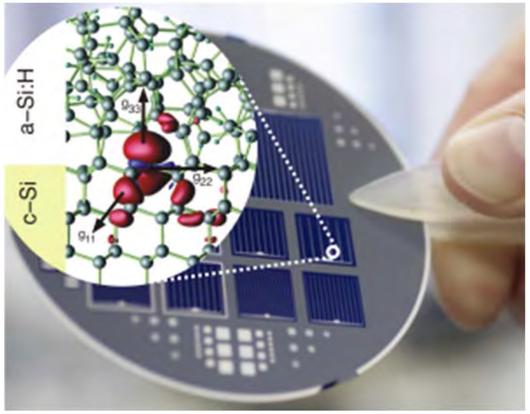
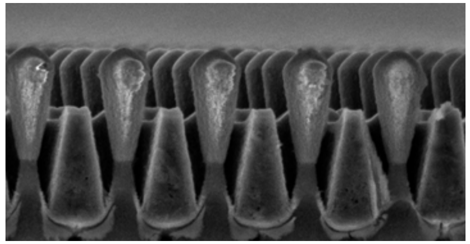




Photovoltaic towards Terawatt scale

Challenges for R&D

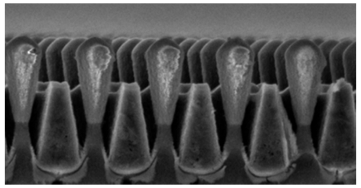
Bernd Rech
Institute Silicon Photovoltaics
HZB & Technische Universität Berlin

Thanks to:
Daniel Amkreutz, Christiane Becker, Silke Christiansen, Roel van de Krol,
Klaus Lips, Rutger Schlatmann, and many more colleagues at HZB
Eveline Rudigier-Voigt (SCHOTT AG)
Claas Helmke (MASDAR PV)

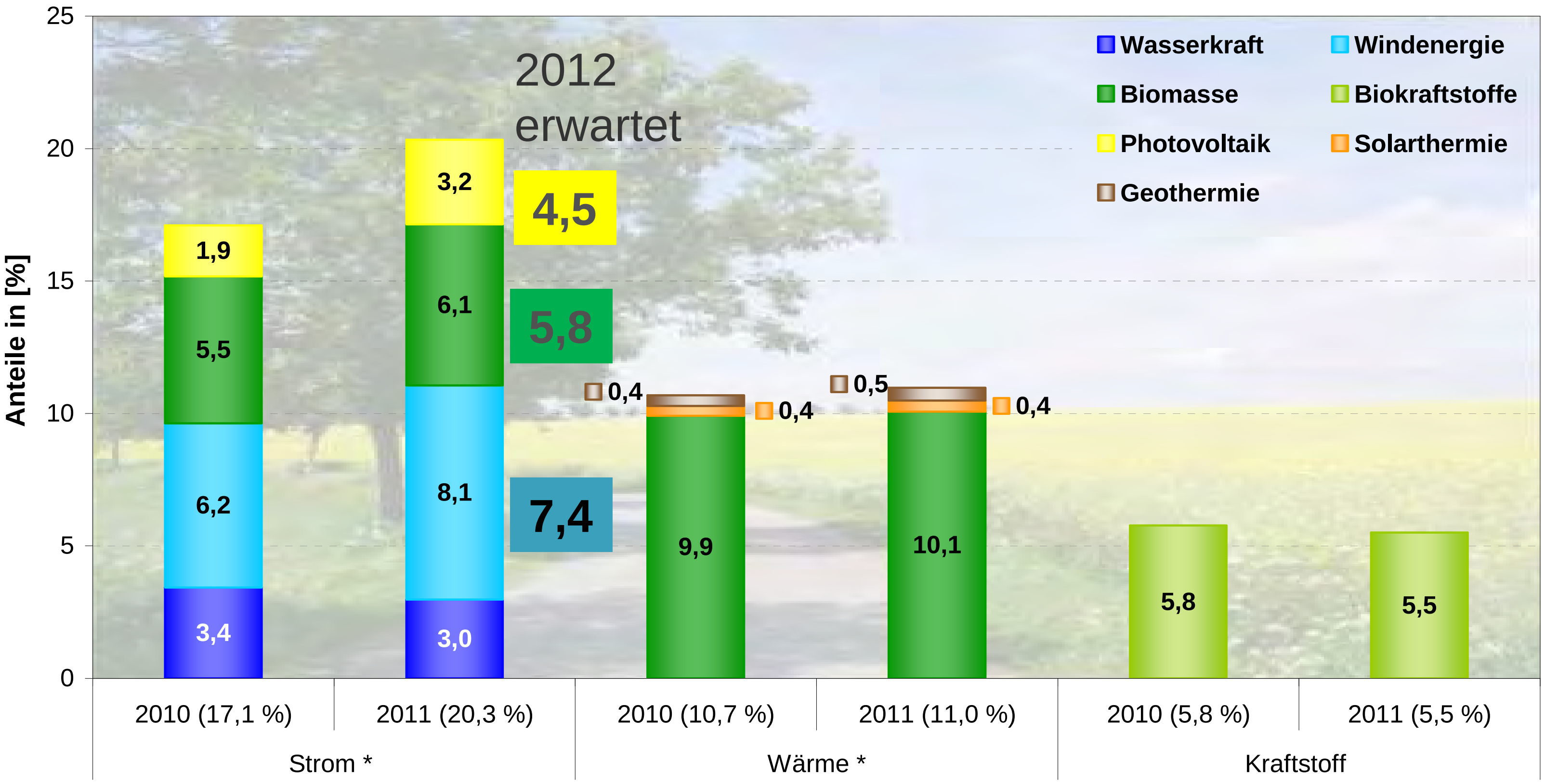
Outline

- **PV: Opportunities & Threads**
- **Challenges for R&D - Examples**
  - Thin Film Si
  - Solar Fuels
  - EMiL a new lab for PV materials research
- **Conclusions**





Renewables in Germany – some recent data

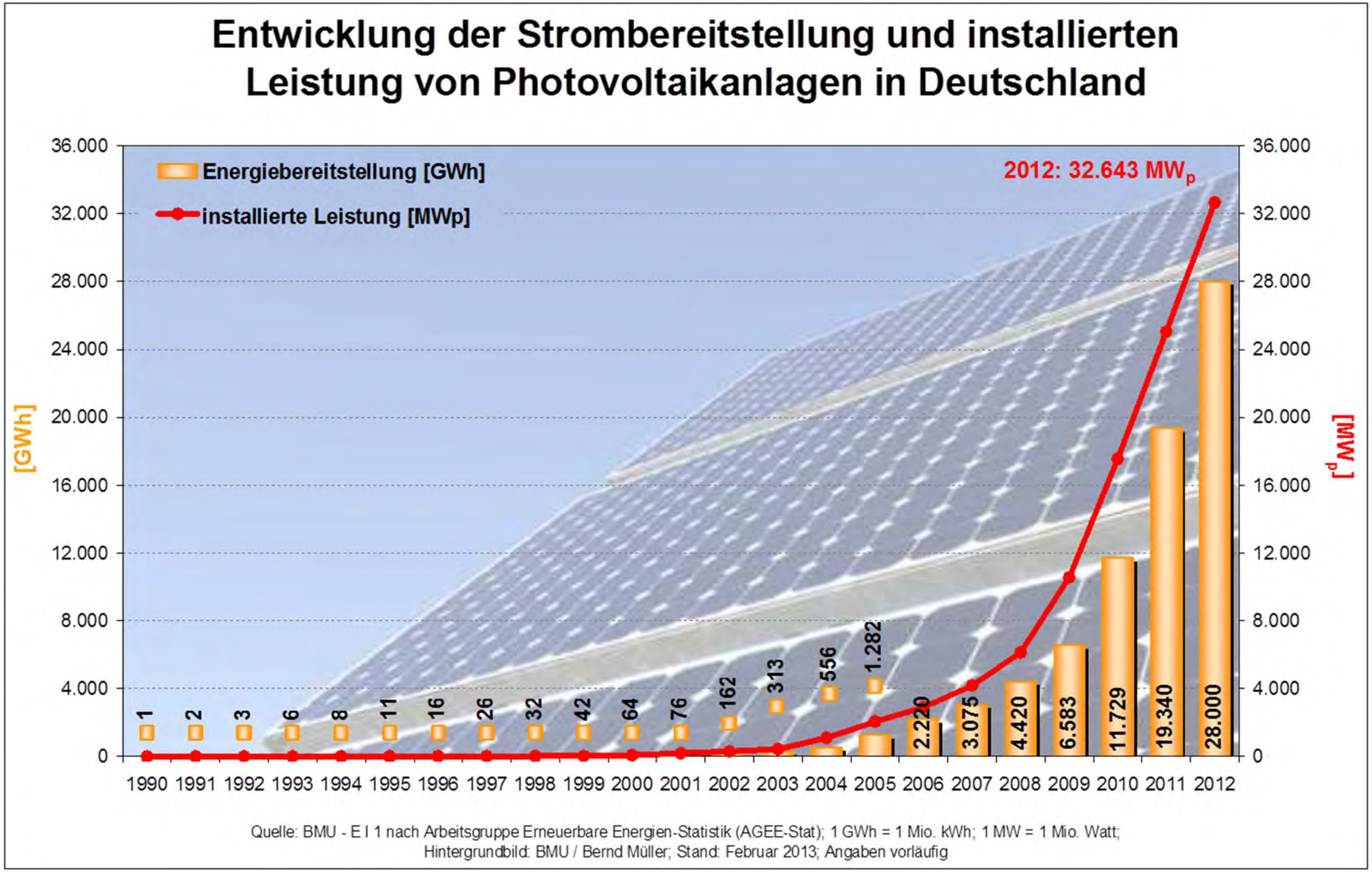


* Biomasse: Feste und flüssige Biomasse, Biogas, Deponie- und Klärgas, biogener Anteil des Abfalls; aufgrund geringer Strommengen ist die Tiefengeothermie nicht dargestellt; Abweichungen in den Summen durch Rundungen; Quelle: BMU-KI III 1 nach Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat); Hintergrundbild: BMU / Dieter Böhme; Stand: Juli 2012; Angaben vorläufig

Sources: BMU (2010/2011)www.ag-energiebilanzen.de (2012)

PV in Germany: 1990 - 2012

HZB Helmholtz Zentrum Berlin

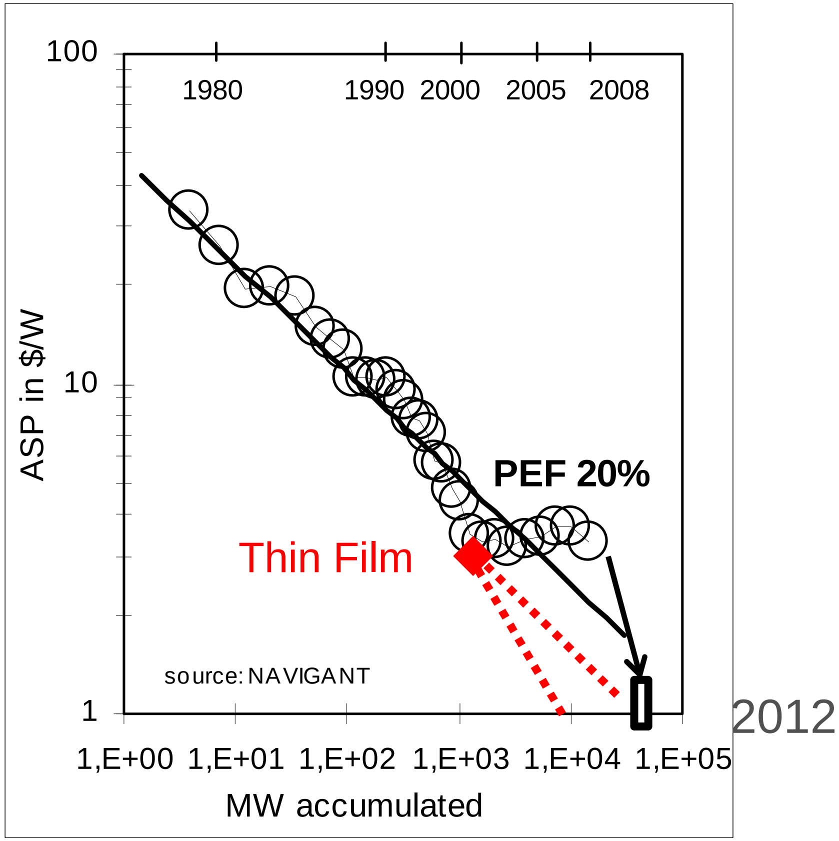


Summary Status PV in D

- Global industry (revenues > 50 Bill. €/y)
  c-Si dominates the market
- production growth > market growth!

  „Solarbranche vor der Sonnenfinsternis"
  (solar sector facing solar eclipse)
  Handelsblatt 14.6.2012)
- PV in German electricity production:
  - up to 30 % peak load in 2012
  - 4,7 % total contribution in 2012
  - on sunny days more than 20 GWp

about 100.000 jobs in D (2012)
(125000 in 2011)



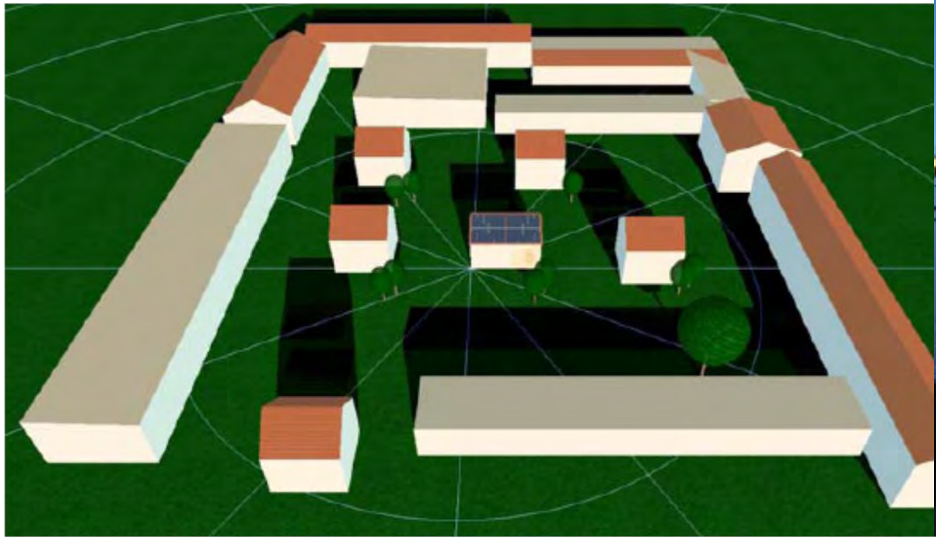
W. Hoffmann et al., 25th EC-PVSEC, 2009

PV can substantially contribute to the overall energy supply!
However, grid integration and/or storage challenging!

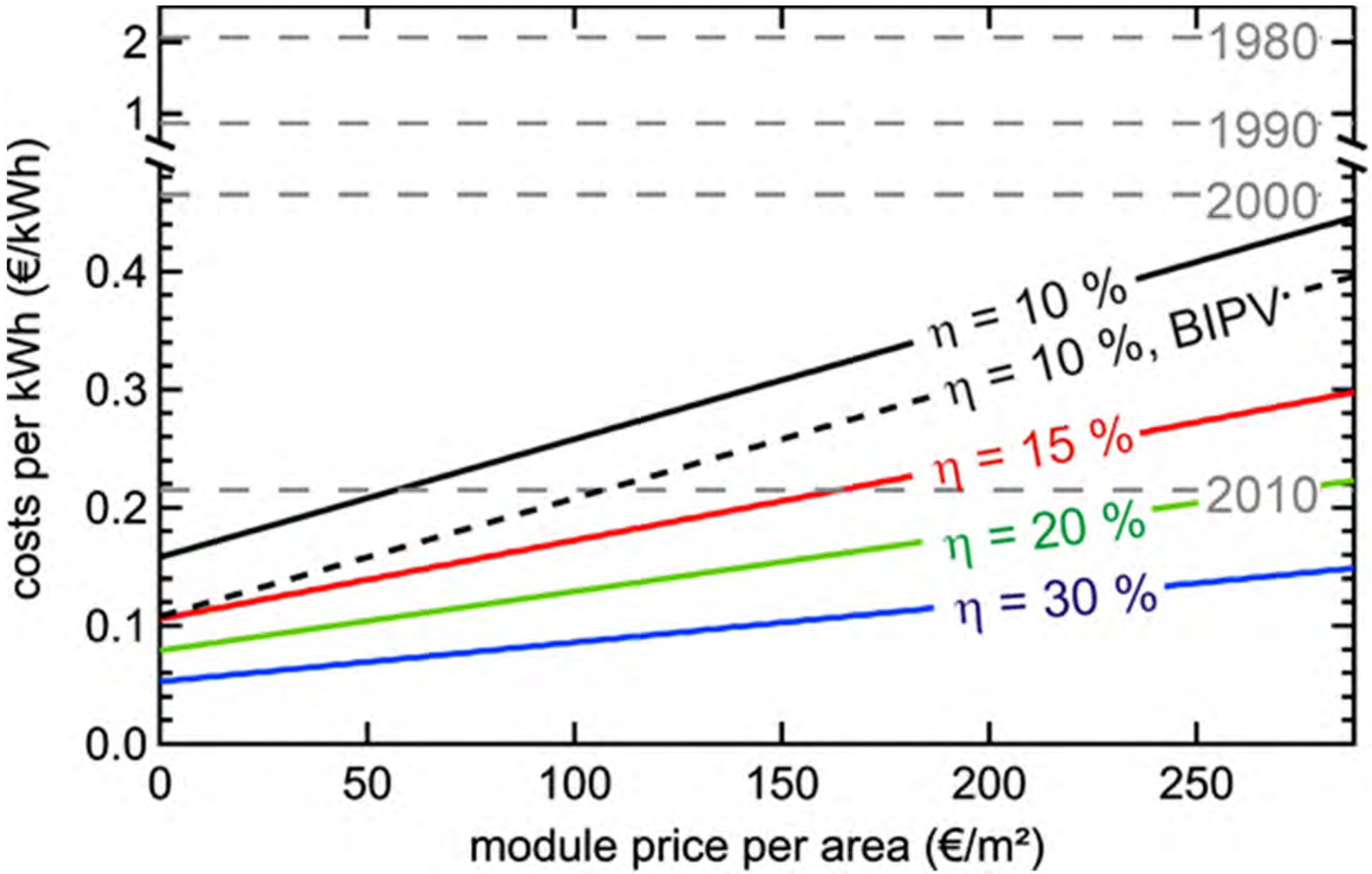
PV in Berlin today – residential home

11.5 KW_p c-Si: installation Sept. 2012
„black design“: η = 15 %
Expected production / y: 10.000 kWh
Electricity generation cost: 18 c/kWh

	costs in €	costs in €/Wp	costs/kWh
Modules	11500.00	1.00	0.10
Inverter	2500.00	0.22	0.02
Installation	7500.00	0.65	0.06
total	21500.00	1.87	0.18

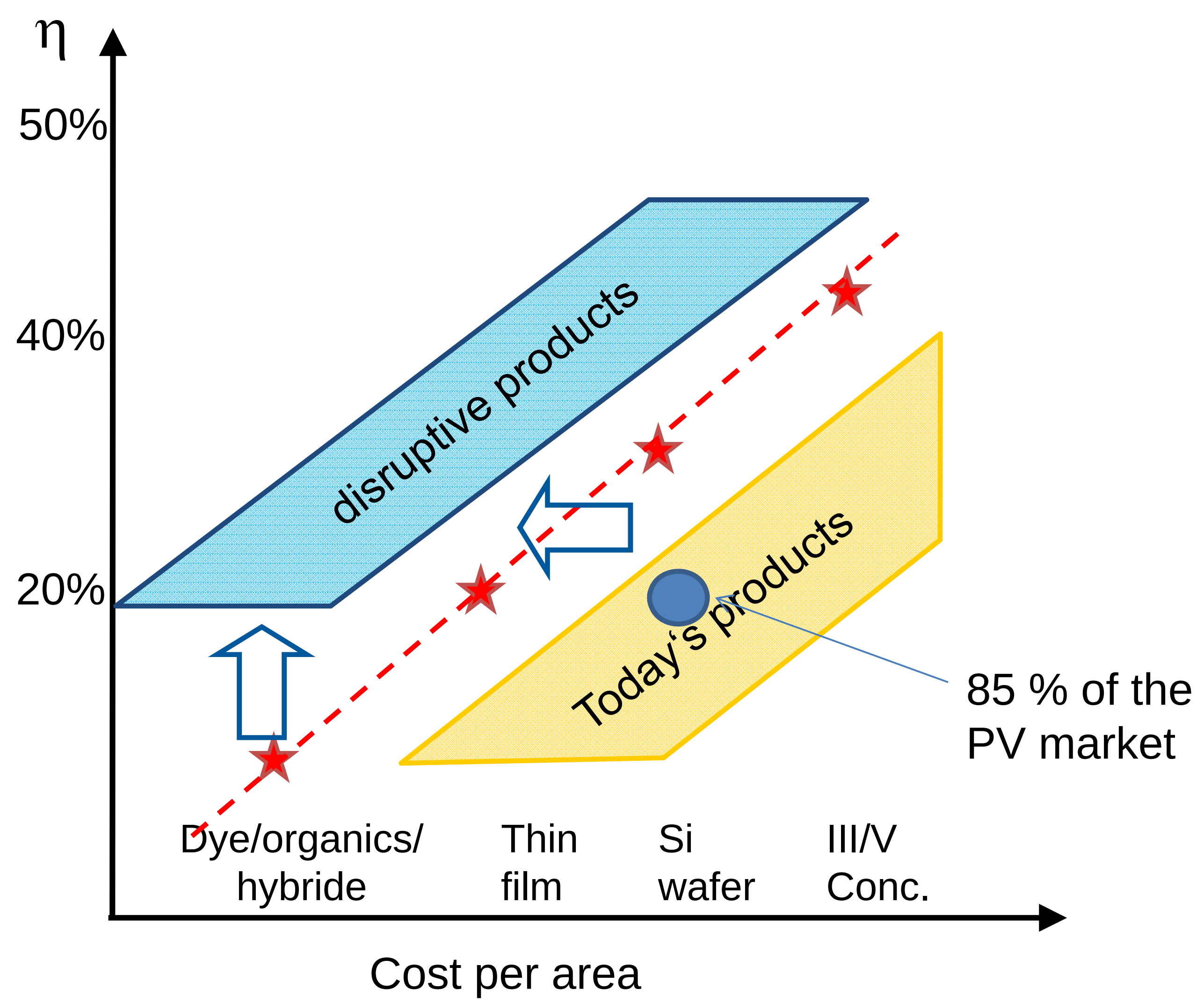


A simple cost model



Note: Calculation done for 1000 sunshine hours. An efficiency of 20 % and 1000 sunshine hours is equivalent to a 10 % system in a region with 2000 sunshine hours.

New Devices and Materials



PV towards Terawatt Scale

- maximum efficient and cost-effective conversion technologies
- enhanced utilization (e.g. building integration, smart grids)
- concepts for storage of solar energy

Scientific Challenge

Fundamental knowledge and technology development based on:

- high quality and abundant materials @ low processing costs
- perfect device designs from nano- to macro-scale
- processing suitable for mass production
- catalysts functionalizing PV devices for solar fuel generation

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  - Thin Film Si – technologies under development in Adlershof
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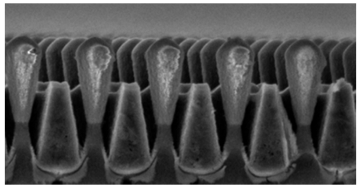
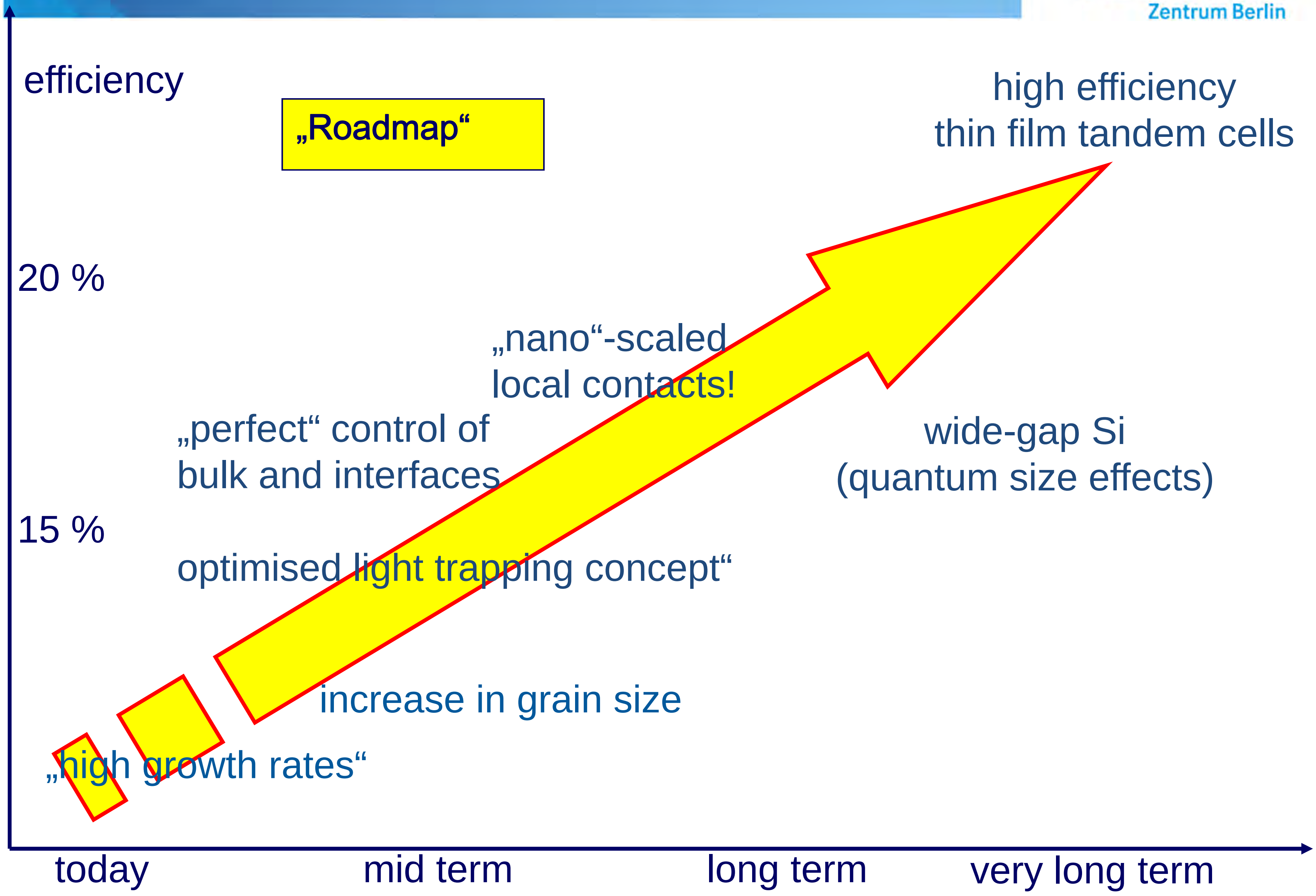
  - EMiL a new lab for PV materials research
- **Conclusions**



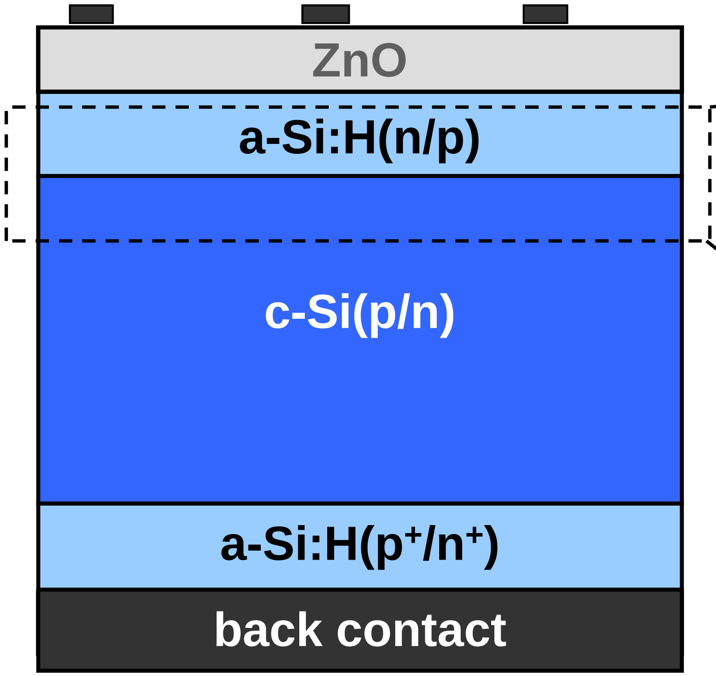



Pathways to a future Si thin film cell

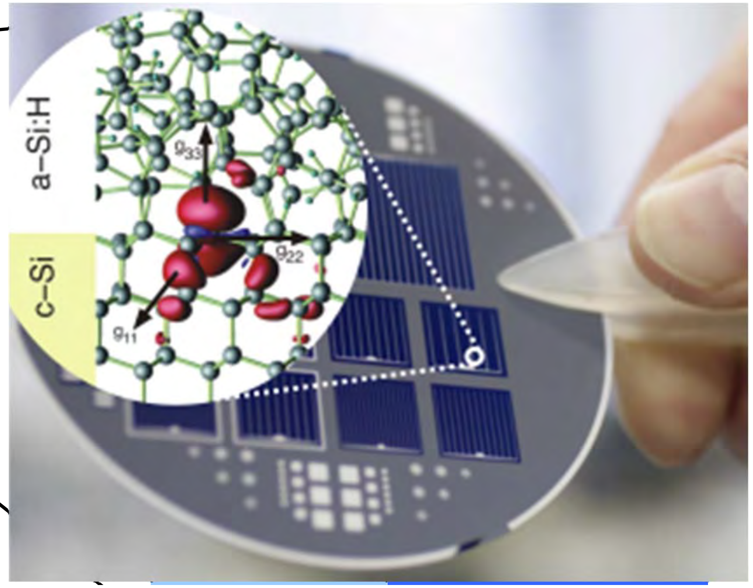


a-Si:H/c-Si Heterointerface – Model System

HZB Helmholtz Zentrum Berlin



band scheme

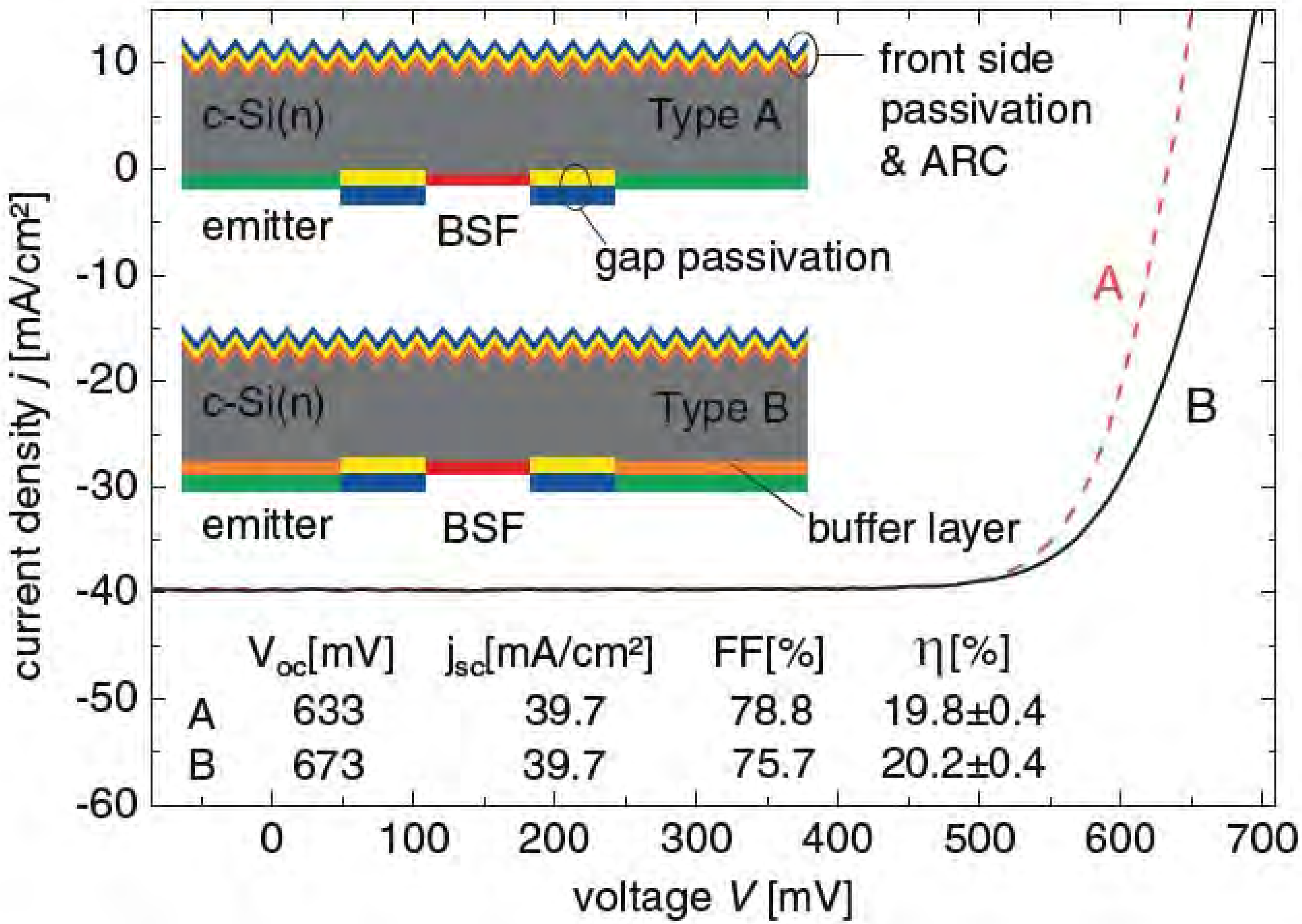


B.M. George et al. Phys. Rev. Lett (2013)

Tasks: • minimize recombination losses at/near *a*-Si:H/*c*-Si interface
• maximize efficiency of charge carrier transport over heterointerface

Remark: Highest V_{oc} for c-Si PV (panasonic HIT) : efficiency > 23 %

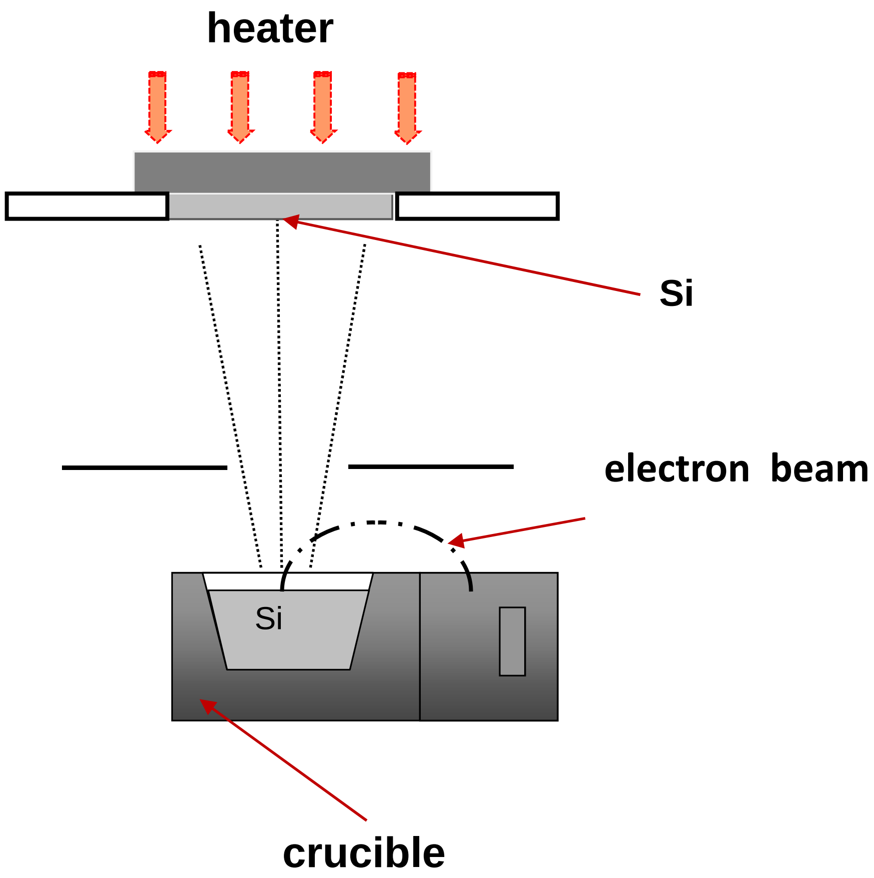
Back Contact a-Si/c-Si Hetero Junction Cell



	V_{oc}[mV]	j_{sc}[mA/cm²]	FF[%]	η[%]
A	633	39.7	78.8	19.8±0.4
B	673	39.7	75.7	20.2±0.4

N. Mingurilli et al., Phys. Status Solidi RRL **5, No. 4, 159–161 (2011)**
in cooperation with ISFH (BMU project "Topshot")

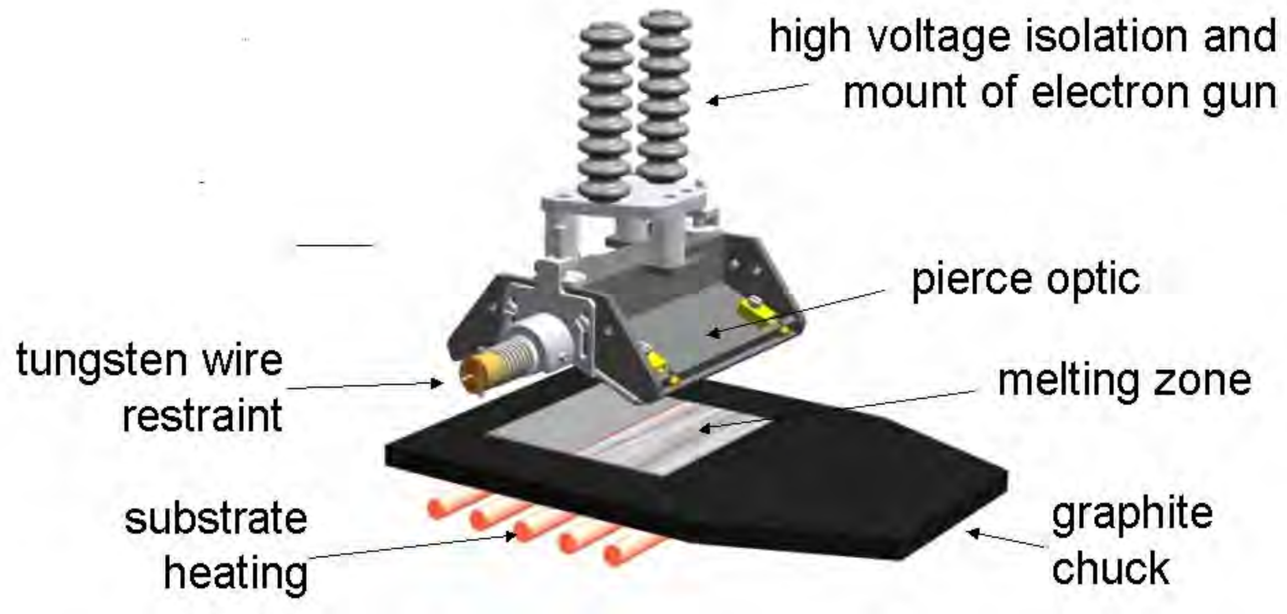
Electron beam evaporation (e-beam)



- **Deposition rates >1µm/min**
- **High Vacuum (not UHV)**
  (10^{-7} to 10^{-6}mbar)
- **No toxic gases**

Electron Beam Crystallization

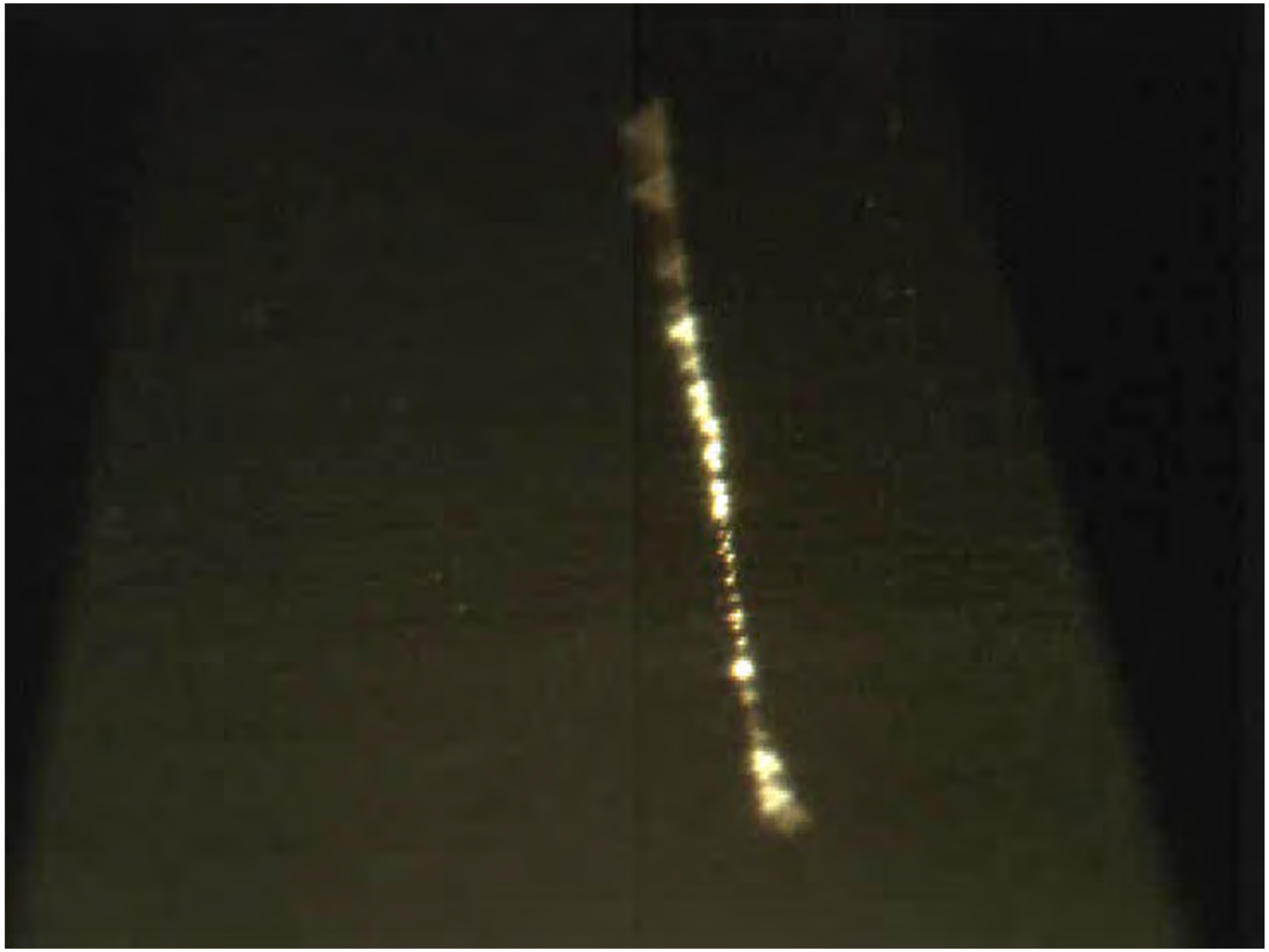
Improving Si thin film material Quality



- Constant current heated tungsten wire
- Pierce electrodes to focus the beam onto substrate [4]

D. Amkreutz et al. Progress in Photovoltaics (2011)

Electron Beam Crystallization

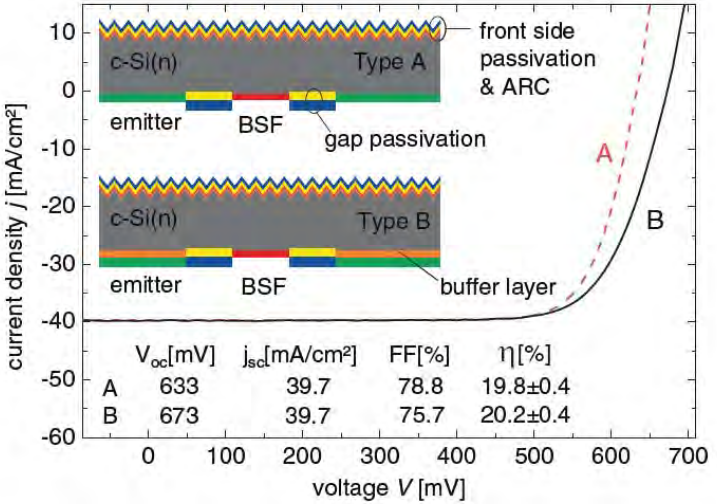


Technische Universität Hamburg-Harburg

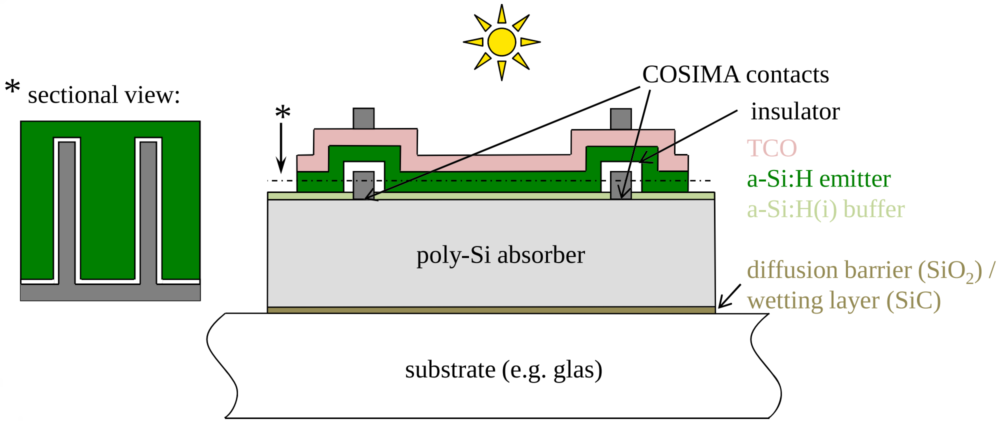
Single-side contacted a-Si/c-Si hetero-junction thin-film solar cell

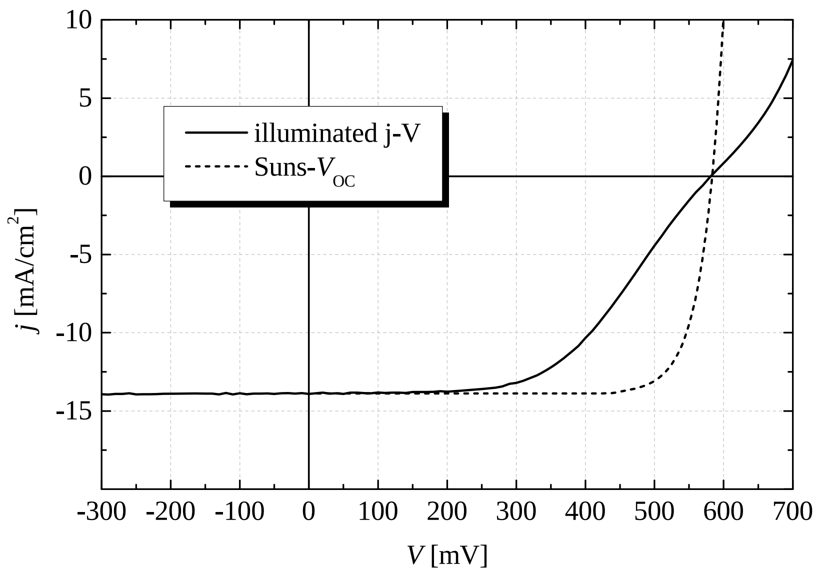
Helmholtz Zentrum Berlin

Back Contact a-Si/c-Si Hetero Junction Wafer Cell



Poly-c-Si thin-film cell on glass Exhibiting 582 mV open-circuit-voltage





key issues:

- **low Jsc due to missing light trapping scheme**
- **Defects at the buried interface (EMIL)**
- low FF due to, distributed Rs, solved meanwhile

Haschke et al., SolMat Vol 115, Issue C, pp 7-11, 2013

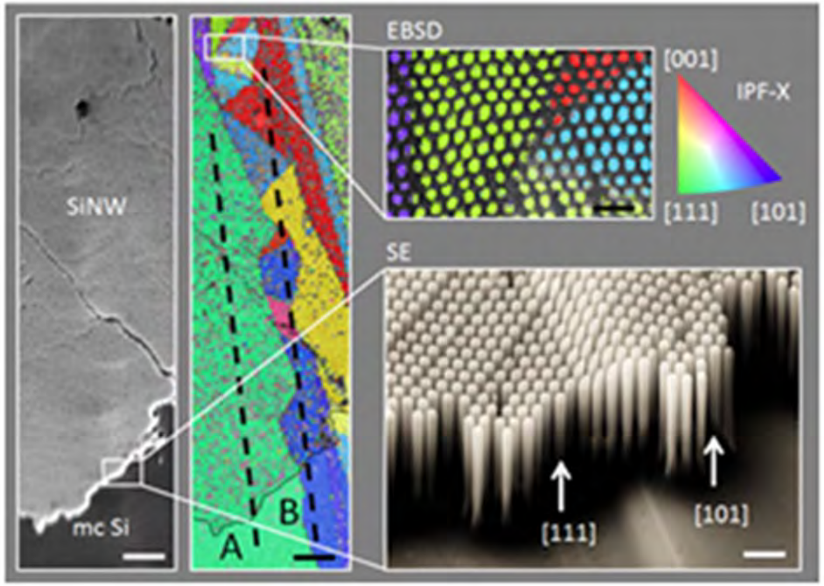
Going – 3 D in thin film Si

Very high light absorption

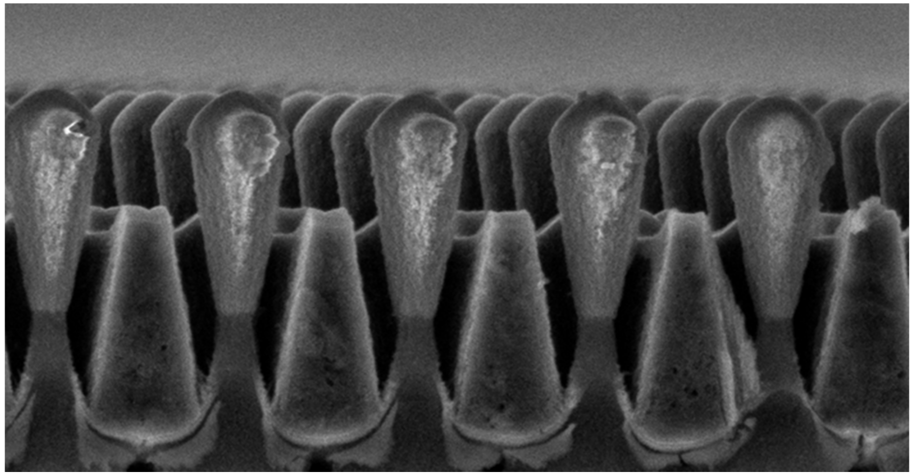
Additional freedom for optimisation

Removal of poor quality material

„cheap is possible“

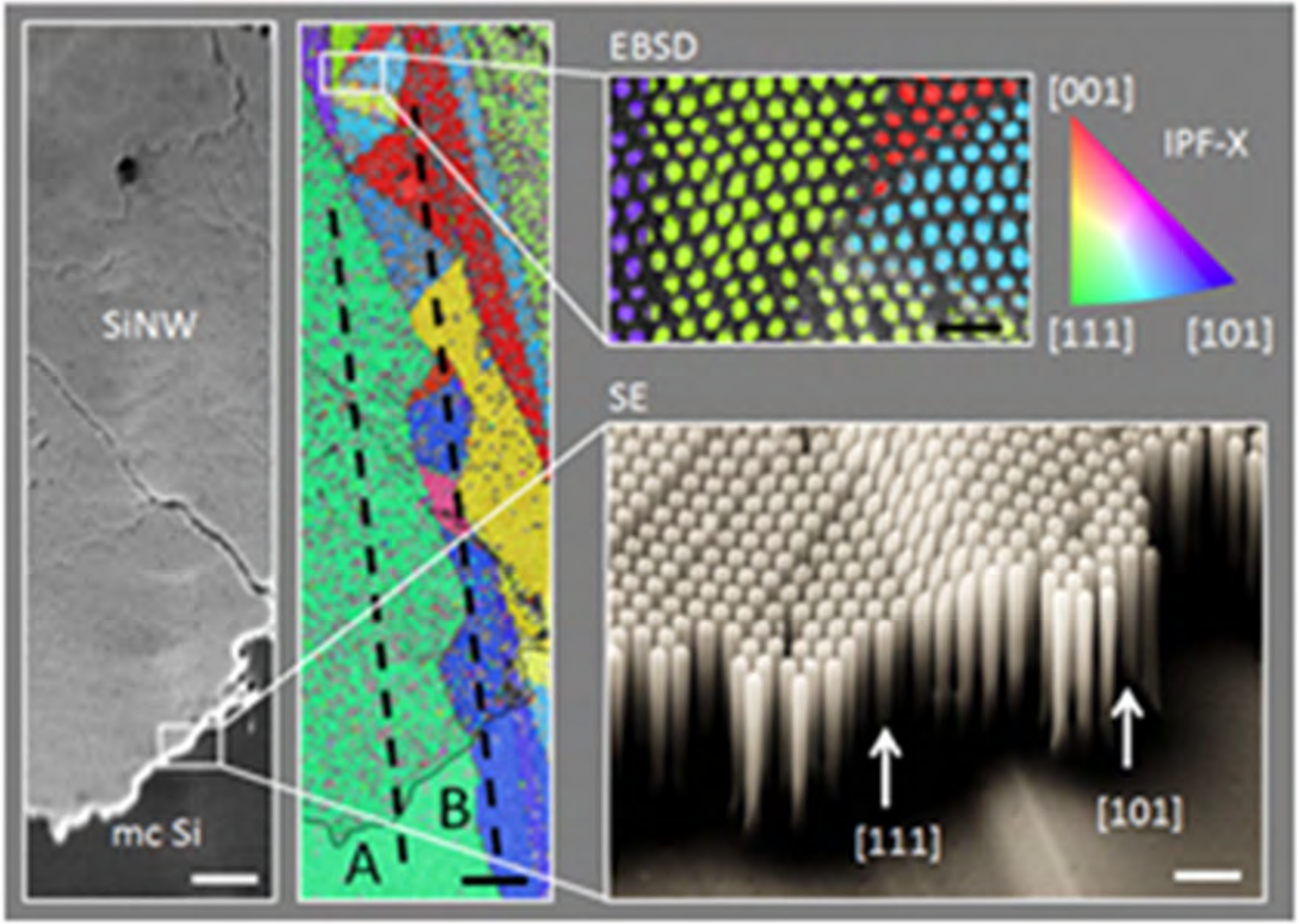


New Institute „Nanoarchitectures
Silke Christiansen



Young Investigator Group of Christiane Becker

Going 3 D in thin film Si



50 µm

3 µm

In cooperation with S. Christiansen HZB&MPI Erlangen
S.W. Schmitt et al. Nanoletters 2012

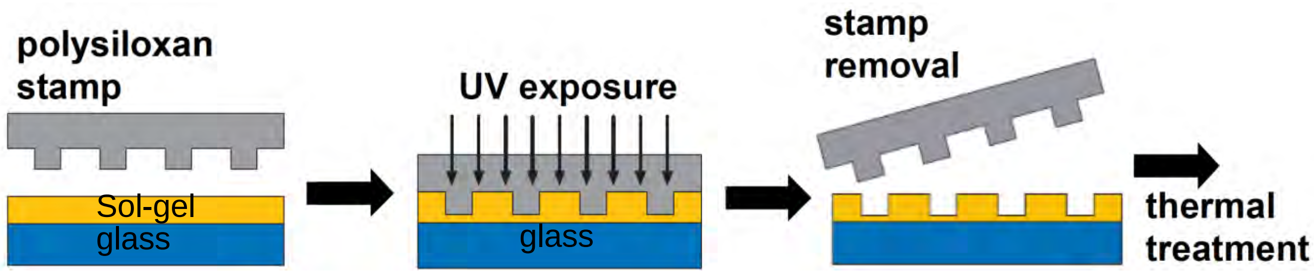
SCHOTT glass made of ideas

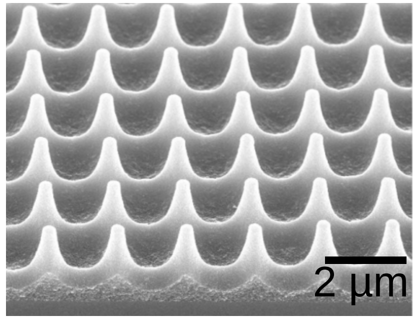
Large-area fabrication of periodic patterns

HZB Helmholtz Zentrum Berlin

Sol-gel based nano-imprinted 2 D periodic light trapping structures

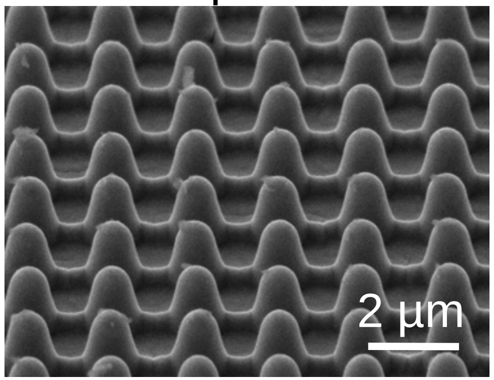
Sol-gel template



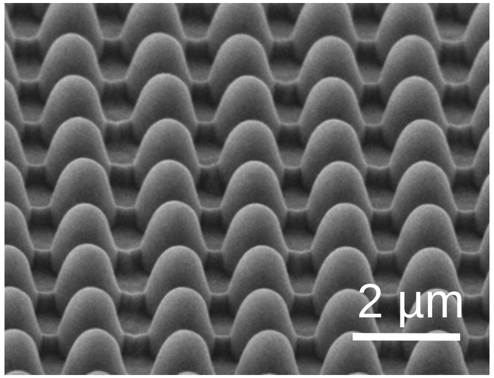


Simple large area fabrication with precisely controlled nanoscale dimensions

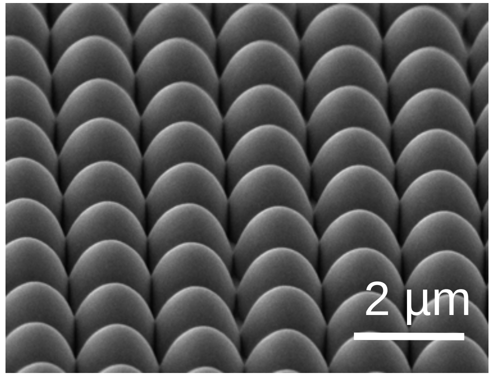
1.5 µm Si



2.4 µm Si

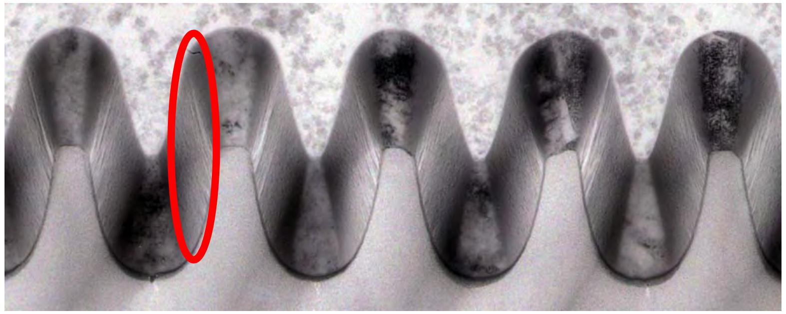


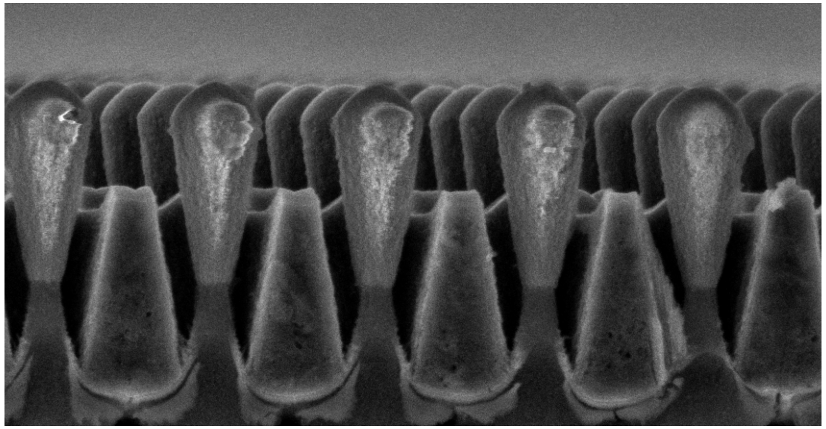
4.1 µm Si



E. Rudigier-Voigt et al, Proc. of 24th EUPVSEC pp 2884 (2009)
T. Sontheimer et al. , ICANS 2011, acc. for publication in journal of non. cryst. colids)
PSS rapid research letter 2011, C. Becker et al, Nanotechnology 2012

Removing the amorphous Si in a selective etch process





Phys. Status Solidi RRL, 1–3 (2011) / DOI 10.1002/pssr.201105437

pss +++rapid research letters+++ www.pss-rapid.com

Large-area fabrication of equidistant free-standing Si crystals on nanoimprinted glass

Tobias Sontheimer[*,1], Eveline Rudigier-Voigt[2], Matthias Bockmeyer[2], Carola Klimm[1], Peter Schubert-Bischoff[1], Christiane Becker[1], and Bernd Rech[1]

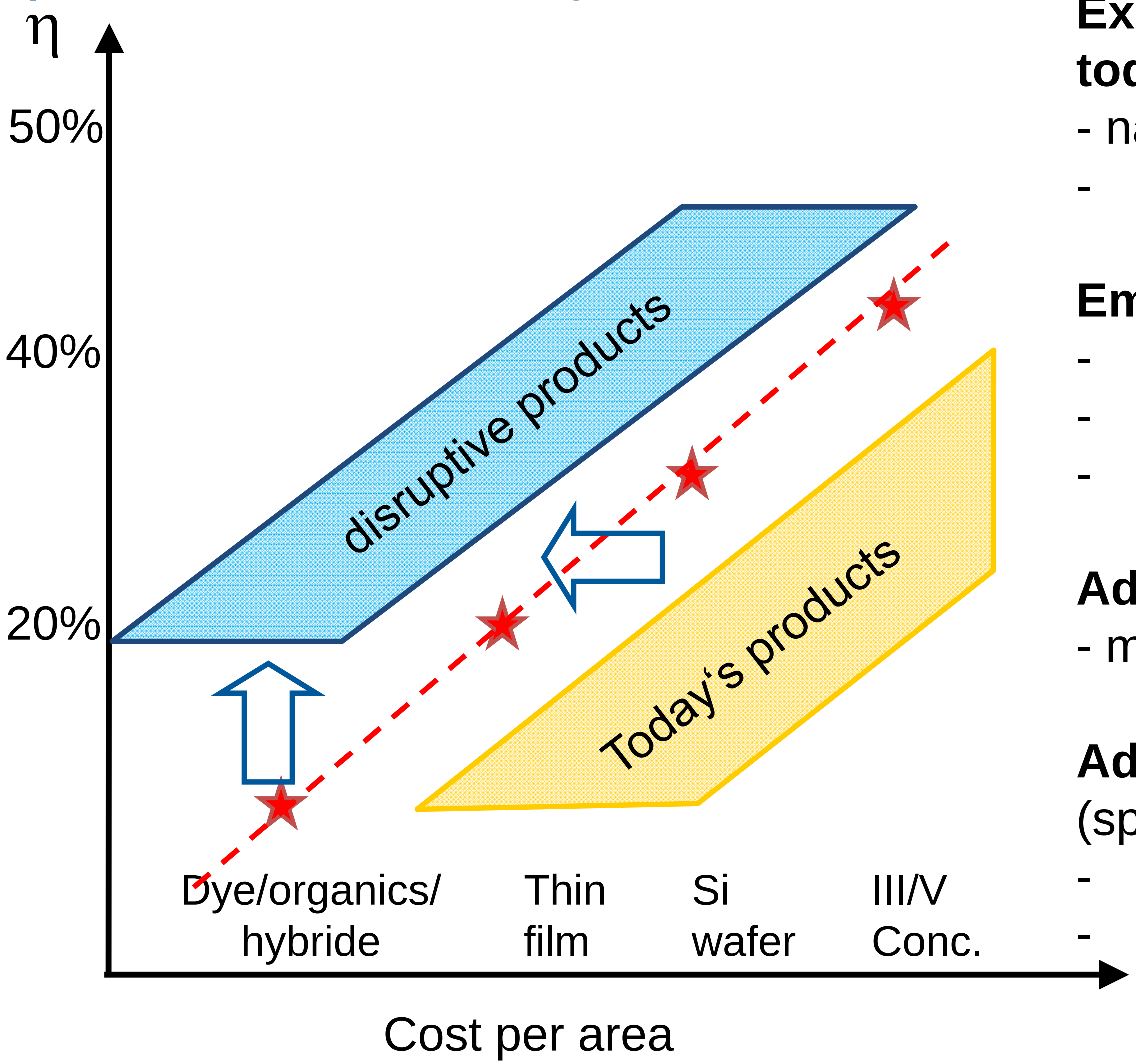
[1] Helmholtz Zentrum Berlin für Materialien und Energie, Silicon Photovoltaics, Kekuléstr. 5, 12489 Berlin, Germany
[2] SCHOTT AG, Hattenbergstr. 10, 55122 Mainz, Germany

Arrays of free-standing Si crystals by selective etching

New Devices, Materials & Functions almost all rely on thin film technology*

HZB Helmholtz Zentrum Berlin

*(*this includes technologies based on wafers*



Explore the limits of todays thin film semiconductors

- nano-structures/technology
- 3-D architectures

Emerging materials

- Organic / Hybrids
- Solid state dye cells (perovskites)
- Novel electrodes (e.g. graphene)

Adaption to the solar spectrum

- multi-junction cells

Adaption of the solar spectrum:

(spectrum shaping)

- up-conversion
- down conversion

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  - **Solar Fuels – New Institute @ HZB headed by Roel van de Krol**
  - EMiL a new lab for PV materials research
- **Conclusions**