



Photovoltaics :
a key pillar for a future sustainable energy supply

"Quo vadis PV and Renewables"

Bernd Rech
Institute Silicon Photovoltaics, HZB
Chair of PV, TU-Berlin
Speaker Programme Renewable Energies, Helmholtz Association

Investing in your future
OPERATION PART FINANCED BY THE EUROPEAN UNION
European Regional Development Fund
Cohesion Fund
European Social Fund

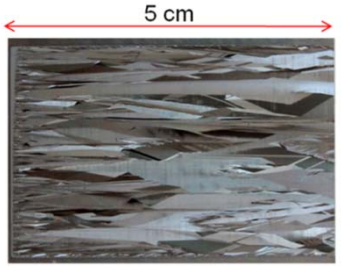
Outline

HZB Helmholtz Zentrum Berlin

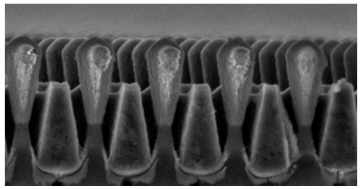
- **Motivation & Status**



- **Photovoltaics**
  - Status, applications, perspectives



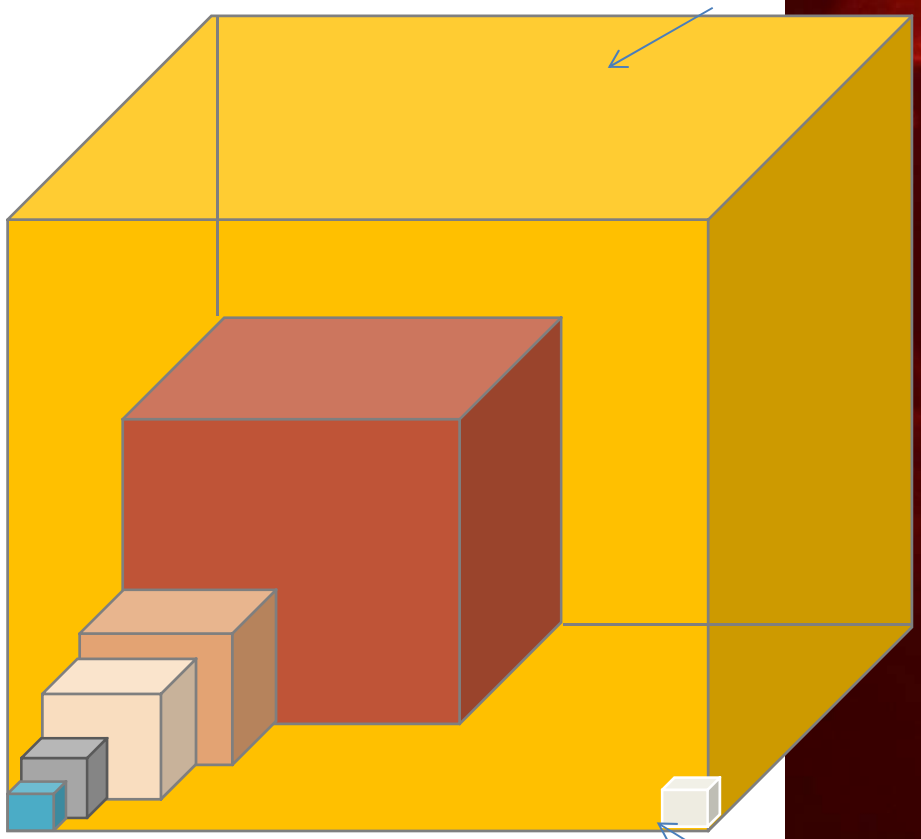
- **Challenges for R&D - Examples**
  - Solar energy @ HZB
  - Crystalline Thin Film Si
  - Si Nanotechnology



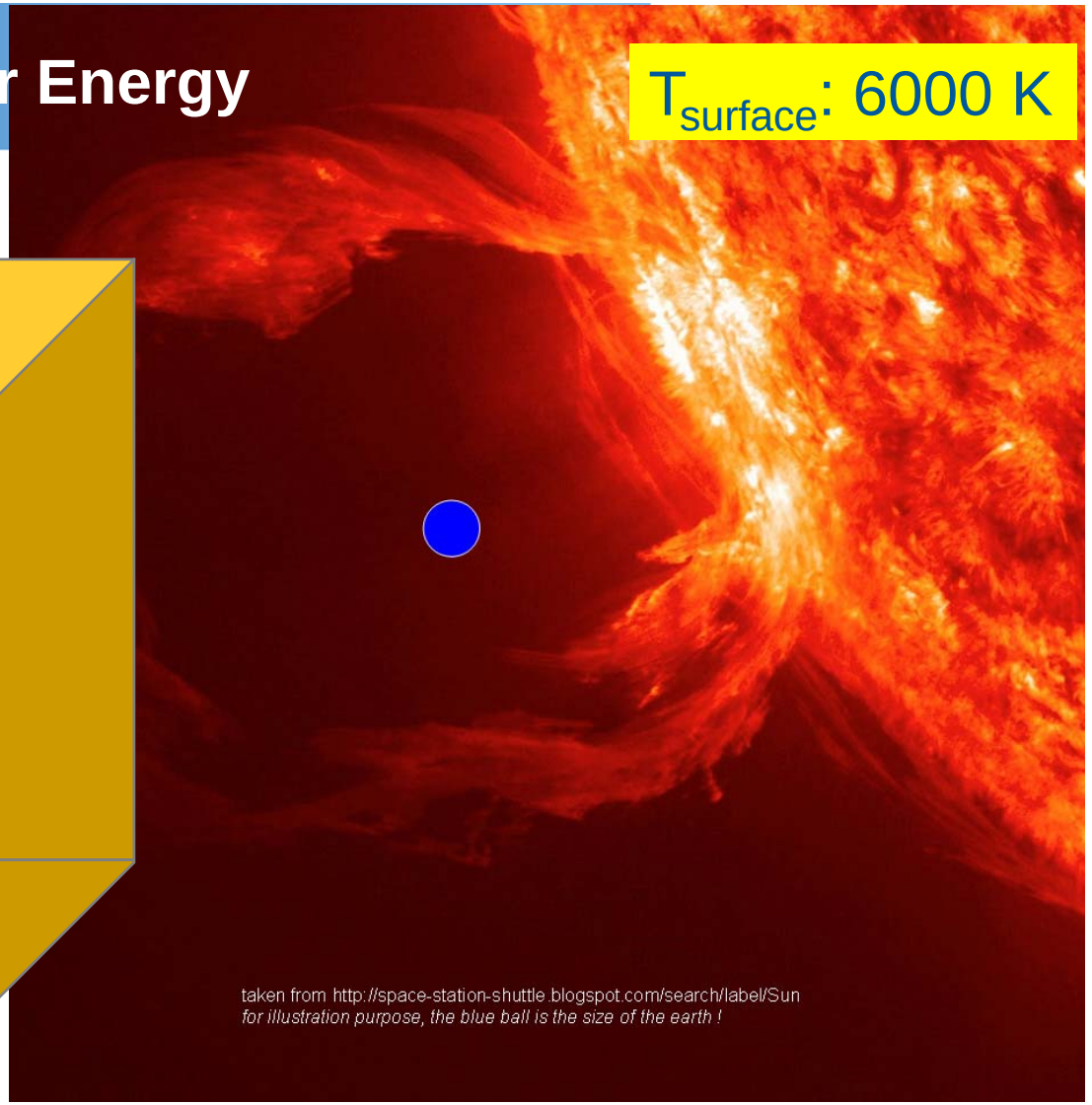
- **Conclusions**

Potential of Solar Energy

Solar energy (continental)



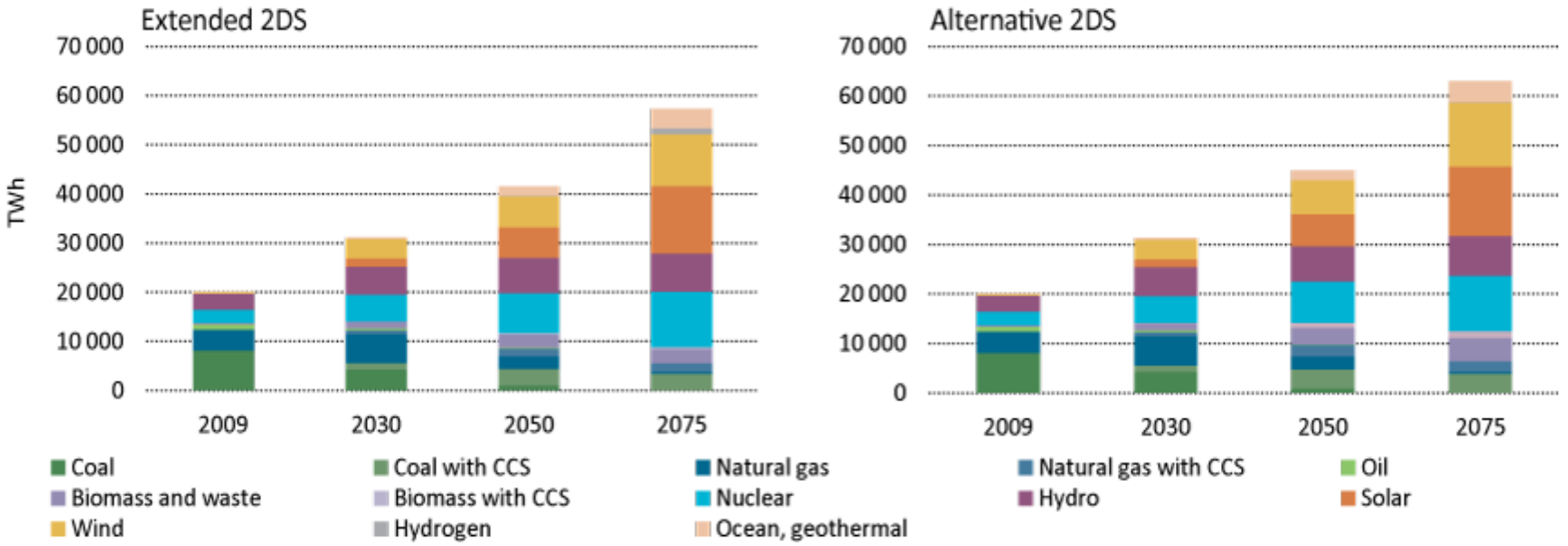
- Wind energy (200 x GPEC)
- Biomass (20 x GPEC)
- Geothermal energy (10 x GPEC)
- Ocean and wave energy (2 x GPEC)
- Hydro energy (1 x GPEC)



Global primary energy consumption

Source: F. Nitsch, DLR

Renewables in the IEA 2DS Scenario



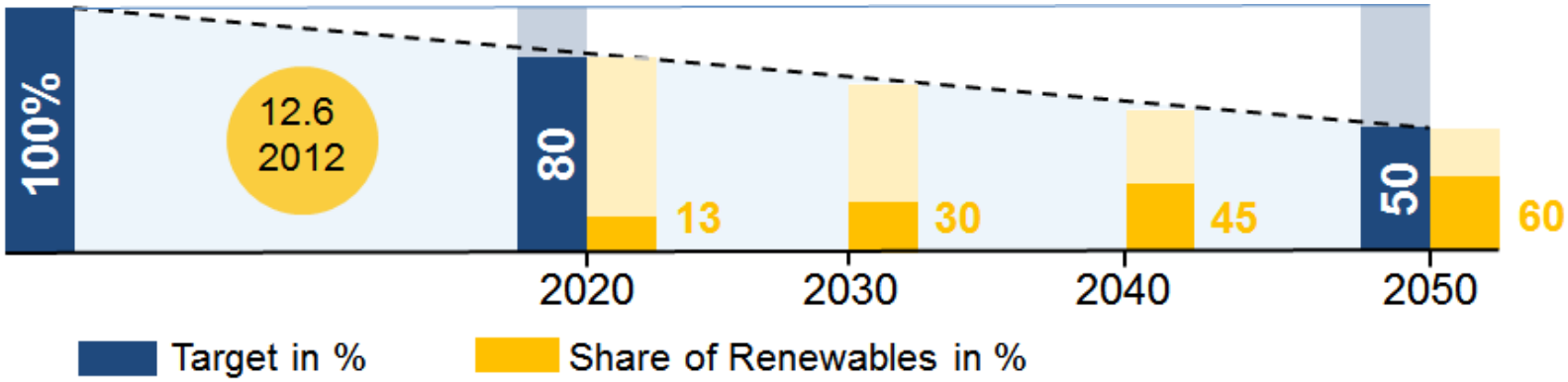
IEA - Energy Technology Perspectives 2012

Towards a Sustainable Energy System

HZB Helmholtz Zentrum Berlin

National German Targets

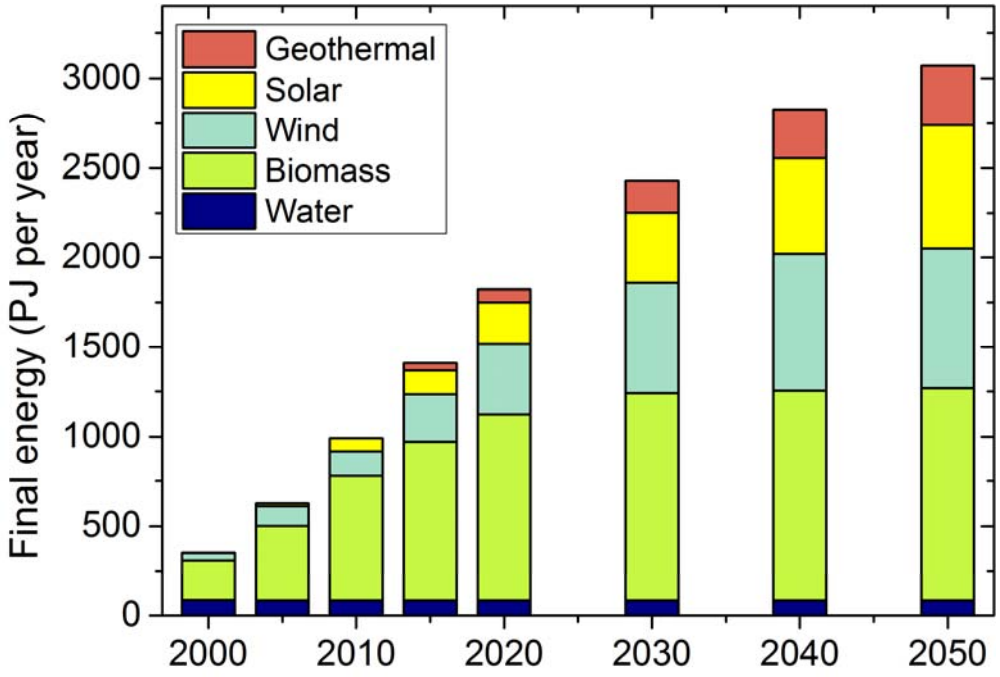
Gross final energy consumption (compared to 2008)



- Security of supply
- Economic efficiency
- Environmental protection

J. Nitsch et al., Leitstudie, BMU - FKZ 03MAP146, 2012,
C. Morris & M. Pehnt, Energy Transition, The German Energiewende, 2012.

The Challenge for Renewable Energies in Germany



Requirements for a sustainable energy solution:

- Complementary approach for heat, electricity and fuels
- Strongly increased utilisation of solar (photovoltaics & solar thermal), wind and geothermal
- Sustainable feedstock for bioenergy
- Development of versatile energy storage options

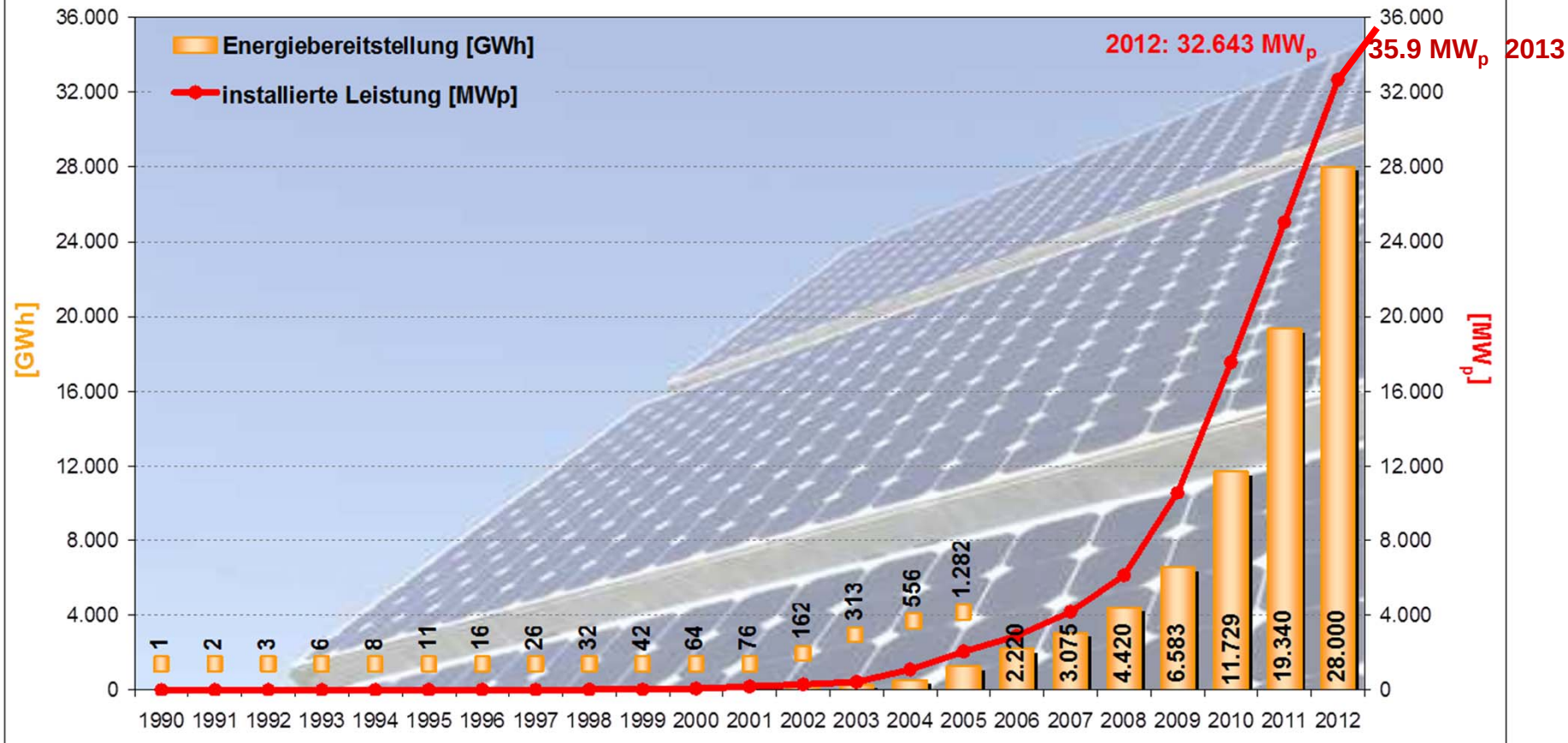
Multi-disciplinary scientific challenge, which must also rely on national and international partnerships

J. Nitsch et al., Leitstudie, BMU - FKZ 03MAP146, 2012,
C. Morris & M. Pehnt, Energy Transition, The German Energiewende, 2012.

PV in Germany: 1990 - 2013

HZB Helmholtz Zentrum Berlin

Cumulative PV installation in Germany
Global installation approx. 100 GW end of 2012



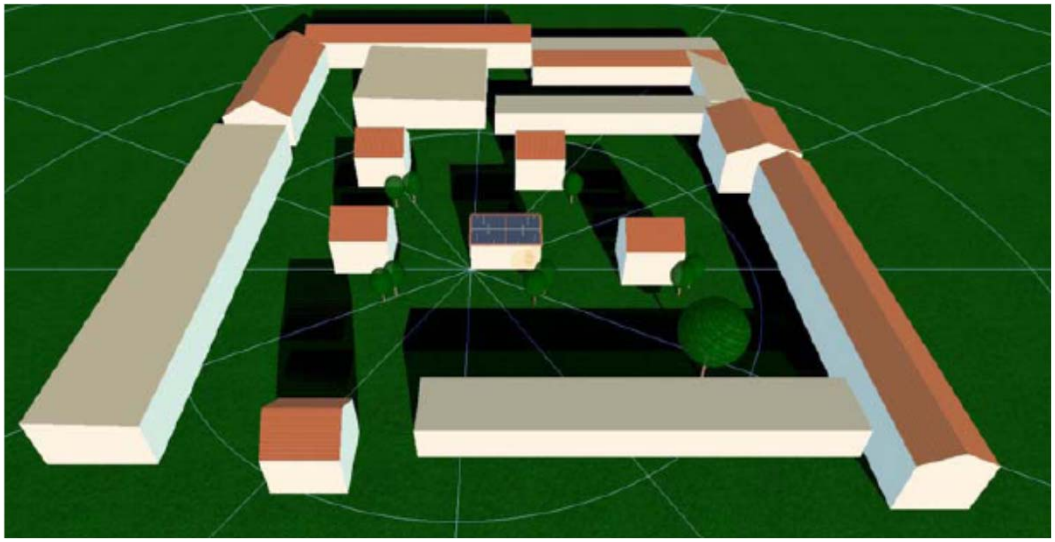
Quelle: BMU - E I 1 nach Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat); 1 GWh = 1 Mio. kWh; 1 MW = 1 Mio. Watt;
Hintergrundbild: BMU / Bernd Müller; Stand: Februar 2013; Angaben vorläufig

PV in Berlin today – residential home

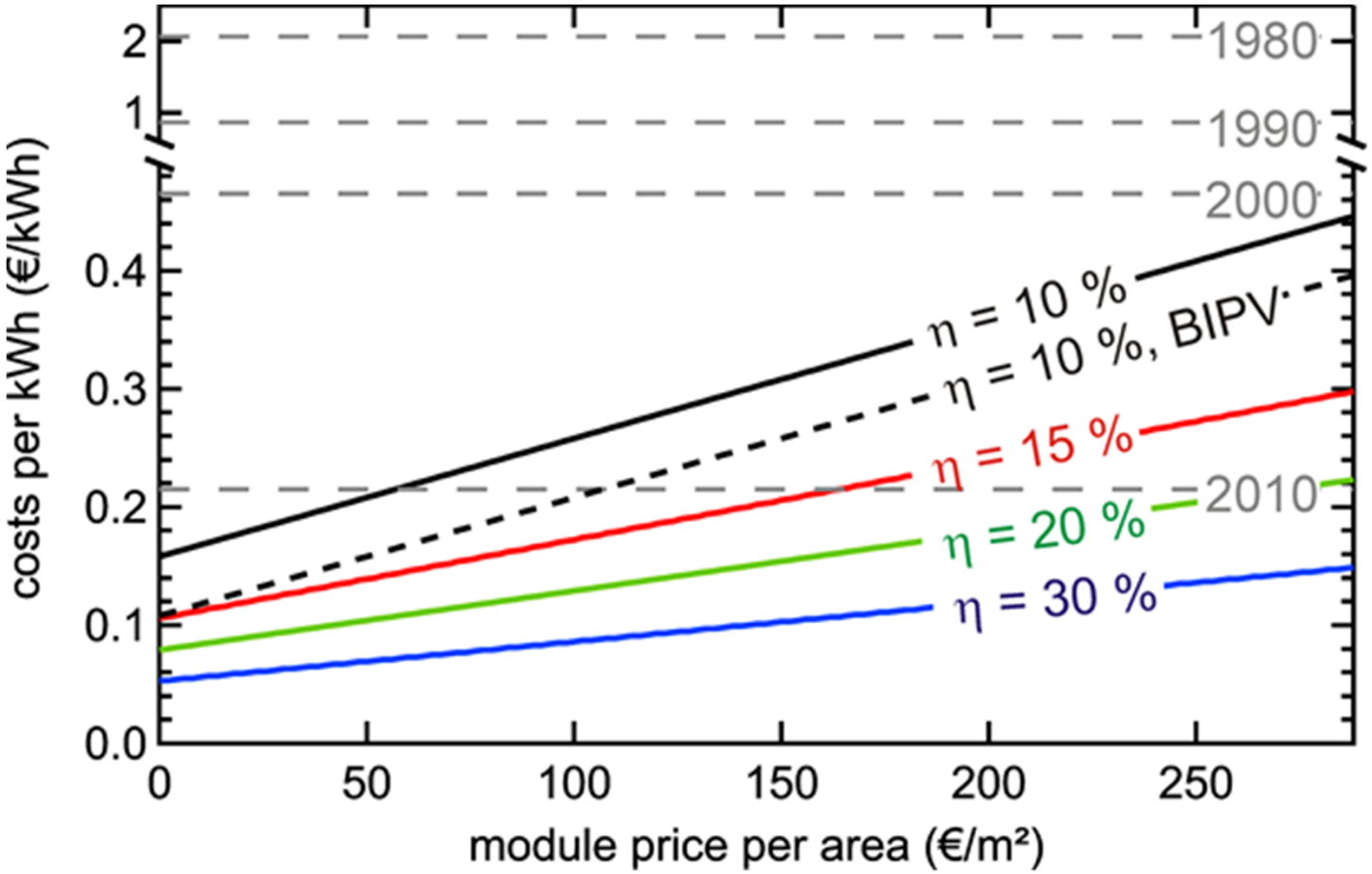
HZB Helmholtz Zentrum Berlin

11.5 KW_p c-Si: grid connection 11/2012
„black design“: η = 15 %
Expected production / y: 10.000 kWh
2013: 10.000 kWh (average y)
2014: 10.500 -11.000 (sunny y)
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

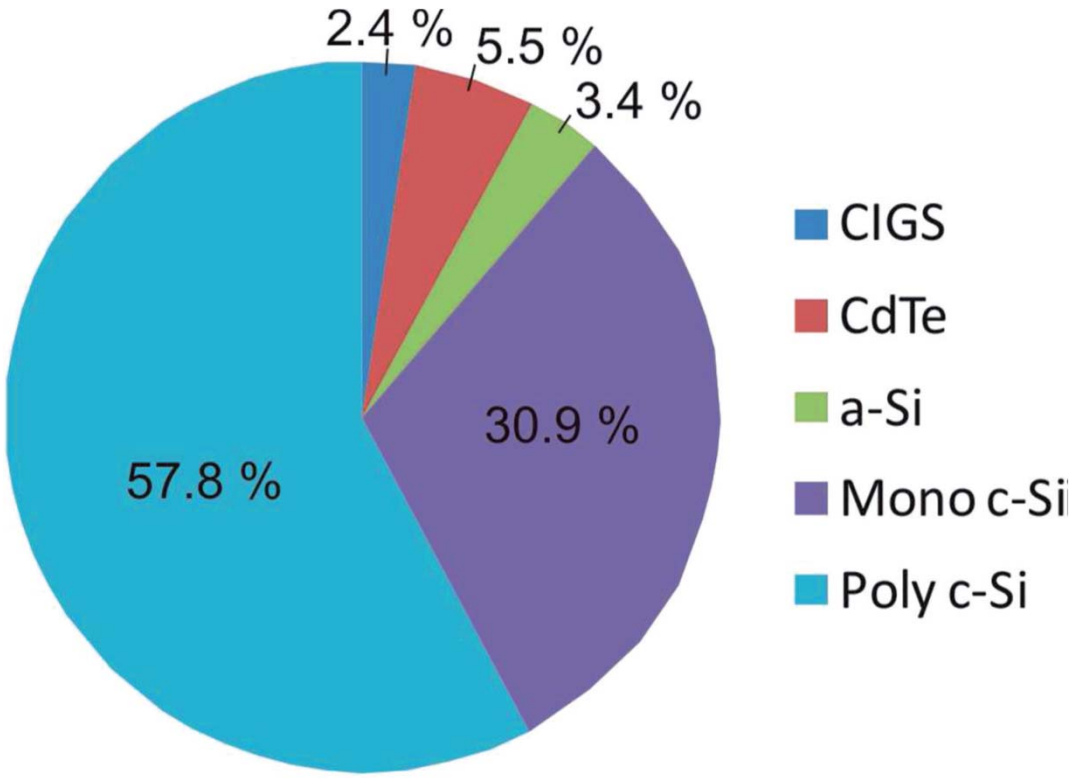


A simple cost model



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.

Share of Different PV Technologies



89 % Wafer based Si
11 % Thin film

Photon Europe GmbH (2012)

Wafer based crystalline Silicon

HZB Helmholtz Zentrum Berlin

50 years manufacturing experience

- monocrystalline
- multicrystalline

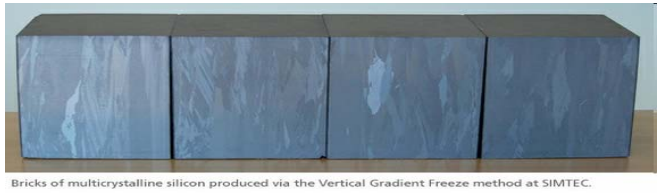
New cell concepts on industrial scale

- rear contacts
- improved texturing and passivation

Laboratory cell efficiency:
23% various approaches
(world record lab cell: 25.6 %)

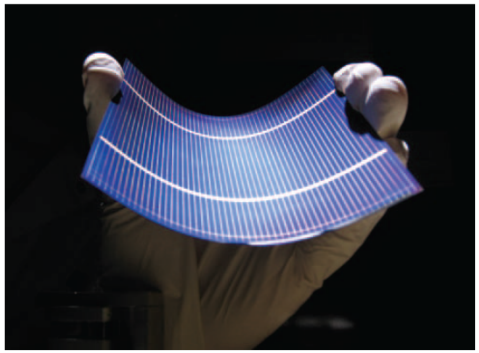
module efficiency range:

- 13 ~ 20%
- 18 ~ 22% (longer term)



Bricks of multicrystalline silicon produced via the Vertical Gradient Freeze method at SIMTEC.

Source: SIMTEC/ FHG ISE





source: ECN

PV Status and growth potential

HZB Helmholtz Zentrum Berlin

Unique features of photovoltaics:

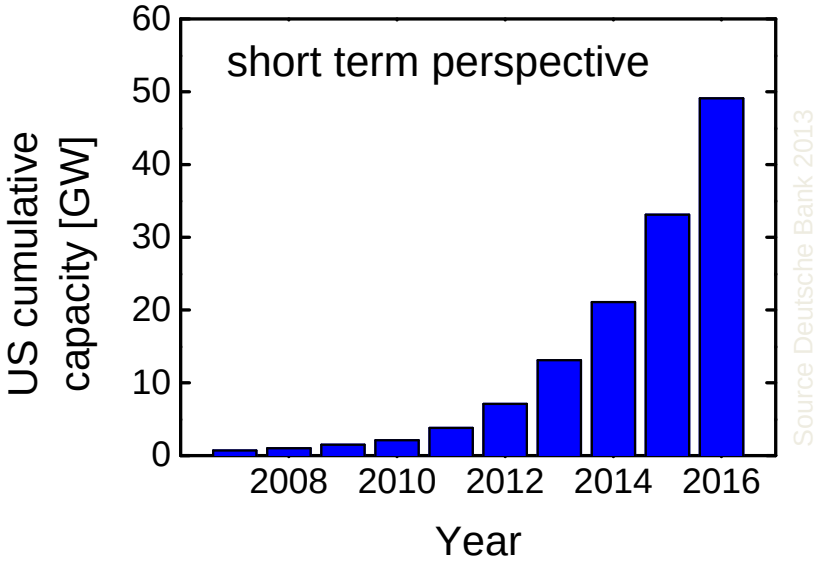
- Direct energy conversion
- No movable parts
- Versatile and scalable

Expected developments:

- futher continous cost reductions
- pillar of world energy supply
- Multi-billion dollar market

5 % of electricity supply in Germany by PV

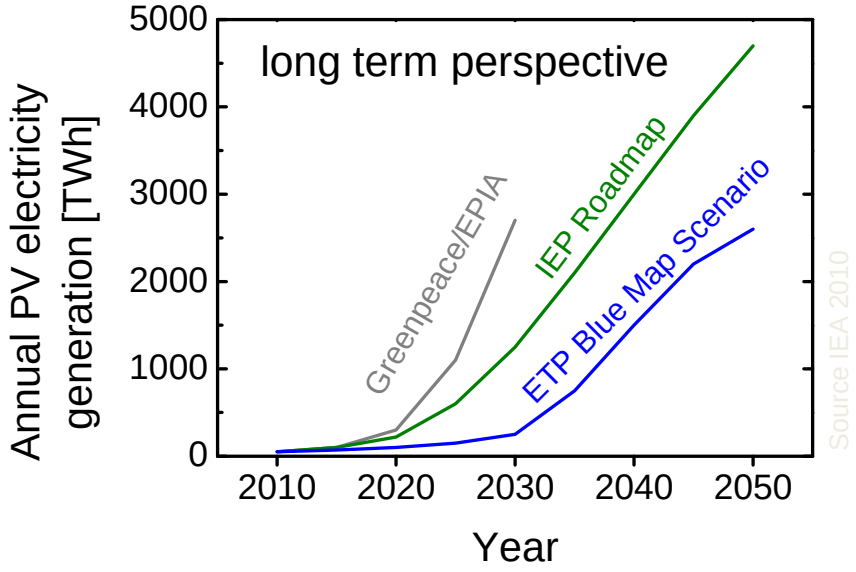
Source AGEE 12.2013



Terawatt scale production

2030: > 2 mio. jobs in PV

Source IRENA 2013

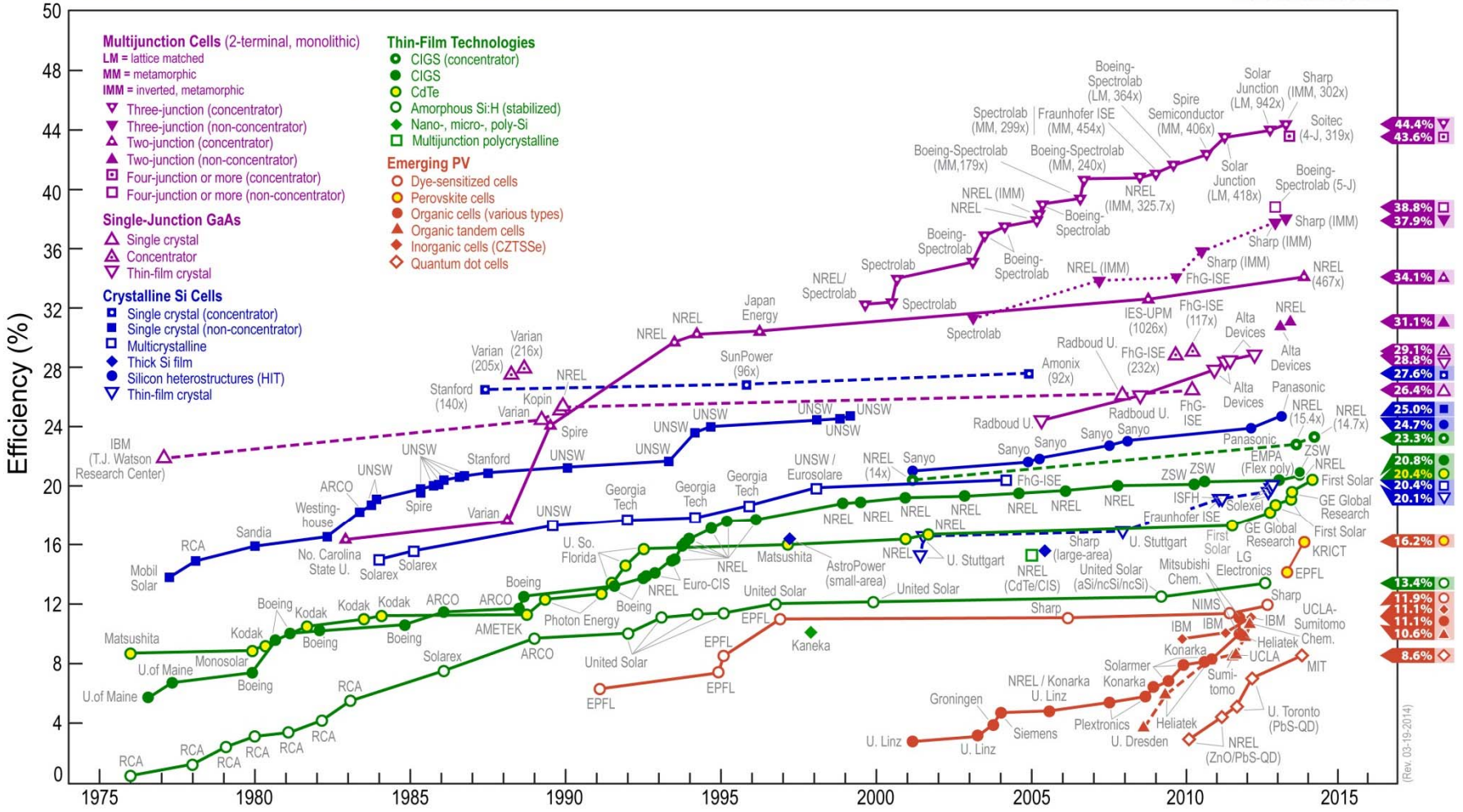


Record Solar Cells

HZB Helmholtz Zentrum Berlin

Best Research-Cell Efficiencies

NREL NATIONAL RENEWABLE ENERGY LABORATORY

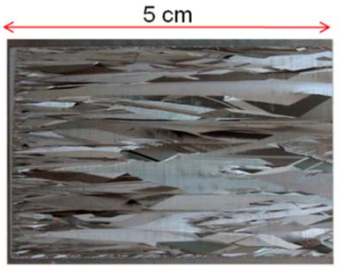


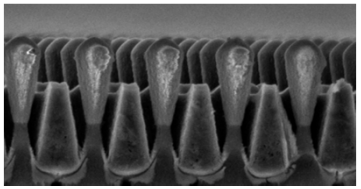
Outline

HZB Helmholtz Zentrum Berlin

- Motivation & Status
- Photovoltaics
  - Status, applications, perspectives
- **Challenges for R&D - Examples**
  - Solar energy @ HZB
  - Crystalline Thin Film Si
  - Si Nanotechnology
- Conclusions







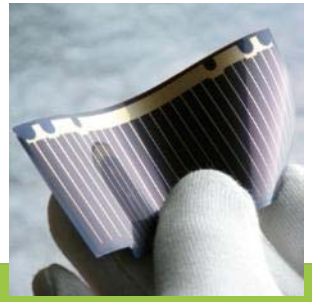
Helmholtz-Centre Berlin

HZB Helmholtz Zentrum Berlin









Neutrons | **Photons** | **User Service** | **Solar Energy**

Total Annual Budget: ~110 million EUR

75% ↘ 70% (2015)

25% ↗ 30% (2015)

Total Staff: about 1,100

Scientists: about 400

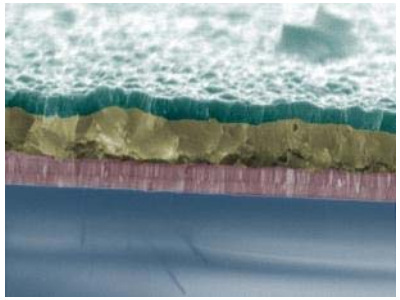
International Users: about 2,800 p.a.

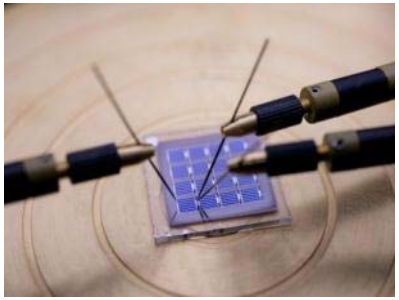
400 → 2,400

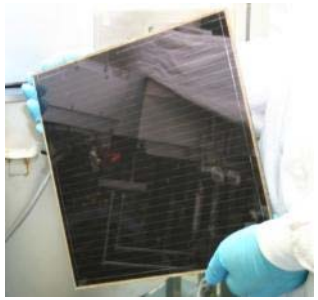
Solar Energy Research

HZB Helmholtz Zentrum Berlin

Fundamentals → Development → Technology Transfer



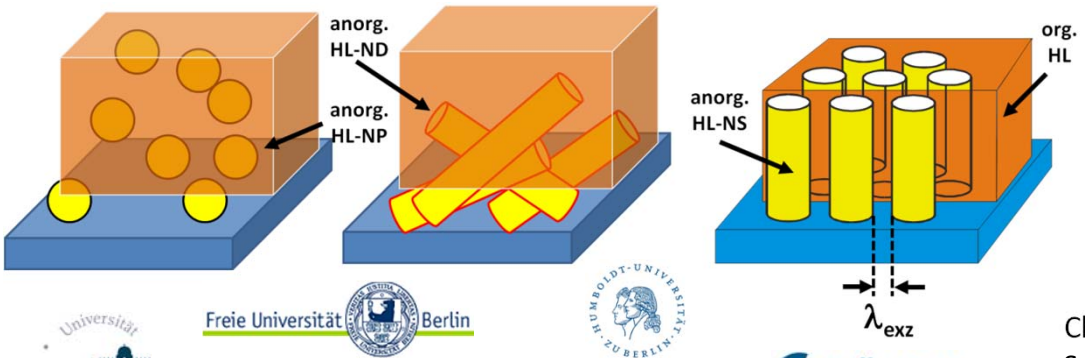




Emerging Materials and Functions

HZB Helmholtz Zentrum Berlin

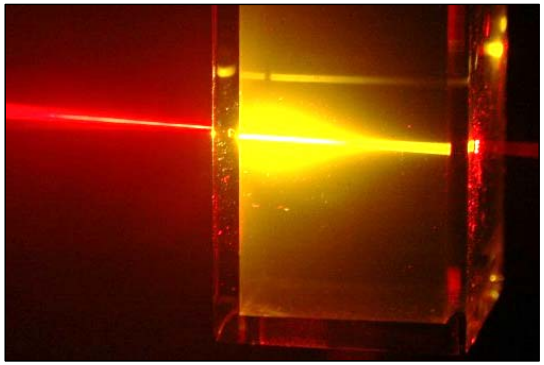
the best of two worlds: inorganic/organic hybrid solar cells



Universität Potsdam · Freie Universität Berlin · Humboldt-Universität zu Berlin · JÜLICH Forschungszentrum

Helmholtz Energy Alliance

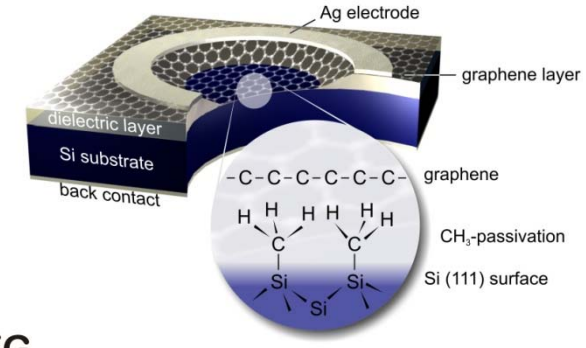
photo-chemical up-conversion



Cheng, Schulze, Lips, et al., Energy Environ. Sci. **5**, 6953 (2012)
Schulze, Lips, et al., J. Phys. Chem. C **116**, 22794 (2012)

Cooperation with Uni Sydney

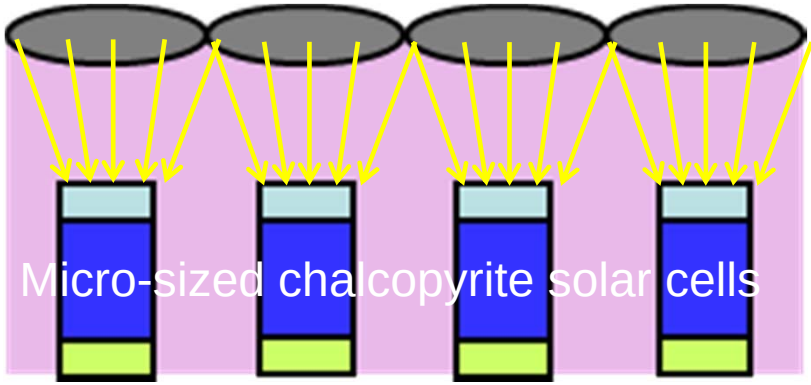
Large area graphene for solar cells



DFG Schwerpunktprogramm 1459 Graphene

Gluba et al., APL (2013).

micro-concentrators



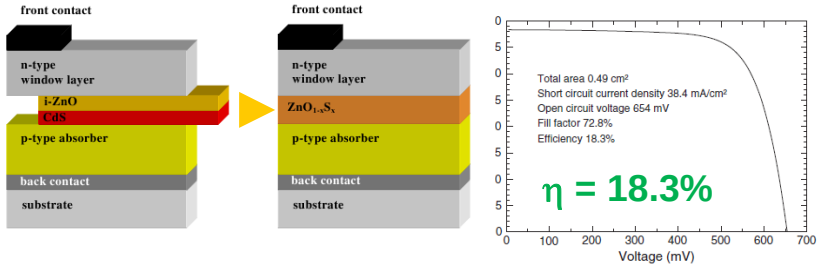
Young Investigator Group Martina Schmid

CIGSe technology development up to 30x30cm²

HZB Helmholtz Zentrum Berlin

CuInGa-Precursor:
- Magnetron Sputtering
- Non-vacuum processes (inks)

Cd-free Buffer layer
- ALD & Ilgar Zn(O,S) & InS (-> Poster PVcomB)
- Sputtered Zn(O,S)



R. Klenk et al, Prog. Photovolt: Res. Appl. (2013)

H. Rodriguez-Alvarez et al, Acta Materialia (2013)

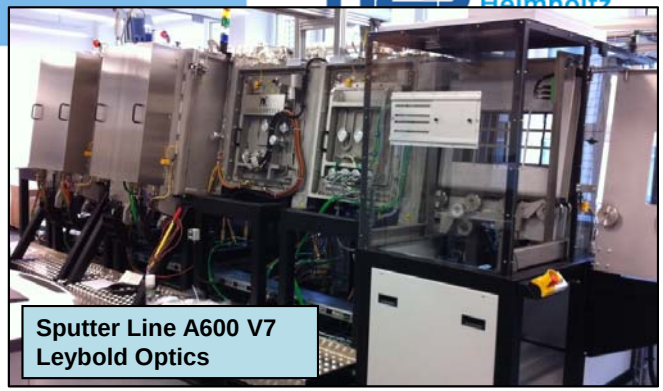
In cooperation with:

SCHOTT glass made of ideas · SAINT-GOBAIN · LAYTEC in-situ metrology · nexcis PHOTOVOLTAIC TECHNOLOGY · IMRA IMRA EUROPE S.A. · solarion MOVING PHOTOVOLTAICS · BOSCH Technik fürs Leben · manz passion for efficiency · SMIT OVENS THERMAL SOLUTIONS · BENEQ

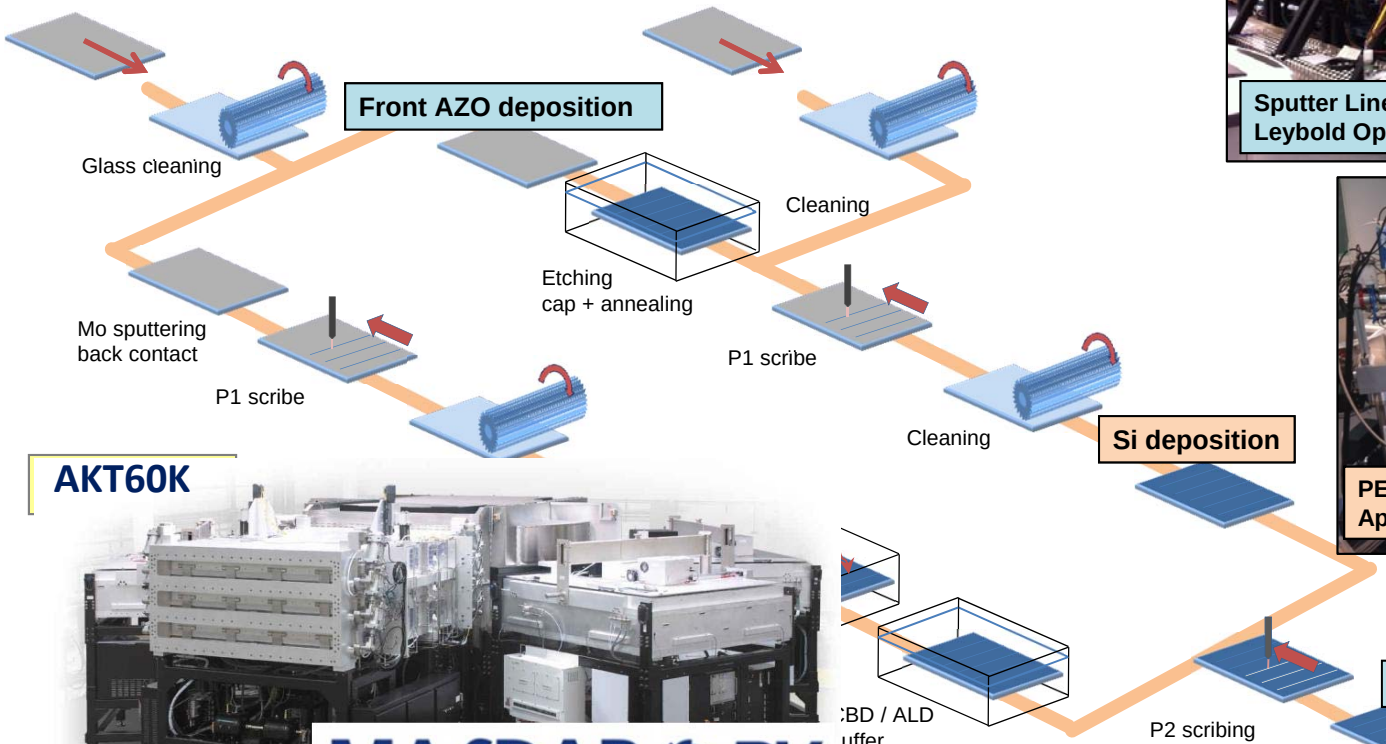
PVcomB technology transfer lines

HZB Helmholtz

a-Si/µc-Si Line





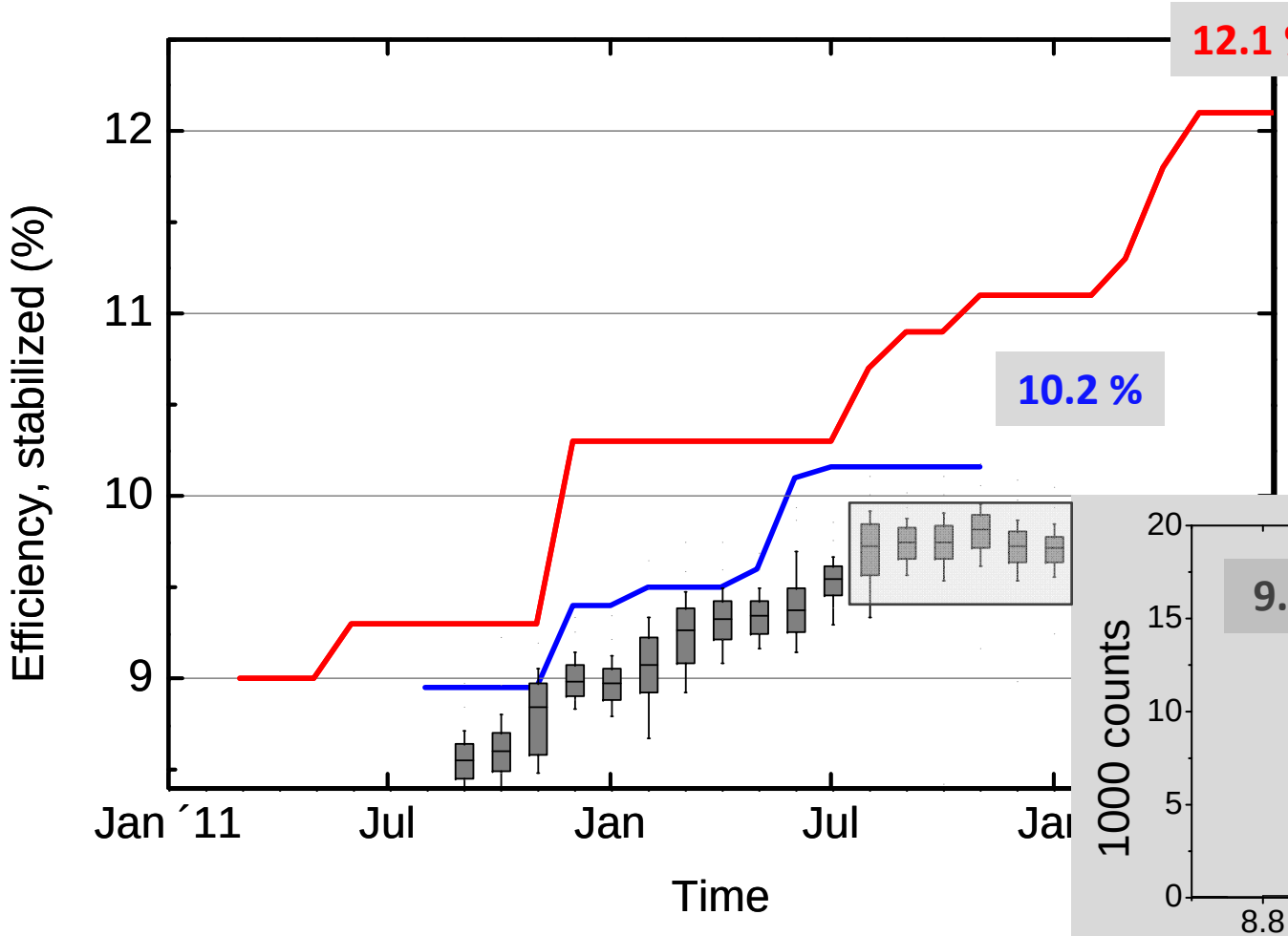


a-Si:H/µc-Si:H modules

MASDAR PV
A MASDAR COMPANY

HZB Helmholtz Zentrum Berlin

pvcomB

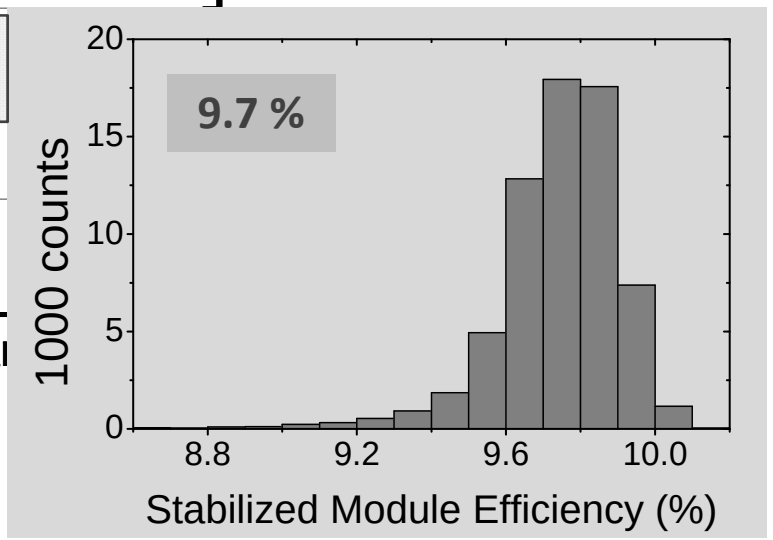


Champion lab cell (1 cm²)

MASDAR PV
A MASDAR COMPANY

Champion module (5.7 m²)

Production average (1.4 m²)



B. Stannowski et al. SolMat (2013)

see PVcomB tour

Power Plants

MASDAR PV
A MASDAR COMPANY

HZB Helmholtz Zentrum Berlin

- 15 MW_p
- 29,826 a-Si/µc-Si modules à 5.7 m²
- 10 % of Mauritania's grid capacity
- Largest PV installation in Africa





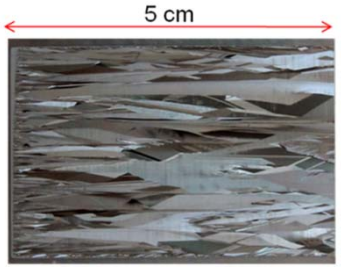
However, MasdarPV
will phase out end of 2014!

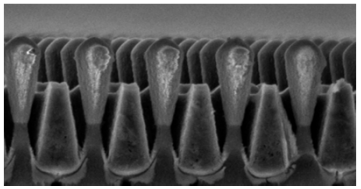
Outline

HZB Helmholtz Zentrum Berlin



- Motivation & Status
- Photovoltaics
  - Status, applications, perspectives
- **Challenges for R&D - Examples**
  - Solar energy @ HZB - overwiev
  - Crystalline Thin Film Si
  - Si Nanotechnology
- Conclusions





Thin-film Si on glass – status&challenge

HZB Helmholtz Zentrum Berlin

Triple junction cells (1cm²)

(a-Si:H/µc-Si:H/µc-Si:H)

13.4*% LG Electronics

13.6 % UniSolar

Tandem cells (1cm²)

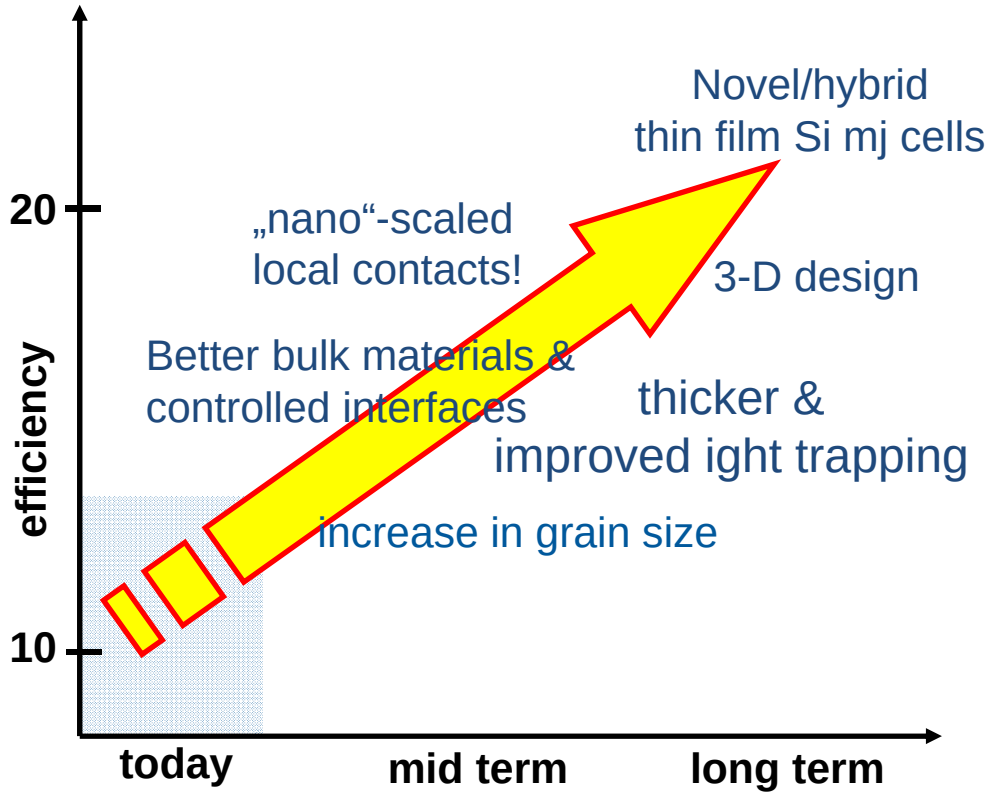
a-Si:H/µc-Si:H: 12.3* % Kaneka

Single junction cells (1cm²)

µc-Si: 10.7*% EPFL/IMT

a-Si:H: 10.1*%TEL Solar

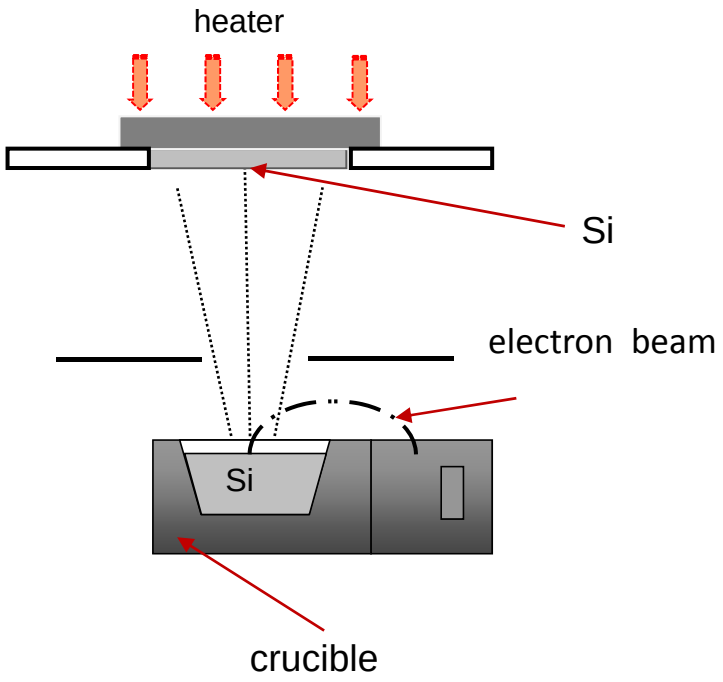
SPC-poly Si: 10.4*% csg solar (94cm²)



see review articles in special issue
Solar Energy Materials and Solar Cells 119 (2013)
ed. by A. Shah and A.N. Tiwari

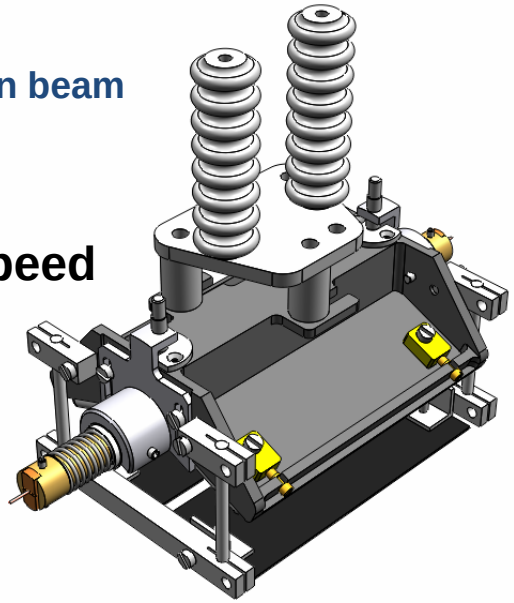
Fast Si deposition & fast crystallisation

HZB Helmholtz



electron beam

crystallisation speed
1 cm/s



CW diode laser

- Deposition rate up to 1µm/min
- film thickness 10-30 µm feasible
- High Vacuum (not UHV)
  (10^{-7} to 10^{-6}mbar)
- No toxic/explosive gases

LIMO
Lissotschenko Mikrooptik

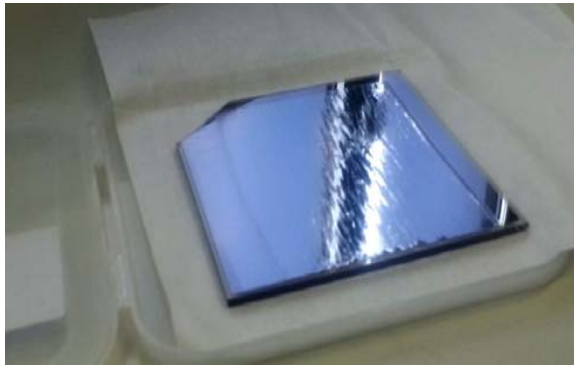


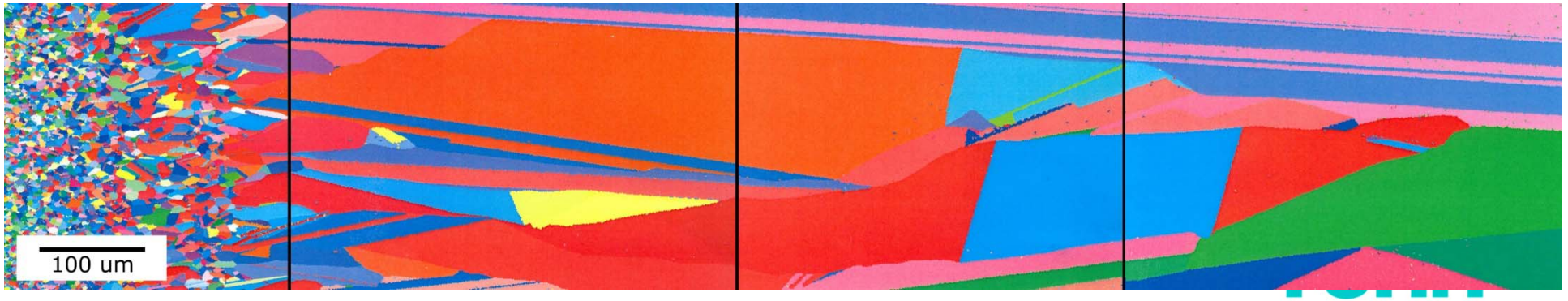
Electron Beam Crystallization on glass

HZB Helmholtz Zentrum Berlin





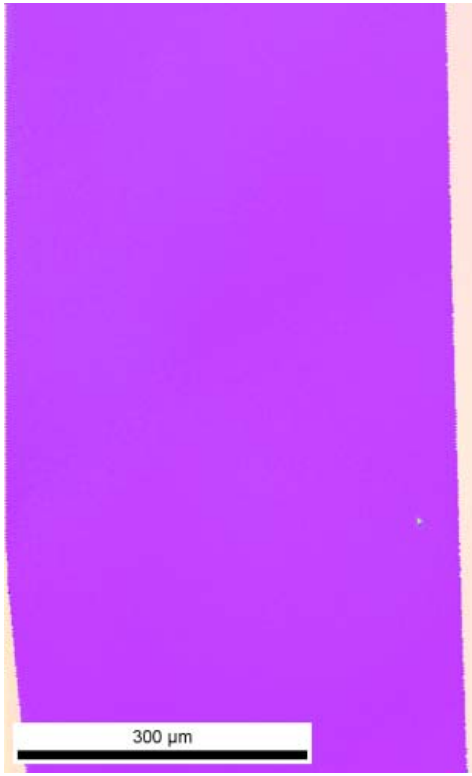




Technische Universität Hamburg-Harburg

Liquid Phase Crystallization on Glass

HZB Helmholtz Zentrum Berlin



Grain size / EFG like

up to cm in length

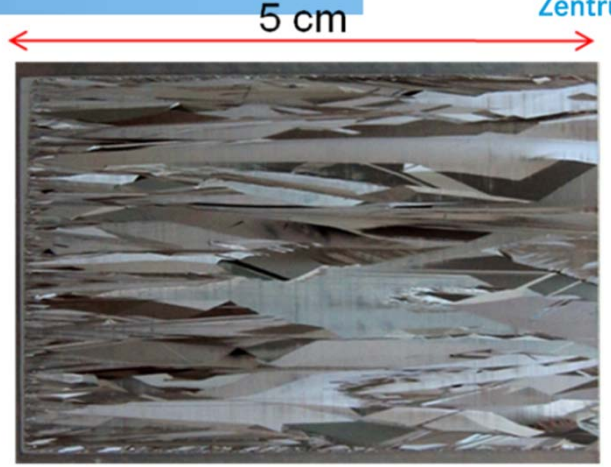
& several 100 µm in width

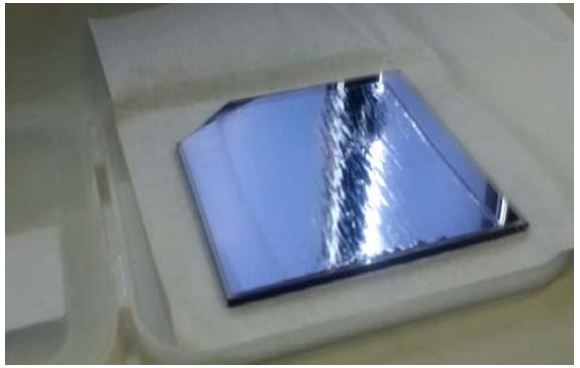
Typical Thickness 10 µm

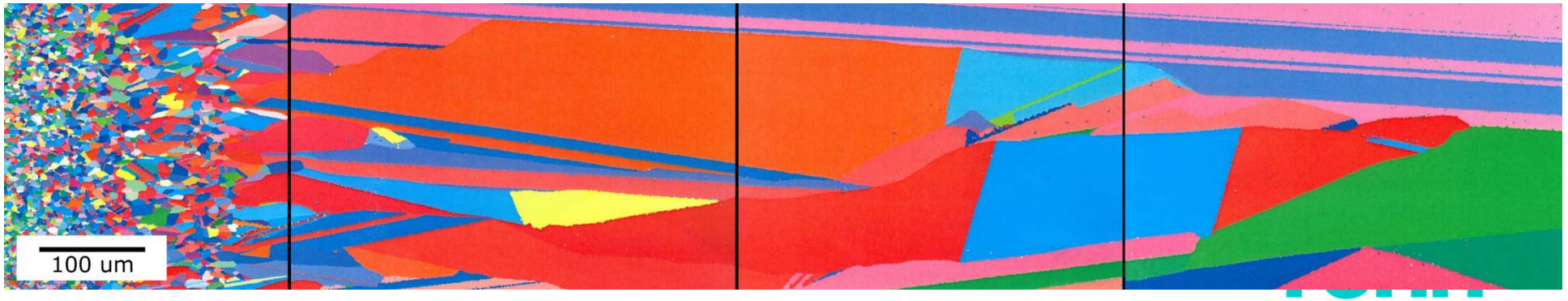
Dislocation densities:

very low in large grains

(comparable to cz-silicon)





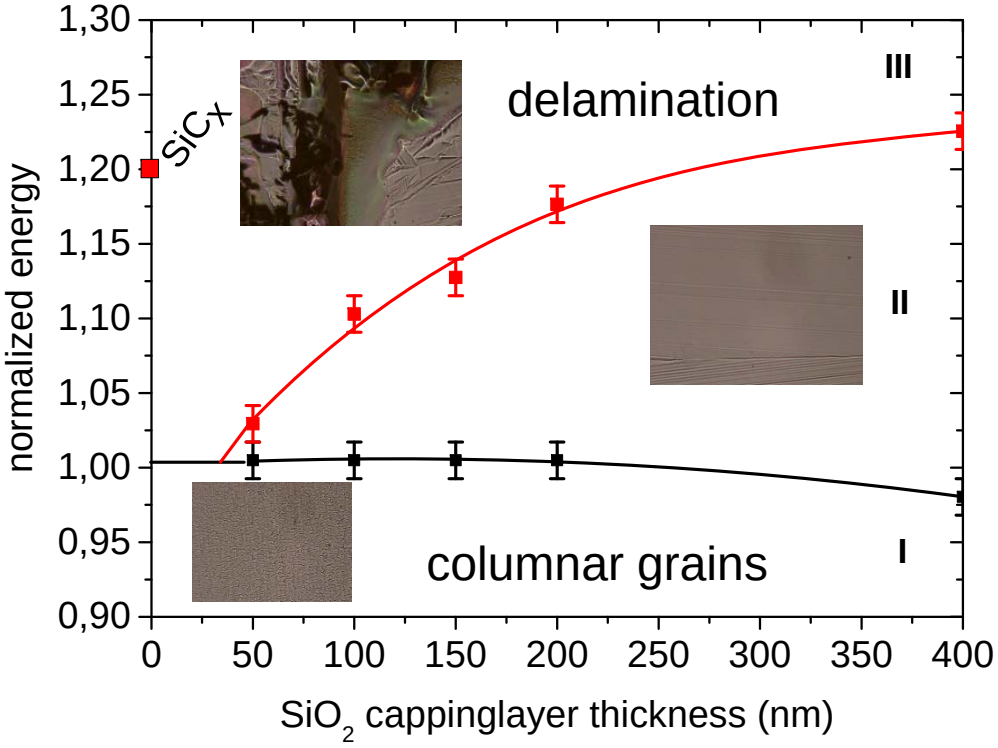


Technische Universität Hamburg-Harburg

Electron Beam Crystallisation

HZB Helmholtz Zentrum Berlin

Process window on SiO_2 and SiC_x



longitudinal grains region II



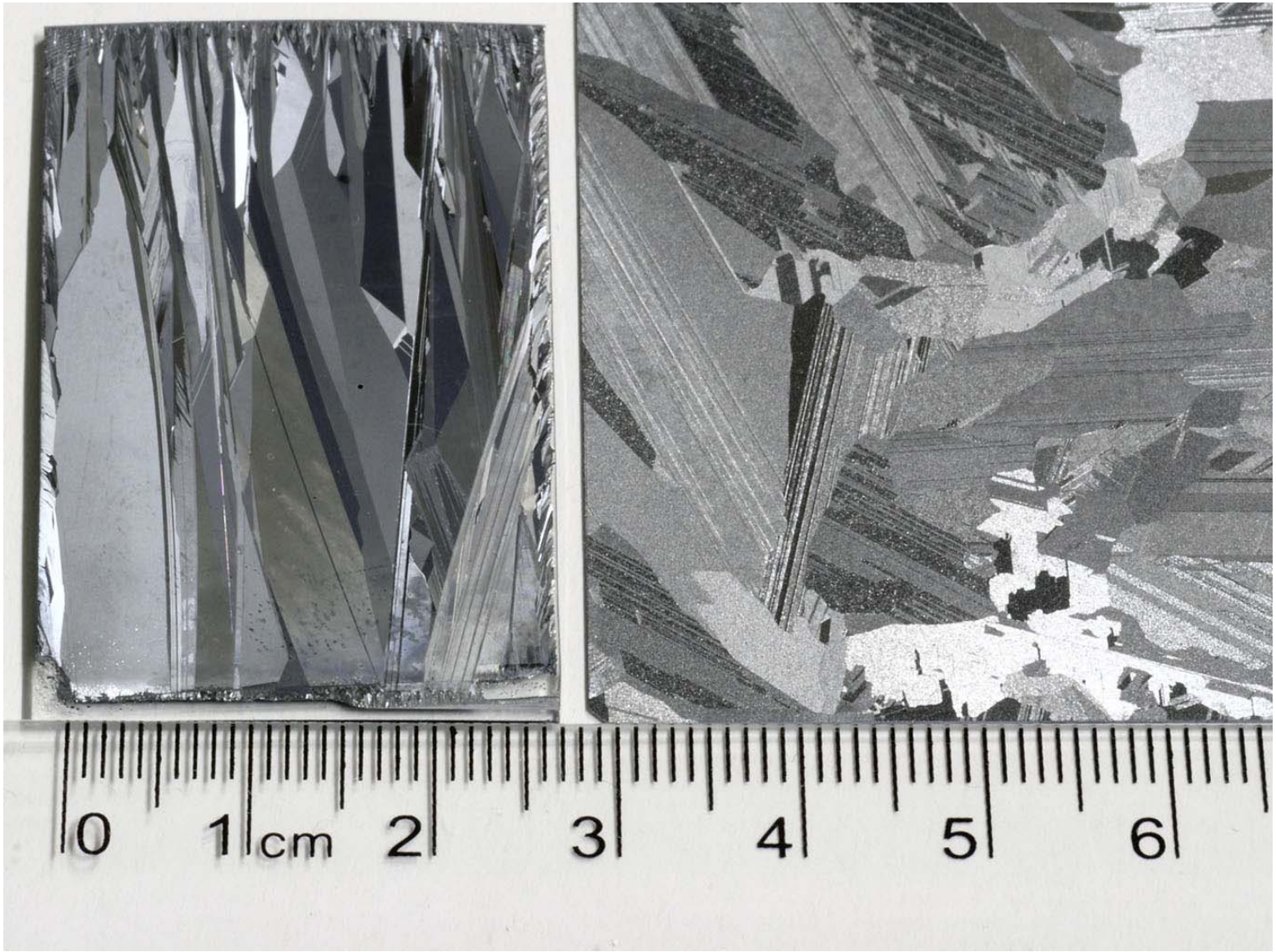
D. Amkreutz et al., SolMat Vol 123 (2014)

Latest progress towards wafer quality

HZB Helmholtz Zentrum Berlin

40 µm crystallised Si on glass

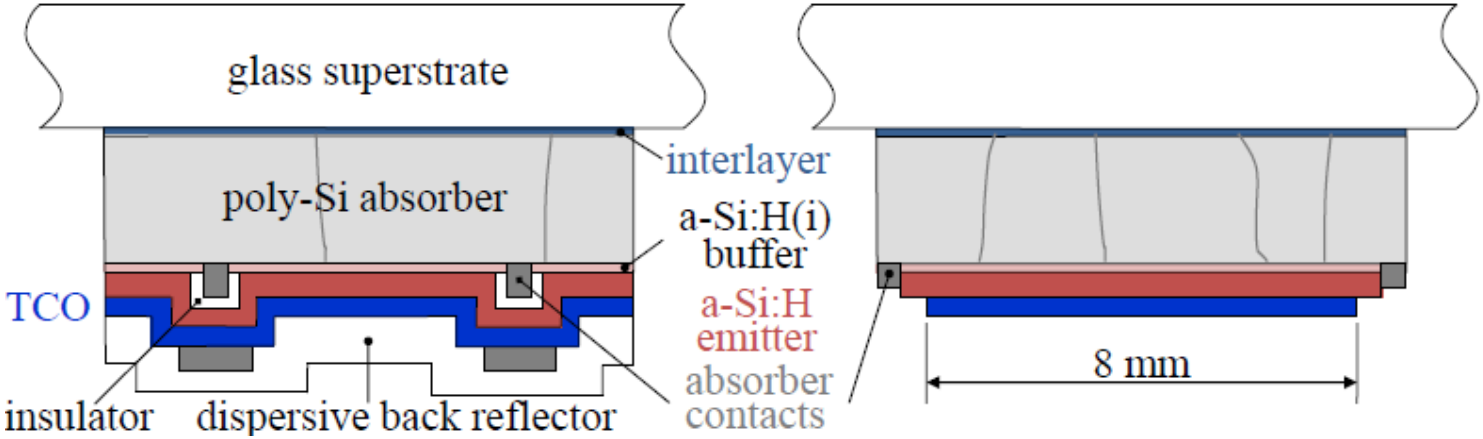
Multi-crystalline Si wafer

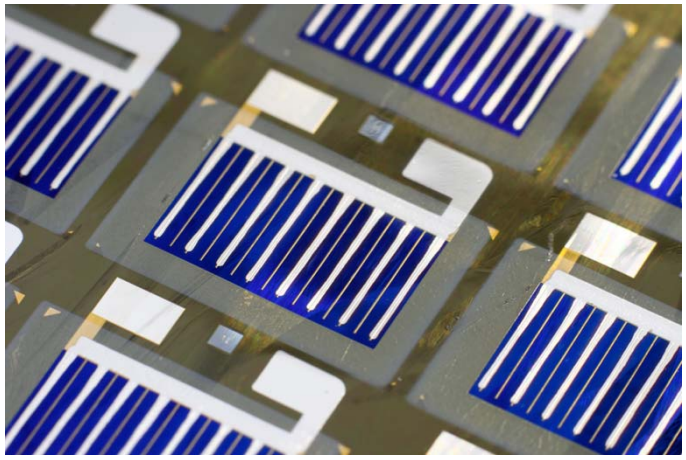


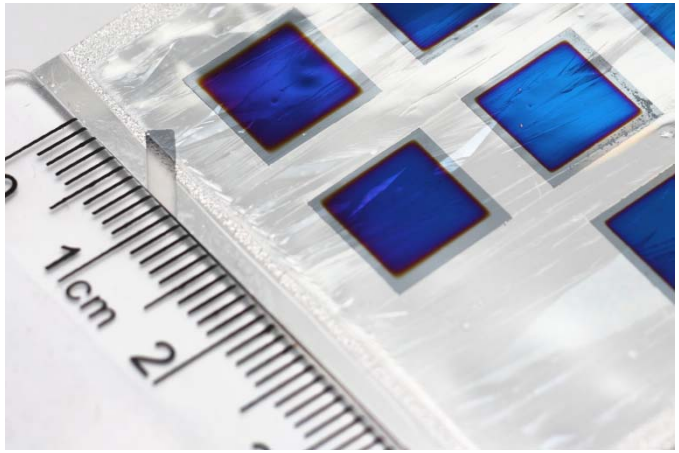
Solar cell structures

„advanced“ design - A

simple design - S

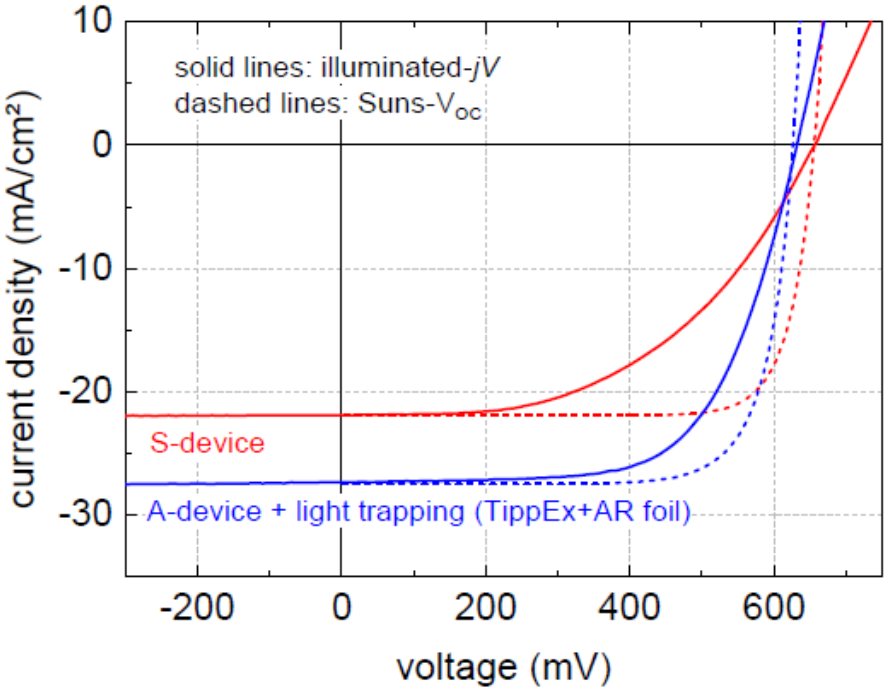


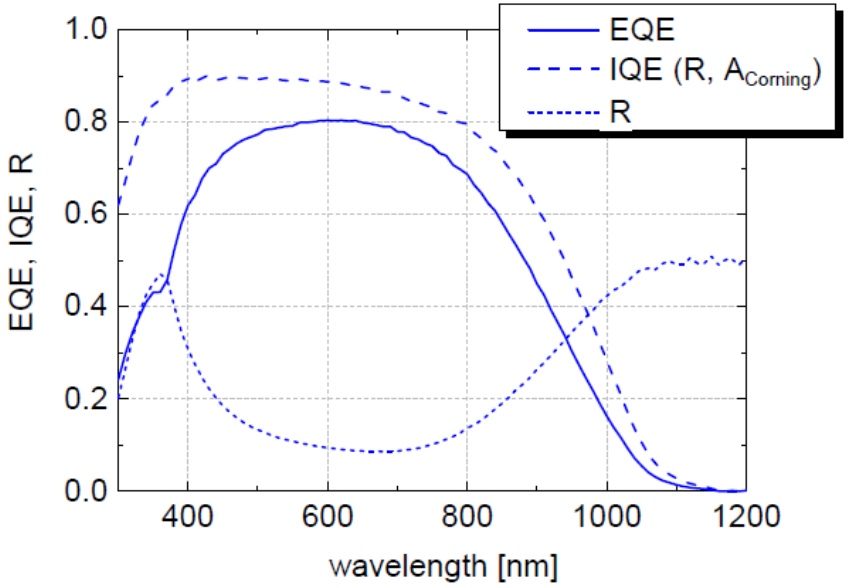




Jan Haschke et al., SolMat (2014) available online

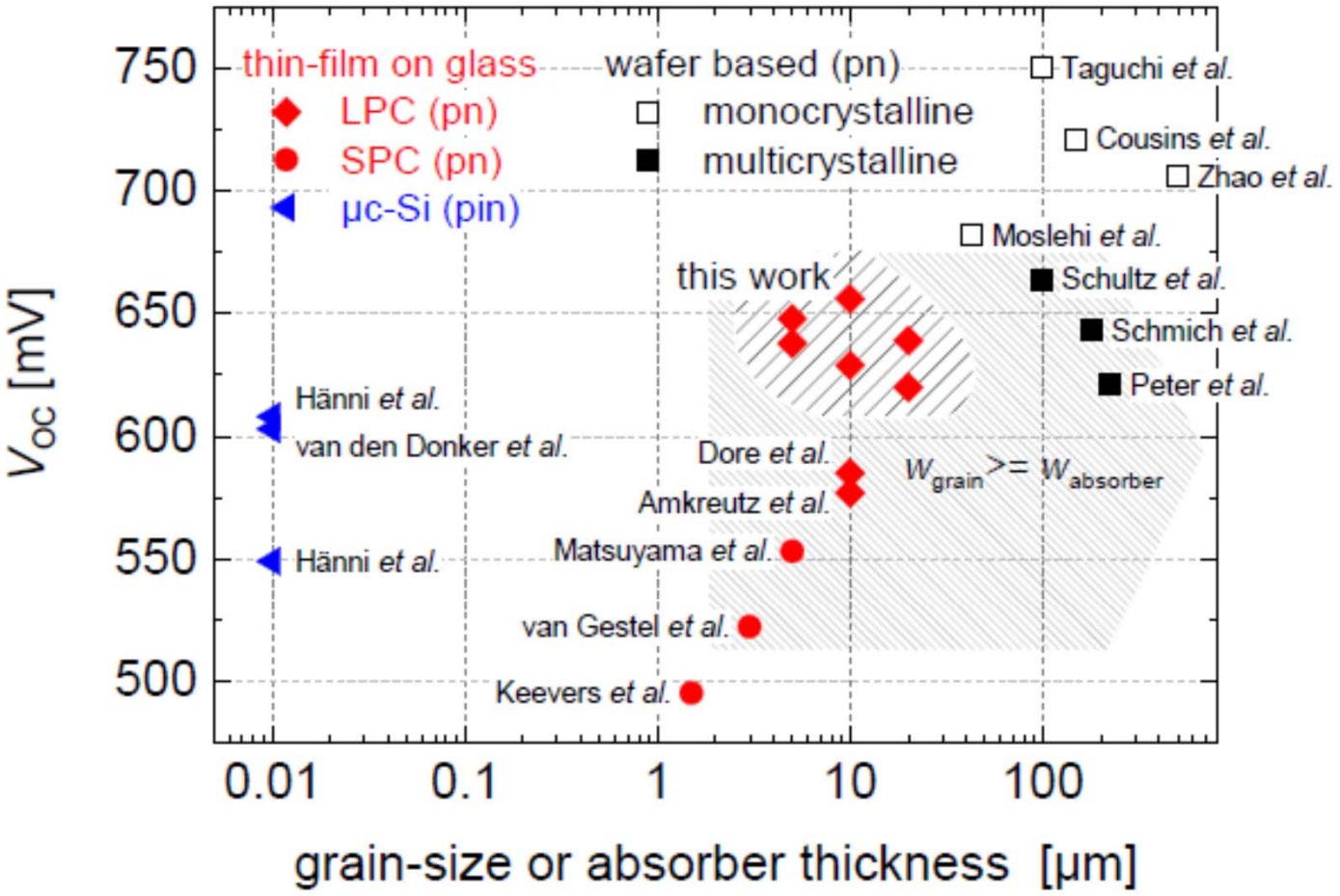
Solar cell performance





	V_{OC} [mV]	j_{SC} [mA cm^{-2}]	FF [%]	η [%]	pFF [%]
S-device[1,i]	656	21.9	50.0	7.2	80.2
A-device (w/ TippEx & ARF)[2,i]	632	27.3	64.8	11.2	75.8
A-device (w/ TippEx & ARF)[2,ls]	629	27.5	66.2	11.5	77.0

Jan Haschke et al., SolMat (2014) available online



Jan Haschke et al., SolMat (2014) available online

Going – 3 D in thin film Si

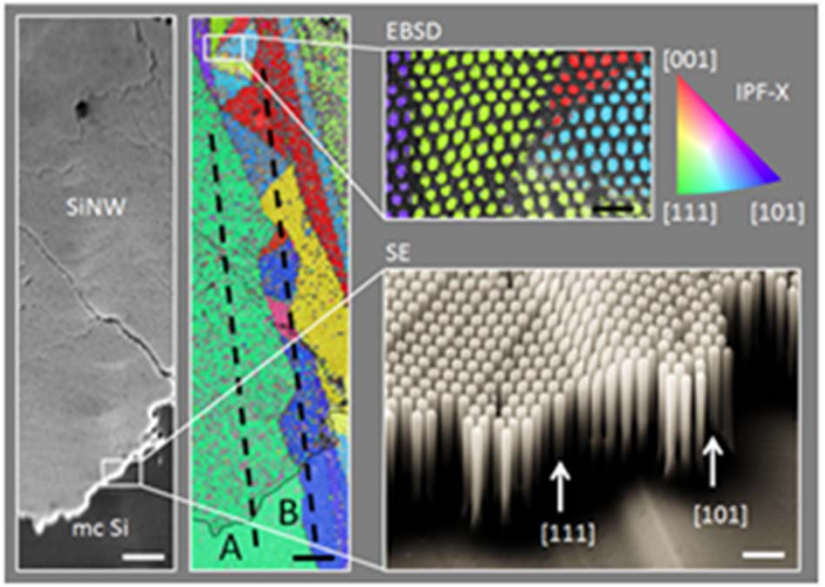
HZB Helmholtz Zentrum Berlin

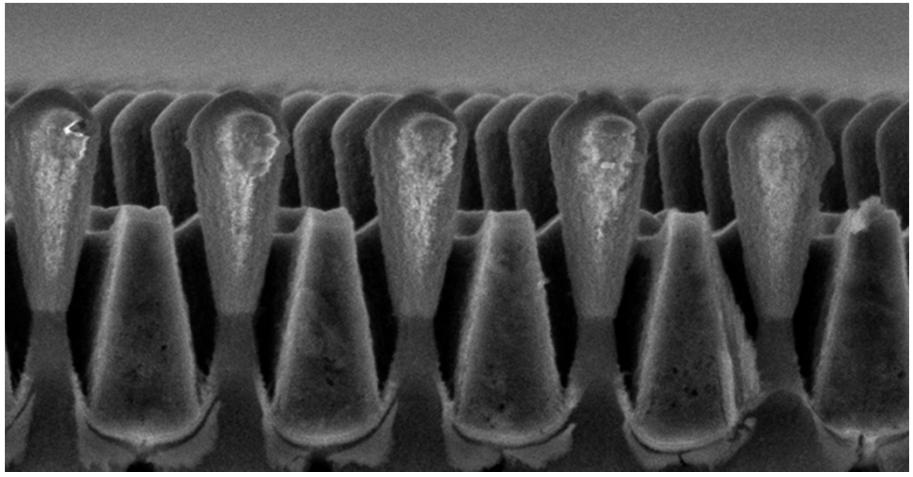
Very high light absorption

Additional freedom for optimisation

Removal of poor quality material

„cheap is possible“



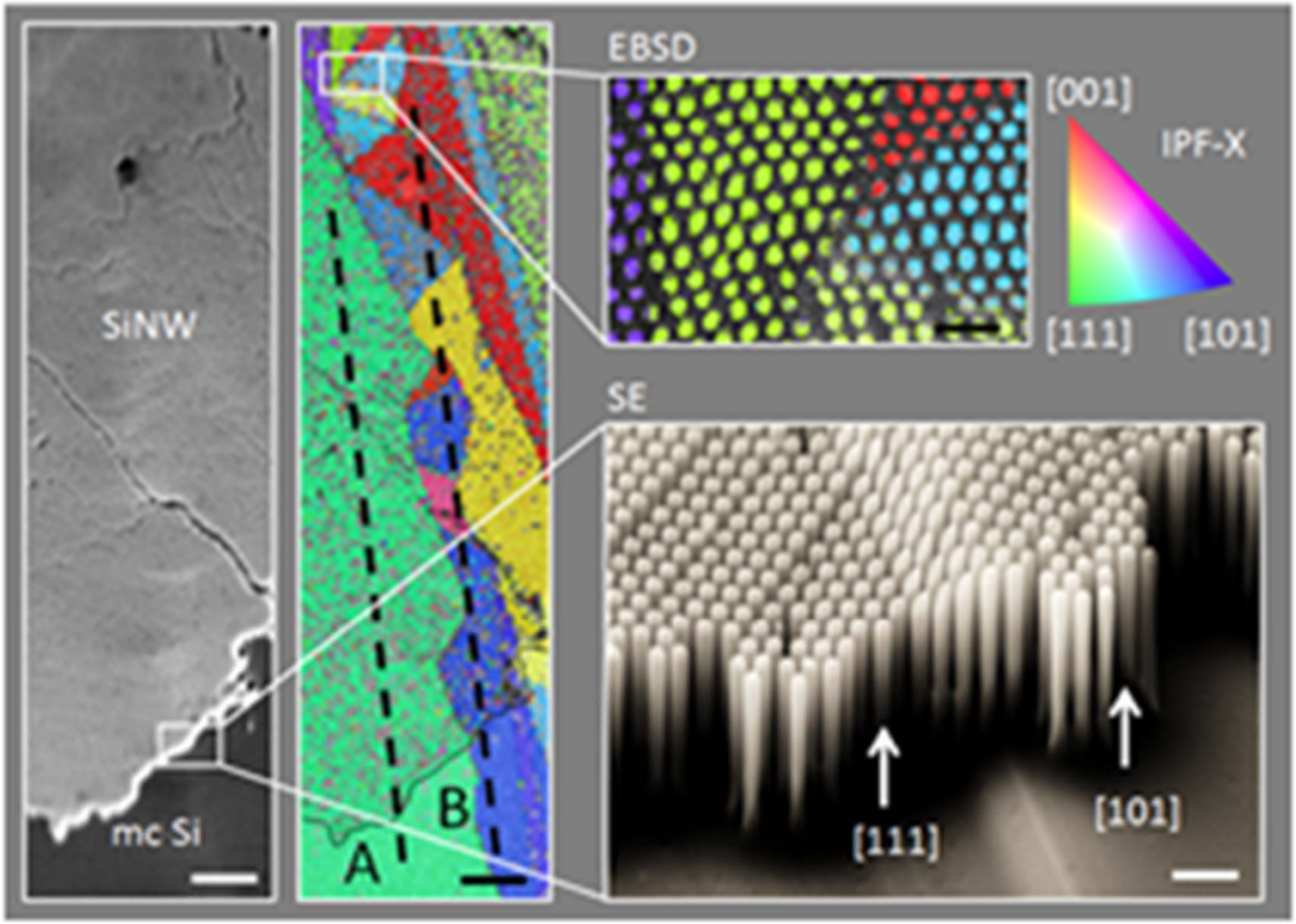


New Institute „Nanoarchitectures
Silke Christiansen

SCHOTT
glass made of ideas

Young Investigator Group of Christiane Becker

Going 3 D in thin film Si



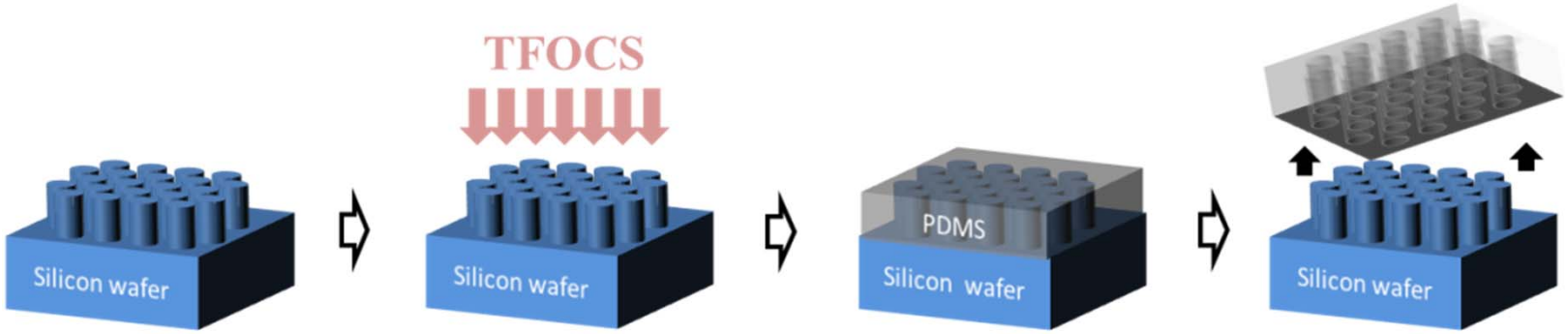
50 µm 3 µm

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

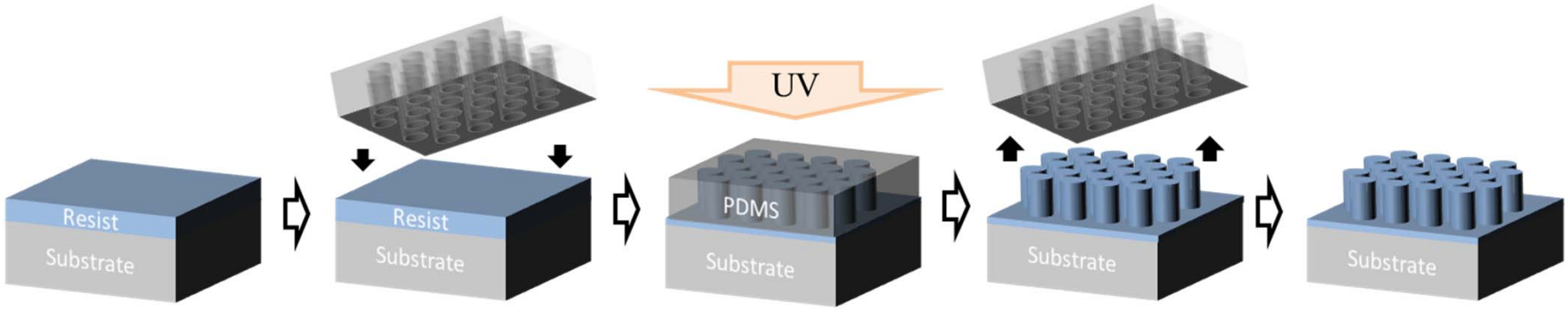
Master Replication
UV-Nanoimprint Lithography



Step 1: Fabrication of the PDMS-stamp



Step 2: Imprinting of the UV-curable sol-gel

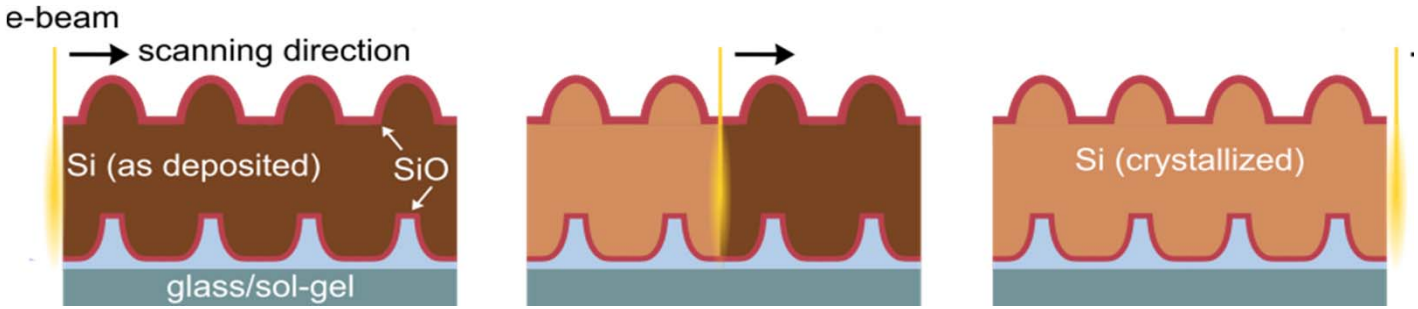


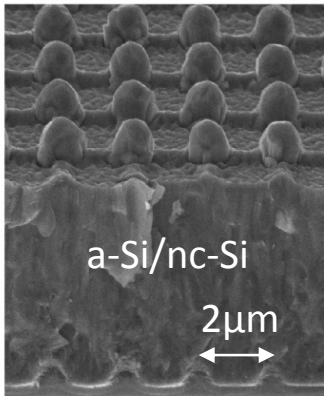
➢ **Repeatable, high throughput**

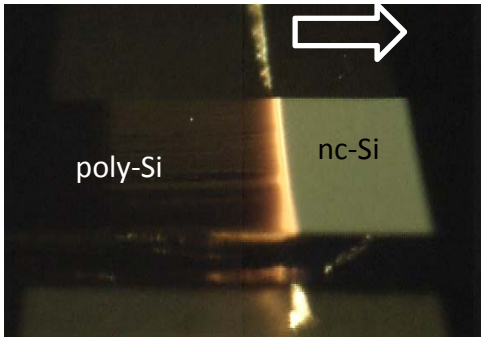
Liquid phase crystallized textured Si films

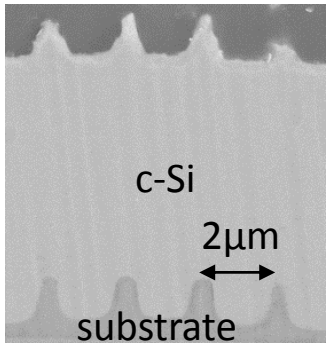
Helmholtz Zentrum Berlin

Double side textured Si architectures by electron-beam crystallization







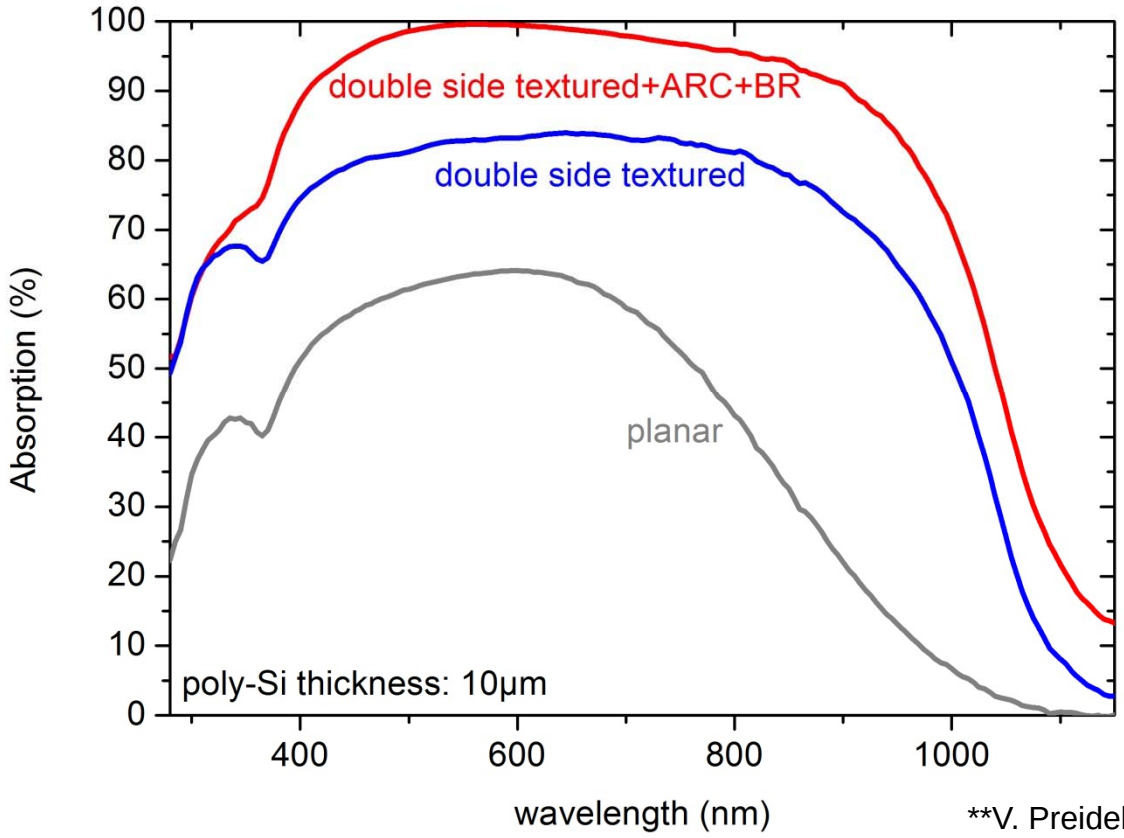


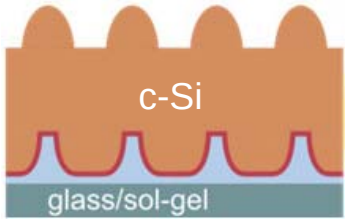
T > 1414°C (Si melting point)

**V. Preidel et al., Proc. SPIE 8823, 882307 (2013)

Double-side textured crystalline silicon film

Absorption enhancement in liquid phase crystallized Si films





Double side texture

**V. Preidel et al., Proc. SPIE 8823, 882307 (2013)

- Absorption enhancement stable up to 60° angle of incidence
- Optical potential for t_{Si} = 10 µm: $J_{sc,max}$ = 38.2 mA/cm² (double side texture)

Conclusions & Outlook I

HZB Helmholtz Zentrum Berlin

Advantages of thin film silicon

- Unlimited raw material availability & low energy consumption
- Unique products & applications
- Thin-film silicon technology is a key for for wafer technology („HIT- approach“)

Opportunity

- Large grained liquid phase crystallised Si on glass - a new player

  - material properties are approaching wafer quality (**>650 mV**)
  - high-rate deposition for silicon precursors (prior to crystallisation)
  - alternative processes for silicon deposition feasible (e.g. via liquids)

  strong efforts in research & development still needed!

Conclusion&Outlook II

HZB Helmholtz Zentrum Berlin

- **Solar energy will become a (the) major energy source in the future. The transformation of the energy system is one of the key global challenges!**

- **PV has proven that it is an Energy and not a Niche Technology**
  - **strong market penetration is needed on a global scale**
  - **system integration is a key**

- **PV has emerged as a major global industry facing strong competition**

- **R&D challenge & opportunity:**
  - **cheaper**
    - **more efficient !**
      - **new appliations**
        - **storable**



Vision

Sustainable Energy for 9 Billion People

Noah´s ark 2050
(artist´s impression, courtesy of Lisa, Emilia and David)

HELMHOLTZ ASSOCIATION

Thanks to my colleagues at HZB, TU-Berlin, Schott, Limo, MasdarPV

Thank you for your attention.



This work was supported by the Federal Ministry of Education (BMBF) and the state government of Berlin (SENBWF) in the framework of the program “Spitzenforschung und Innovation in den Neuen Ländern” (grant no. 03IS2151) and by the BMBF and the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) in the framework of the program “Innovationsallianz Fotovoltaik” (grant no. 0325317C).