Materialforschung für Dünnschichtphotovoltaik-
Status und neue Entwicklungen

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Forschungszentrum Jülich GmbH

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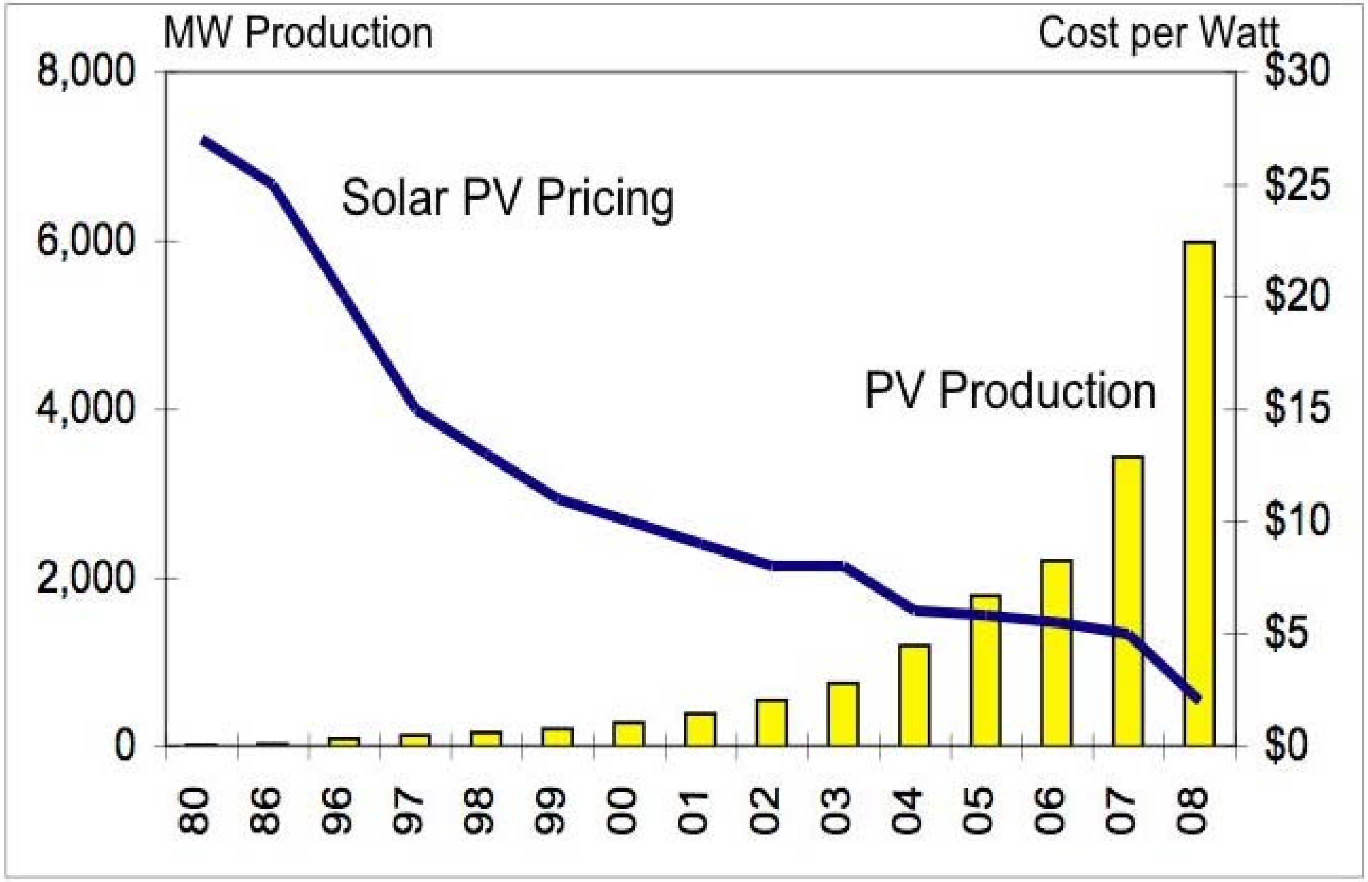
1. **Marktentwicklung**

2. **Solarzellentechnologien und allgemeine Prinzipien**

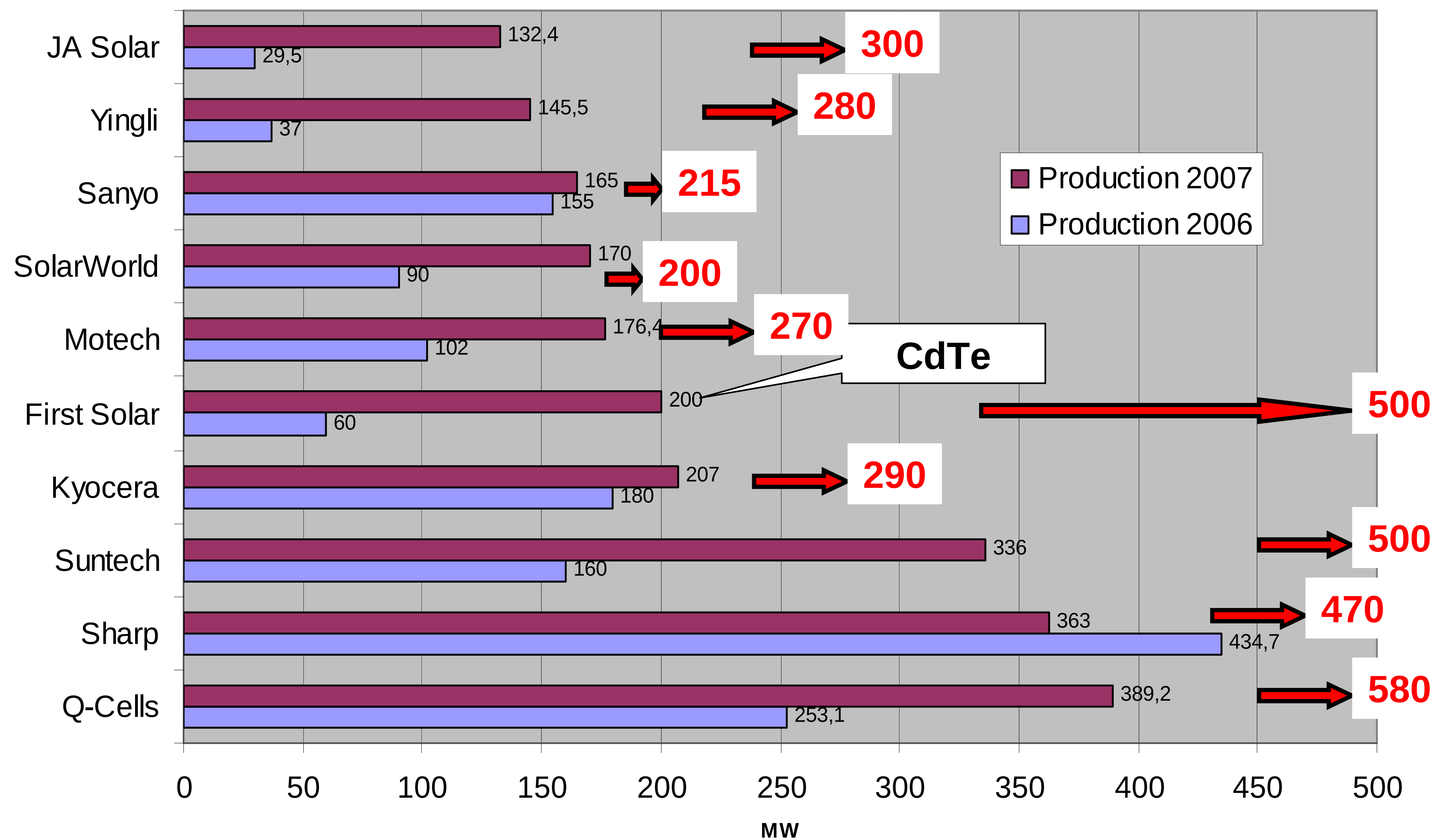
3. **Dünnschichttechnologien (CIGS,CdTe, a/μc-Si)**
   - Forschungsbeispiele

Solar PV Global Production and Cost per Watt



Source Solar Buzz, Company reports,, Green Econometrics research

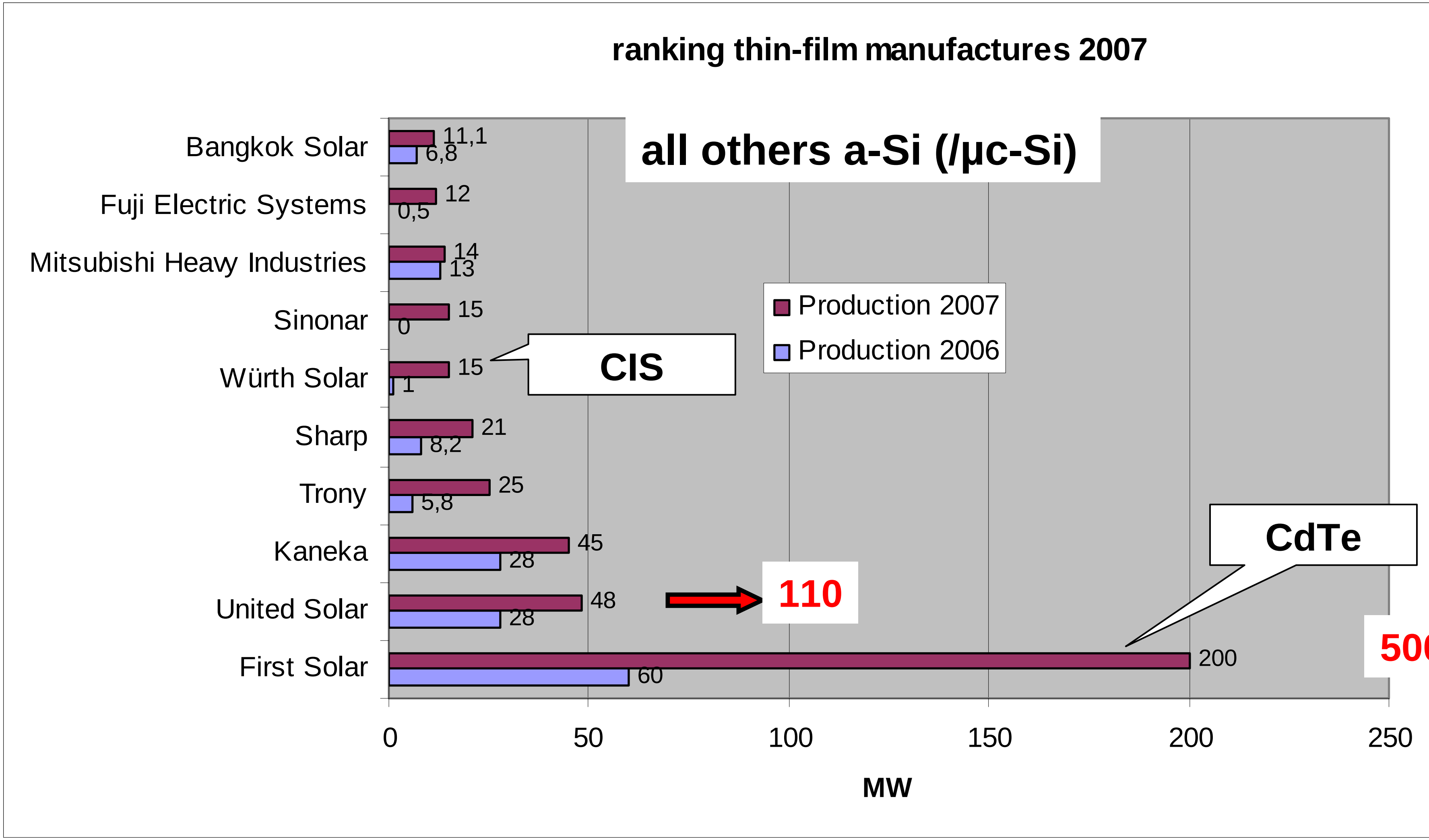
Top 10 producers in 2007



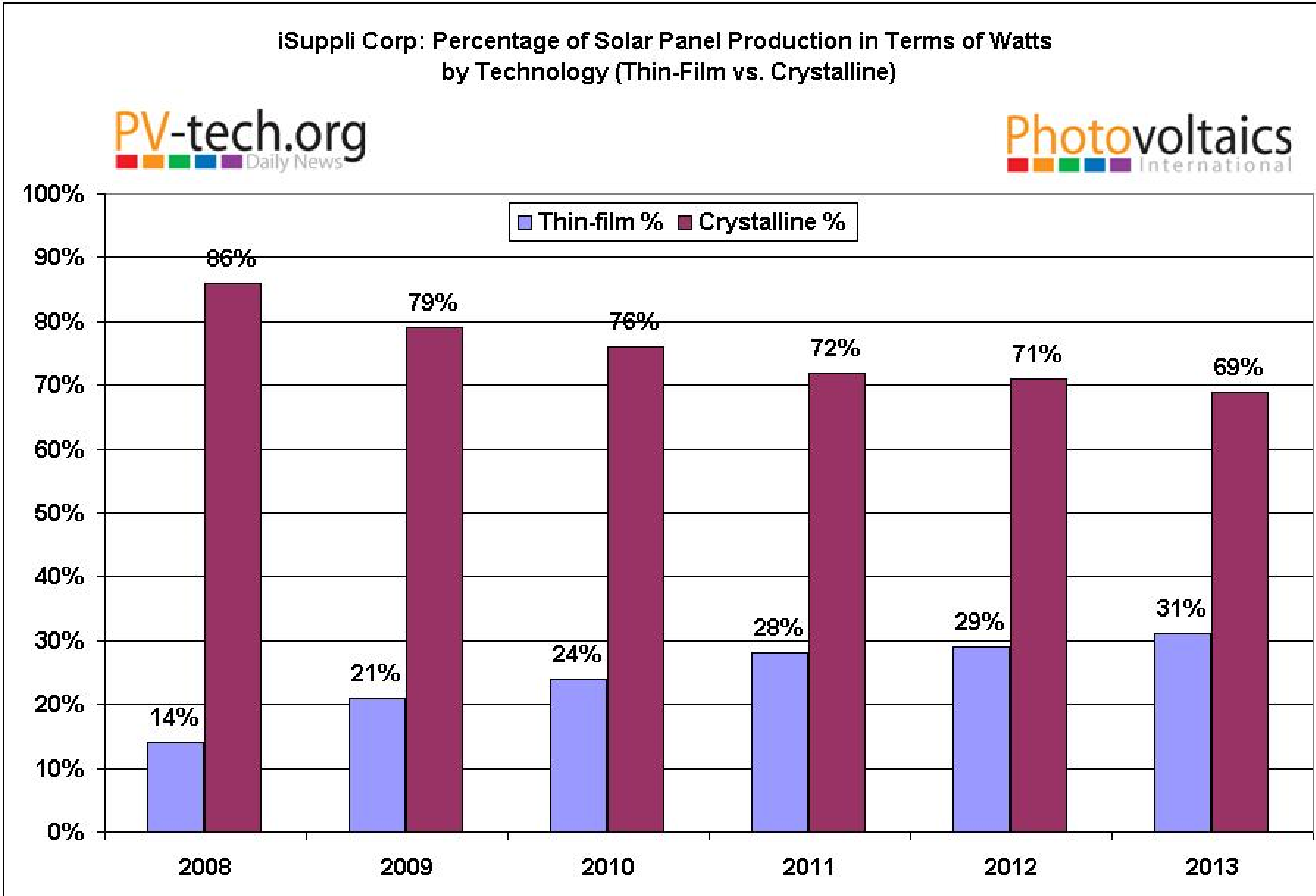
source: PHOTON International 3/2008

D

Thin-film module manufacturers



source: PHOTON International 3/2008

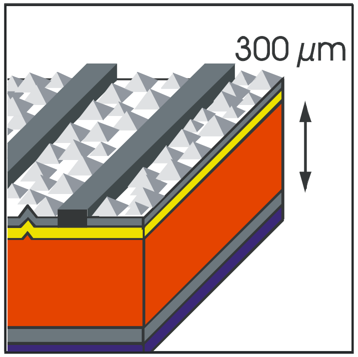
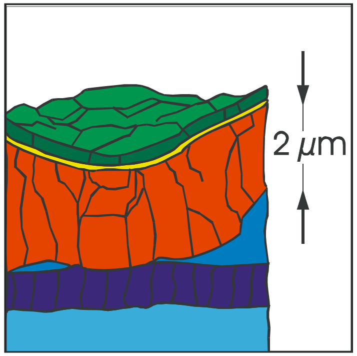
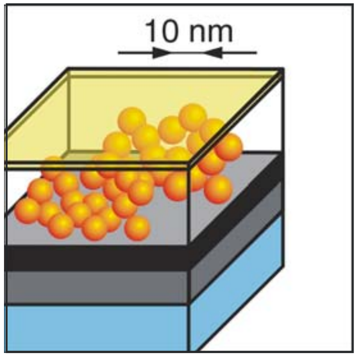
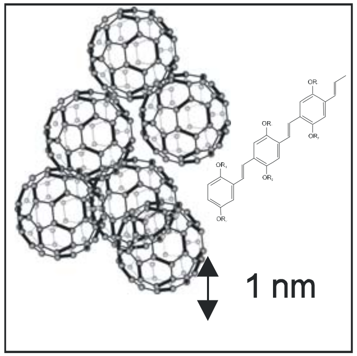


iSuppli Corp: Percentage of Solar Panel Production in Terms of Watts
by Technology (Thin-Film vs. Crystalline)
PV-tech.org
Daily News
Photovoltaics
International
Thin-film %
Crystalline %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
14%
86%
21%
79%
24%
76%
28%
72%
29%
71%
31%
69%
2008
2009
2010
2011
2012
2013

Photovoltaic technologies

(and their working principles)

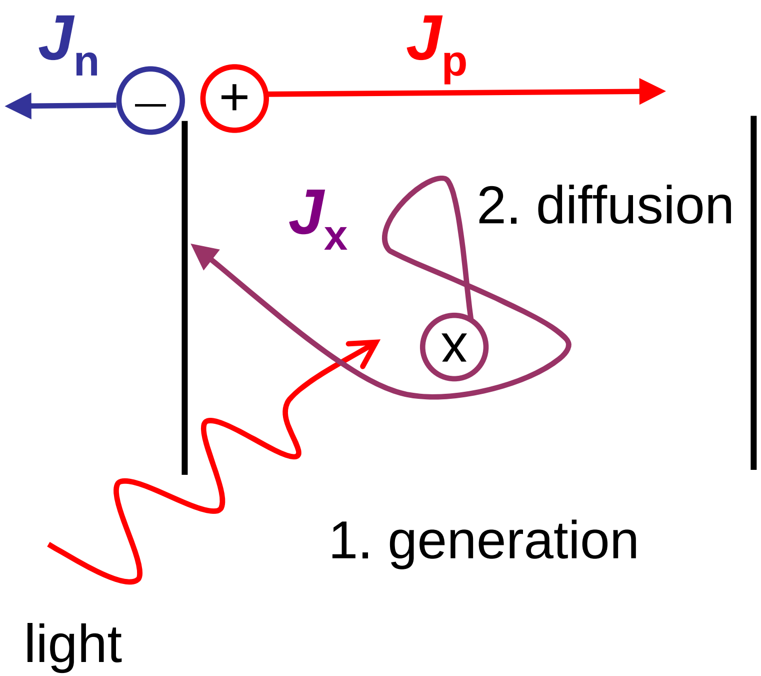
Different types of solar cells

Wafer cell	Thin-film cell	Electrochemical cell	Organic solar cell
			
cryst. Si	amorph. Si, $Cu(In,Ga)Se_2$, CdTe	nanopor. TiO_2	PPV/C_{60}
Efficiency 25 %	19 %	10 %	5 %

Excitonic and bipolar (classical) solar cells

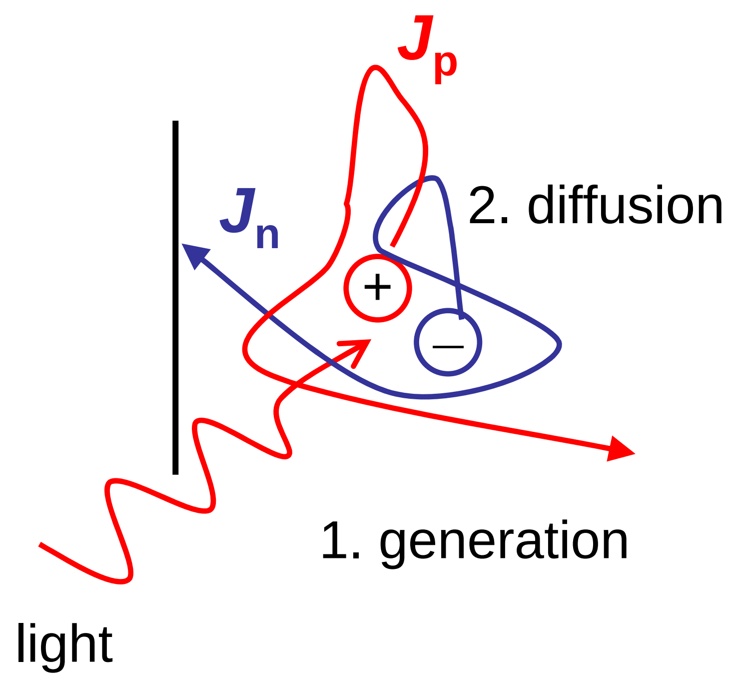
Excitonic

3. charge separation at interface



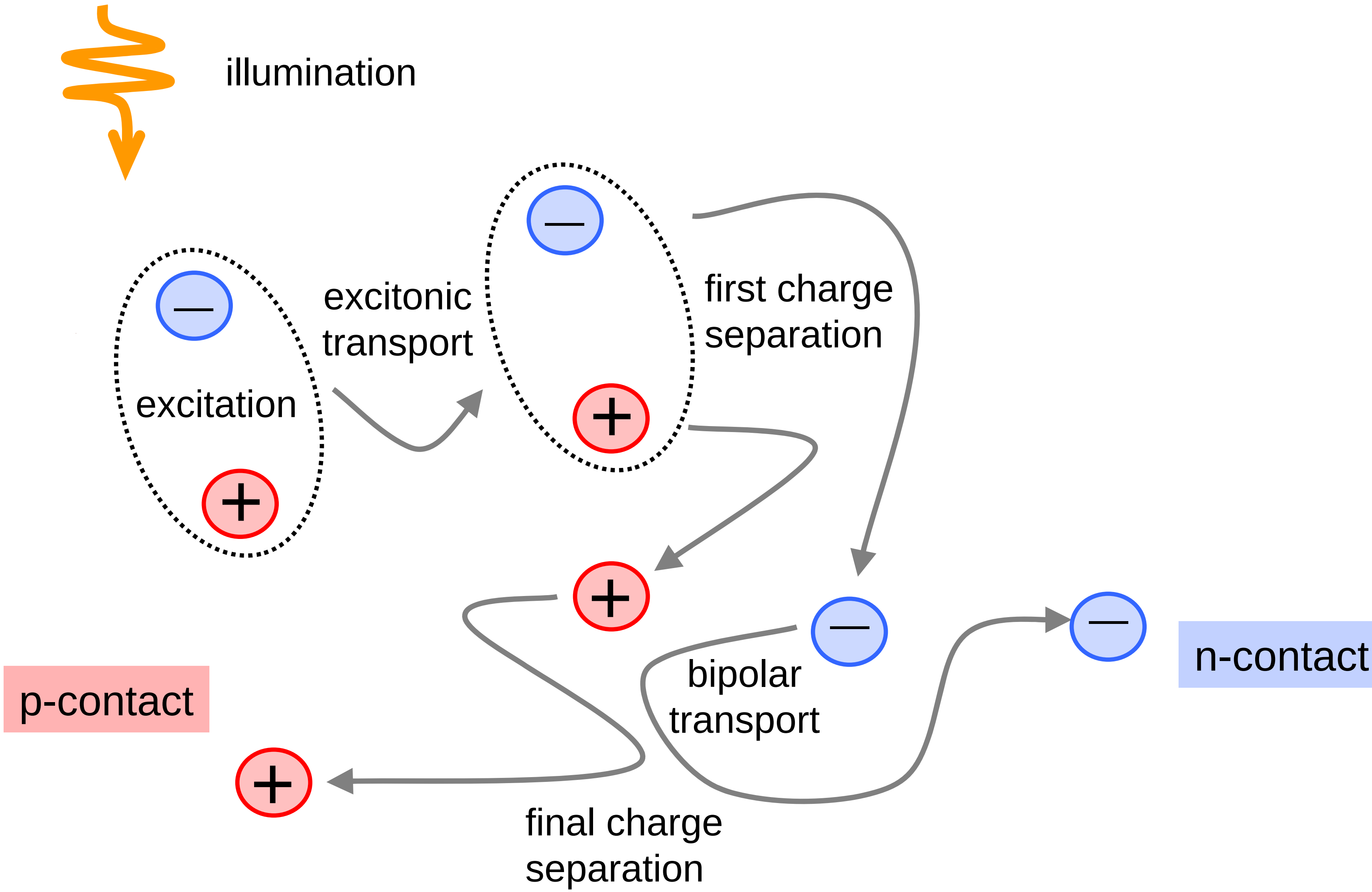
Bipolar

3. charge separation by built-in field



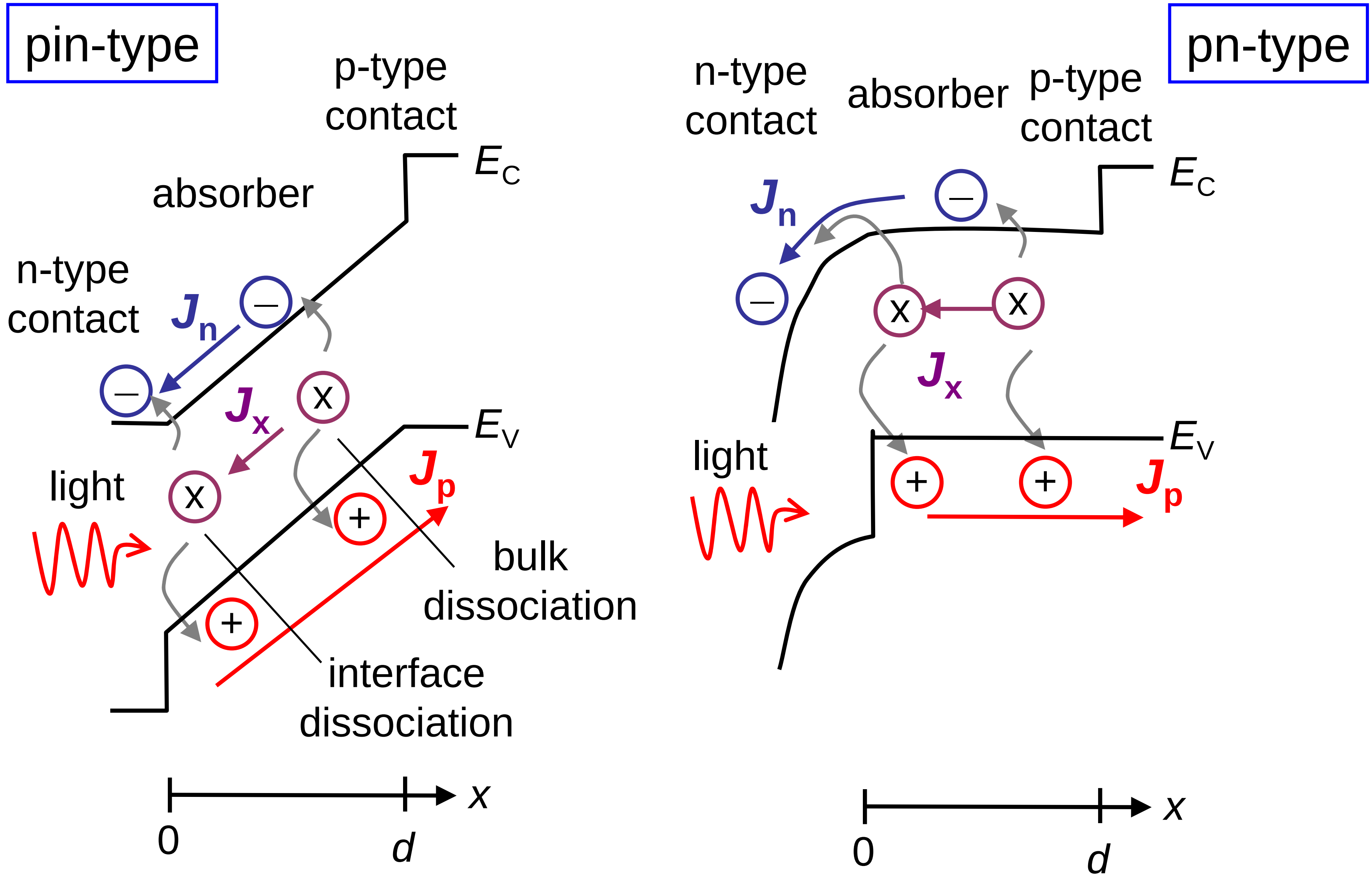
Gregg and Hanna, J. Appl. Phys. 93, 3605 (2003).

General charge separation scheme



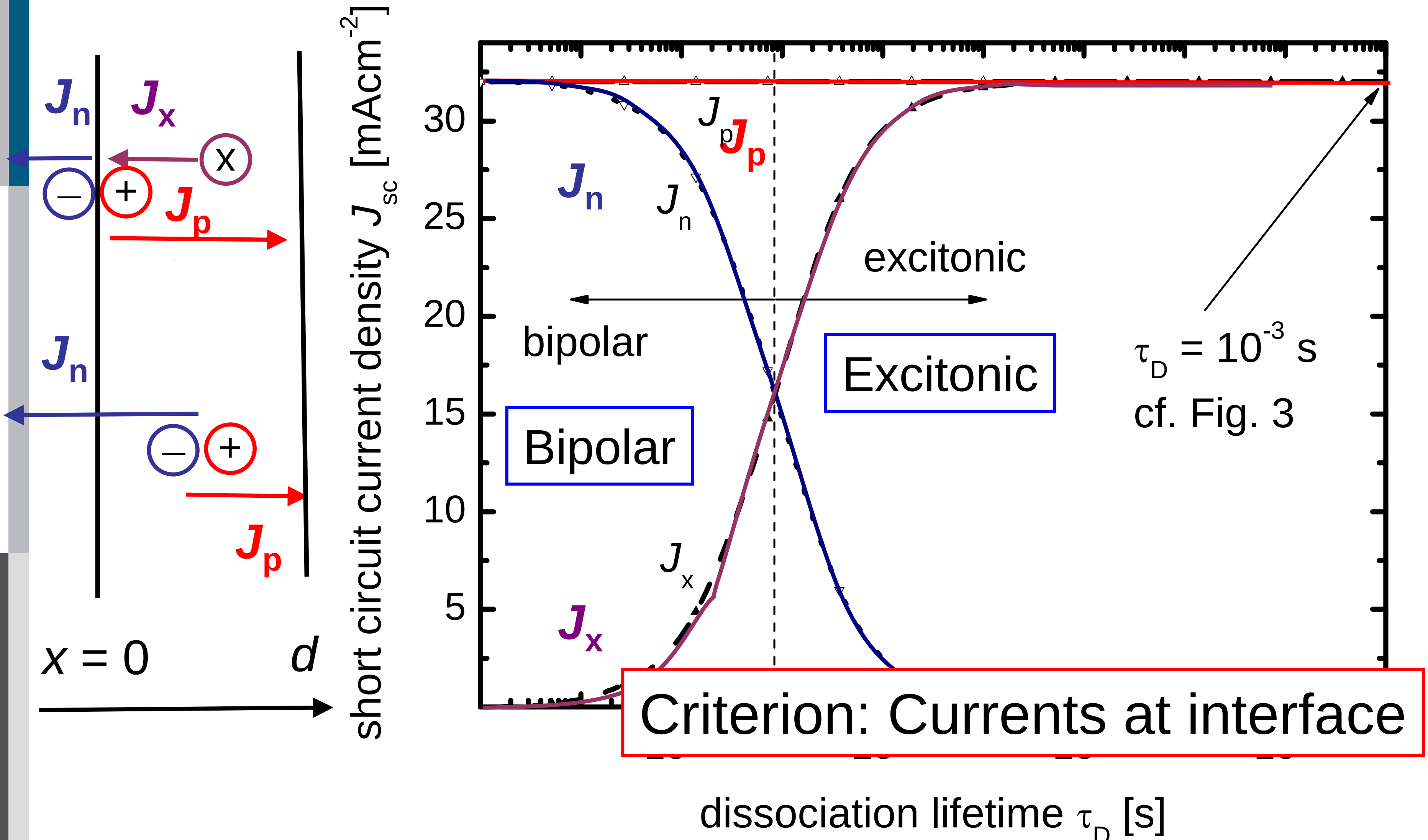
U. Rau et al., J. Phys. Chem B (2003)
K. Schwarzburg et al., Coord. Chem. (2005).

pin-type and pn-type devices



T. Kirchartz, J. Mattheis, U. Rau, Phys. Rev. B 78 (2008)

Dominant currents at junction (x=+0)

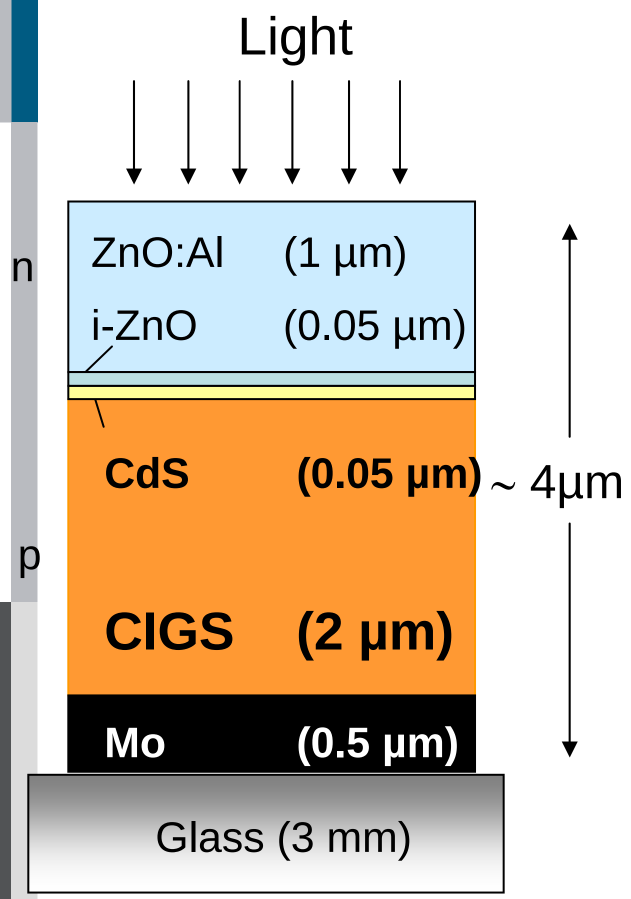


T. Kirchartz, J. Mattheis, U. Rau, Phys. Rev. B 78 (2008)

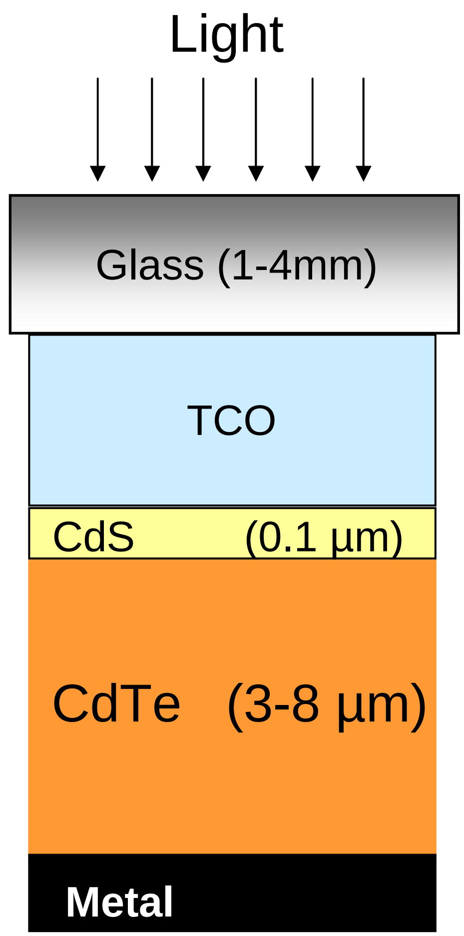
Thin-film photovoltaic technologies

Thin film PV technologies

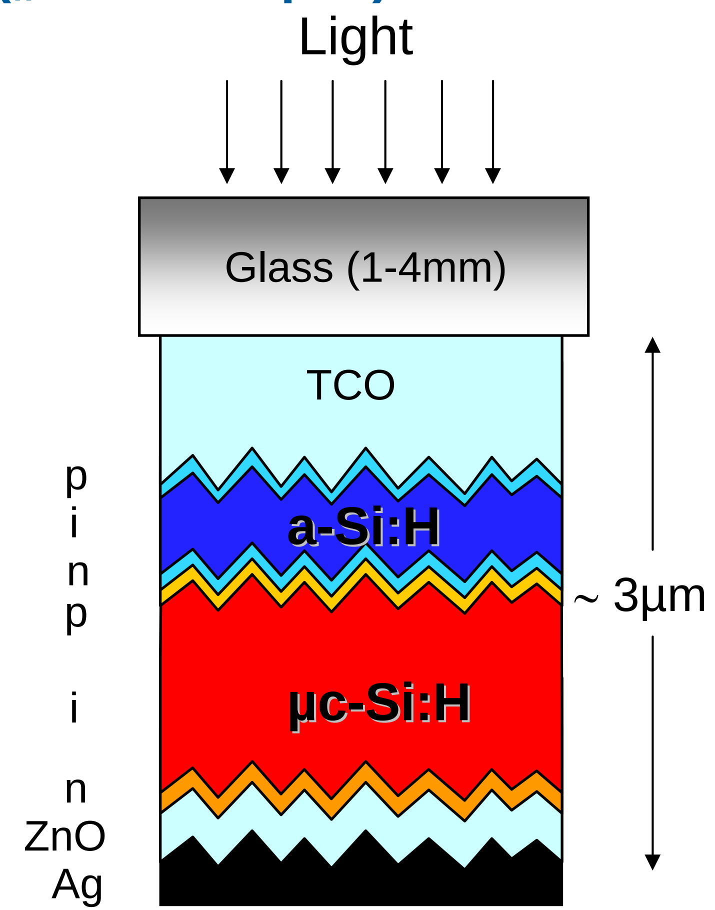
CIGS-solar cells:
$CuIn_{1-x}Ga_xSe_{1-y}S_y$



CdTe-solar cells:
CdTe



a-Si technology
Example:
a-Si/µc-Si tandem cell
(„Micromorph“)

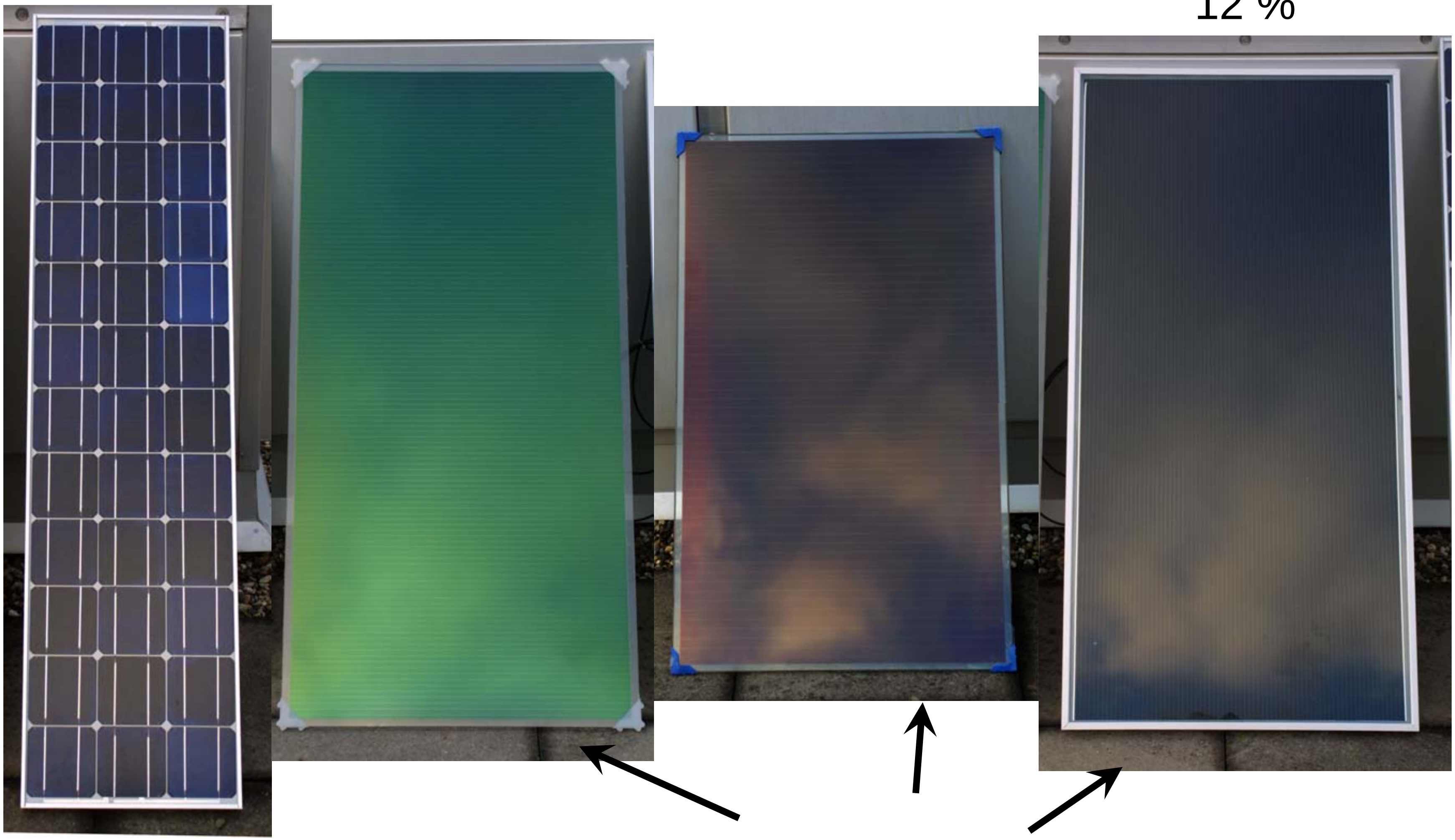


c-Si
15 %

CdTe
11 %

a-Si
6 %

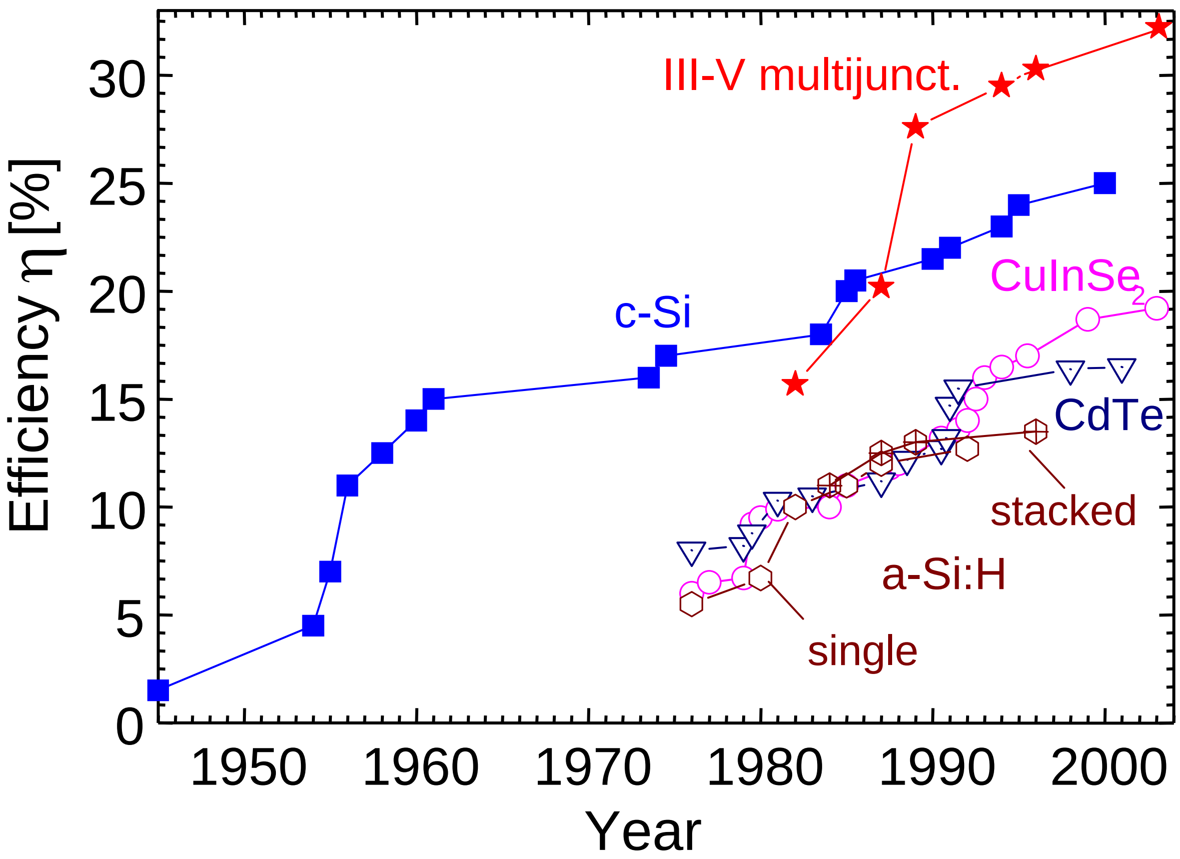
Cu(In,Ga)Se_2
CIGS
12 %



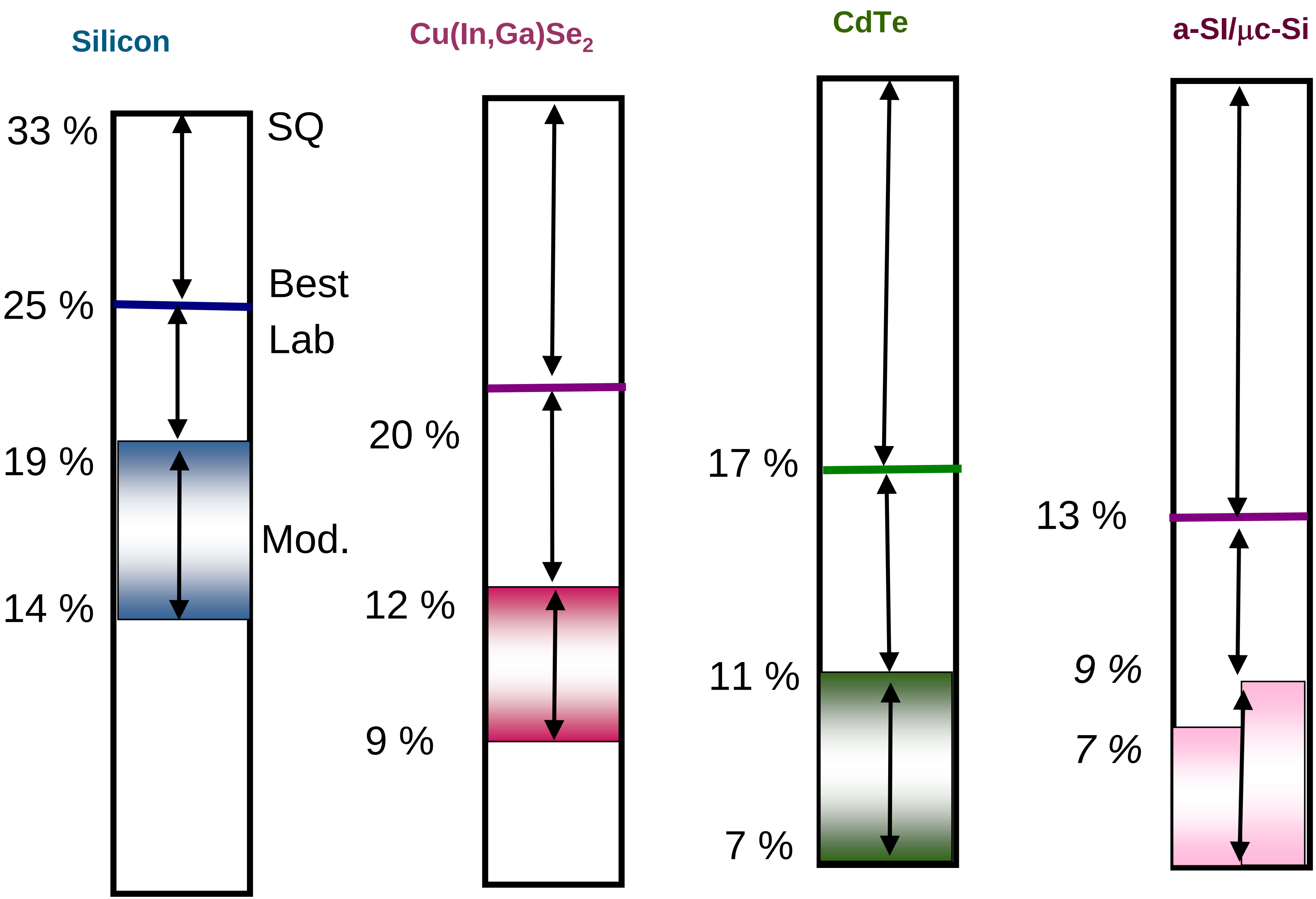
Crystalline silicon

Thin-films

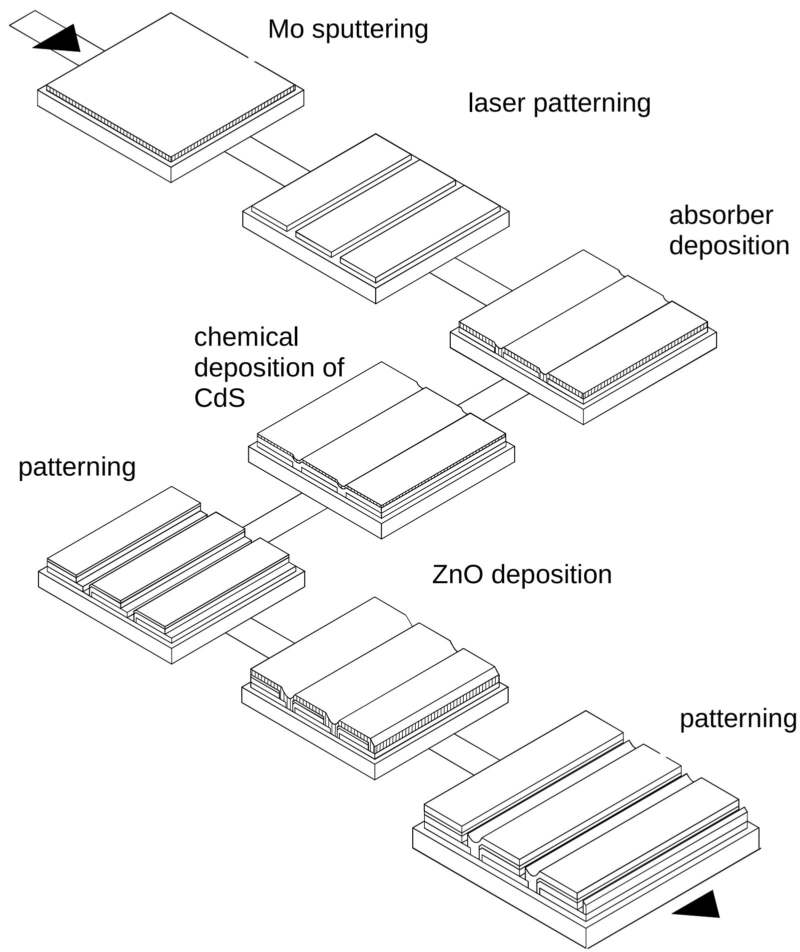
Solar cell efficiencies (Labscale)



Efficiency limits



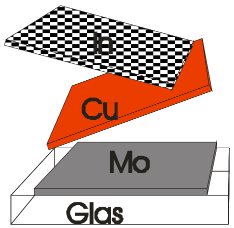
Schematic representation of a CIGS module fabrication process.



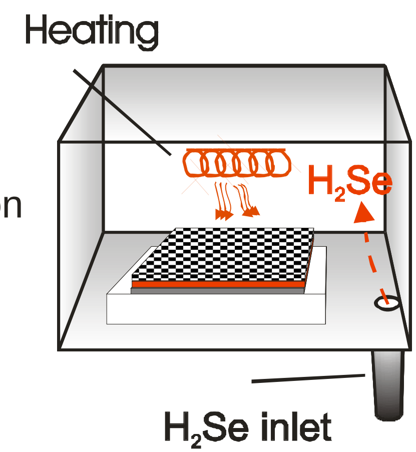
Absorber deposition CIGS solar cells

Selenization (two-stage)

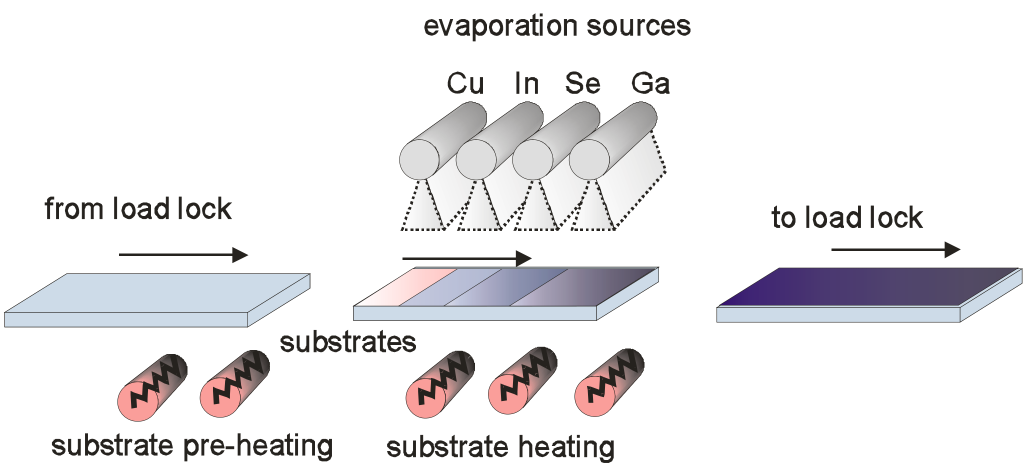
I. Deposition



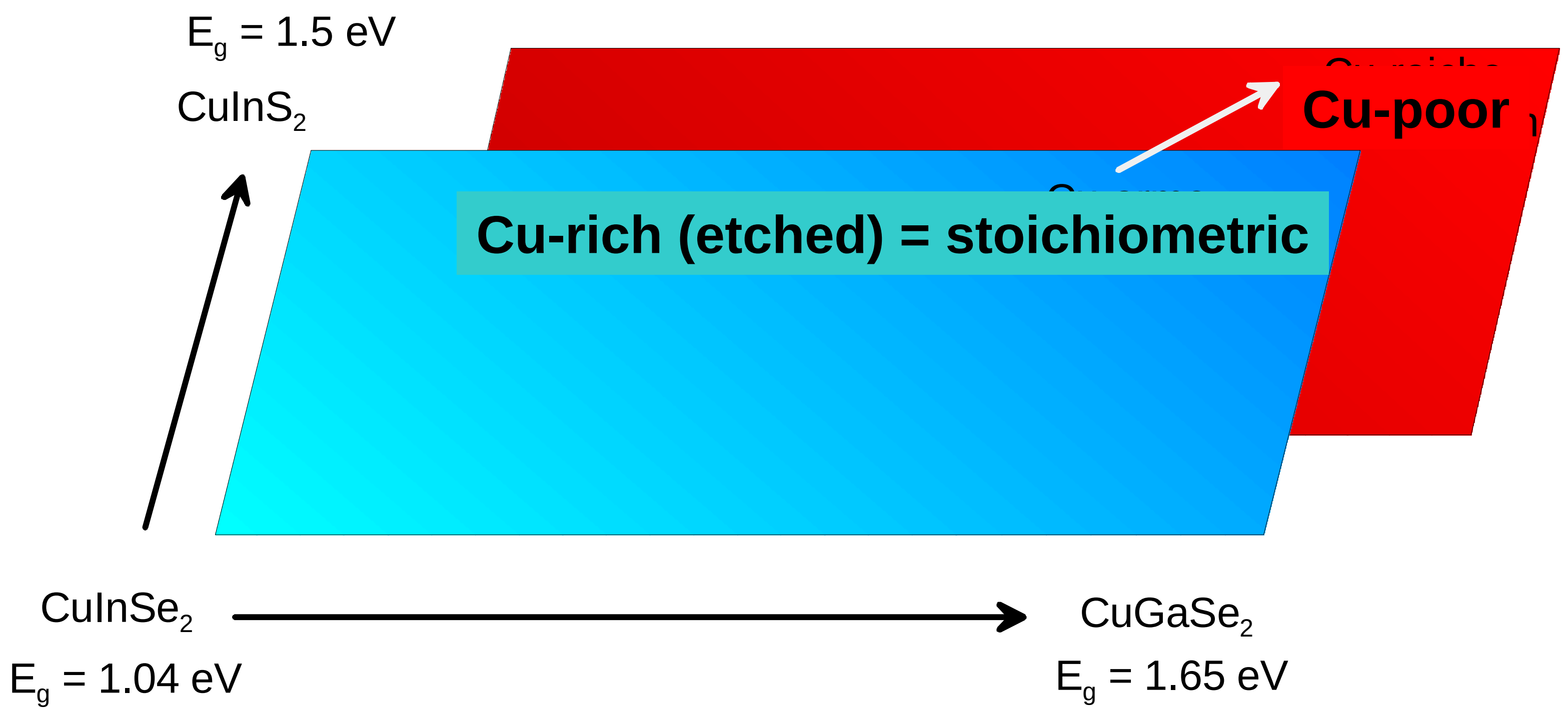
II.Selenisation



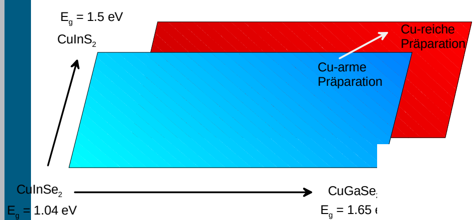
Co-evaporation



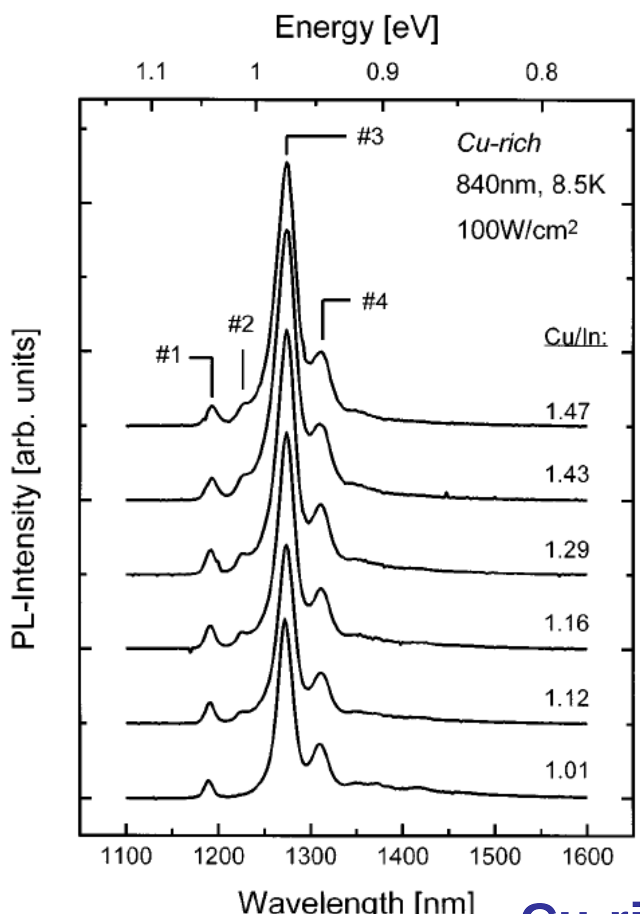
Cu-poor and Cu-rich $CuInGaSe_2$



Photoluminescence of $CuInGaSe_2$

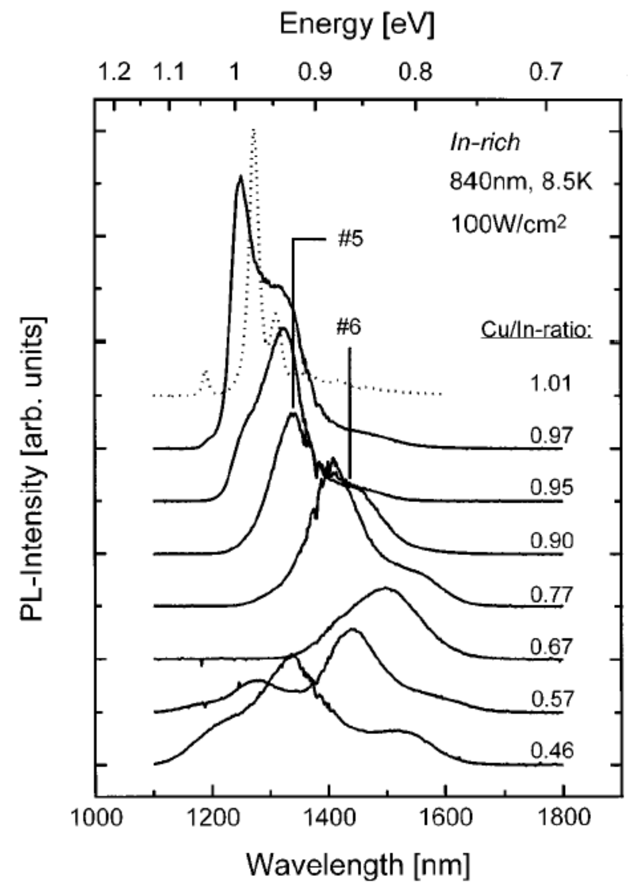


Cu-rich (etched)



Cu-rich

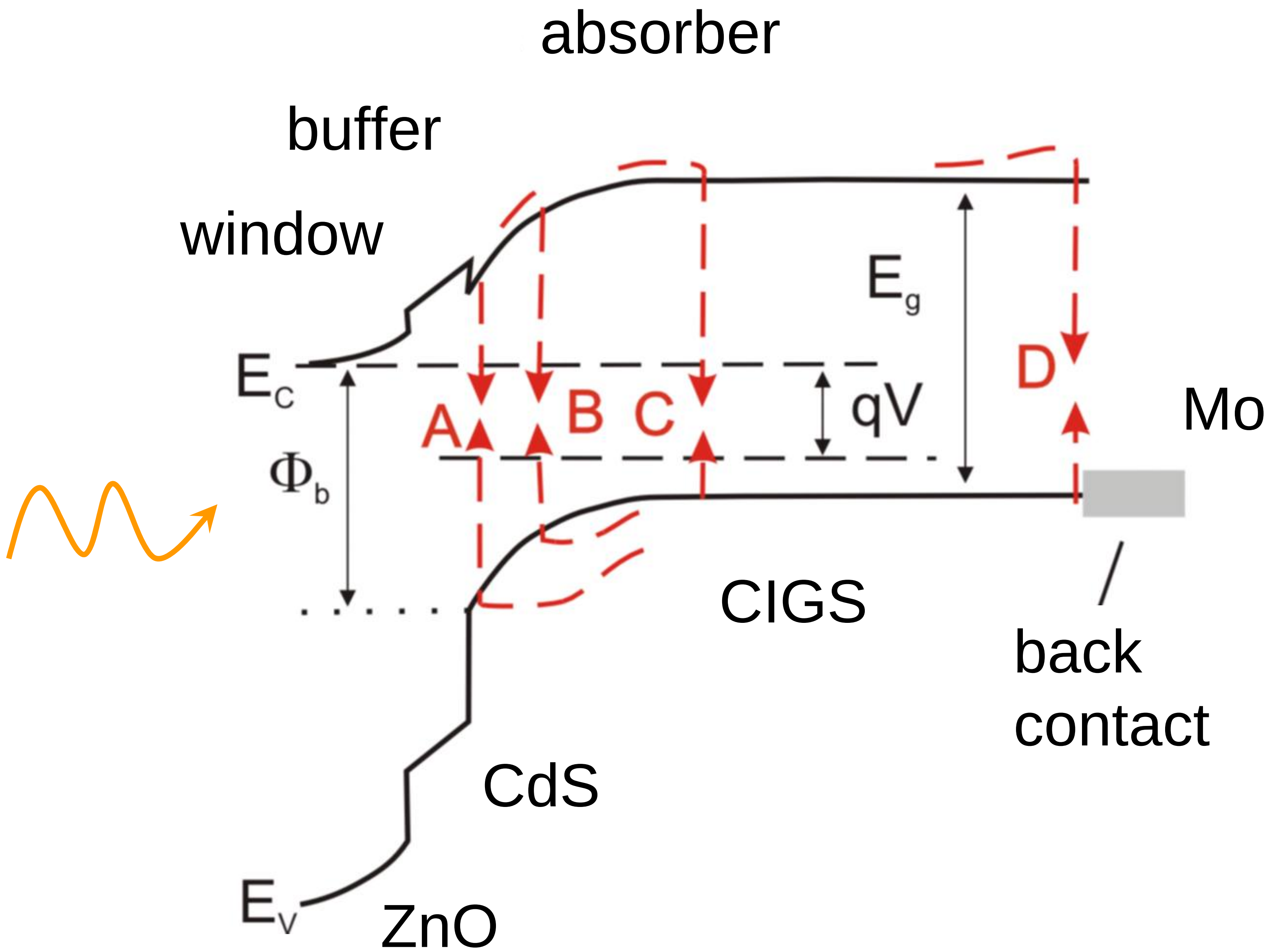
Cu-poor



Cu-poor

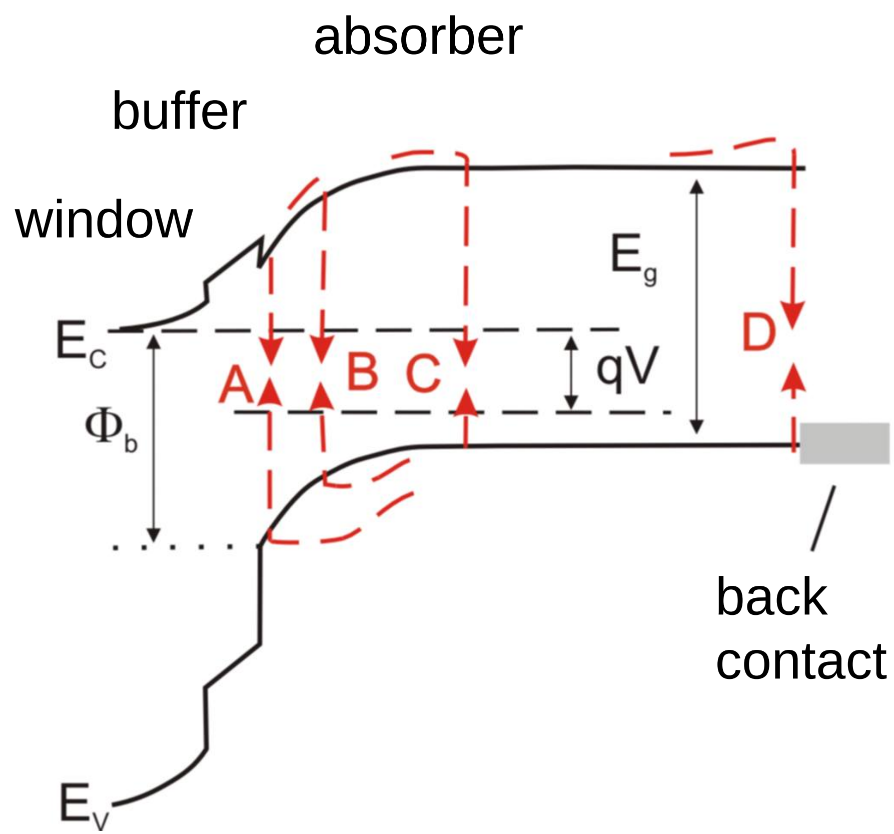
S. Zott, K. Leo, M. Ruckh, H.W. Schock, J. Appl. Phys. **82** (1997)

Band diagram ($CuInGaSe_2$)



Recombination mechanisms

$$V_{OC} = \frac{E_a}{q} - \frac{nkT}{q} \ln\left(\frac{j_{00}}{j_{SC}}\right)$$



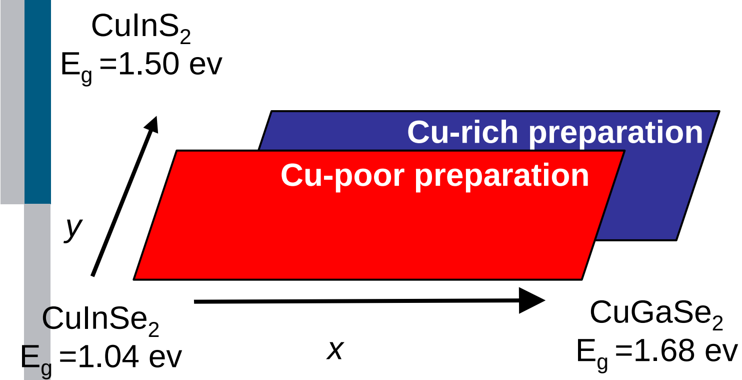
(A): Interface recombination

$$E_a = \Phi_b$$

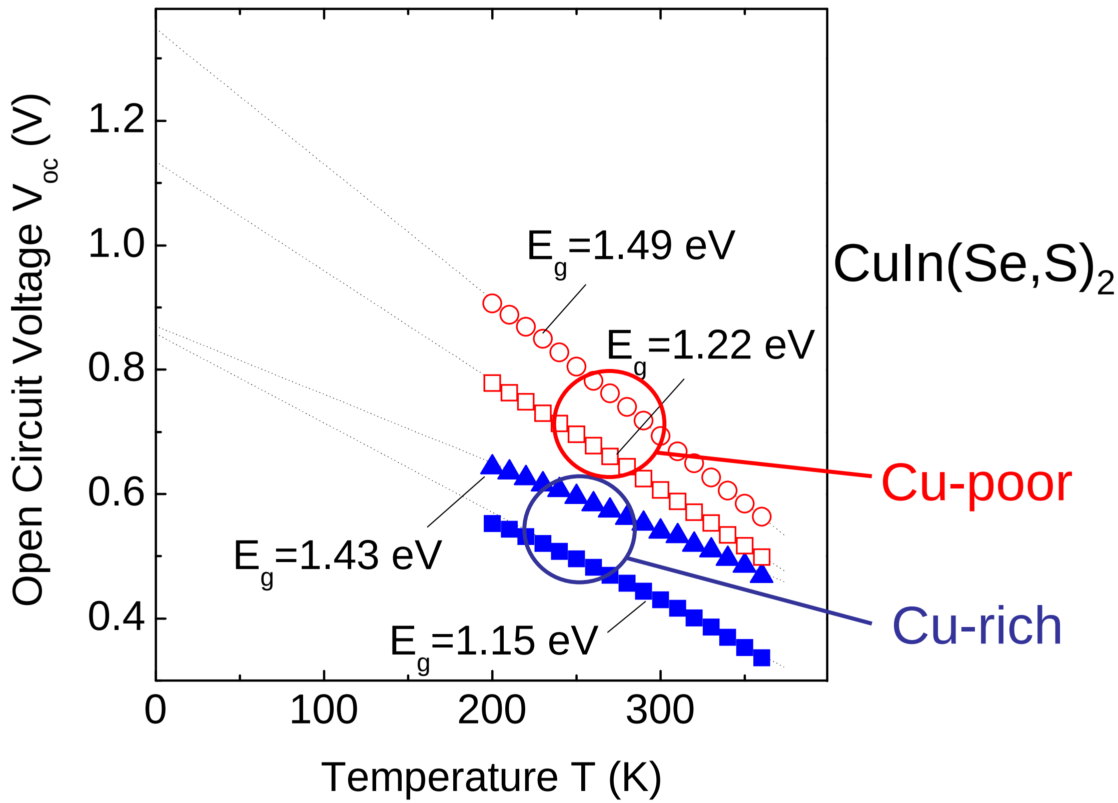
(B-D): Volume recombination

$$E_a = E_g$$

Recombination mechanisms

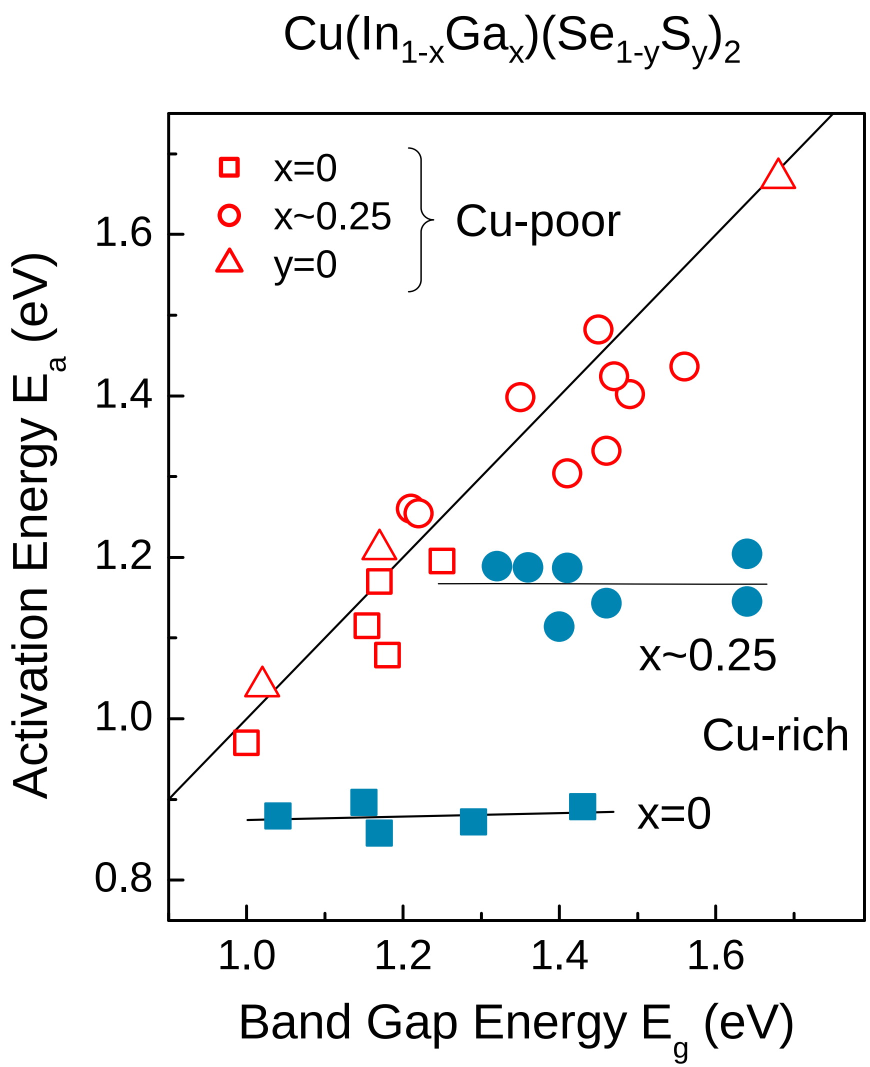


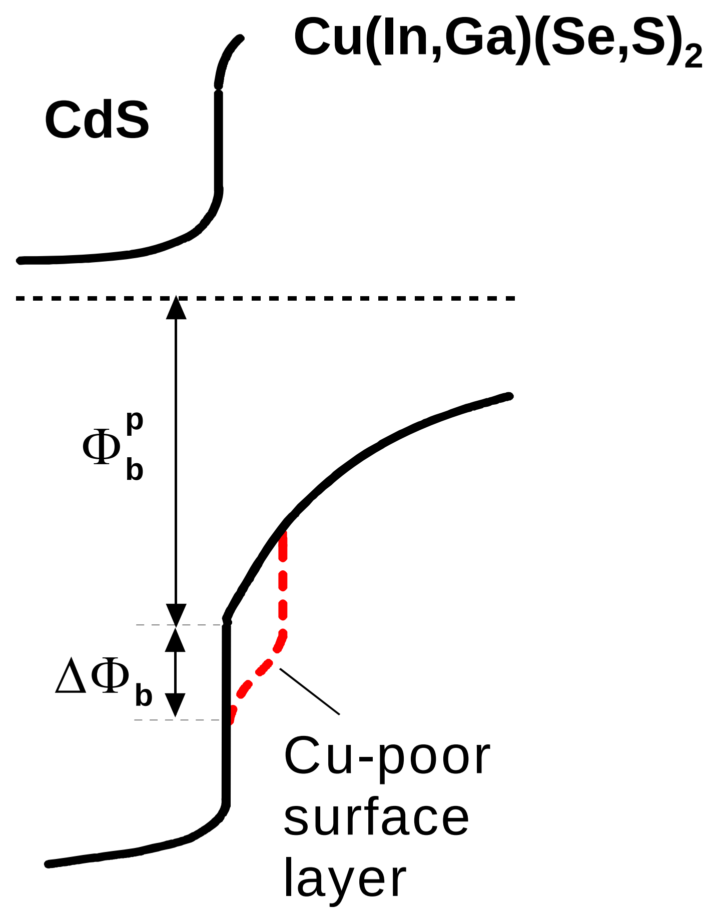
$$V_{OC} = \frac{E_a}{q} - \frac{nkT}{q} \ln\left(\frac{j_{00}}{j_{SC}}\right)$$



M.Turcu, O. Pakma, U. Rau, Appl. Phys. Lett. **80 (2002)**

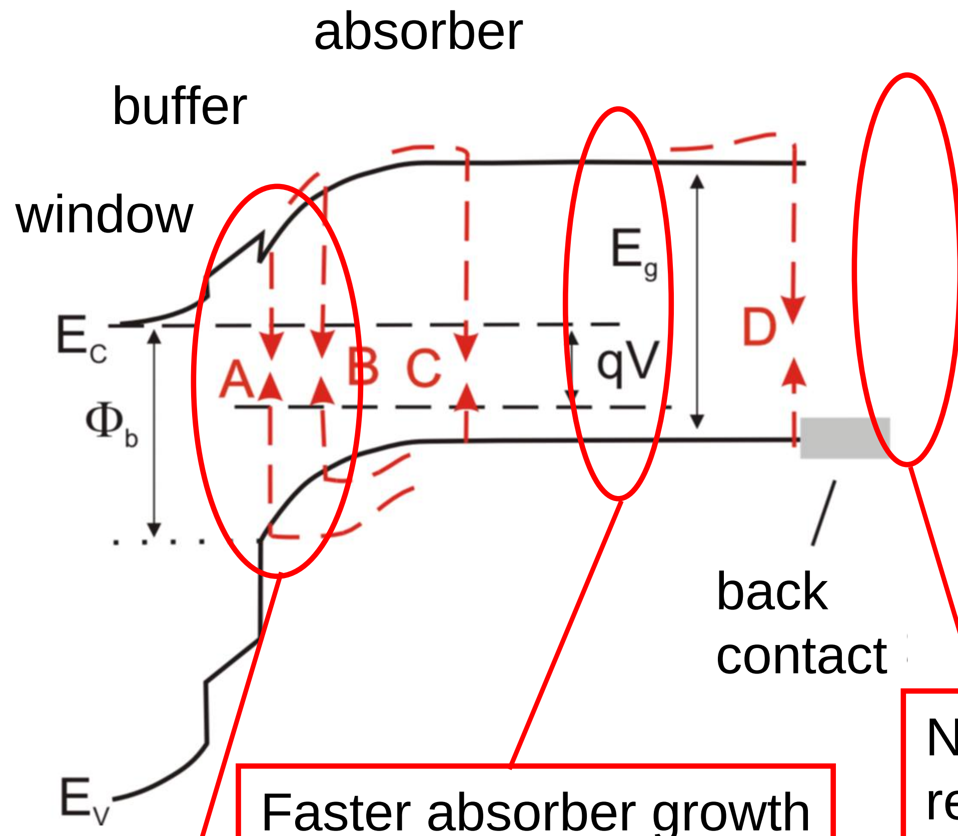
Recombination mechanisms





M.Turcu, O. Pakma, U. Rau, Appl. Phys. Lett. **80 (2002)**

$Cu(In,Ga)(Se,S)_2$ research issues



Improved buffer window/combinations (Cd-free) stability

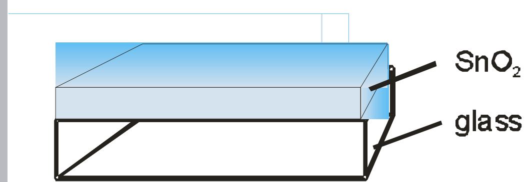
Faster absorber growth
Metastability

Na from glass reproducibility

Process sequence for CdS/CdTe solar cells

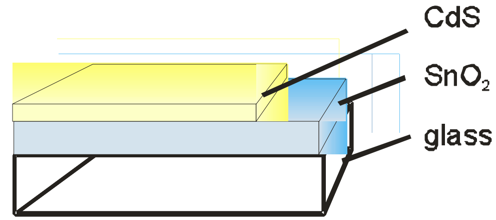
Front contact deposition

Sputtering
or Chemical Vapor Deposition (CVD)



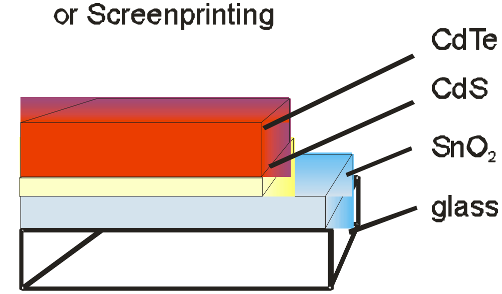
CdS deposition

Chemical Bath Deposition (CBD)
or Electrodeposition (ED)
or Close Spaced Sublimation (CSS)



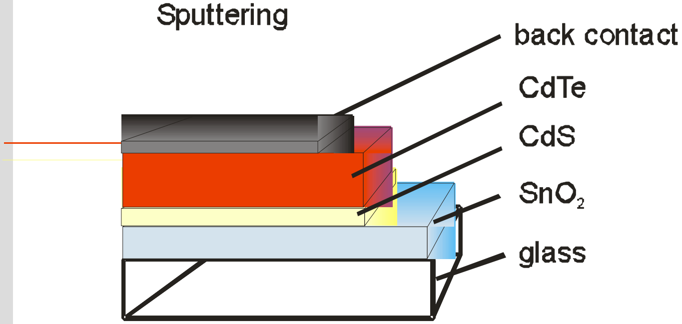
CdS deposition

Electrodeposition (ED)
or Close Spaced Sublimation (CSS)
or Screenprinting

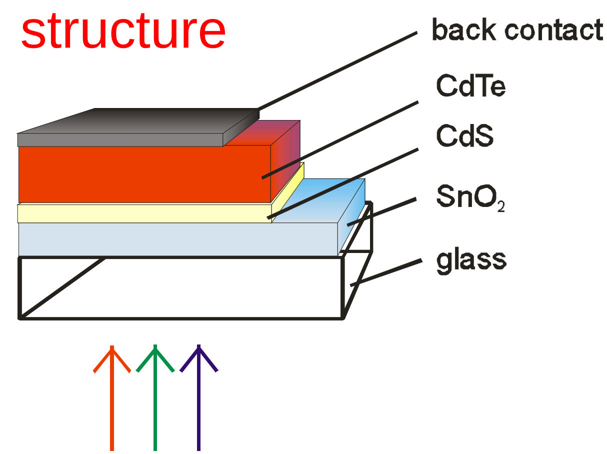


back contact

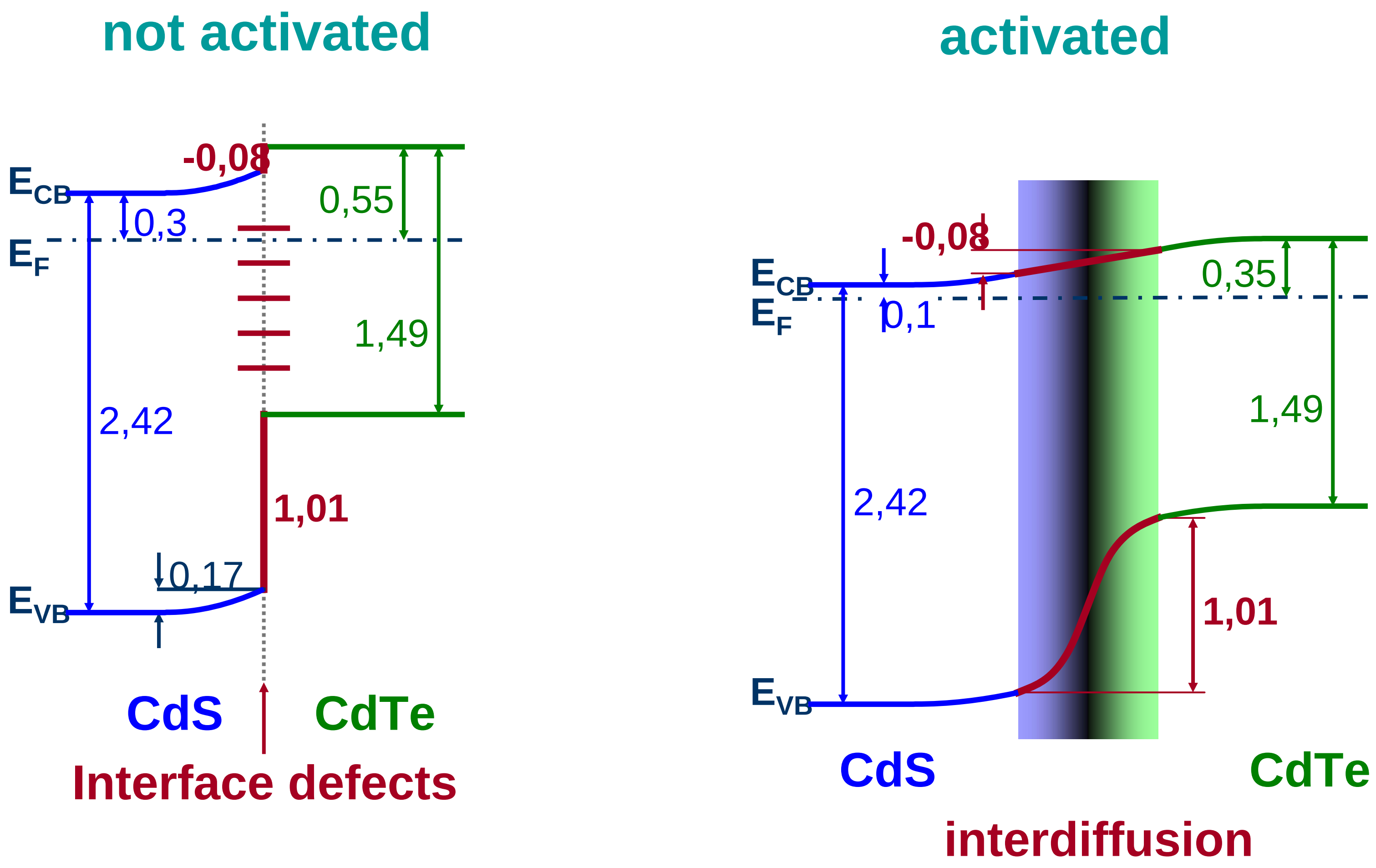
Sputtering



final structure device

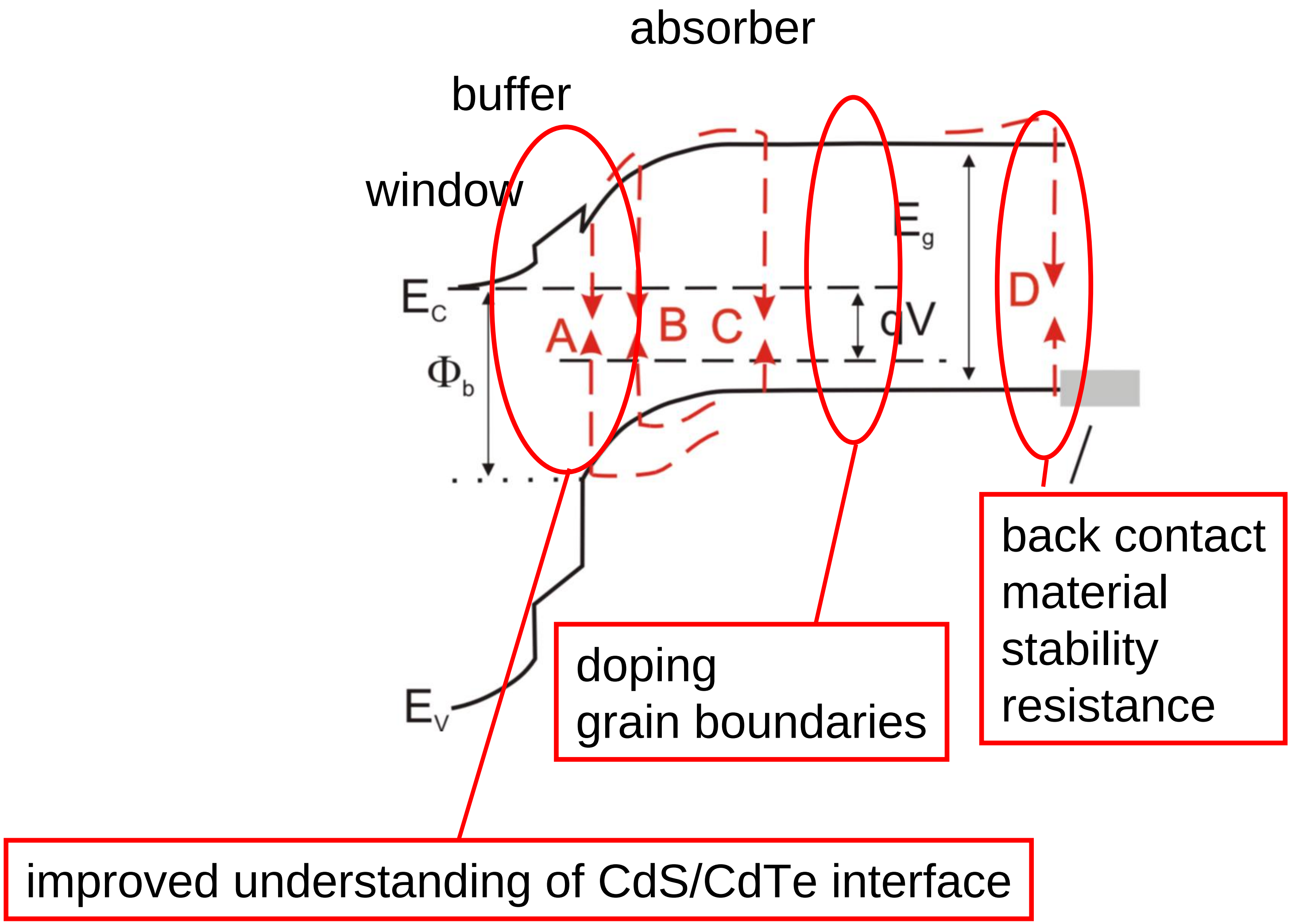


CdS/CdTe interface electronic structure

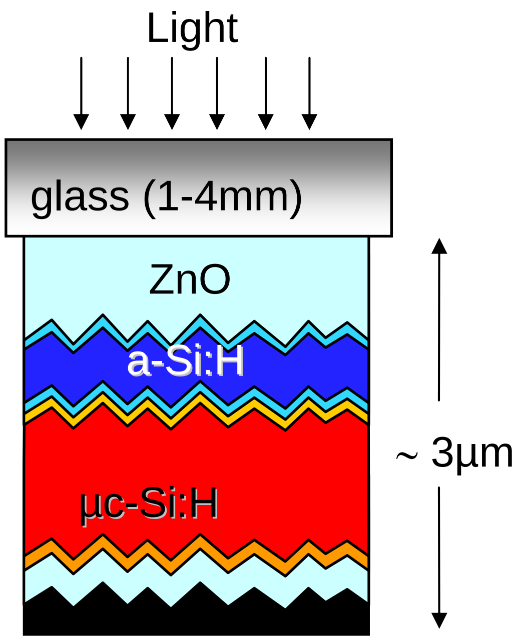


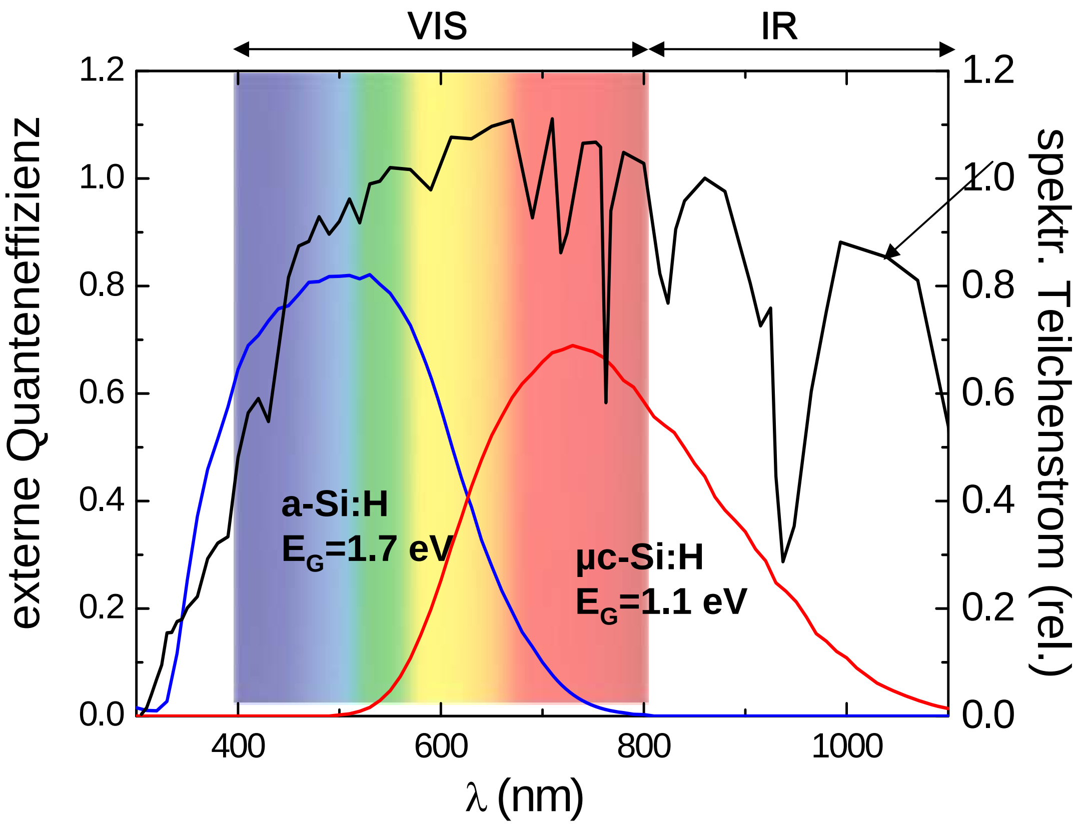
W. Jaegermann, A. Klein, T. Mayer, Adv. Mat. . **21** (2009)

CdS/CdTe research issues

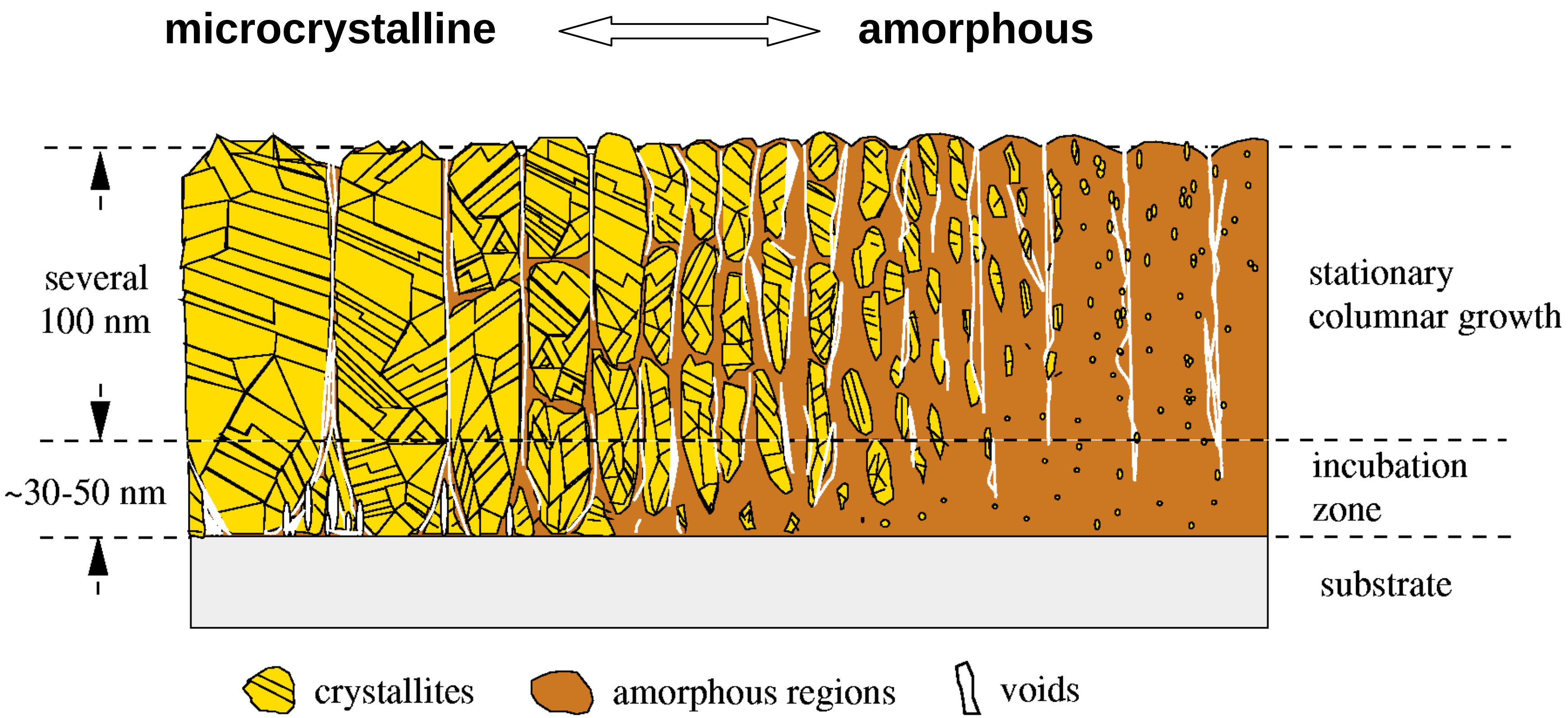


a-Si/μc-Si thin-film tandem solar cell



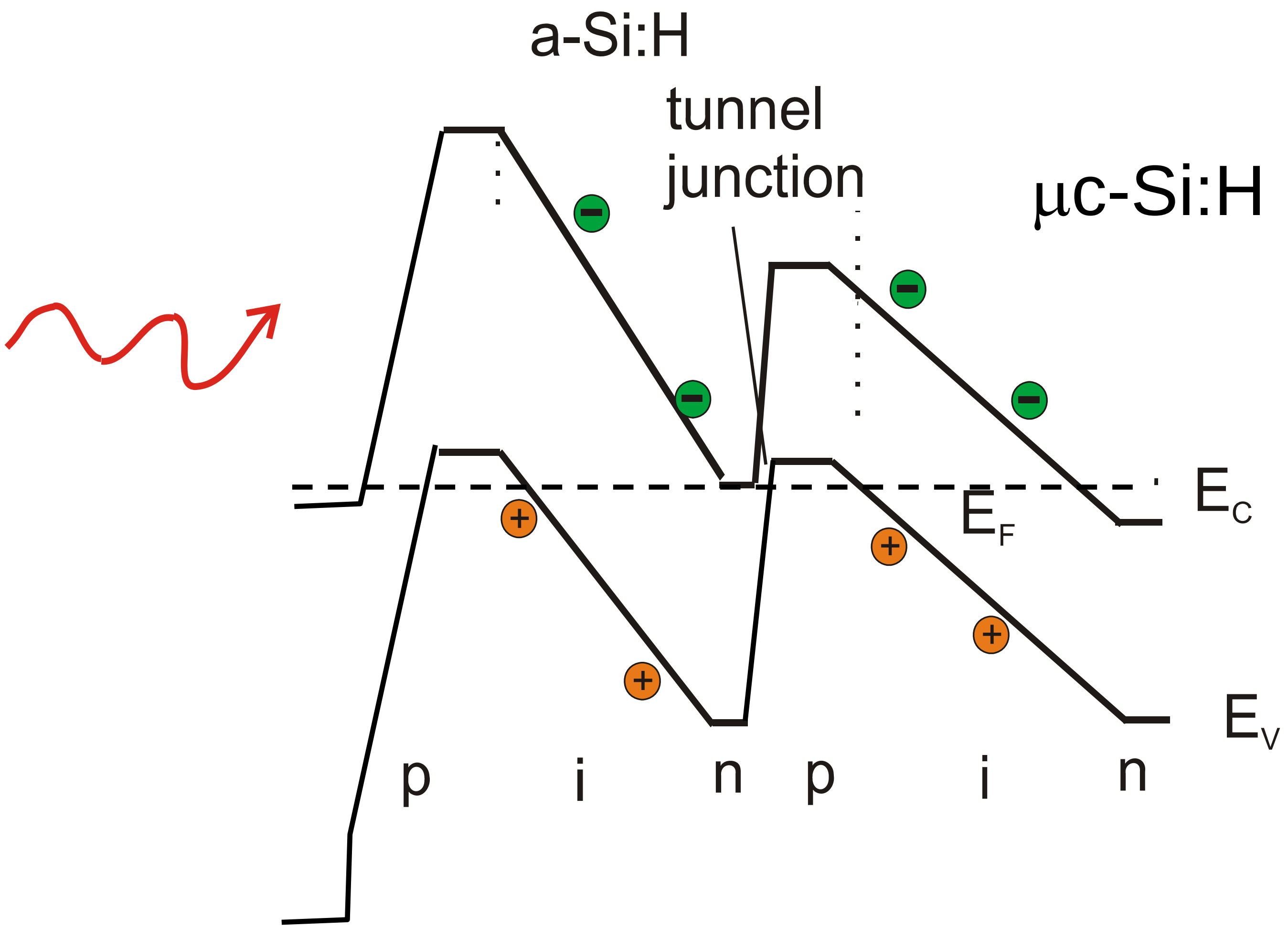


a:Si:H/µc-Si:H phase transition

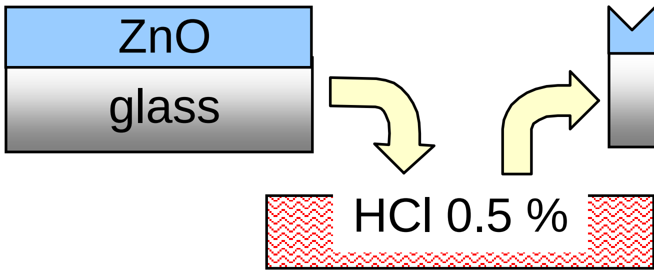


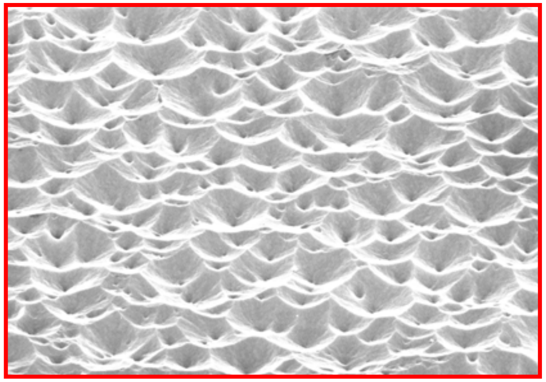
L. Houben, Dissertation, FZJ (IFF/IPV), Uni Düsseldorf
O. Vetterl et al., Sol. Energ. Mat. Sol. Cells 62 (2000) 97-108

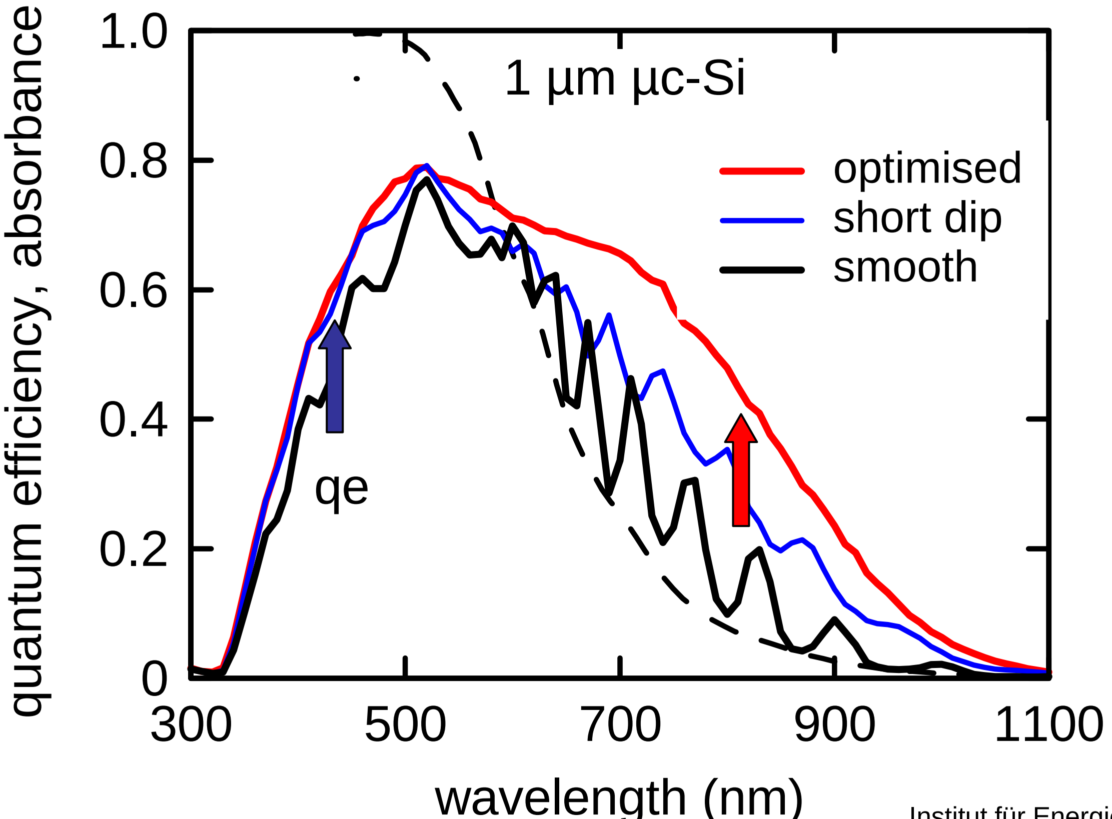
Multi-junction solar cells



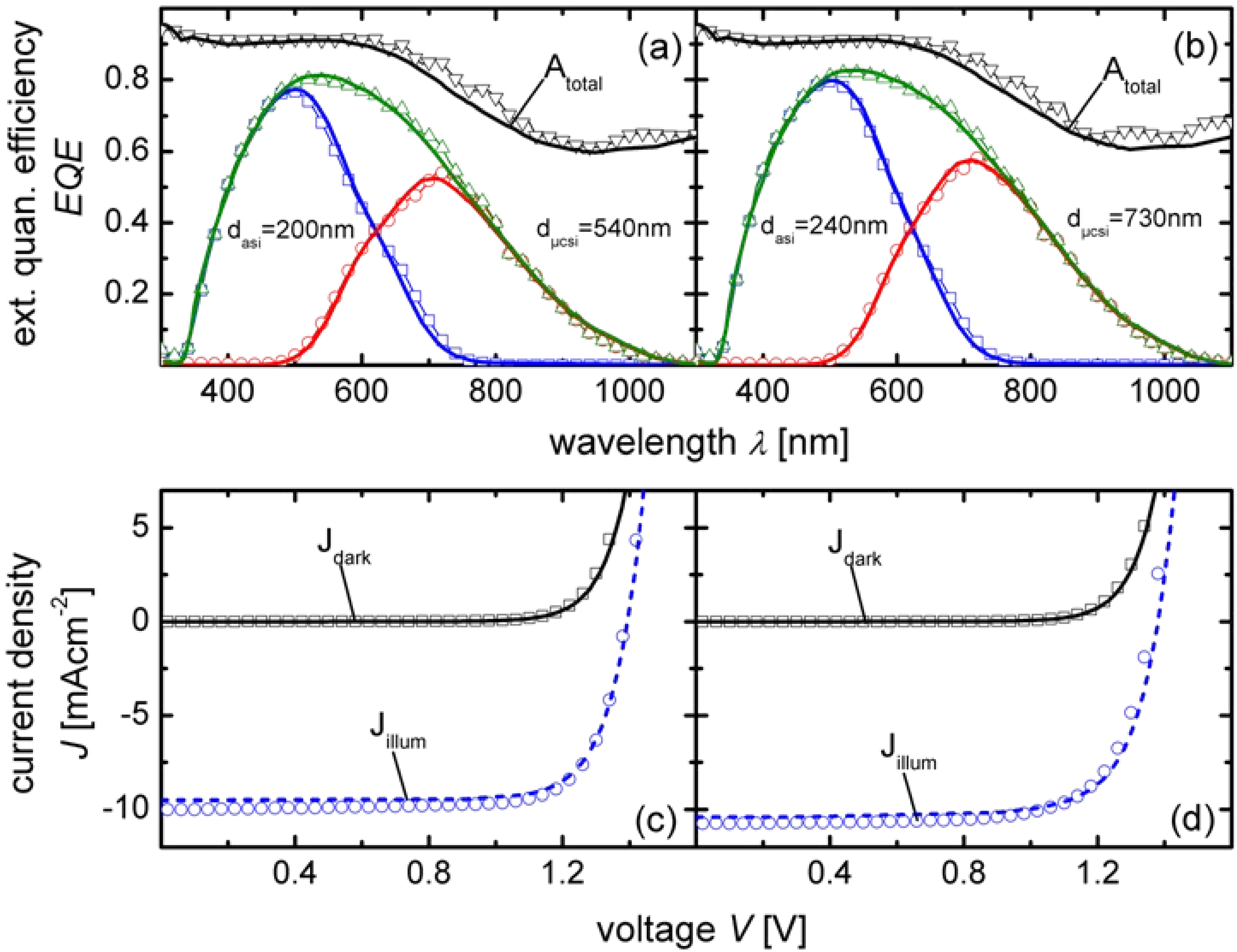
Optimized ZnO for light trapping



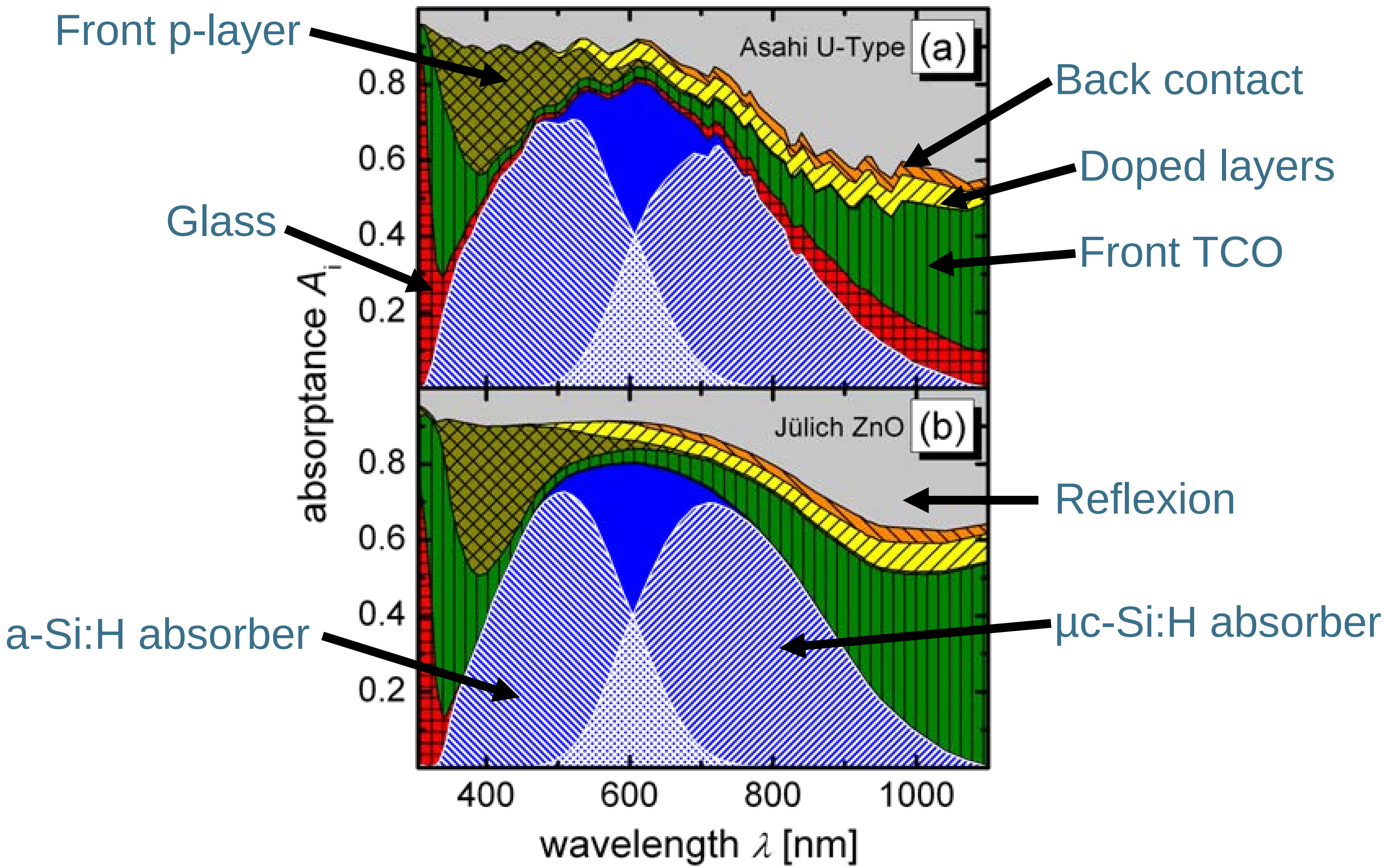




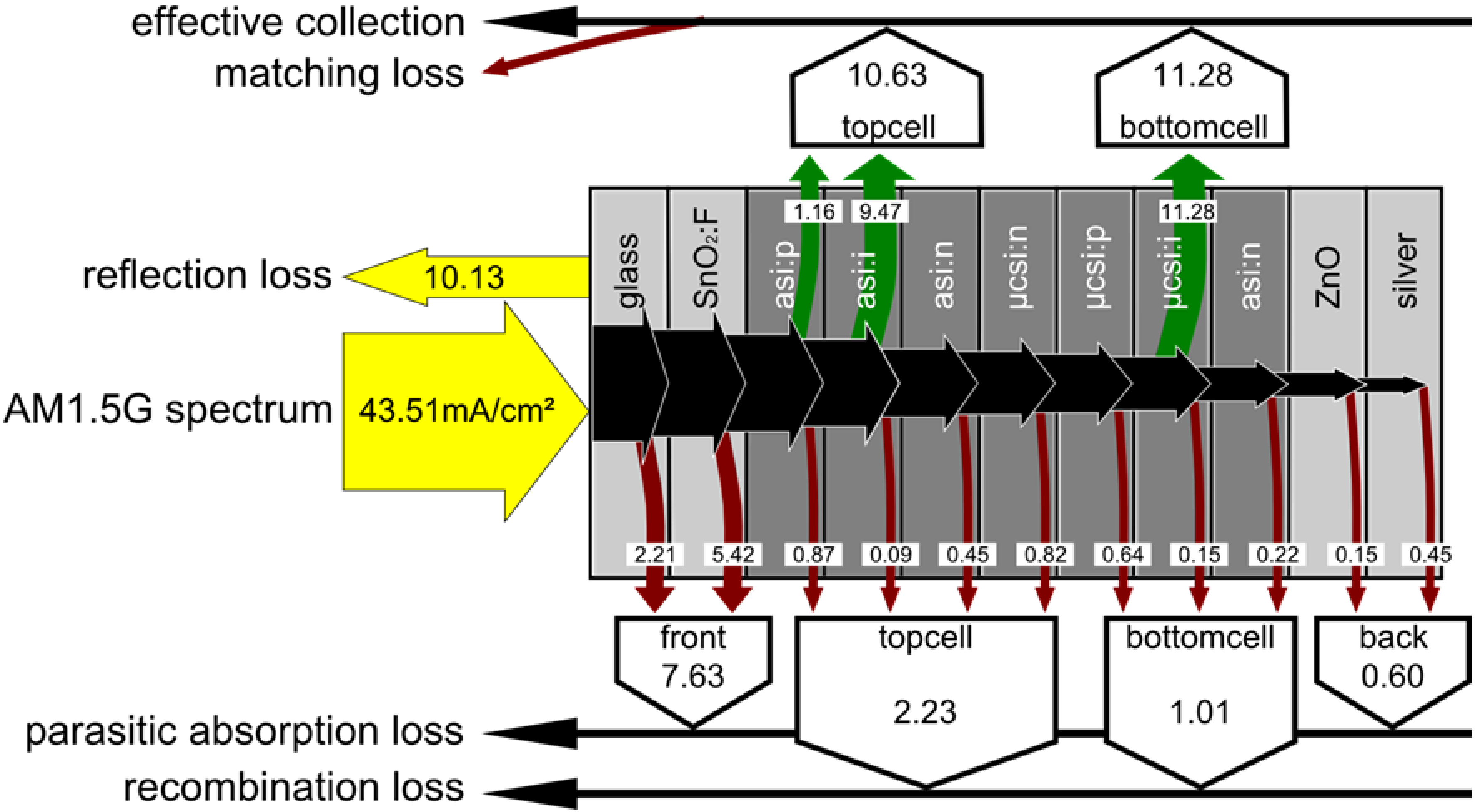
Simulations: Tandem cells on textured ZnO:Al



Absorptance distribution



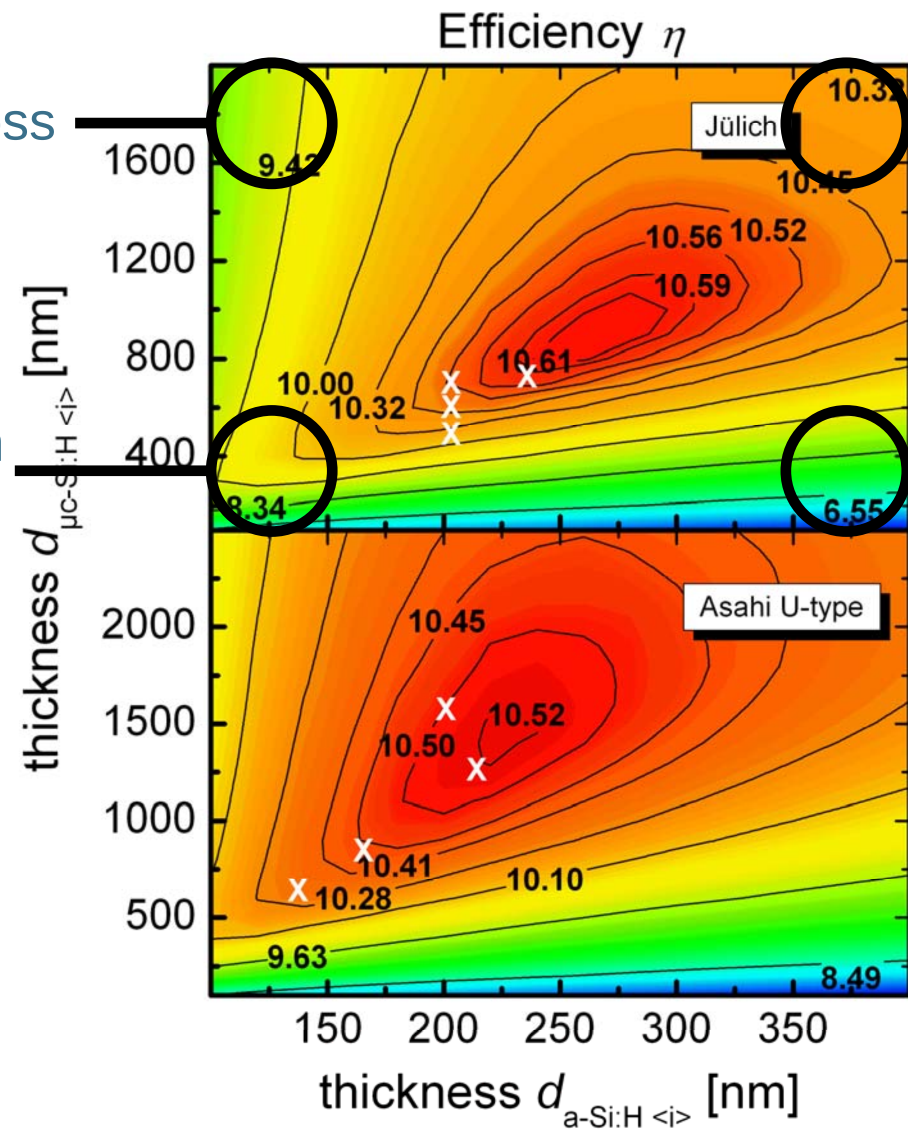
Loss analysis (0V)



III: Thickness dependence

Matching loss

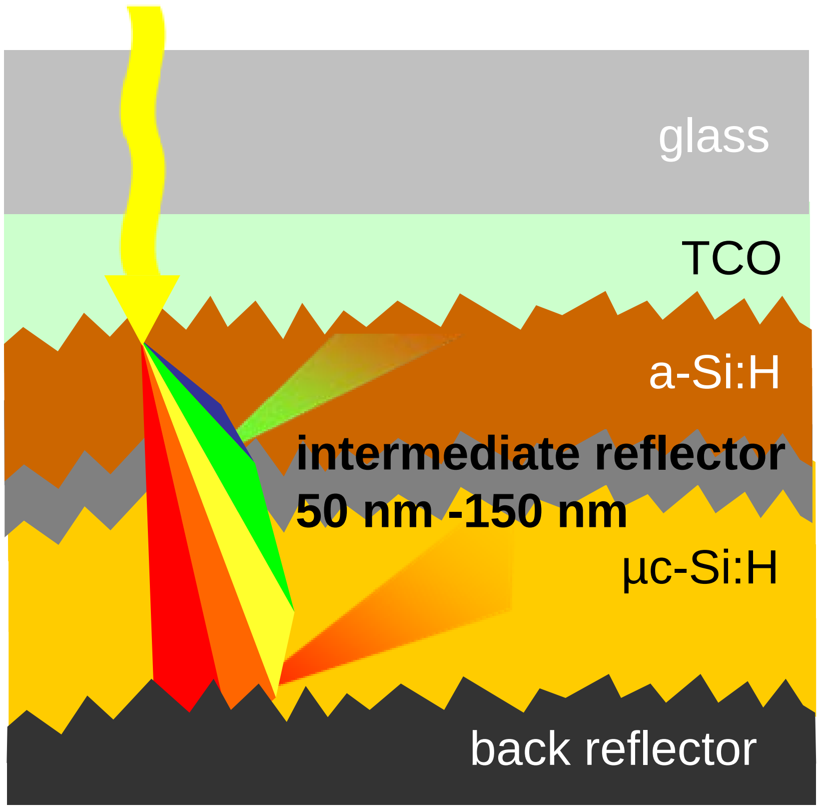
Transmission loss



Recombination loss

Matching loss

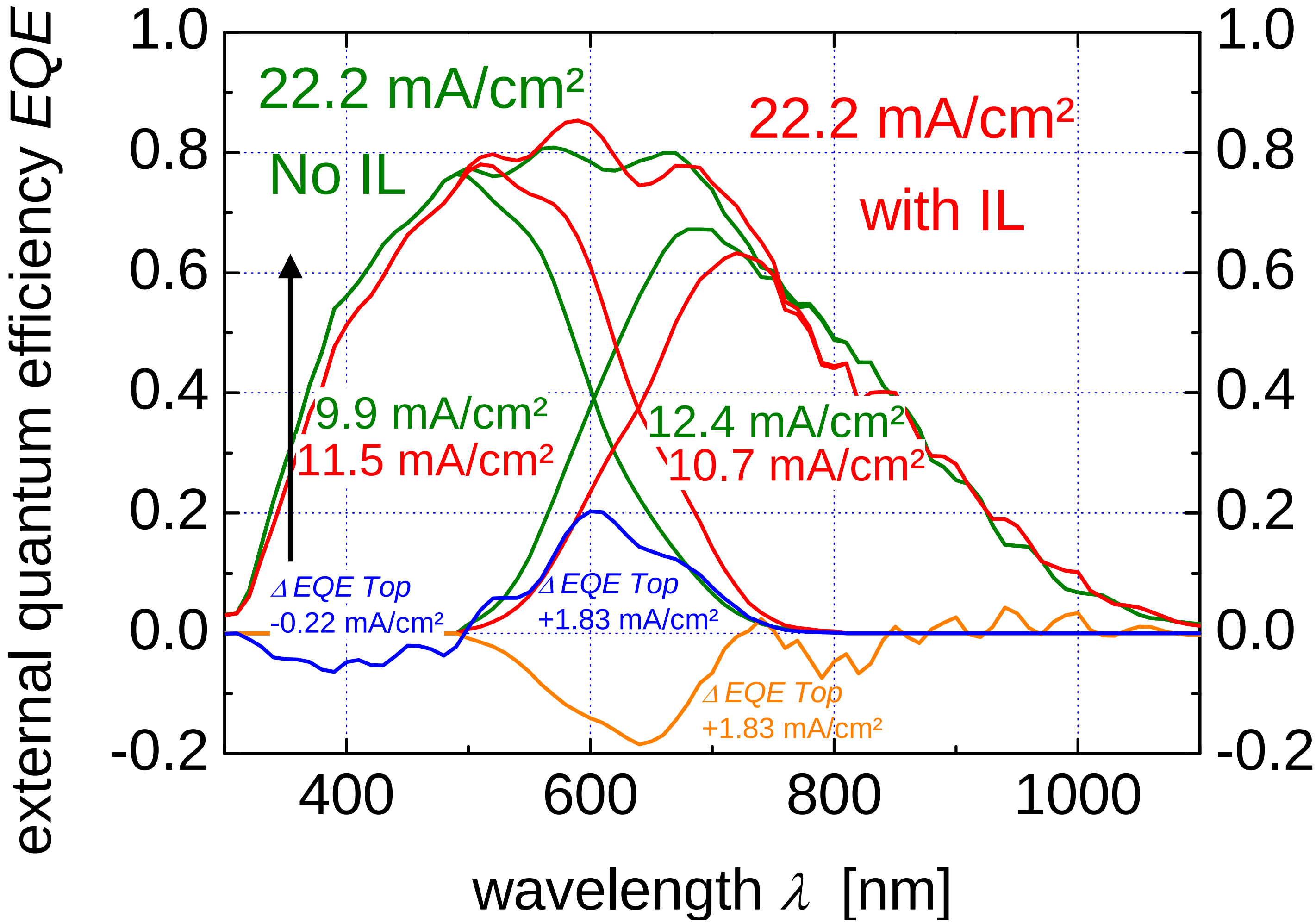
Tandem Solar Cell with Intermediate Reflector



Requirements for the Intermediate Reflector:

- sufficient conductance
- low absorption
- low refractive index to achieve high refractive index difference between Si and SiO_x

SiO_x intermediate reflector

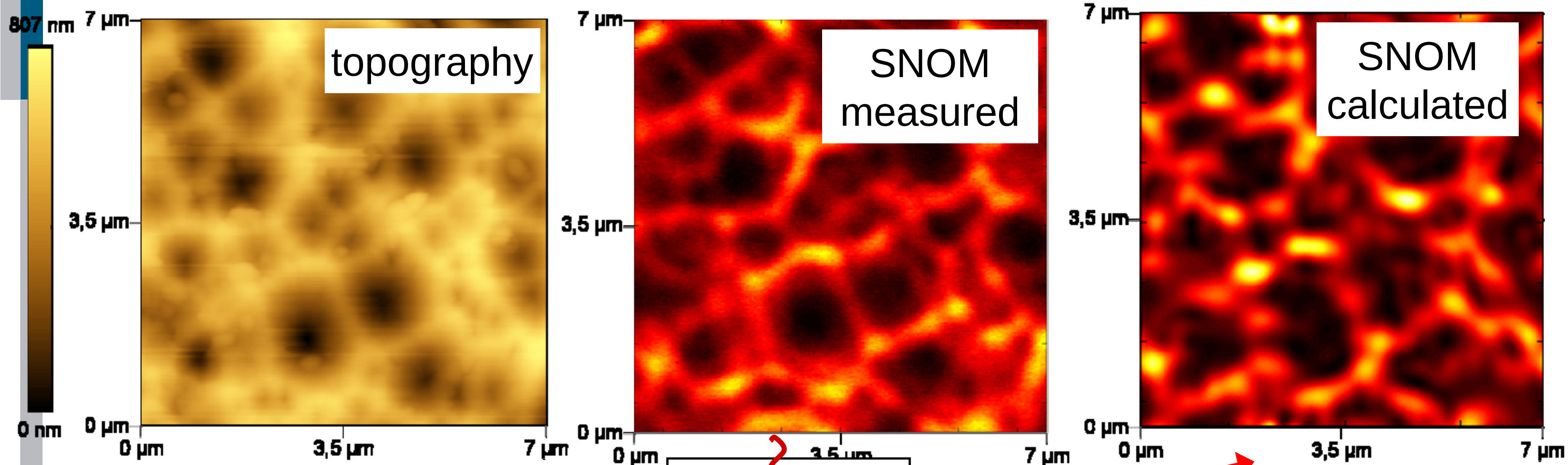


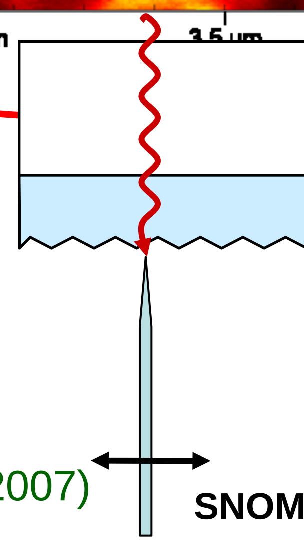
C. Das, et al., Appl. Phys. Lett. **92** (2008)

Scanning near-field optical microscopy

Effect of micro-/nano-structures of textured ZnO on local optical properties

Analyzed by Scanning Near field Optical Microscopy

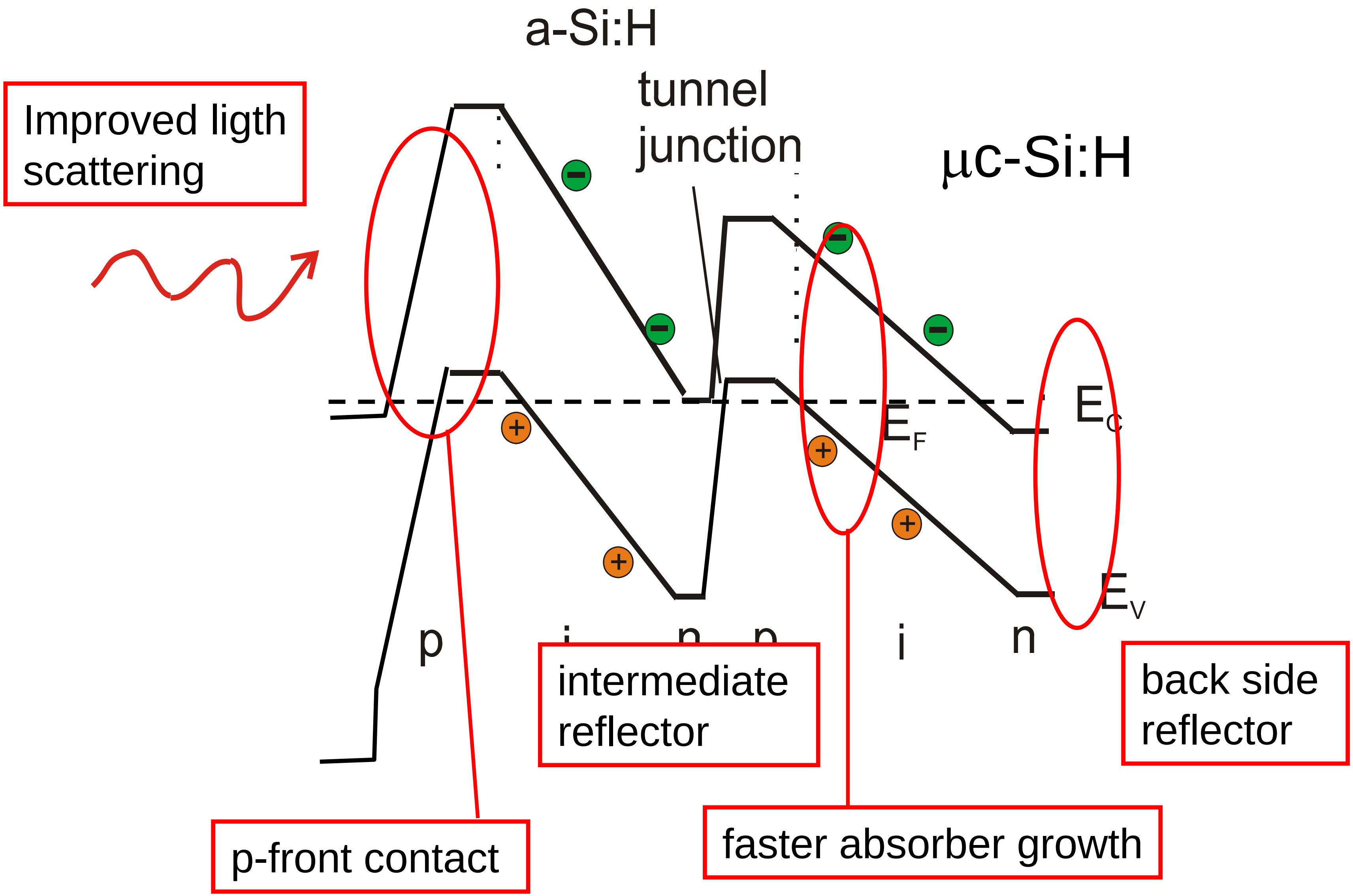




Topography enters into first principle calculations

K. Bittkau, et al., Phys. Rev. B **76** (2007)

aSi/µcSi research issues



Conclusions

- Photovoltaics has become a billion € business
  .. on a partly (but then heavily) subsidized market
- Political goals can be met (on the technological level)
- Cost reduction is still (and more than ever) a major issue
- Challenges for thin-film technologies:

→ Close the gap between lab and production scale efficiencies

→ Faster and more reliable production methods

→ Improved scientific understanding of optics, materials and interfaces