Next generation solar cells II

Modern materials and developments

Contents

- Modern materials and techniques
- Amorphous silicon (a-Si:H Cell)
- Non-silicon semiconductors
- Gallium arsenide (GaAs) multijunction
- CIS ($CuInSe_2$) and CIGS ($CuIn_xGa_{1-x}Se_2$)
- Dye-sensitized solar cells
- General ecological aspects of solar cells

Modern materials and techniques

- Amorphous silicon *
- CdTe
- GaAs *
- Multijunction*
- CIS/CIGS *
- Dye-sensitized solar cells *
- Nanocomposite solar cells
- MIB-cells (metallic intermediate band)
- Organic/ Polymer solar cells

*Referred to in this presentation

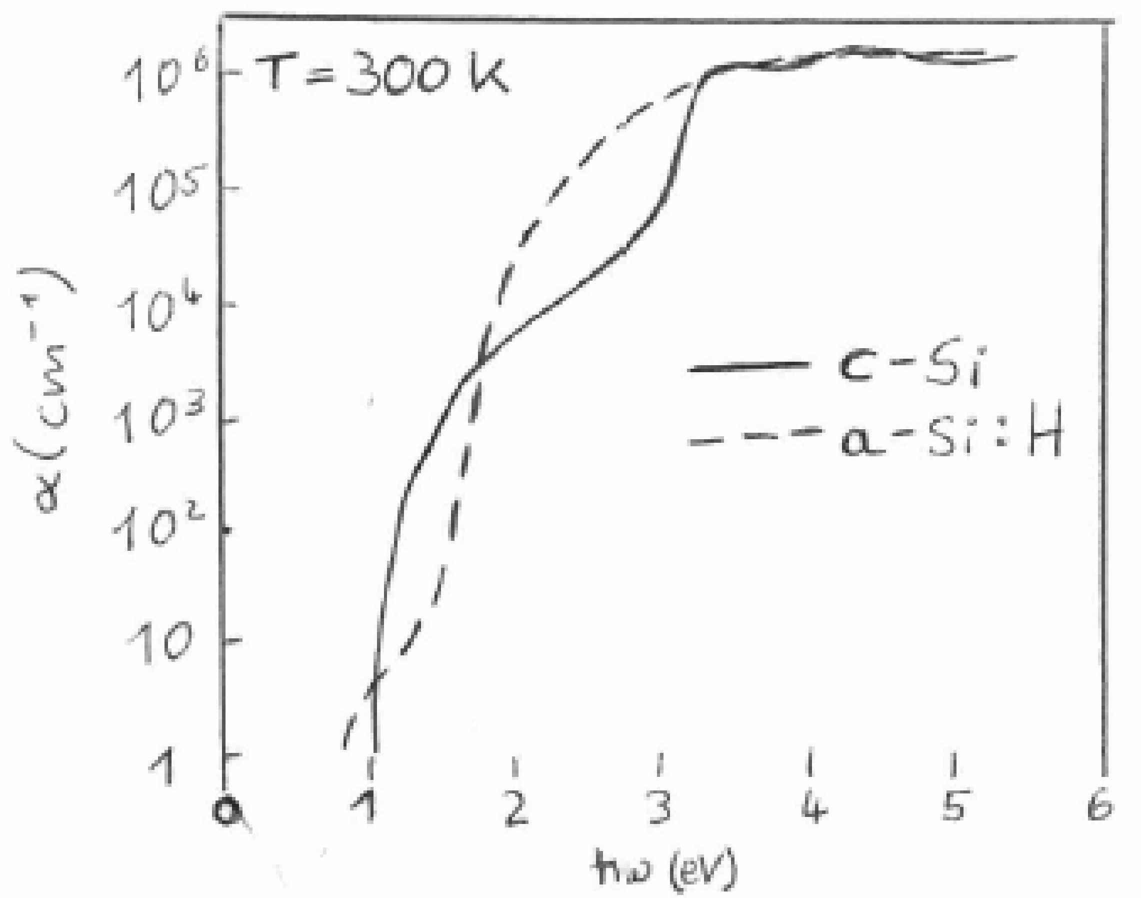
Amorphous silicon (a-Si:H)

- High Absorption in the visible spektrum → thin films!!

  (0,5-0,7µm)

- easier to produce than bulk silicon

→ lower costs



Properties:

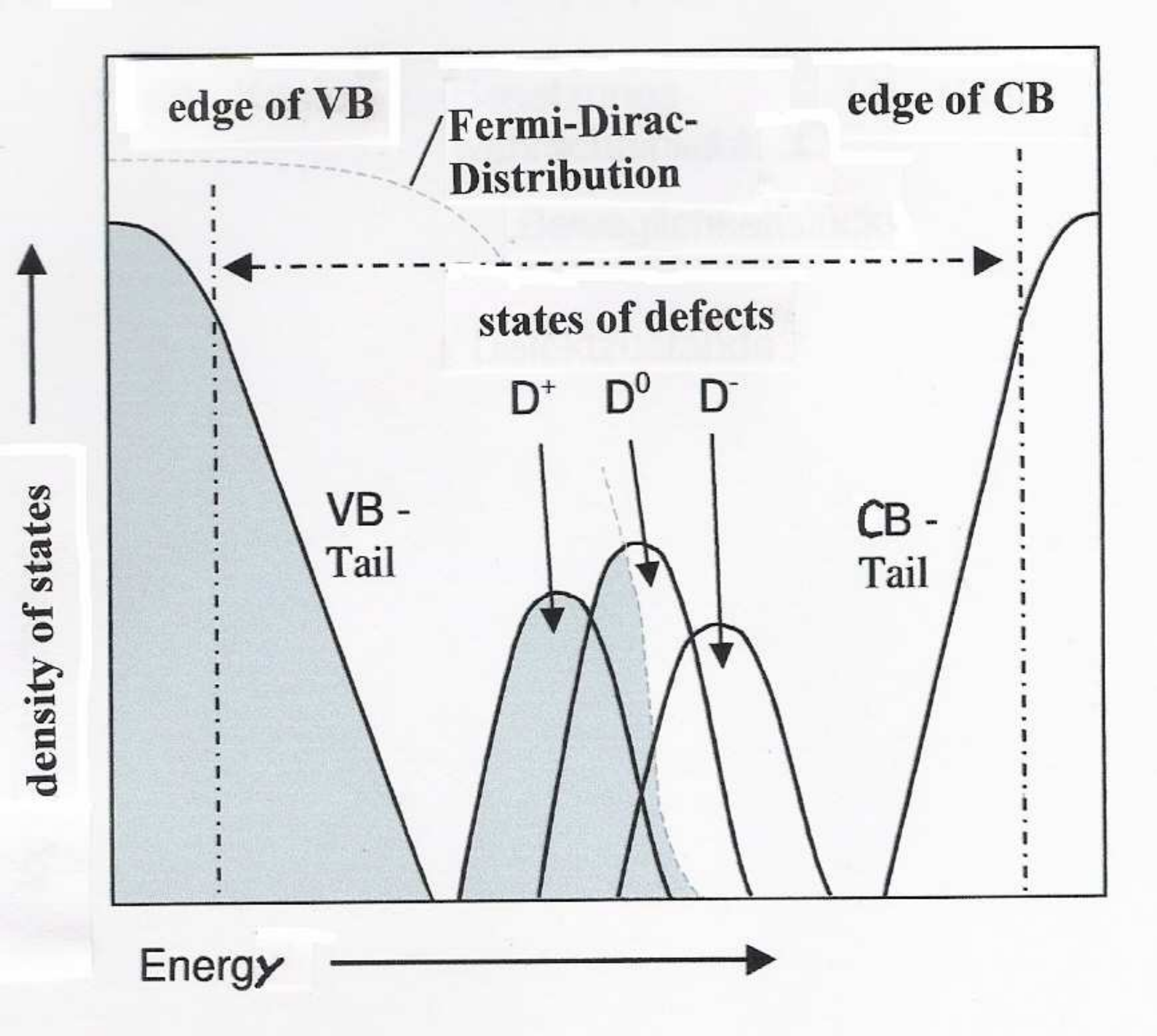
- No long range order
- Band tails obstruct the flow of electrons
- Broken covalent bonds (dangling bonds) increase the recombination rate

→ partly passivation with hydrogen

Density of State

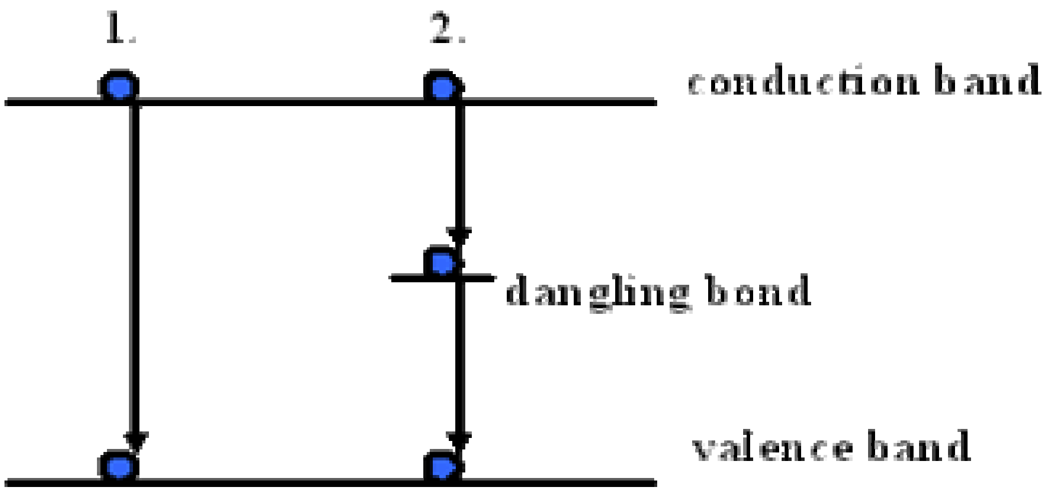
No permitted area

→ Possibility of absorbing light with low energy



Recombination because of dangling bonds

1. **Need to emit energy in one step**
2. **Possibility to emit energy in two or more steps (less phonons or photons at once necessary)**



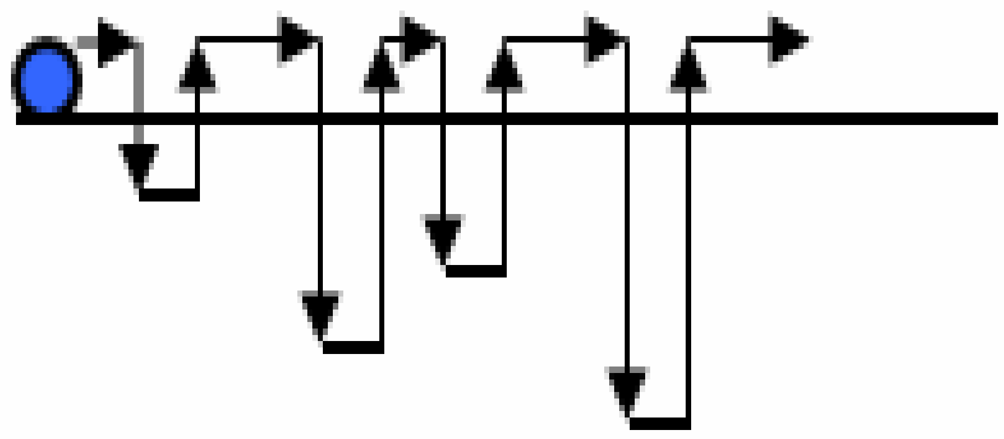
→ Recombination with dangling bonds is more likely

Short diffusions length because of band tails

Electrons “fall” to band tail states

Get back by thermal activation

→ Very short diffusion length



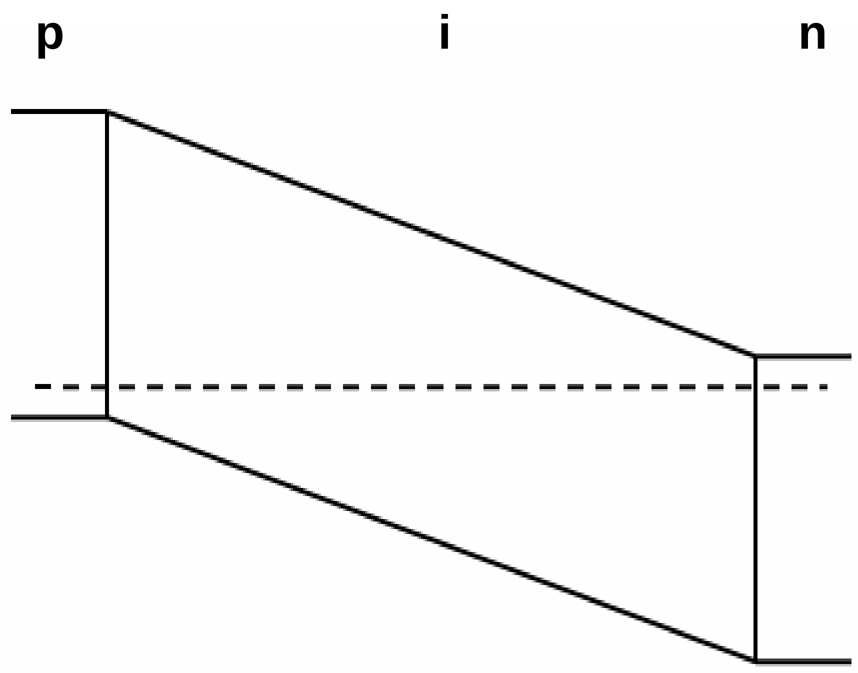
Consequence for the a-Si:H solar cell

diffusion barely possible

(in doped a-Si:H even worse)

→ Need to transport electrons (and holes) by an electric field

Realization with an intrinsic absorption layer and high doped n/p-layers at the edges (pin)



Structure:

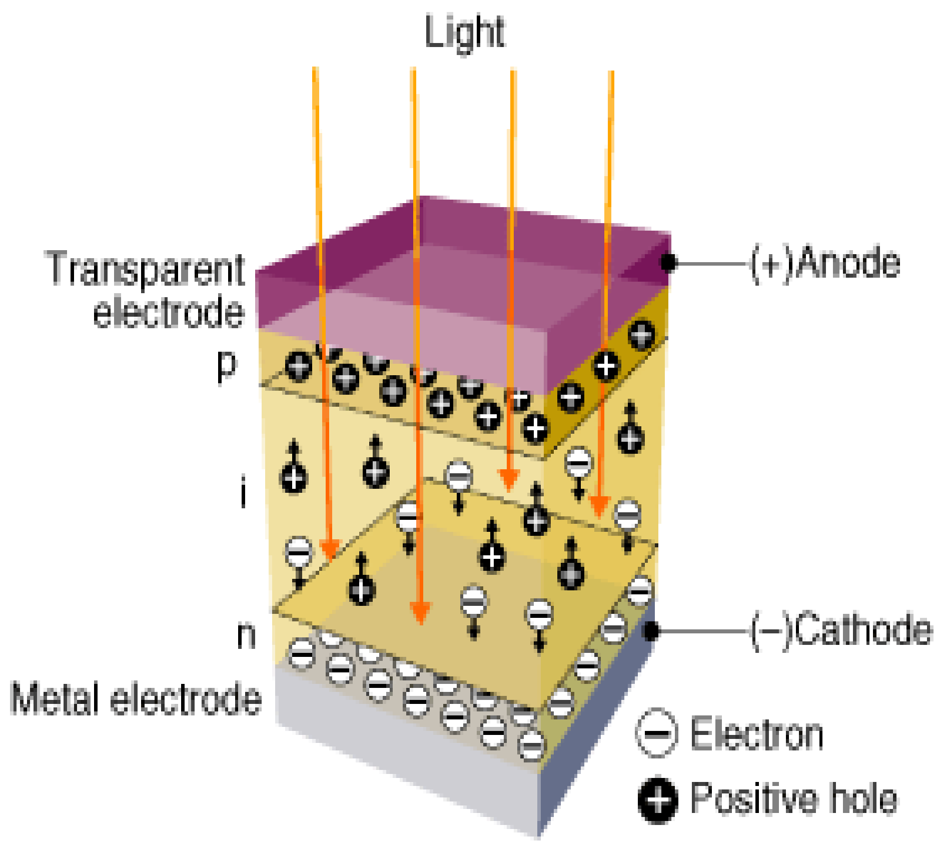
1. **Glas or transparent plastic coated with TCO (transparent conductive oxide) working as anode**

2. **p-doped layer**

3. **intrinsic layer (better conductivity)**

4. **n-doped layer**

5. **metal cathode (Al/Ag) with reflecting properties**



Source: Sanyo Semiconductors

Staebler-Wronski-Effect: light induced degradation

1. Covalent bonds break, increasing of defects $D \sim \Phi$^2/3 * *t*^1/3 (Φ: flew of electrons, t: lighting time)
2. Si-H breaks, free H reacts: Si-Si + H→ Si-H + Si
3. (1) and (2) are reversible processes

→ Equilibrium after 1000 h of lighting time (degradation of ca. 25%)

Advantages ←→ Disadvantages

(a-Si:H compared to bulk silicon cells)

- Less material
  (ca. 90%)
- Easier to produce
- High absorption of diffuse light
  (because of irregular surface)

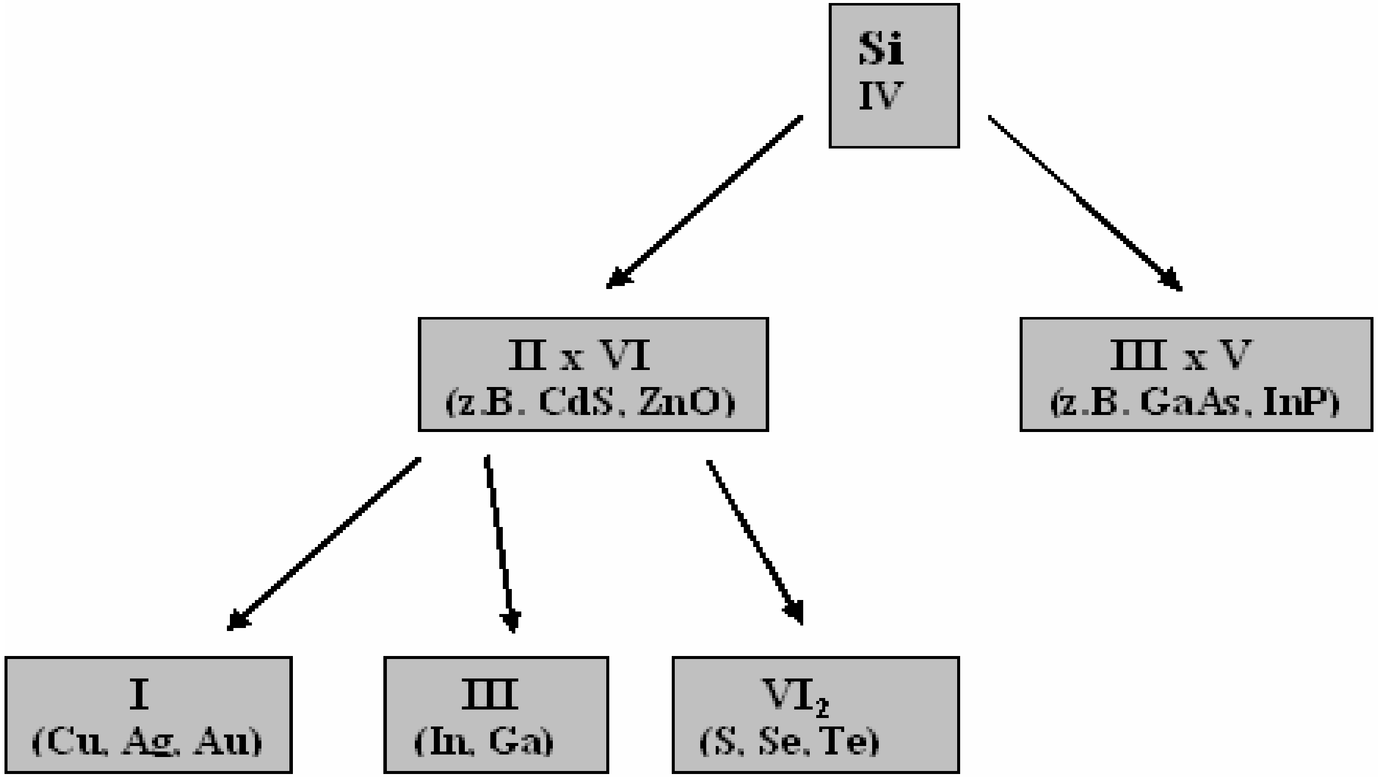
- Lower efficiencies
  (laboratory: 13% (c-Si:24%)
  industrial production: 5-7%)
- Shorter life-time
  (about 20 years)

Applications

- comparatively high absorbtion of diffuse light → indoor applications (watches, calculators)

- Production under low temperatures possible → flexible polymer material

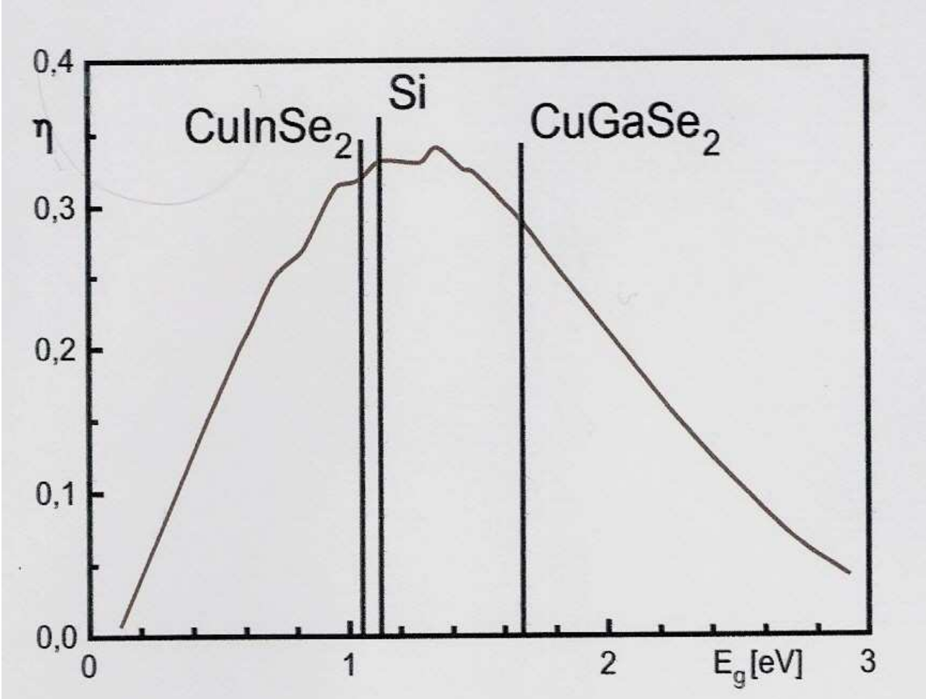
Non-silicon semiconductors



Energy gaps

Material	EG (eV)
Ge	0,66
$CuInSe_2$	1,05
Si	1,12
InP	1,24
GaAs	1,42
CdTe	1,45
$CuInS_2$	1,52
$CuGaSe_2$	1,68
a-Si:H	1,7
CdS	2,4

Theoretical efficiency depending on EG



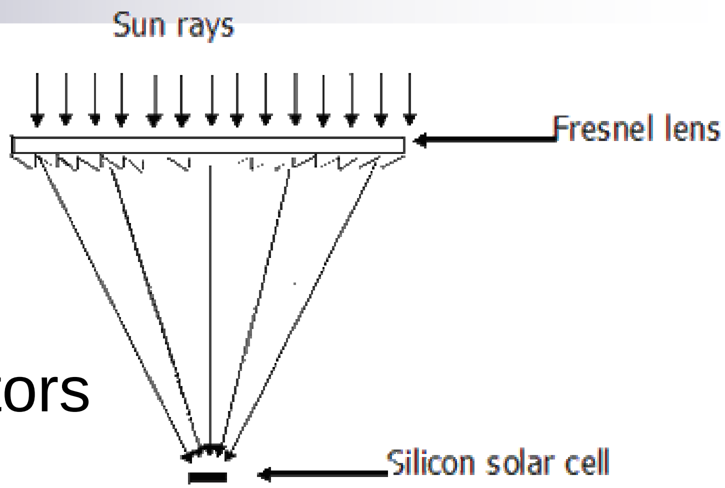
Source: Dissertation of Andreas Schulz

→ Best theoretical efficiency with EG≈1,4 eV

→ Optimum results with

- **GaAs** or
- Mixture of **$CuInSe_2$** and **$CuGaSe_2$**

Solar concentration



- Lenses are cheaper than semiconductors

- Efficiency increases under solar concentration (ca. 2% per decade)

  Reasons:

  - short-circuit current increases linearly with concentration

  - open-circuit voltage increases (ca. 0,1 V per decade)

→ One cell under 1000-sun concentration can produce the same power output as about 1300 cells under 1 sun

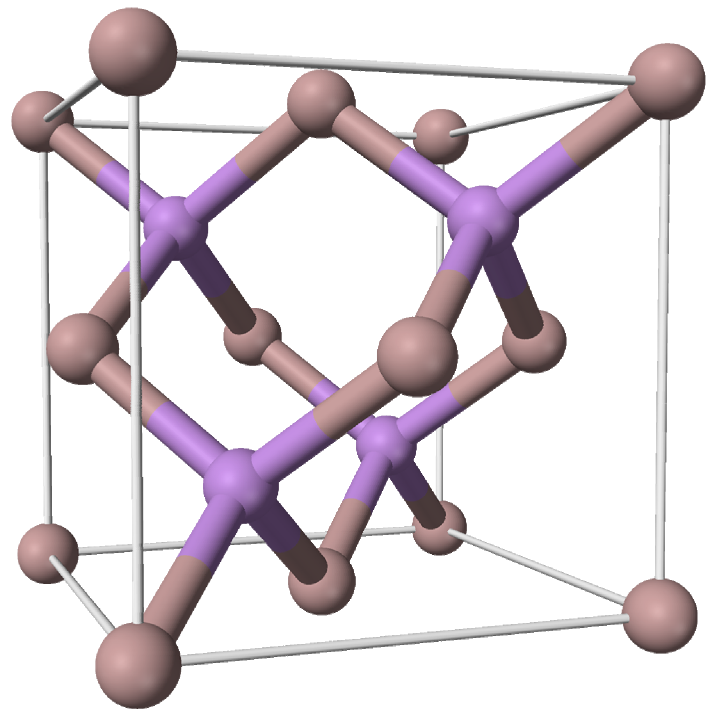
Gallium arsenide (GaAs) multijunction

Most multijunction systems use GaAs and other III-V Semiconductors

Strong material →

Can be used in space and concentrator systems

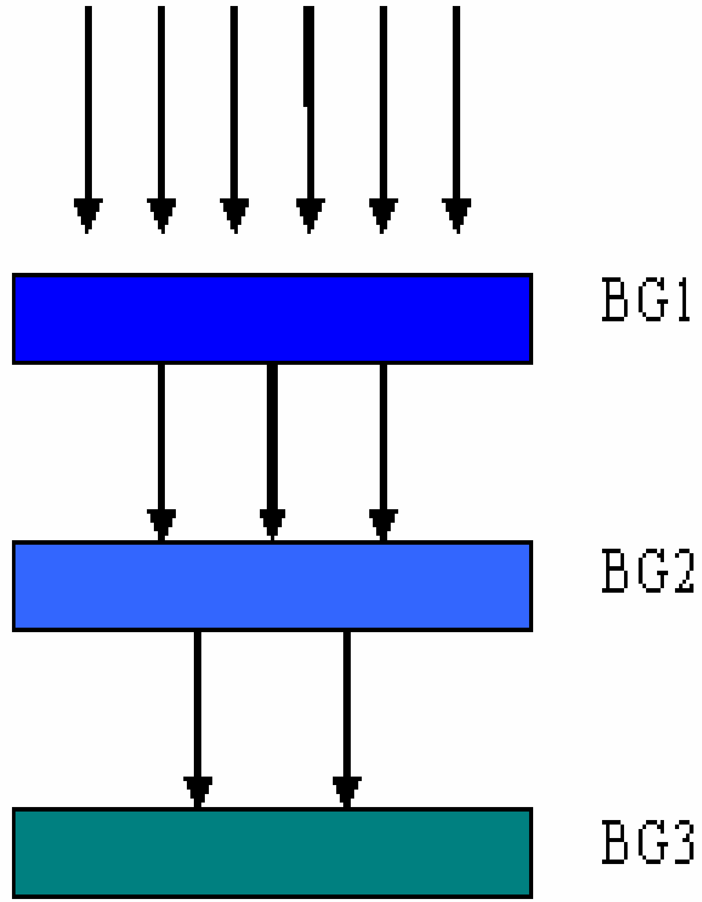
Structure of GaAs: Zincblende (ZnS)



Source: http://commons.wikimedia.org/wiki/Image:Gallium-arsenide-unit-cell-3D-balls.png

Principle

- Several layers of semiconductors with different band gap
- BG1>BG2>BG3
- First layer absorbs light with hv>BG1, Photons with lower energy get through it

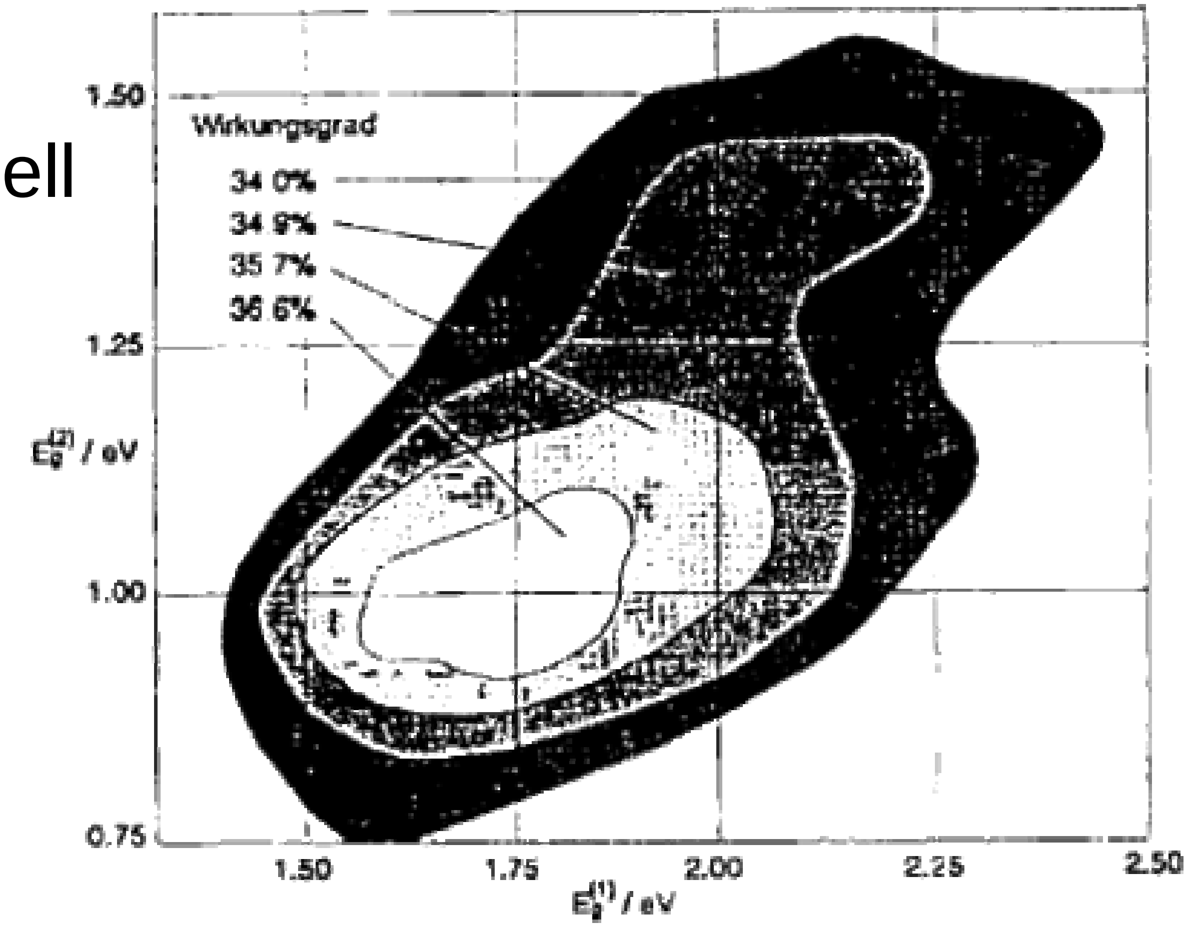


- Hier soll das Schaltbild einer Tandemsolarzelle rein

Efficiency of tandem cells

E2: top cell

E1: bottom cell



Under solar concentration in laboratory:

A system of 20-30 layers reaches an efficiency of 40,7 %

Theoretical limit: 58 %

Realistic efficiencies in future: 45-50 %

Advantages ←→ Disadvantages

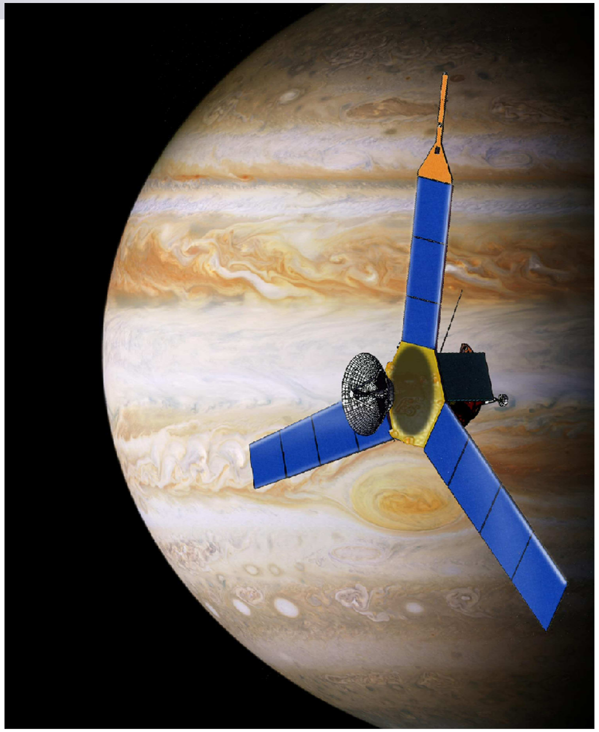
(GaAs compared to bulk silicon cells)

- Higher efficiencies
  (in laboratory: 40,7 %
  (c-Si:24%))
- UV- and heat-resistant

- Production more expensive
- Heigher weight than silicon
  ($\rho(Si)=2{,}33\ g/cm^3$,
  $\rho(GaAs)=5{,}31\ g/cm^3$)

Applications

- space power systems



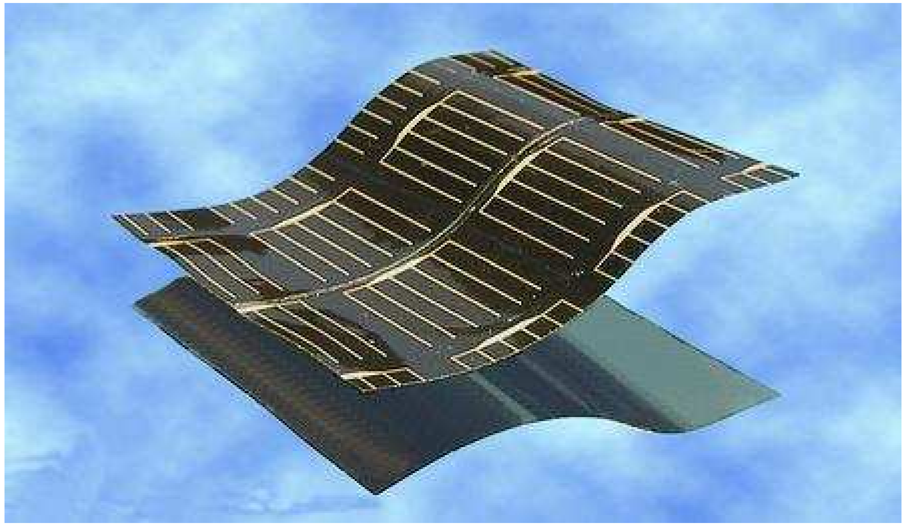
http://de.wikipedia.org/wiki/Bild:Juno_space_probe.jpg

- Terrestrial application with concentrator systems

http://i.treehugger.com/files/PARC-ConcentratorCell.jpg

CIS and CIGS

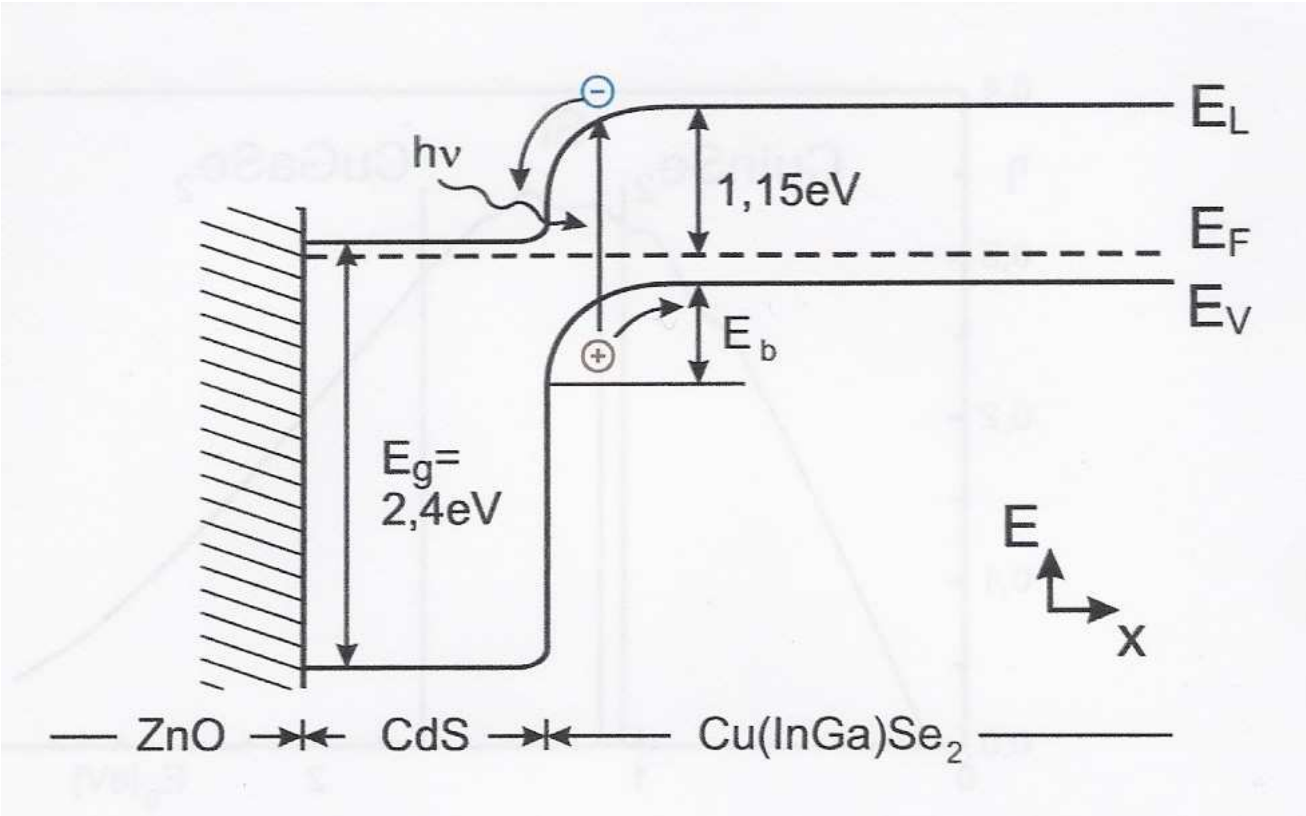
($CuInSe_2$, $Cu(InGa)Se_2$)



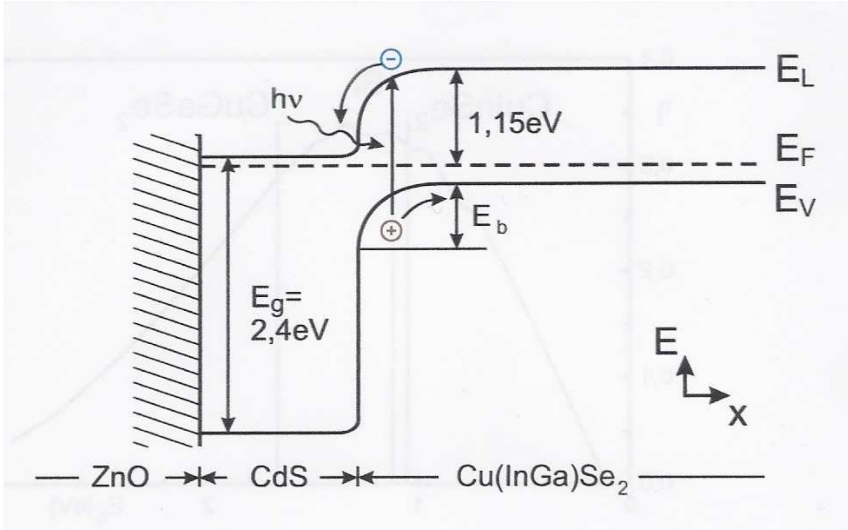
- High absorption of photons with hν≈EG permits thin layers

- Depending on the composition, EG varies from 1,05 eV (pure CIS) to 1,65 eV (pure $CuGaSe_2$)

Structure of a CIGS-cell



Principle



-CIGS inherently p-doped

→ use CdS (n-type)

EG(ZnO)= 3,3 eV > EG(CdS)= 2,4 eV > EG(CIGS)= 1,4 eV

→ highest absorbtion in CIGS layer

Same principle as bulk silicon cell

Advantages ←→ Disadvantages

(CIS/CIGS compared to bulk silicon cells)

- Need less material
- Can be deposited on flexible materials

- Low efficiencies
  (laboratory: 17% (c-Si: 24%)
  industrial production: 14%)
- Not much Indium available
- Usage of toxic Cadmium

Application

- Coats and backpacks of walkers →

  e.g. cooking and ligthing

  (Need to accumulate energy)

Source: www.solarserver.de

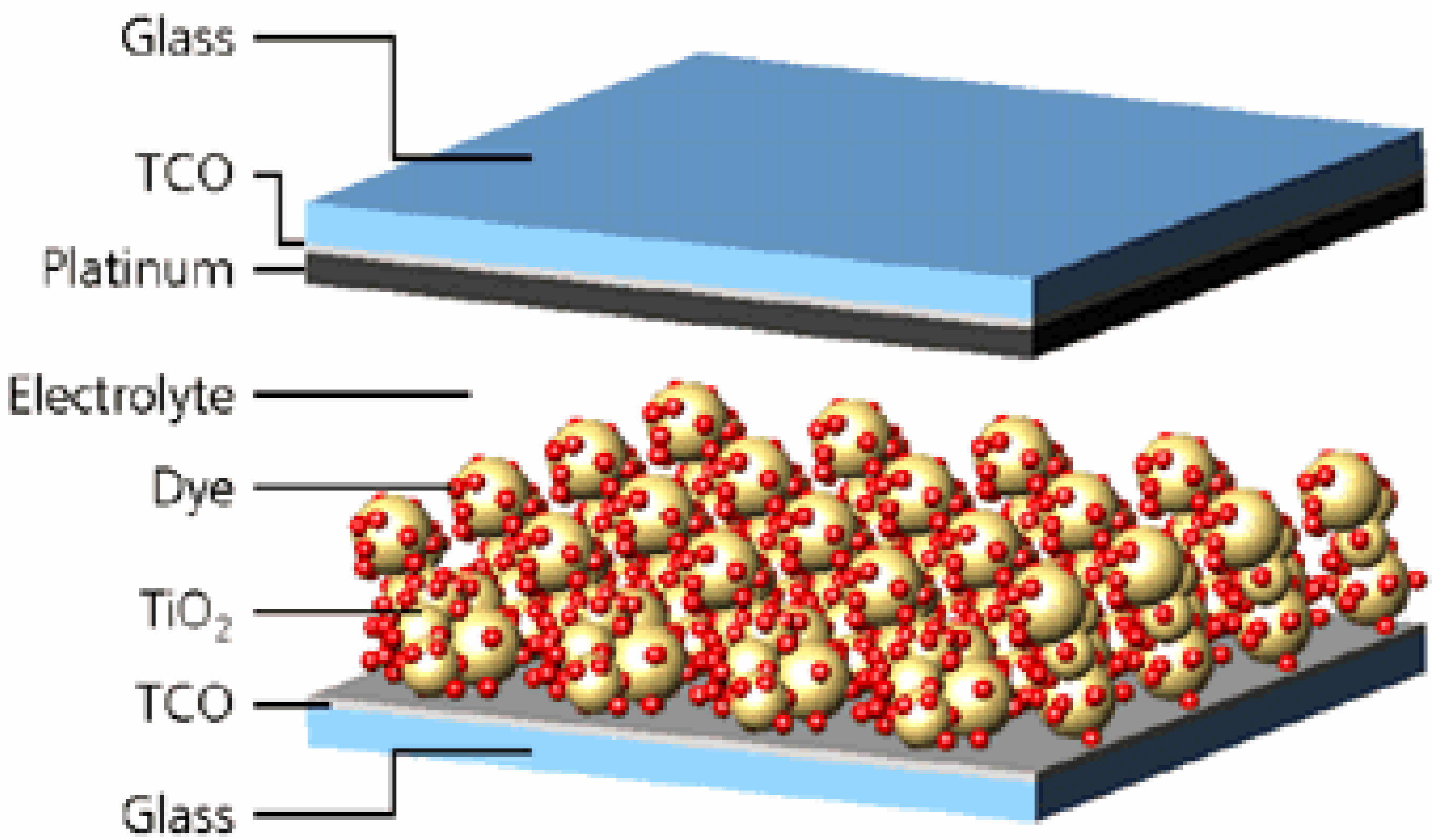
- Solar power plants

Dye-sensitized solar cells

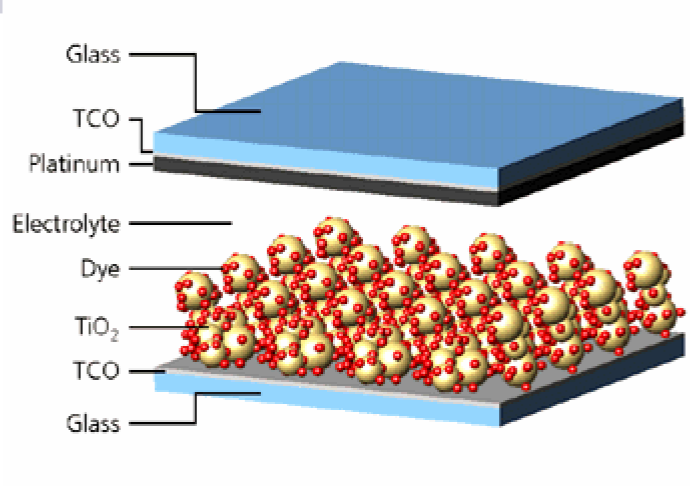
- Photoelectrochemical System
- invented by Michael Grätzel and Brian O'Regan in 1991

http://en.wikipedia.org/wiki/Image:Dye.sensitized.solar.cells.jpg

Structure

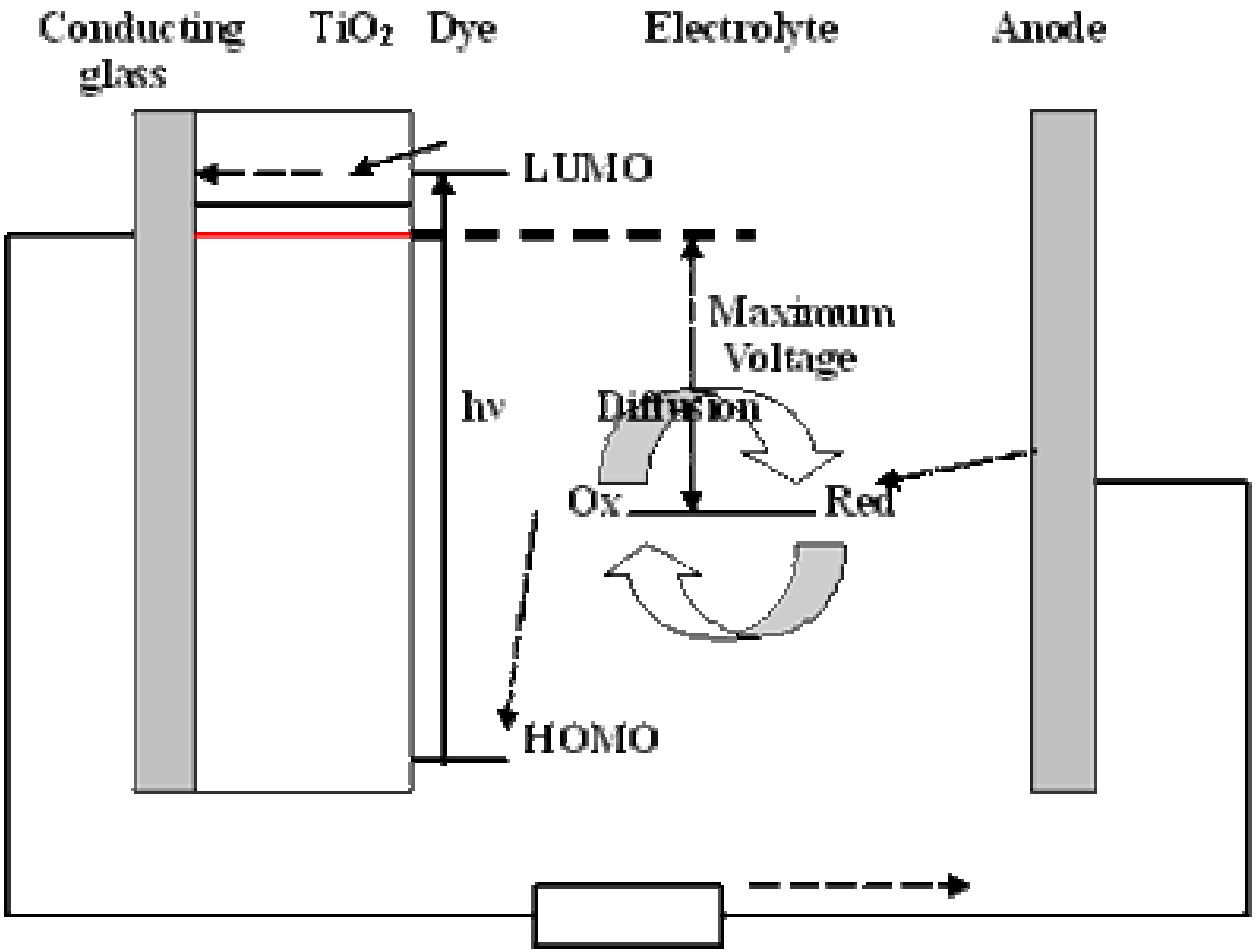


Principle



- Photons activate the dye
- Activated dye generates electron-hole pairs in titanium oxide
- Electrons travel to cathode (here: bottom)
- Postively charged dye is reduced by the electrolyte (usually I^- / I^-_3)
- Closed circuit: I^-_3 is reduced at the anode (here: top) to 3 I^-

Energy scheme



LUMO: Lowest unoccupied molecular orbital

HOMO: Highest occupied molecular orbital

Maximum voltage: Difference between Fermi energy and chemical redox potential

___Energy of CB

___ Fermi energy

Advantages ←→ Disadvantages

(DSC compared to bulk silicon cells)

- Easy production (possible in school)
- Components and production less harmful to the environment

- Low efficiencies (ca. 10%)
- Lower economic life-time (in process)

Application

Building Integrated Photovoltaics (BIPV)

Source: http://www.heise.de/tp/r4/artikel/24/24457/1.html (25.02.2008)

Energy payback period of different solar cells

cell type	payback time
bulk silicon	48-75 month
Amorphous silicon	17-41 month
CIS	24 month

As the economic life-time of all these cells is longer than 20 years, they all have an positive energy balance!

Net energy gain (NEG)

$$NEG = \frac{\text{produced energy}}{\text{invested energy}}$$

- **NEG > 1 → positive energy bilance**
- **NEG < 1 → negative energy bilance**

Taking account of fuels only renewable energy has a NEG > 1 !!!

NEG of the most important energy sources

Energy source:	NEG (without taking account of fuel)	NEG (taking account of fuel)
oil	2-19	0,15 - 0,3
carbon	5-8	0,3-0,45
nuclear power	3 - 20	0,3 - 0,35
hydroelectricity	15	15
wind turbins	19	19
solar thermal energy	5 - 16	5 - 16
photovoltaik	1,5 - 12	1,5 - 12

Life cycle assessment (LCA)

LCA evaluates the sustainability e.g. in terms of:

- Primary energy consumption
- Environmental burden
  - Global warming potential GWP (CO_2 emission)
  - Acidification potential AP (SO_2 emission)
  - Eutrophication potential EP (phosphate emission)
  - Photochemical oxidant potential POCP (ethylene emission)

The evaluation takes in account:

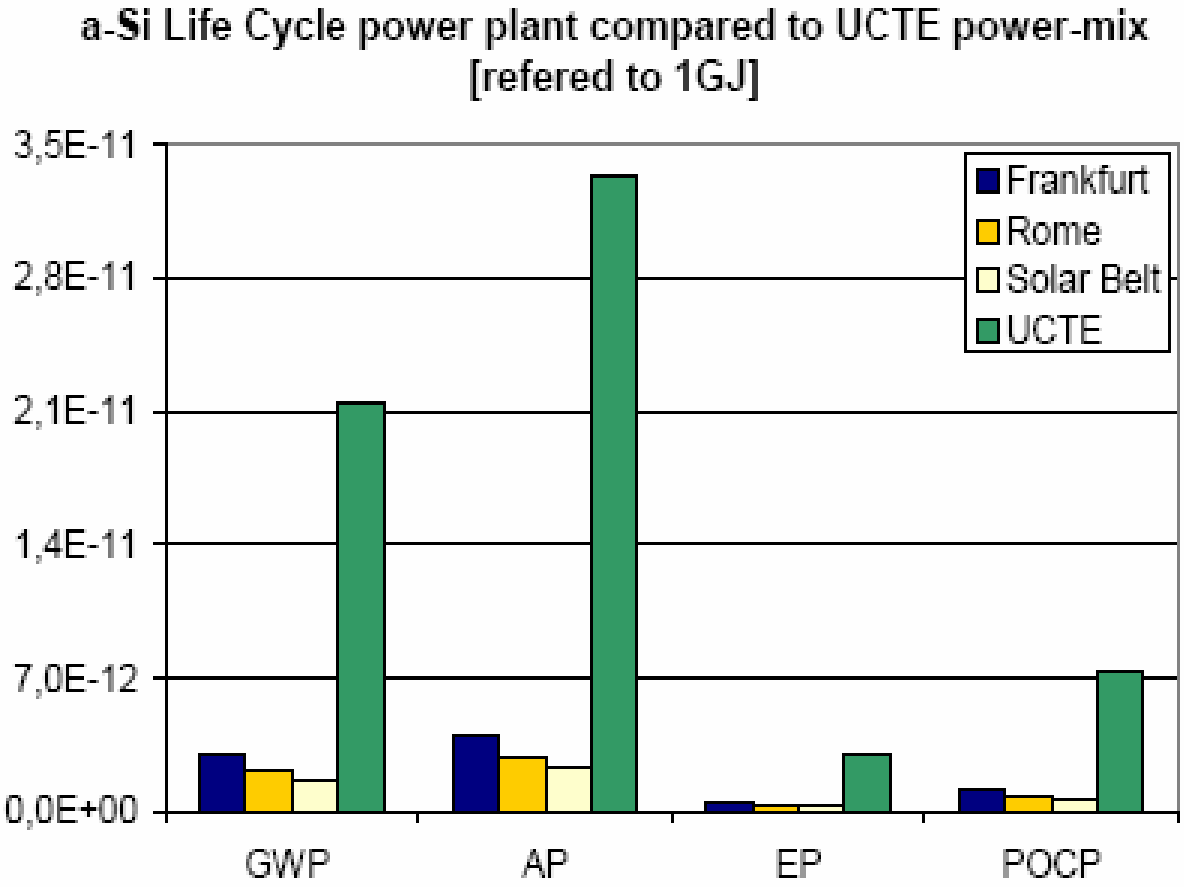
- Manufacturing
- Application

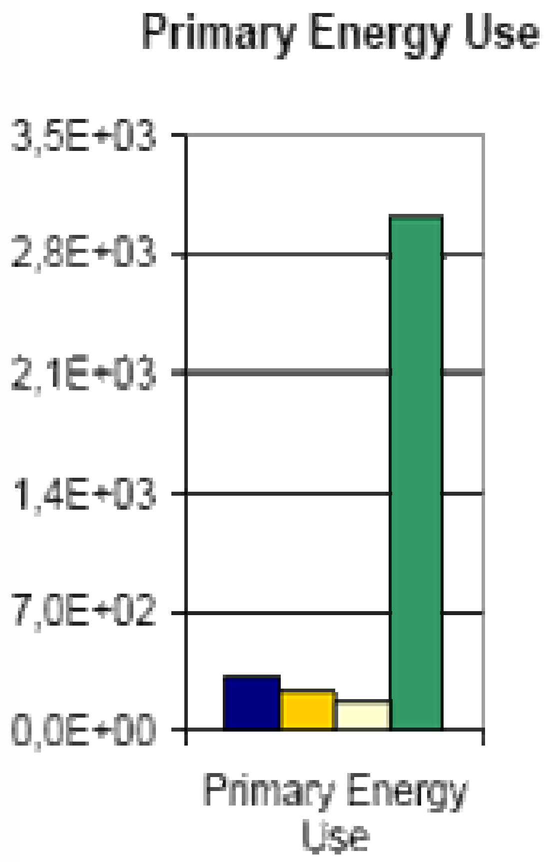
  (considering BOS: Balance Of System)
- Recycling

LCA of a CIGS cell

avaluated by SENSE (University of Stuttgart)

SENSE
Sustainability EvaluatioN of Solar Energy systems





SENSE:

“The results show, that present

thin film PV modules cause significantly less environmental burdens compared to conventional energy

carriers.”

For detailed information about LCA see:

http://www.sense-eu.net/

http://www.ipcrystalclear.info/Paginas/About%20the%20project.aspx

http://88.149.192.110/eclipse_eu/resource.html

It is safe to say that in terms of energy and ecobalance the extension of photovoltaics is advisable.

Unfortunately solar cells are not likely to establish until the price approximates conventional energy.

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