 30 – 40 µm thick
- Pros:
  - Very low Si feedstock consumption
  - Medium/high quality layers
  - General patents expire ~ 2016, open domain concept fuels activity
- Cons:
  - High capex costs for layer manufacturing (porous etch, epi)
  - Requires a different approach to cell manufacturing
  - Value chain disruption



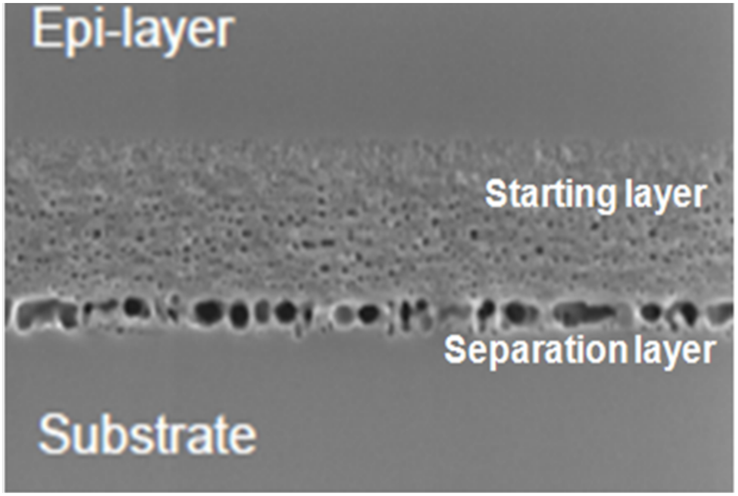


Image source: ISFH

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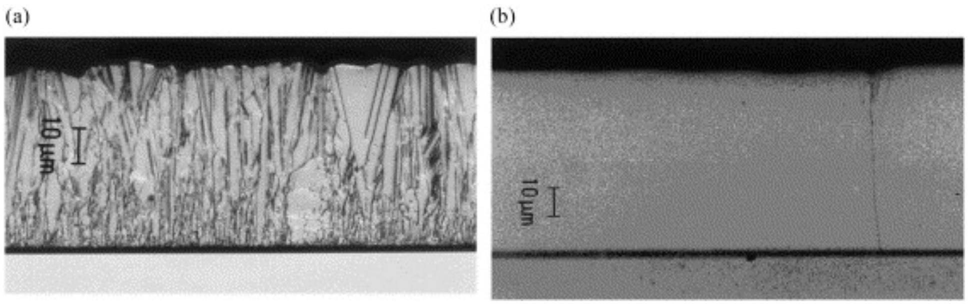
Absorber Deposition on Permanent Substrate

- Deposition or growth of absorber quality Si on low cost permanent substrate
  - LPE on MG-Si (limited attractivity)
  - Low cost deposition techniques available
- Pros:
  - Regular thickness wafers possible
  - Potential for swap-in usage in existing cell/module manufacturing
  - Potentially the lowest cost Si wafers (arguable)
- Cons:
  - Certain wafer properties requires special care in cell manufacturing
  - Limited material quality
  - Strict substrate cost requirements



Si-layer deposited on a SiO2-intermediate layer (a)
After recrystallization (b)
Image source: A. Goetzberger [6]

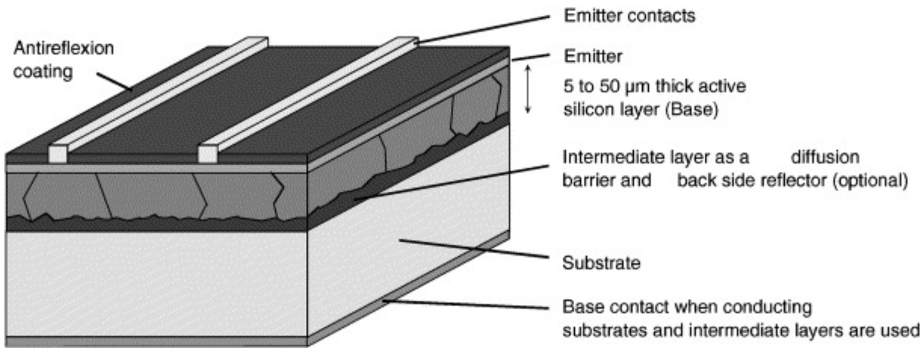


Image source: A. Goetzberger [6]

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Requirements for Kerf-less Si PV

- Must significantly reduce the wafer cost, both in terms of Si feedstock usage and wafer conversion cost (crystallization, wafering)

- Must not generate excess cost, complexity or yield losses in the cell/module manufacturing

- Must not require excessive capital deployment for equipment / manufacturing capacity

- Must deliver a comparable or better product to the customers than current state-of-the art Si PV
  - Efficiency, energy yield, form factor, cost/Wp

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Obstacles for Kerf-less Si PV

- May require a complete value chain disruption
- Changes existing value chain hand-shake
  - Many kerf-less technologies erase or move the existing borders between wafer, cell and module
  - Market penetration may become significantly more difficult and expensive
- Difficult to gradually implement in existing manufacturing lines
  - Requires abrupt changes in technology roadmaps
- May require that new capacity is added simultaneously across the entire value chain by the same manufacturer
- "Cheaper" may not be enough….

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Thank You!

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Bentzen Consulting
www.beacon.no

+47 92 22 80 64
andreas@beacon.no

References

1. T. Palathra and R. Adomaitis, ISR Technical Report 2008-9 (2008)
2. J. Wohlgemuth and M. Narayanan, NREL Subcontractor Report SR-520-37738 (2005)
3. REC, Fourth Quarter 2012 Presentation, February 8th (2013)
4. A. Lorenz, NREL Subcontract Report SR-5200-51934 (2011)
5. http://www.1366tech.com/technology/product/
6. A. Goetzberger, Materials Science and Engineering: R 40, 1-46 (2003)

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Document Revision History

Date	Revision	Comment
14.03.2013	v1.0	First complete version
02.04.2013	v1.1	Minor edits and corrections
08.04.2013	v1.2	Minor corrections
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Bentzen Consulting
Arups gate 11B
NO-0192 Oslo, Norway
Phone: +47 922 28 064
NO 998 878 144 MVA
www.beacon.no