Advances in nanostructuring of titania thin films for dye-sensitized and hybrid photovoltaics

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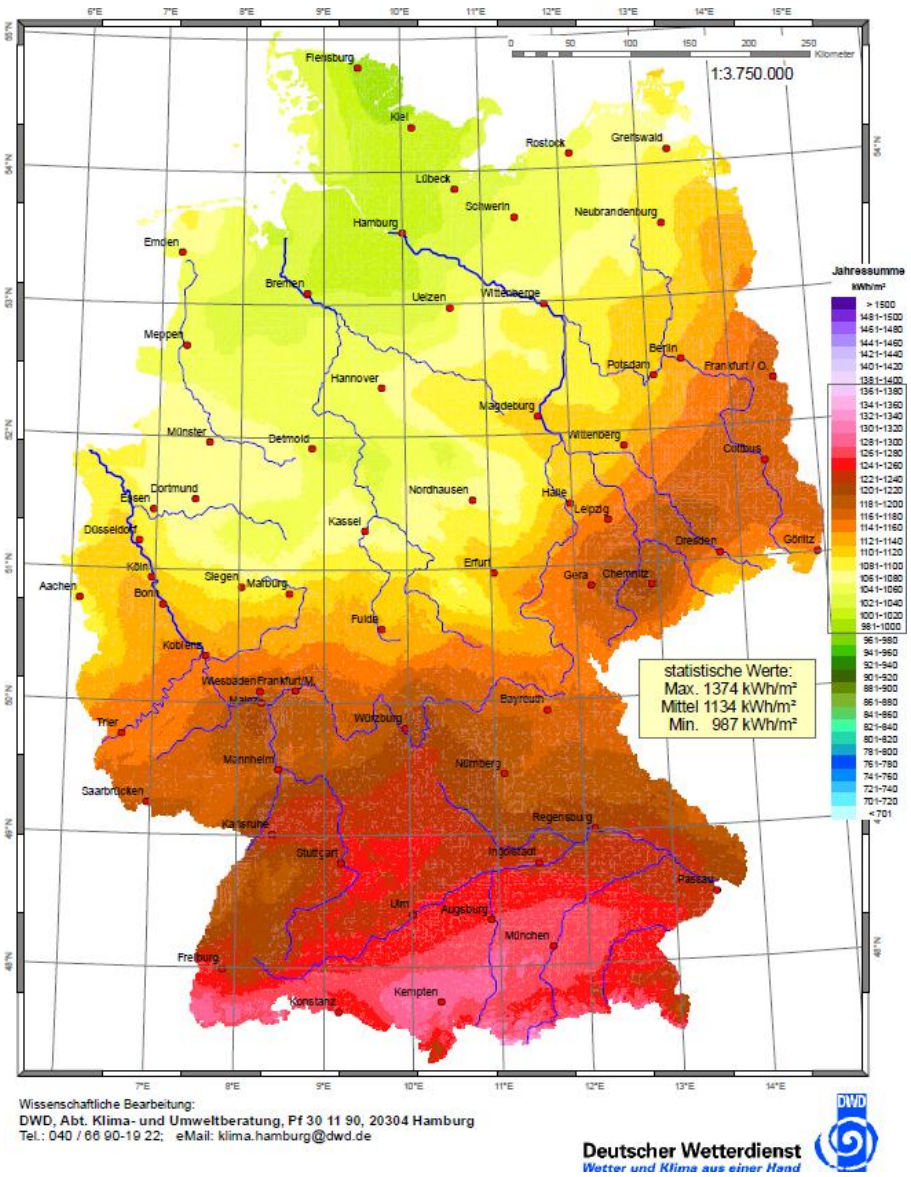
photovoltaics in Germany



- solar energy available in Germany
- current technology mostly silicon (Si) based

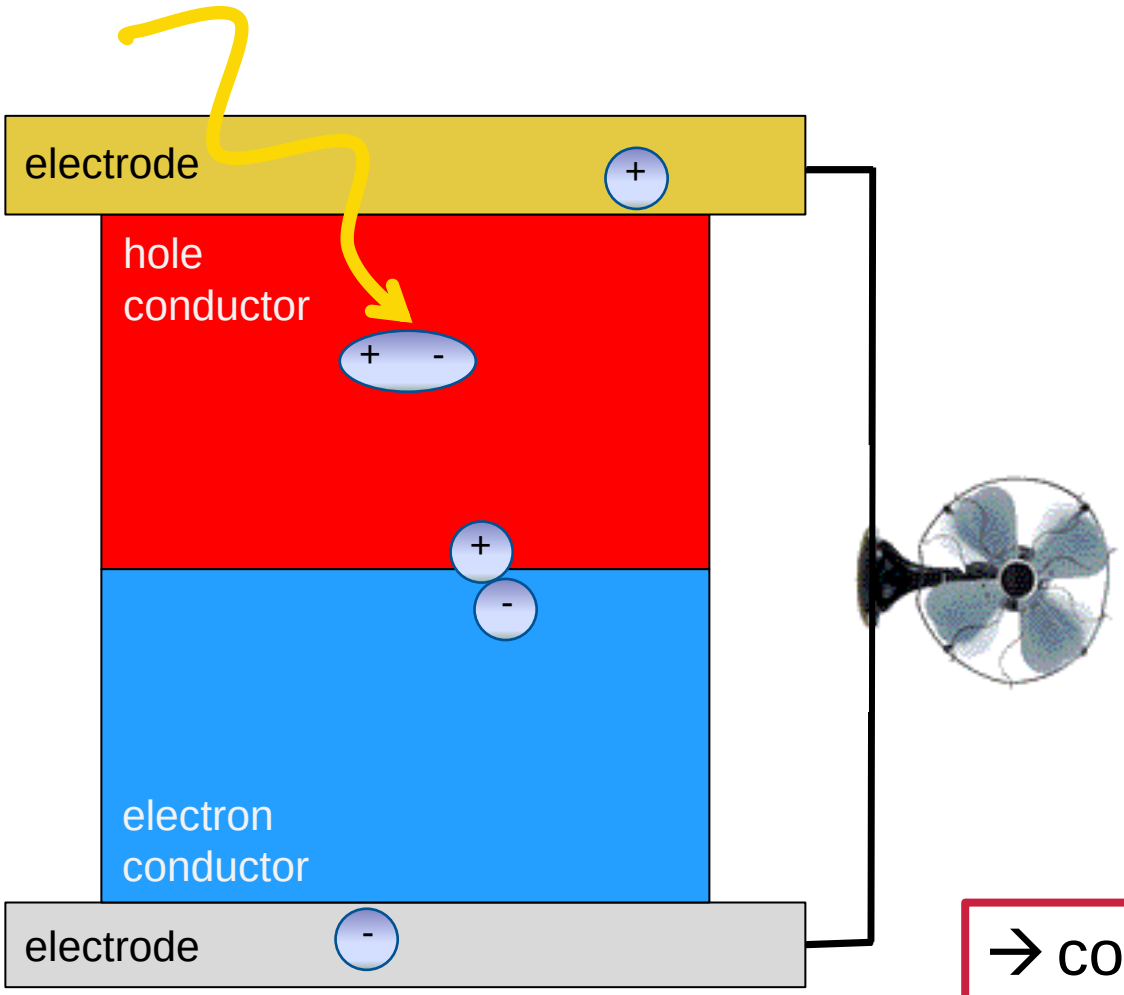
Wildpoldsried.de: Das Energiedorf

yearly sum of global horizontal irradiation (direct and diffuse radiation) in Germany, in the year 2011

measured in kWh/m^2

max: 1374 kWh/m^2
mean: 1134 kWh/m^2
min: 987 kWh/m^2

basic principle of a solar cell



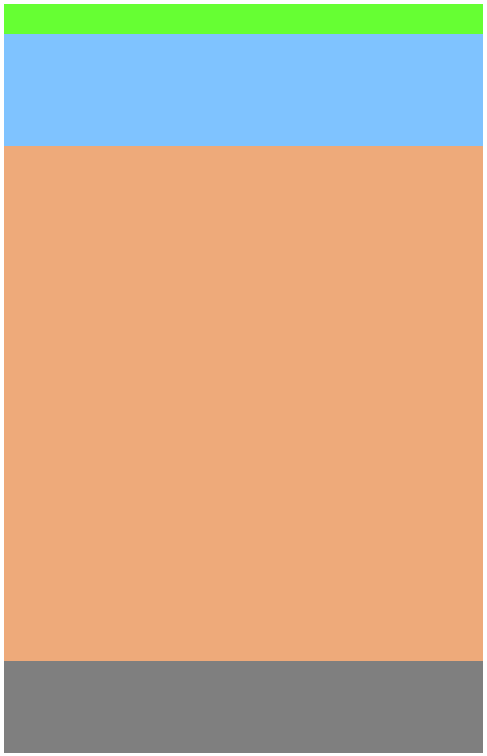
1. light absorption
2. exciton creation
3. exciton diffusion
4. charge separation, transport and extraction
5. charge recombination via external load

→ conversion of solar energy into electricity

need for research on solar cells

thickness and type of active layer → amount of required material
→ recicability
→ toxicity
→ weight

conventional Si
min. 150 µm;



„thin film“,
amorphous Si
10 µm

thin film
technologies
1-2 µm

examples:

- CdTe
  (Cadmium Telluride)
- CIGS (Copper Indium
  Gallium Selenide)

novel technologies
< 0.5 µm = 500 nm

examples:

- organic solar cells
- hybrid (inorganic-
  organic) solar cells
- dye-sensitized
  solar cells

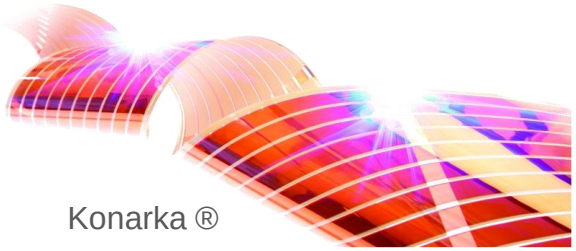
need for research on solar cells

further important aspects of novel technologies:

- no need for expensive production (clean room, high temperatures)

phys.org: Si solar cell manufacturing centre of Trina Solar in Changzhou, China

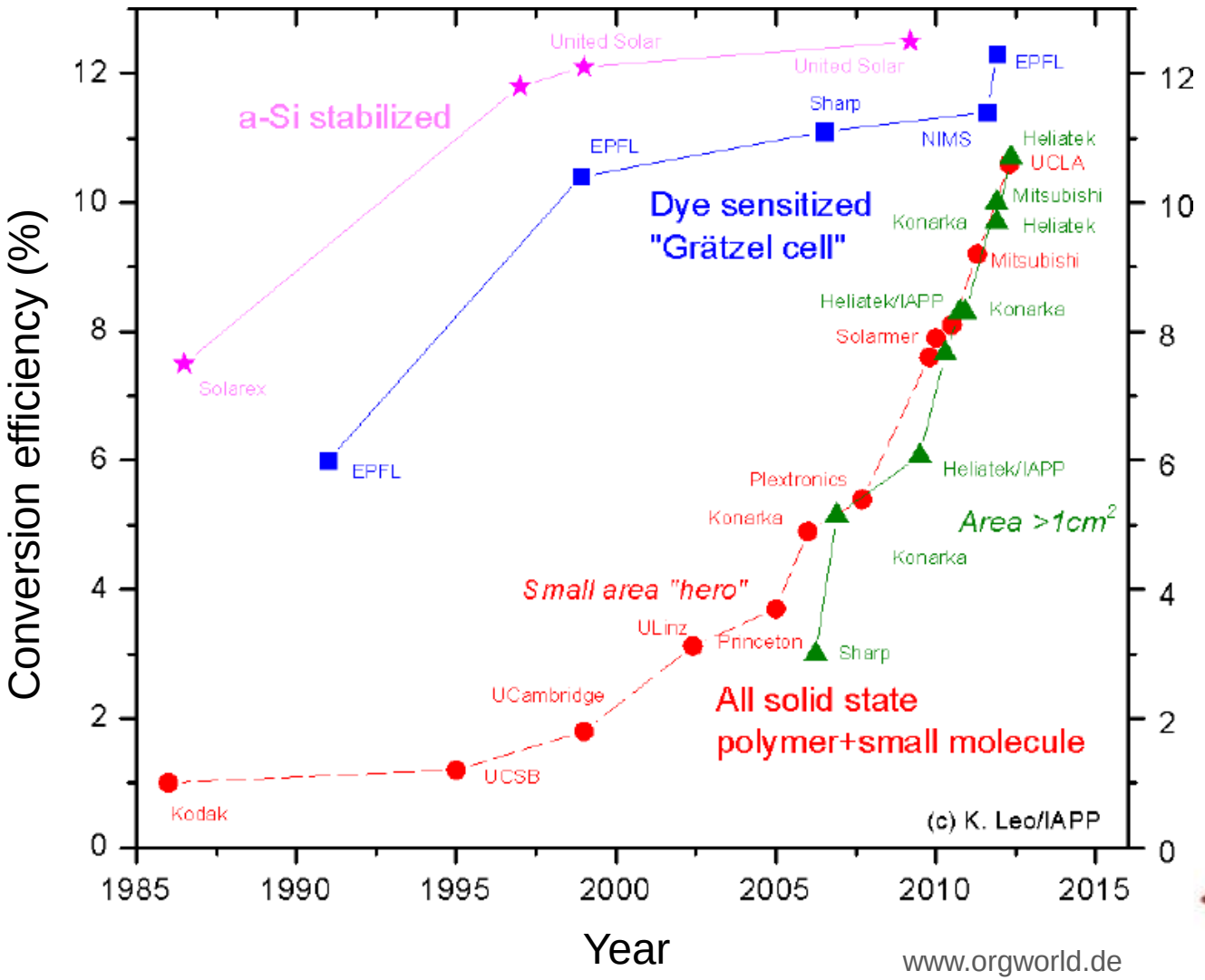
- mechanical flexibility
  → roll-to-roll printing



Konarka ®

- performance under cloudy conditions and at operation temperatures better than silicon

efficiencies



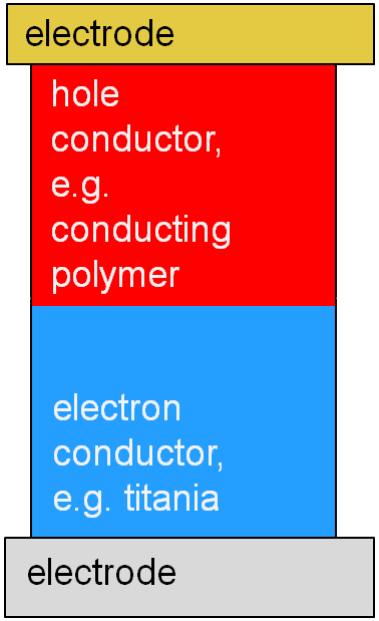
- promising trend of efficiencies
- soon exceeding amorphous silicon to be expected

> 10 %
in 2012

konarka.com

types of novel solar cells 1

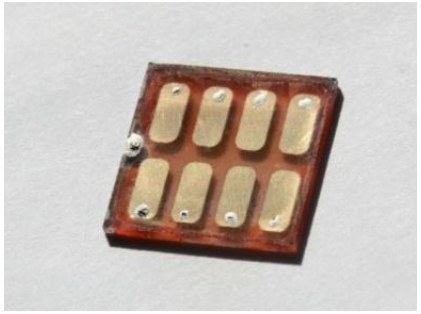
- **hybrid solar cells:**
  combination of inorganic material and organic material

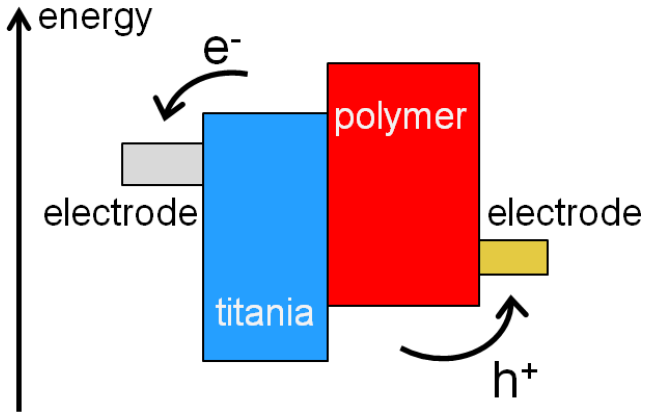


- inorganic (titania)
- organic (polymers = plastics)

→ cheap and easy to manufacture
→ flexible
→ thin films, little amount of material
→ good at operation temperatures

- efficiencies: max. 4 %
  K. Kreis et al., Solar Energy Materials & Solar Cells 2002, 73, 51.

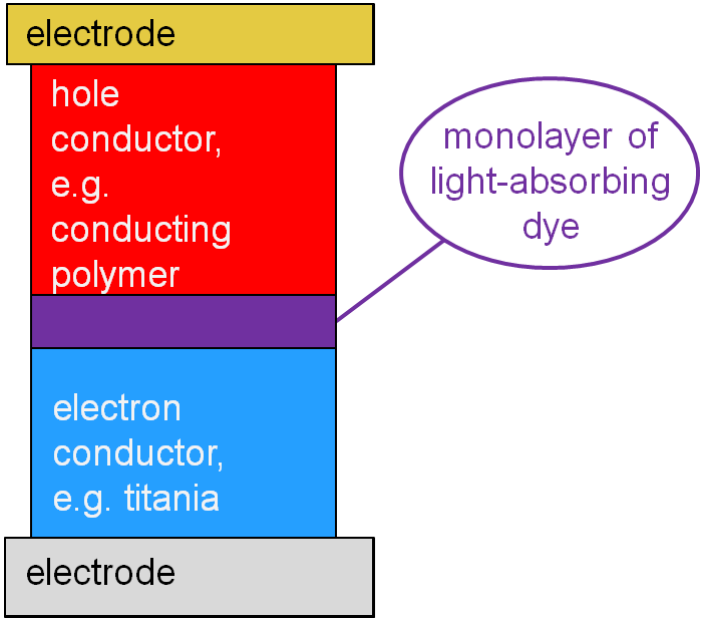




types of novel solar cells 2

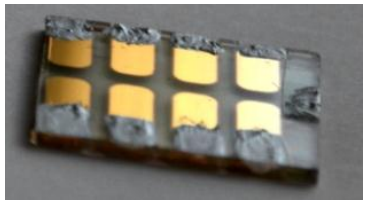
- **dye-sensitized solar cells:**
  additional light-absorbing dye layer between organic and inorganic material

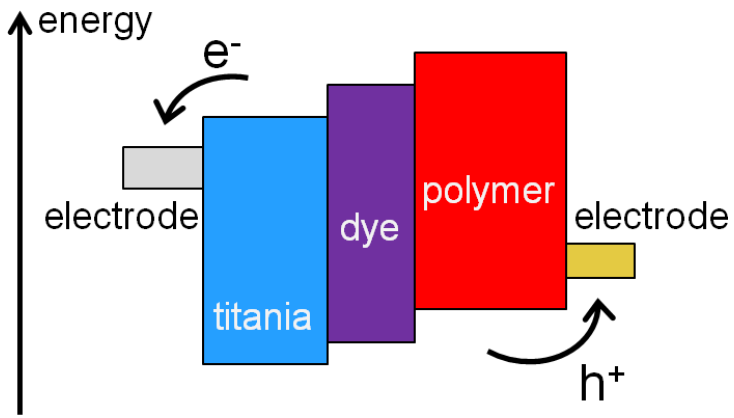
- with liquid electrolyte as hole-conductor:
  efficiency max. 12.3 %
- with solid hole-conductor:
  efficiency max. 5 - 7.1 %



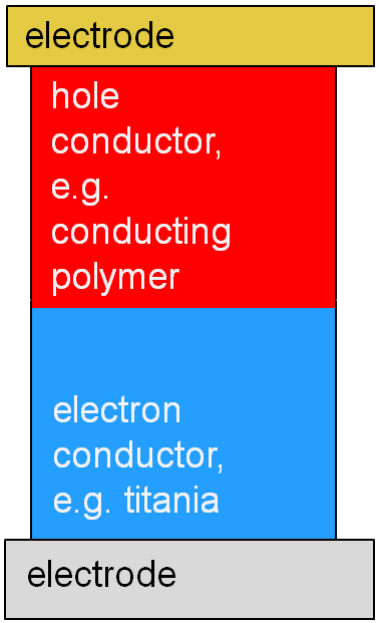
M. A. Green, et al., Prog. Photovolt.: Res. Appl. 2012, 20, 12-20; B. E. Hardin et al., Nature Photonics 2012, 6, 162-169

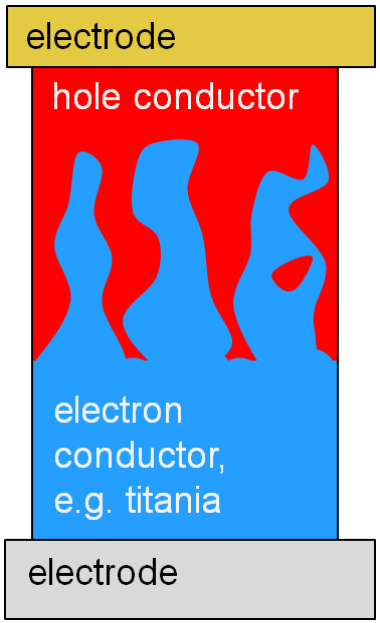
Fraunhofer ISE

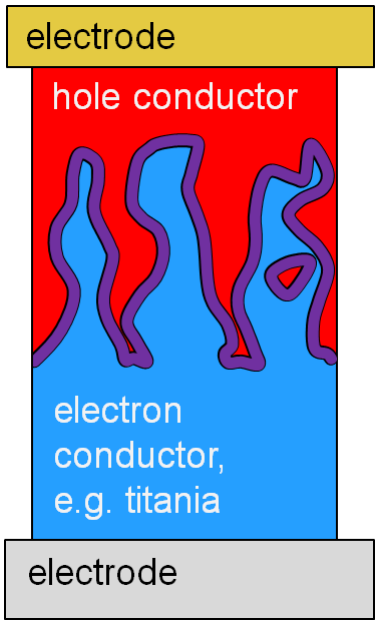




importance of nanostructures







bilayer structure:
→ small interfacial area
→ low efficiency of solar cells

nanostructures:
larger interfacial area
→ better charge separation
→ more efficient solar cells

nanostructures with **dye**:
larger interfacial area
→ higher absorption
→ more efficient solar cells

Titania

Titania:

- „q[illegible] of fairies“ in Shakespeare‘s midsummer night‘s dream

painting by Henry Fuseli, 1796

- largest moon of Uranus

titania as electron acceptor

titania = titanium dioxide, TiO_2

- ✓ cheap
- ✓ readily available
- ✓ non-toxic, biocompatible

common applications:

- pigment: titanium white
- food coloring: E171
- cosmetics: toothpaste, sunscreen

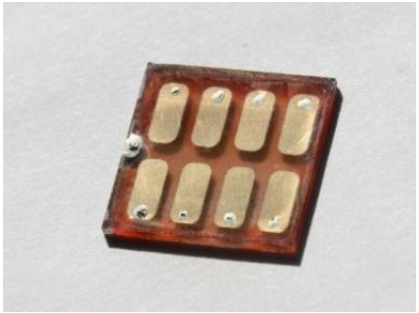
as semiconductor:

- solar cell
- photocatalyst
- gas sensor
- electrode material


1


2


3



5

4

[1]fddb.info

[2]www.toptenz.net

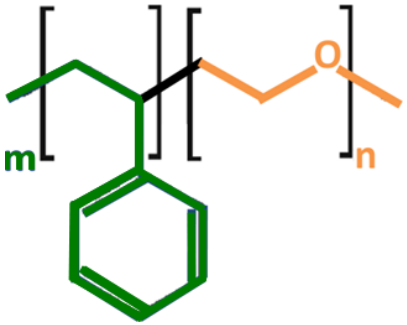
[3]www.profil-marketing.com

[4]www.rxbright.com

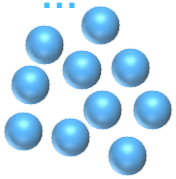
[5]www.treatment-skincare.com

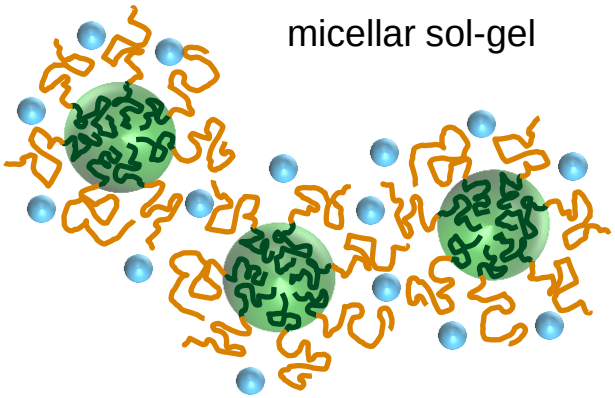
synthesis of nanostructures

- usage of ***block copolymer*** template in synthesis of titania:
  block copolymer can be imagined like a two-colored spaghetti, e.g. **PS**-*block*-**PEO**
  chemically bond hydrophobic (e.g. **PS**) and hydrophilic polymer (e.g. **PEO**)



HCl +
precursor
TTIP, **EGMT**,
…





- titania goes into the hydrophilic **PEO** block

→ solution with titania only in nanostructured regions

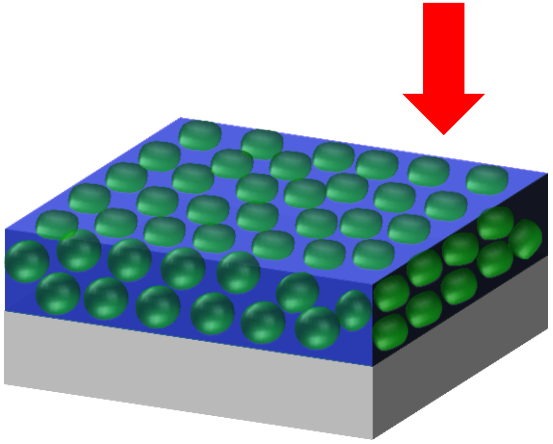
- deposition on substrate:

→ nanostructured polymer-titania film

- calcination:

→ combustion of polymer template

→ titania in crystalline phase

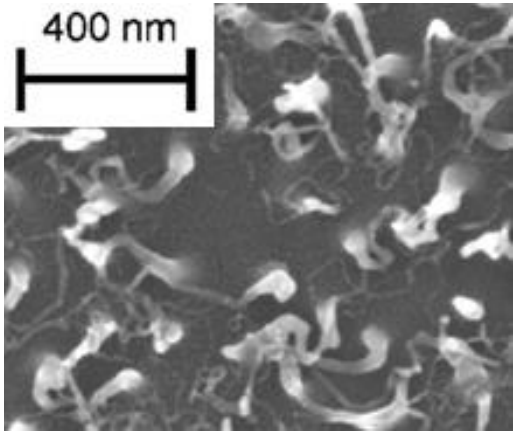


titania nanostructures

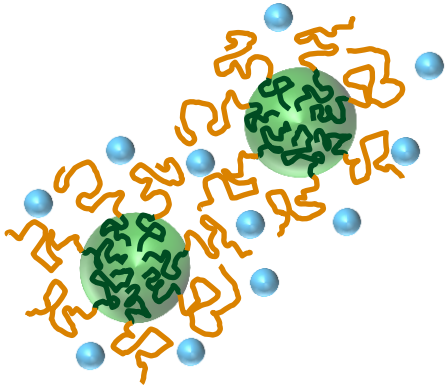
- titania from precursor **TTIP** with **PS**-*b*-**PEO** as template: worm-like nanostructures

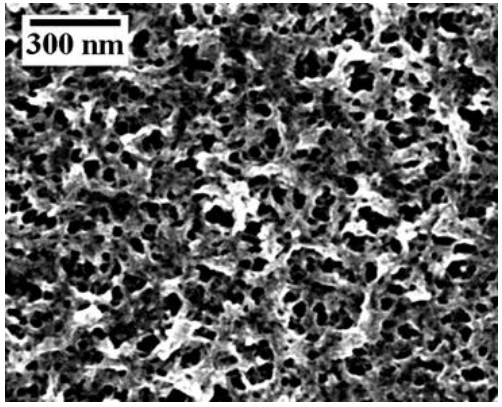
- titania from precursor **TTIP** with **PDMS**-*b*-**PEO** as template: foam nanostructures

- titania from precursor **EGMT** with **PS**-*b*-**PEO** as template: crystalline titania at temperatures below 100 °C, nano-network

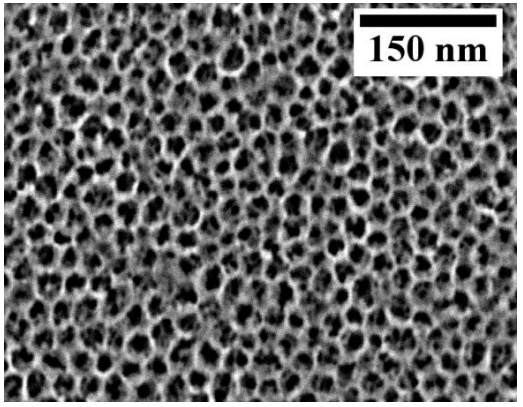


M. Rawolle et al., Chem. Soc. Rev. 2012, DOI: 10.1039/c2cs15321





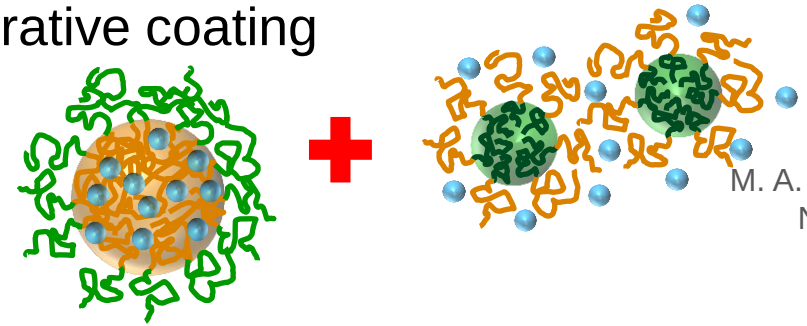
M. Rawolle et al., ChemPhysChem 13 (2012), 2412.



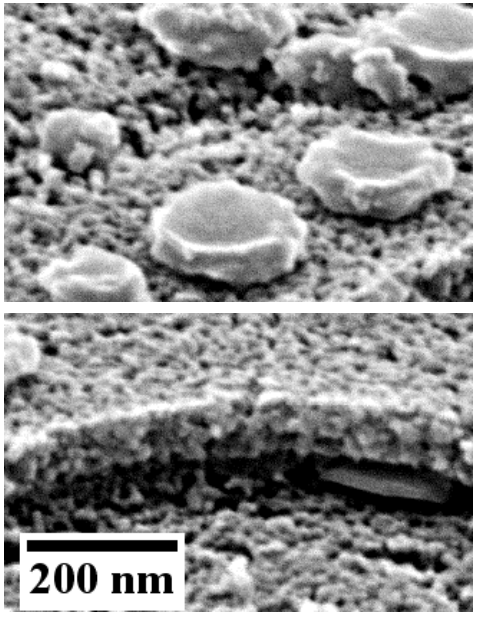
M. Rawolle et al., Small 7 (2011), 884.

hierarchical titania structures

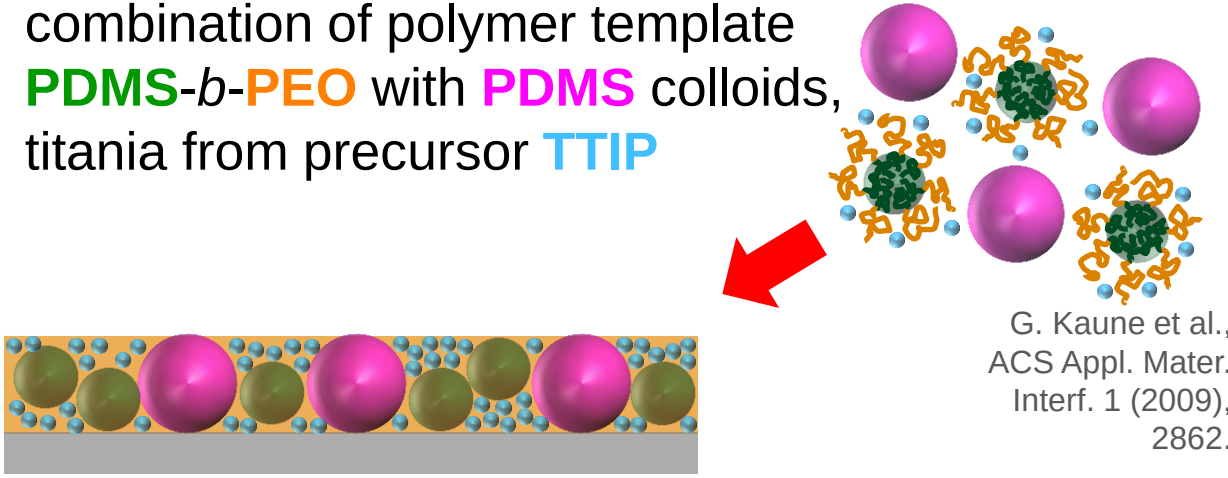
- combination of different sol-gel structures:
  - titania sponge and titania granules from precursor **TTIP** with polymer template **PS**-*b*-**PEO** (different weight fractions)
  - iterative coating



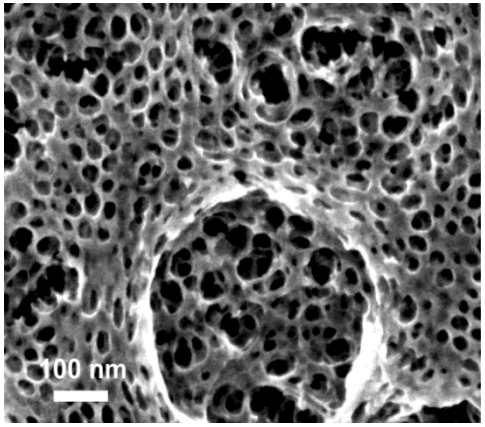
M. A. Niedermeier et al., Nanotechnology 23 (2012), 145602.



- combination of polymer template **PDMS**-*b*-**PEO** with **PDMS** colloids, titania from precursor **TTIP**

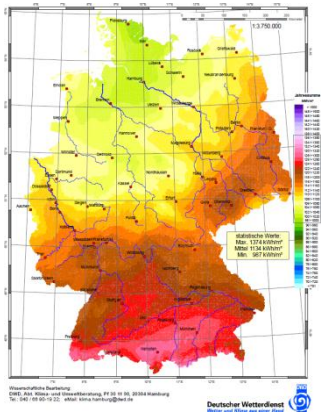


G. Kaune et al., ACS Appl. Mater. Interf. 1 (2009), 2862.

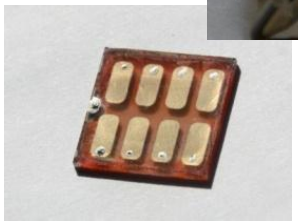


summary

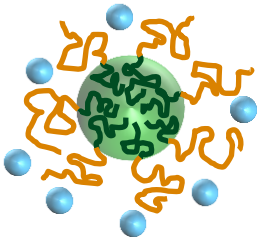
- research on solar cells necessary

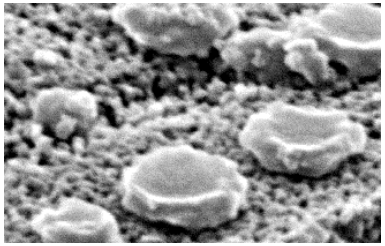


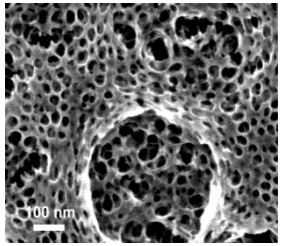
- interesting novel technologies:
  - hybrid solar cells
  - dye-sensitized solar cells

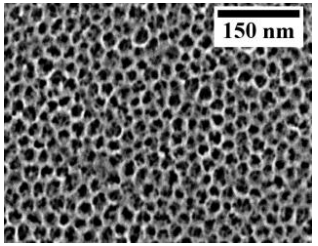


- nanostructuring of inorganic semiconductor material (e.g. titania) necessary:
  - combination of block copolymers as templates with sol-gel chemistry
  - towards hierarchical structures with addition of iterative coating or colloids in sol-gel









Acknowledgements

- all the members of the Chair for Functional Materials, Physik-Department, TUM

- funding: DFG SPP 1181 “Nanomat” (MU1487/2, HU1427/1 and GU771/2)

DFG Deutsche Forschungsgemeinschaft

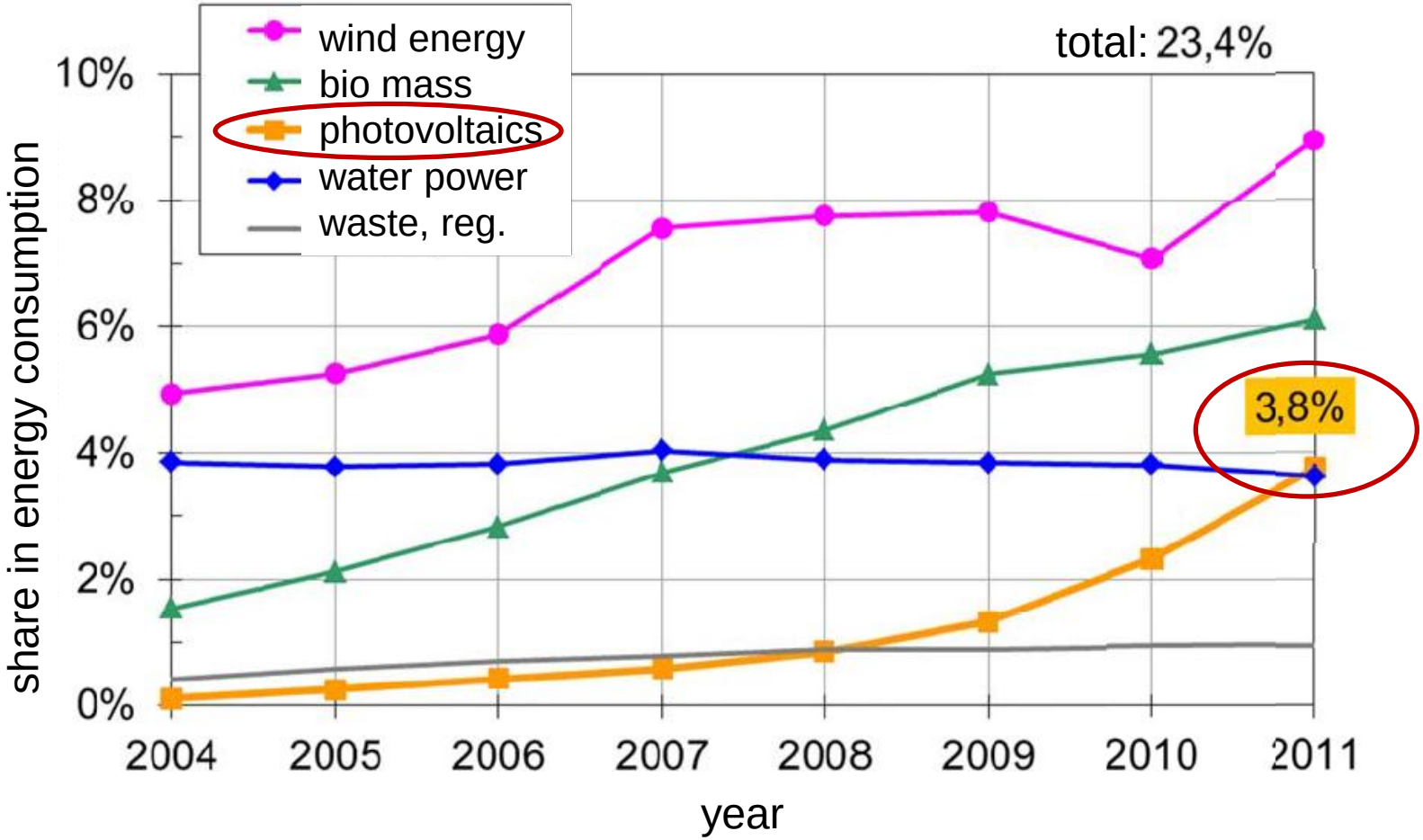
Thank you!!

outline

- motivation: solar cells and the need for research
- basic principle of a solar cell
- different types of „novel“ solar cells
  - the need for nanostructures
    - hybrid solar cells
    - dye-sensitized solar cells
- ways to tackle the synthesis of nanostructured materials
    - titania as electron acceptor
    - synthesis with block copolymer templates
    - towards hierarchical structures
- summary

photovoltaics in Germany

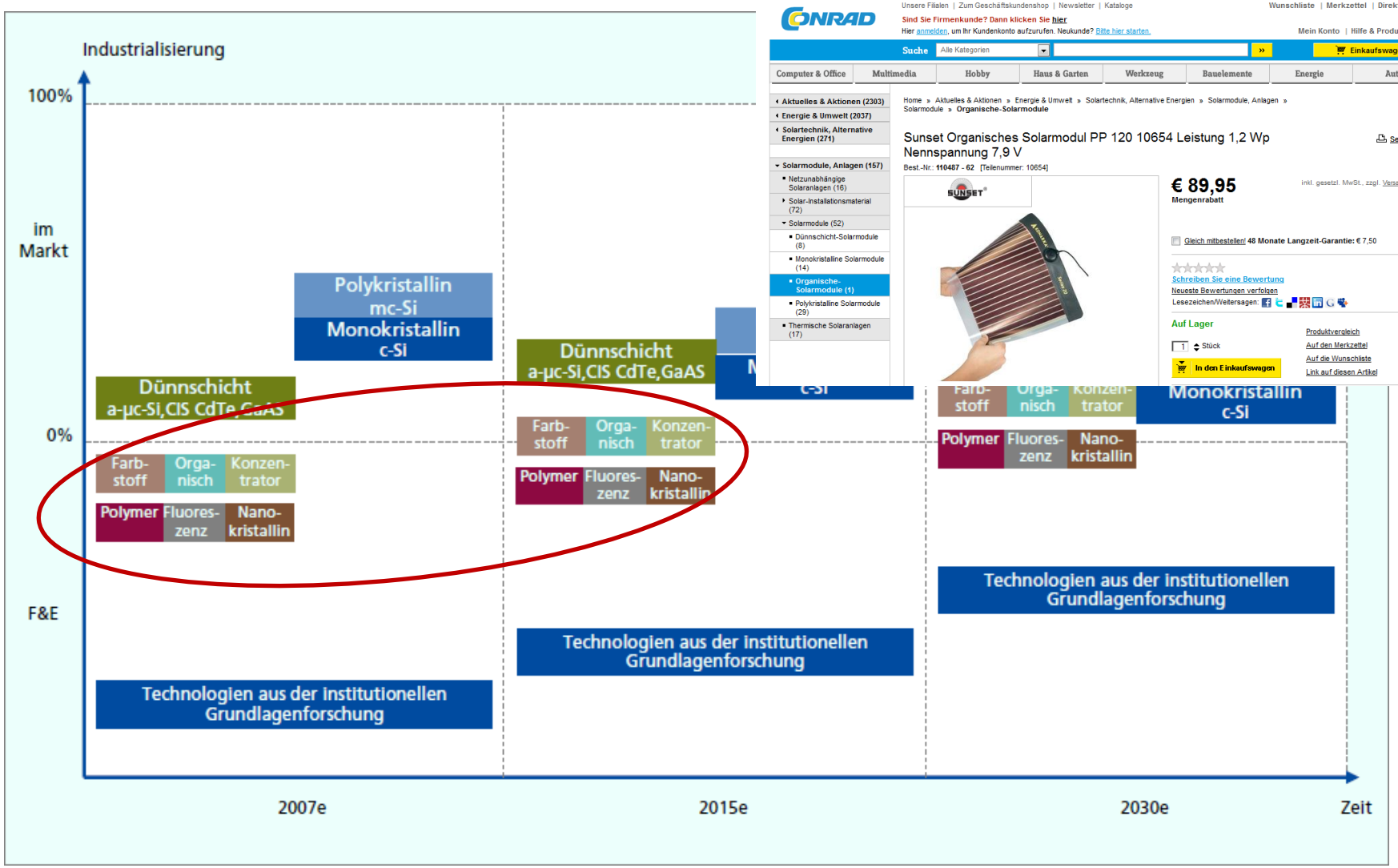
installed PV power in Germany



→ huge growth potential

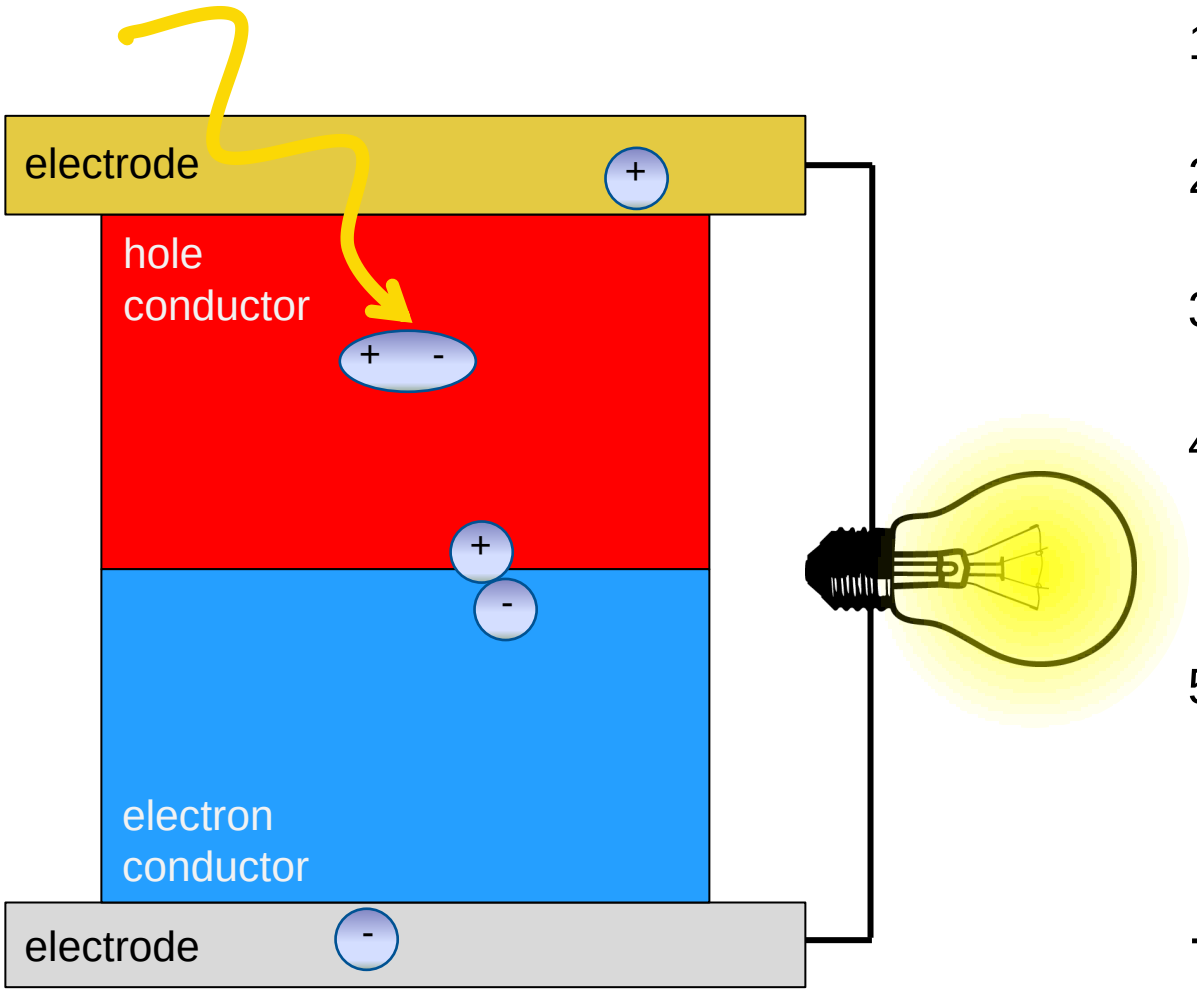
Aktuelle Fakten zur Photovoltaik in Deutschland, Dr. H. Wirth, Fraunhofer ISE, Freiburg, 30.4.2012

industrialisation of solar cell technologies



Standortgutachten Photovoltaik in Deutschland, EuPD Research + ifo Institut München, 2008

basic principle of a solar cell



1. light absorption
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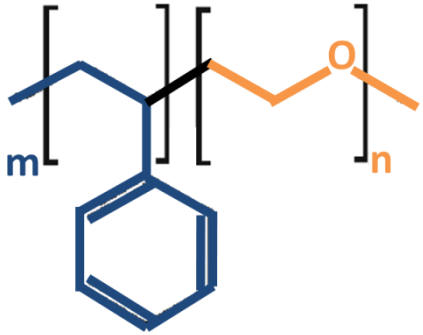
5. charge recombination via external load

→ **conversion of solar energy into electricity**

variety of structures from polymer templates

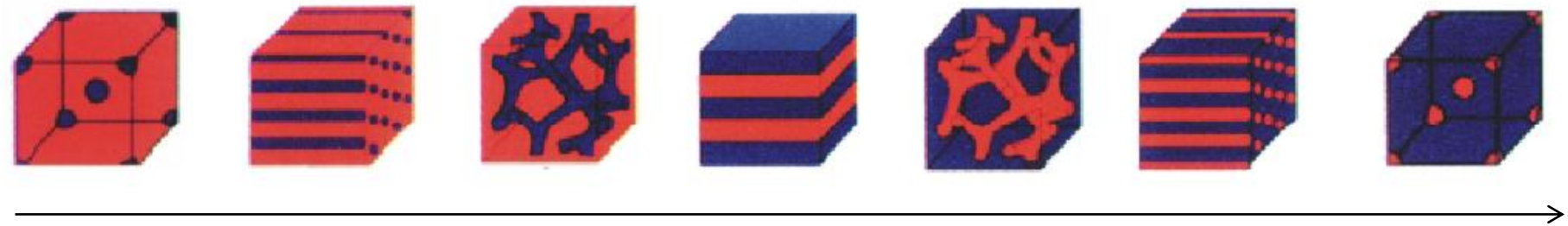
- polymer template for the creation of nanostructures:
  block copolymer, e.g. PS-*block*-PEO



two polymers with different chemical and physically properties – chemically bond

can be imagined like a two-colored spaghetti

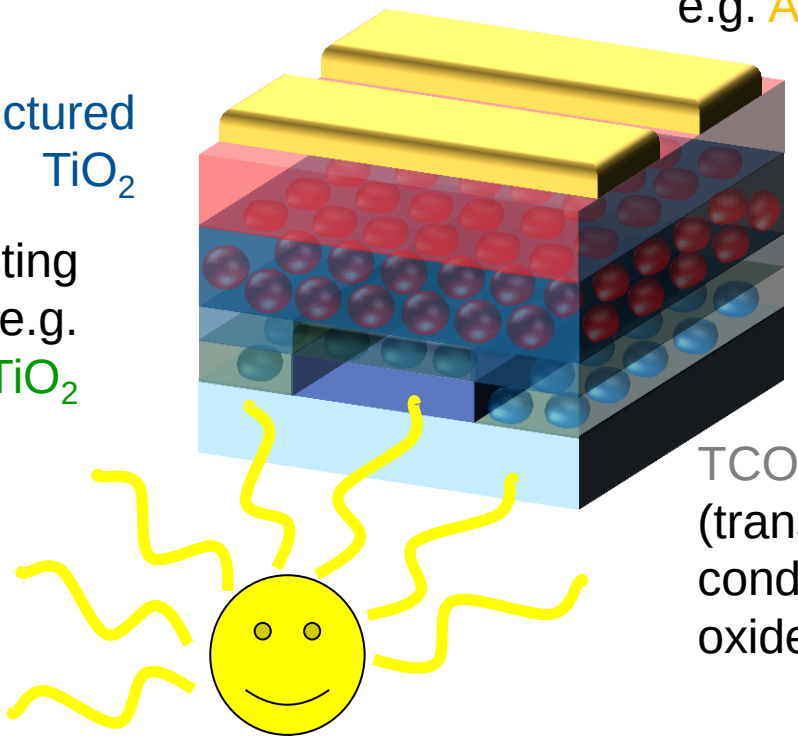
- amphiphilic block copolymer:
  one hydrophobic block (e.g. PS) and one hydrophilic block (e.g. PEO)
  → microphase separation



increasing volume fraction of blue part (in example PS block)

G. Strobl, The Physics of Polymers, Springer, 1997

hybrid solar cell setup



dye-sensitized solar cell setup