PH Pädagogische Hochschule Wien

# TECHNICAL PHOTOVOLTAICS

I.Hantschk/H.Fibi 2009

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**2009**

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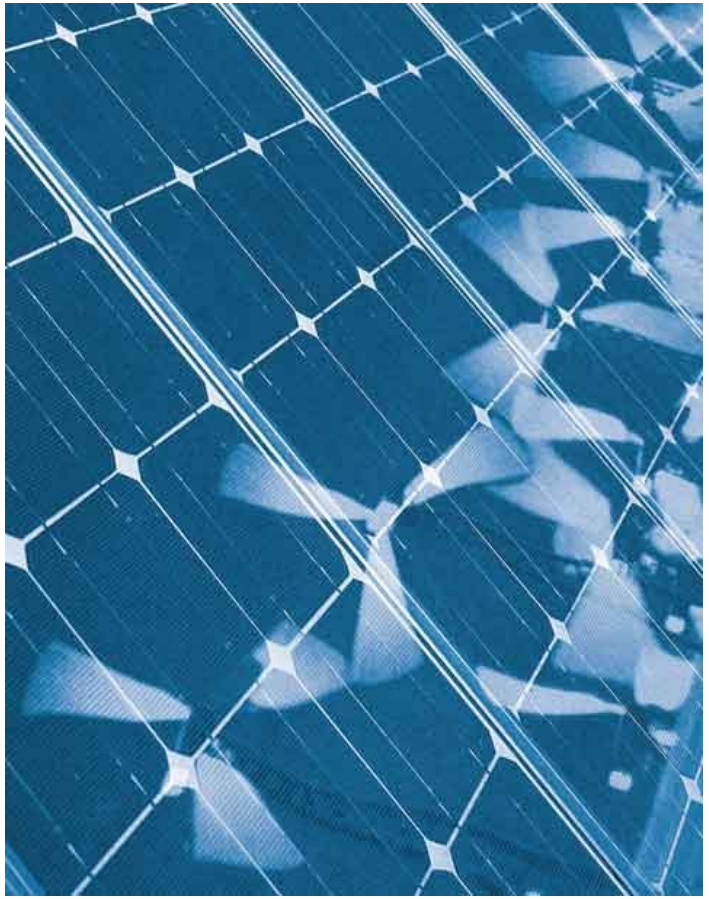
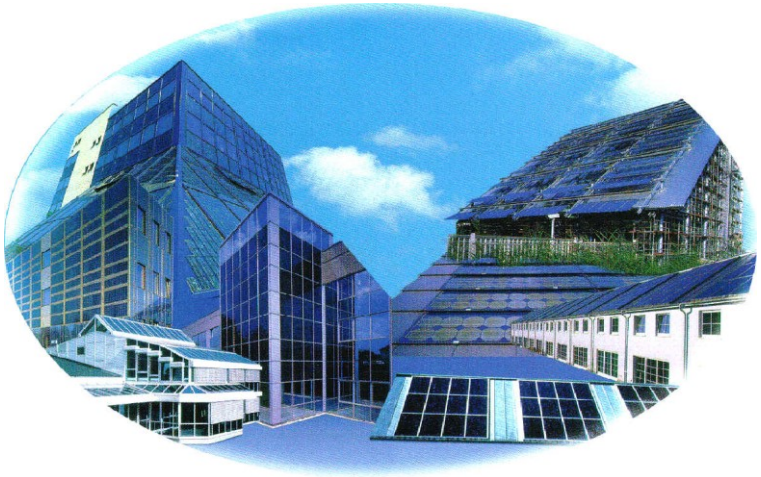
# From the Sun to Energy

Austria...1000 kW/m²

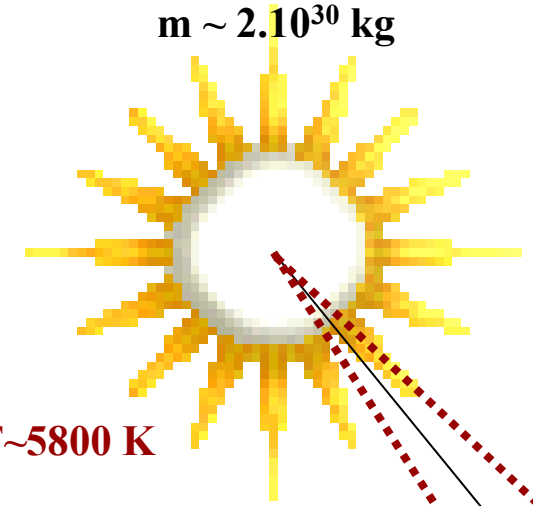
Desert...2500 kW/m2

**500 GWh/a worldwide**





# Sun´s Energy



d ~ 1392000 km
m ~ $2.10^{30}$ kg

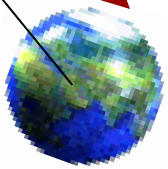
T~5800 K

radiation power: $3,85.10^{26}$ W
responding to (nuclear fusion)
a loss of Hydrogene-Mass
$4.10^{9}$ kg/s

r ~ 149000000 km

$120.10^{9}$ MW

P~1,3 kW/m²

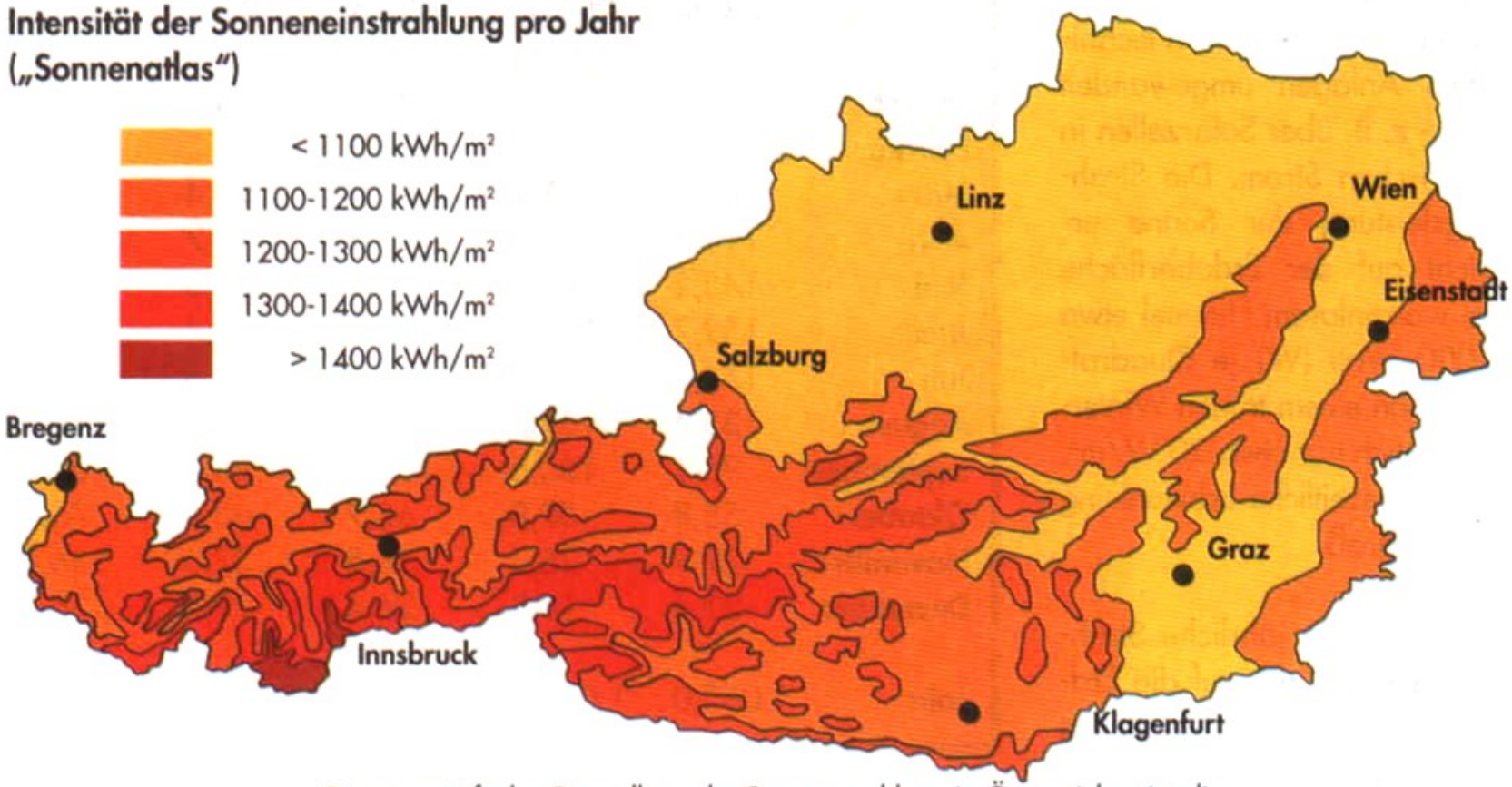


d ~ 12756 km
m~$6.10^{24}$ kg

30 % being reflected
46 % being absorbed
23 % for evaporating water
1 % for wind, and sea-waves
0,03 % for photosynthesis

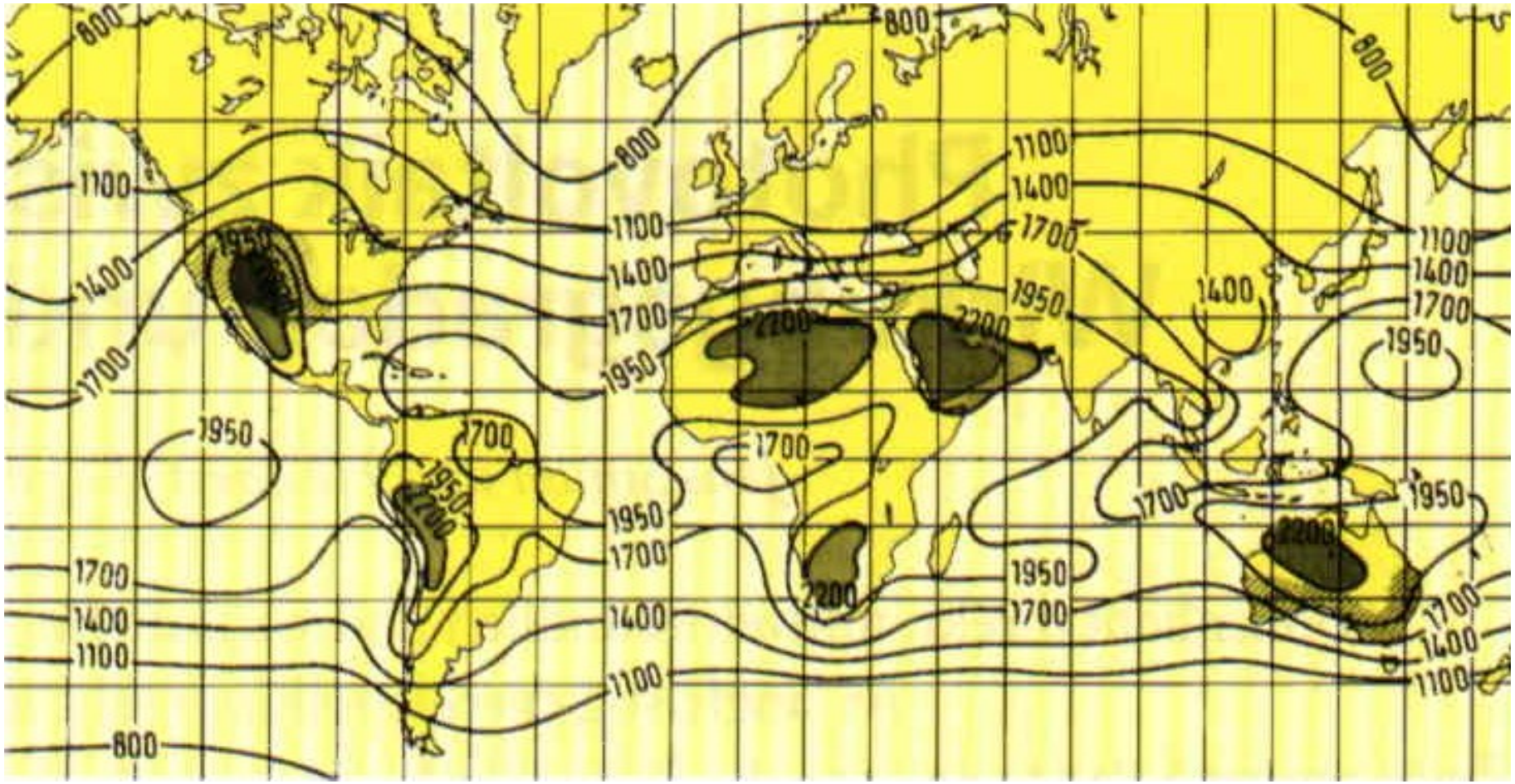
yield of scattered (diffuse) radiation:
summer, bright: 10%
summer, high humidity (haziness): 30%

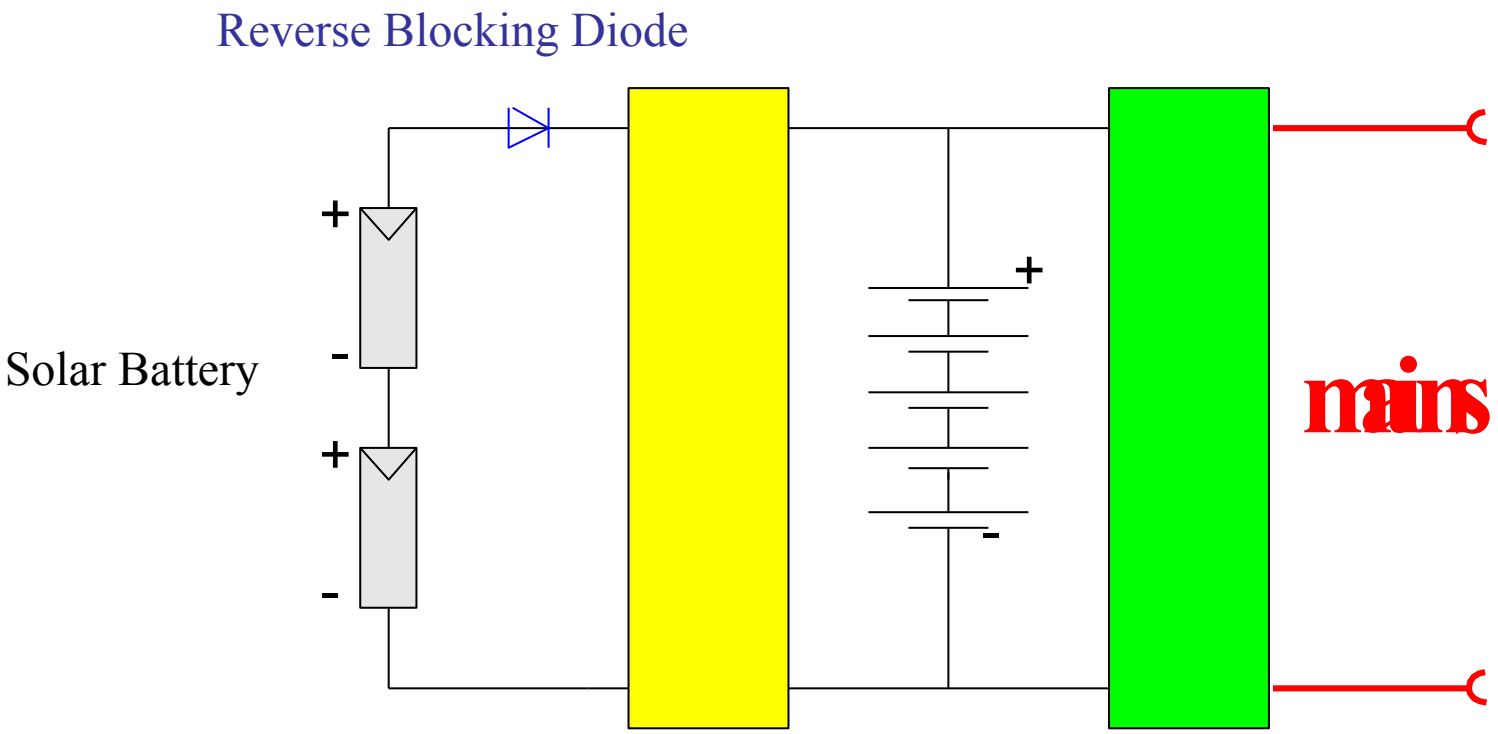
# Irradiated Energy




*Diese vereinfachte Darstellung der Sonnenstrahlung in Österreich zeigt die begünstigten und weniger begünstigten Regionen.*

# Irradiated Energy worldwide





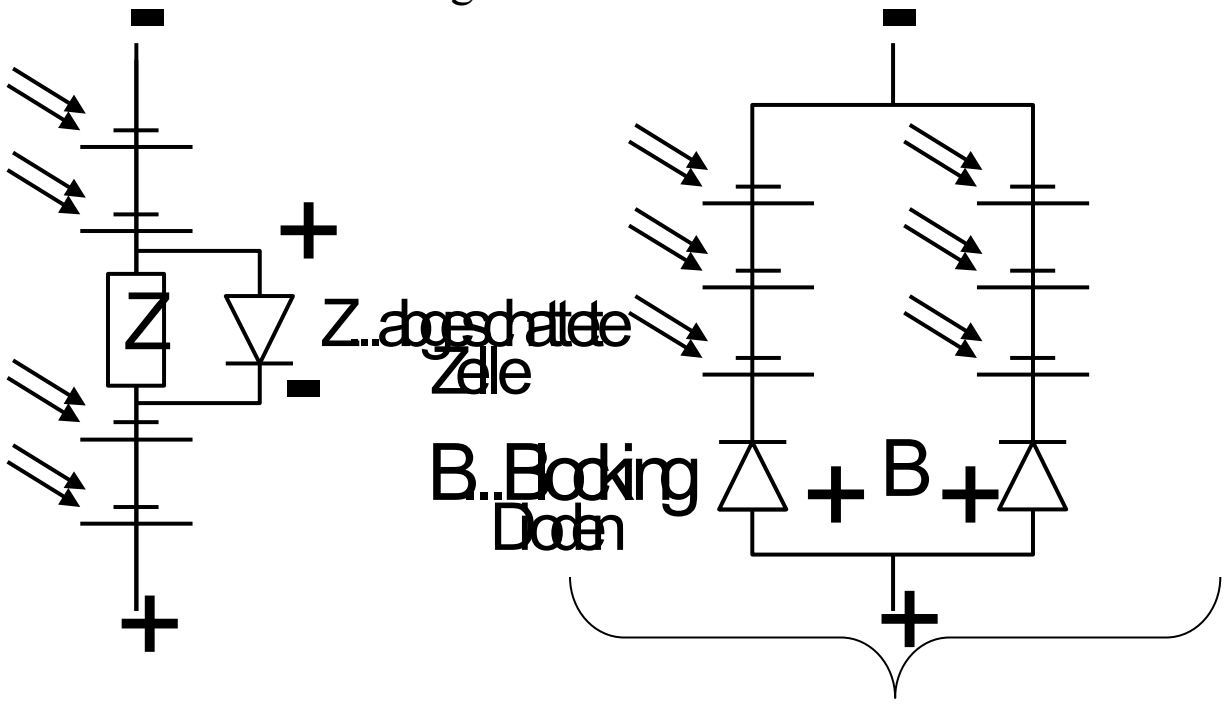

**Storage Batteries**
**Voltage limited by development of gas**

**Charging Controller**

**Electric Inverter Transformer**

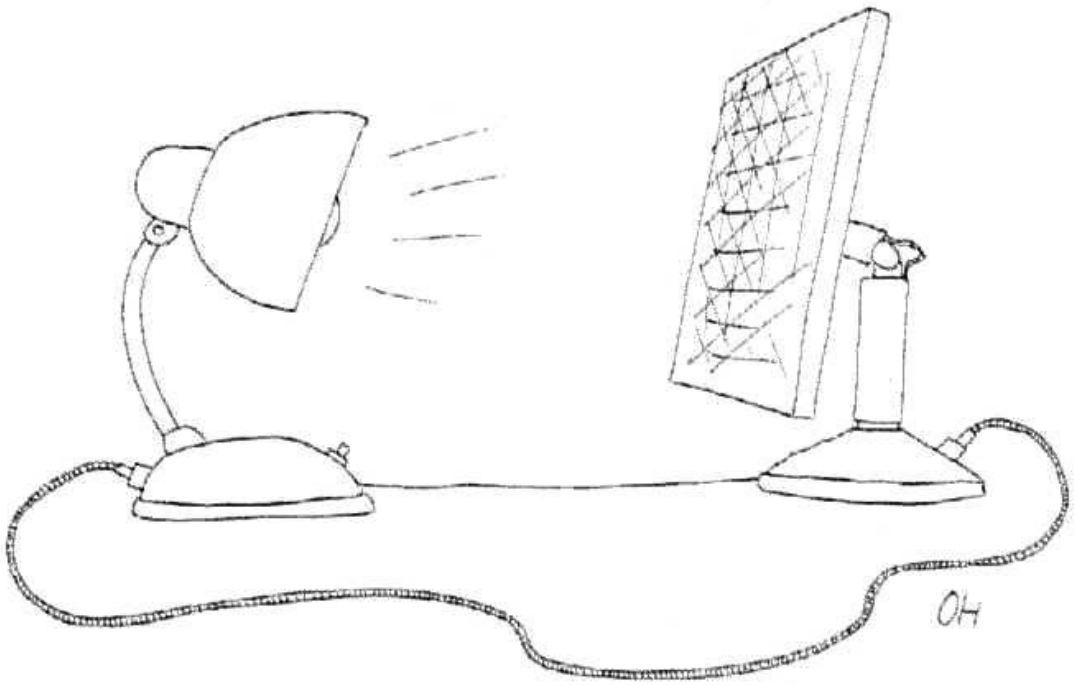
Bypass-diodes enables current to pass cells in case they are shadowed (Z). Because of their high resistance the entire voltage would break down.

Z...this cell is shadowed




If connected in parallel the blocking diodes hinder electric current to flow back in case one of the blocks supplies only with a lower intensity.

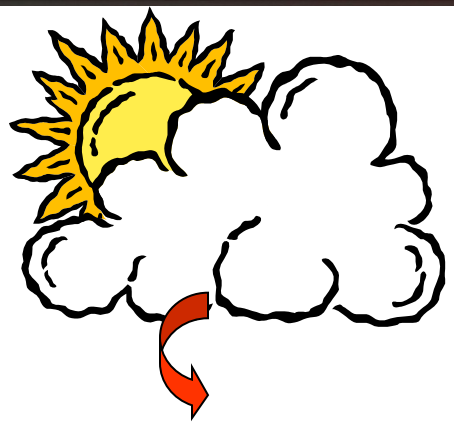
# Efficiency



Source: unknown newspaper

...would be fine, but does not work !
In any case you have losses, energy
is devaluated at any step of conversion !

# Energetic Overview



**Energy from the Sun**
**1 MWh/a.m²**

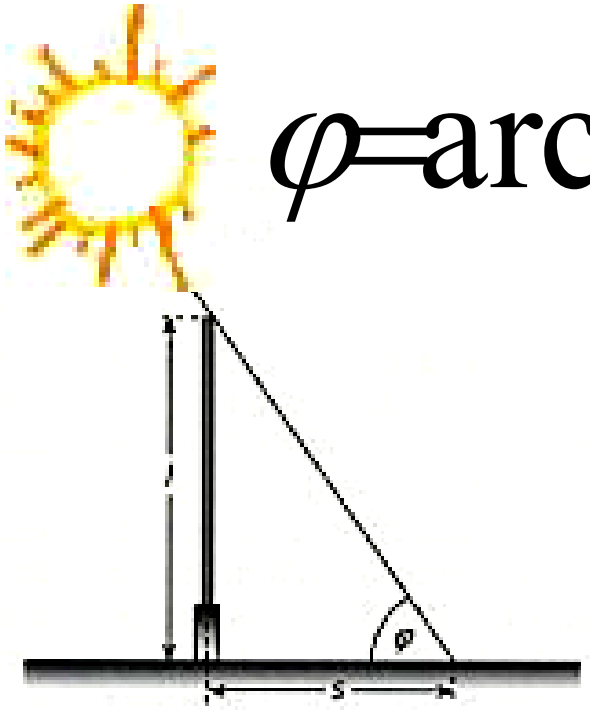
**Solar Cell: η = 0,1 / Transfer η = 0,7 / Total η = 0,07**

**Energetic Output: 70 kWh/m².a**
**2,7 kWh/m².d**

Summer up to 10 kWh/m².d

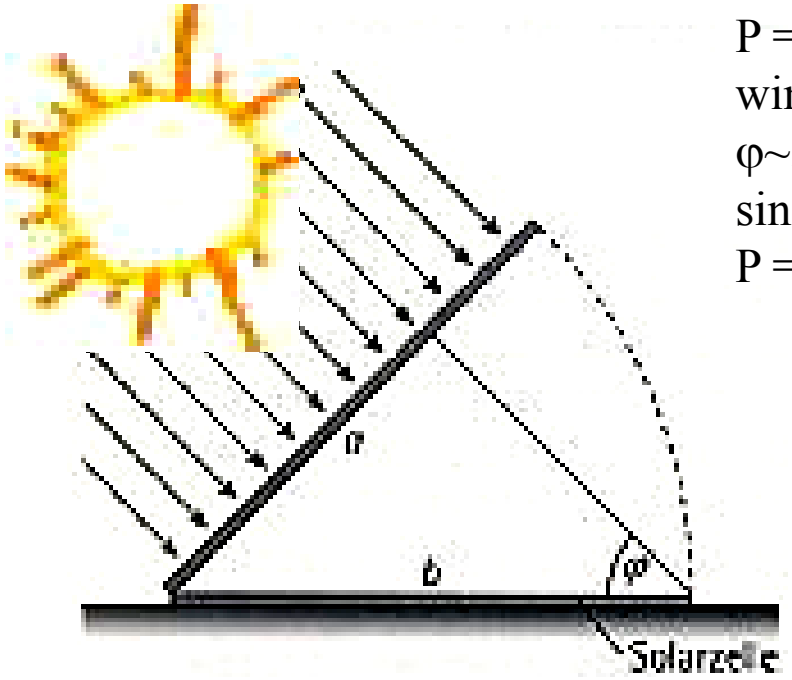
Winter: 150 Wh/m².d

# Positioning Solar Cells



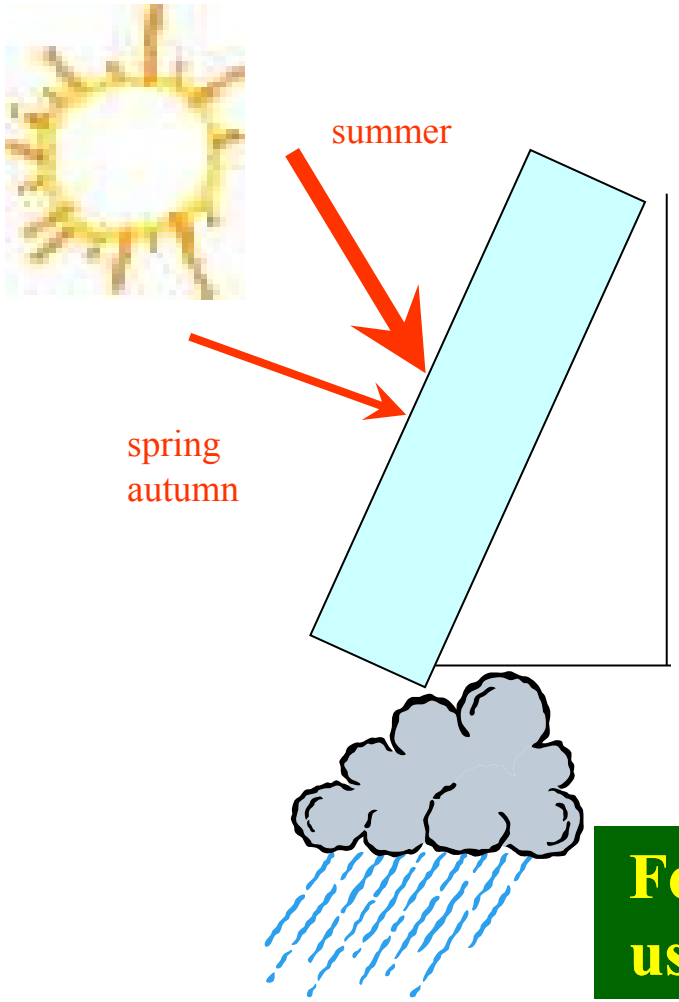

$$\varphi = \arctan\frac{l}{s}$$

l...length of a rod
s...shadow line
φ...angle of aparture




june (Austria)
φ~60°
sin60°=0,87
$P = 0{,}87\ P_S$
winter
φ~30°
sin30°=0,5
$P = 0{,}5\ P_S$

# Positioning Solar Cells

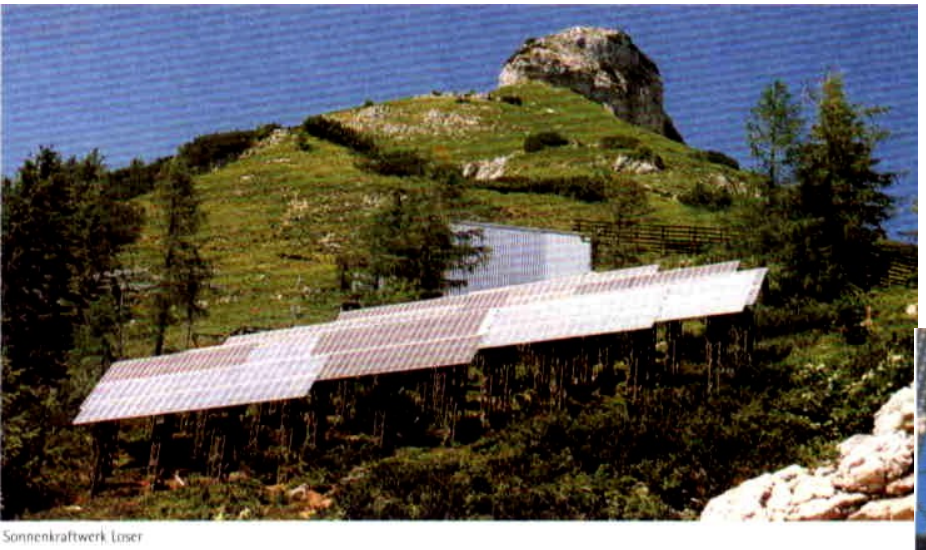



**two maxima of power**
**spring and autumn**

**because of shadowing area increases by factor 6,5**

**For ensuring a safe power supply: use the factor 3 times !**

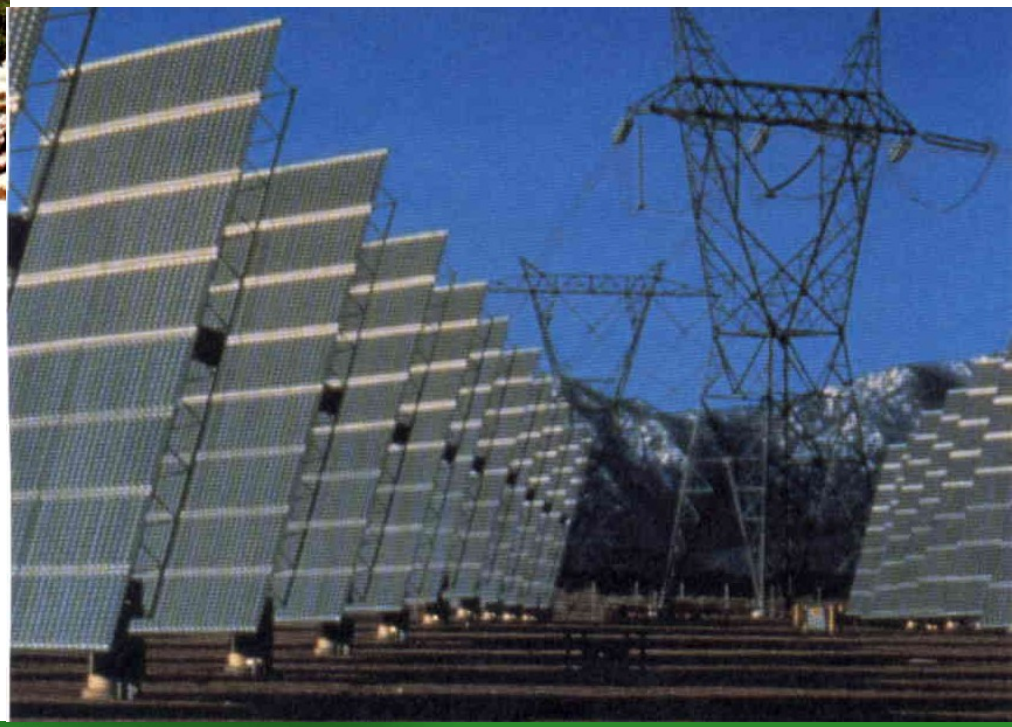
# Positioning Solar Cells



Sonnenkraftwerk Loser

Loser,
Austria
P = 30 kW

American Solar Power Plant

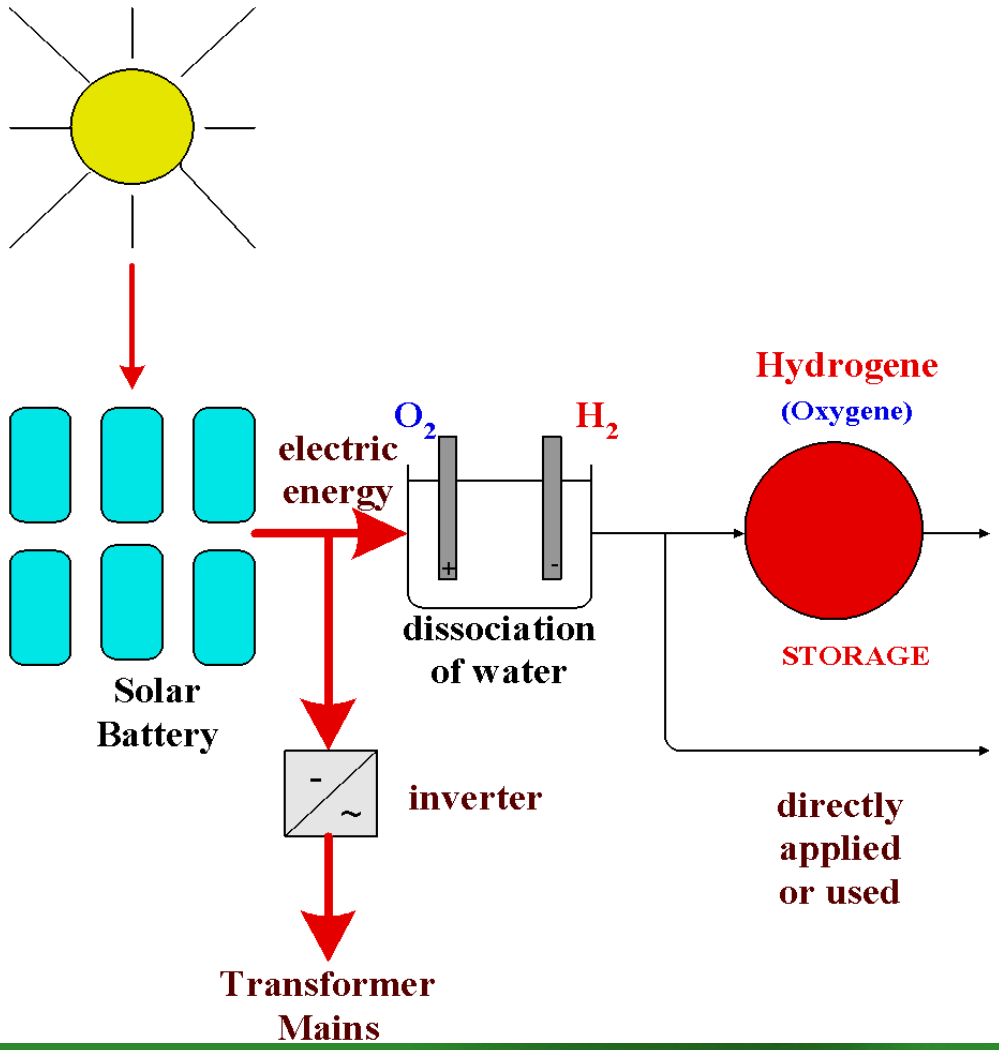


# Buildings

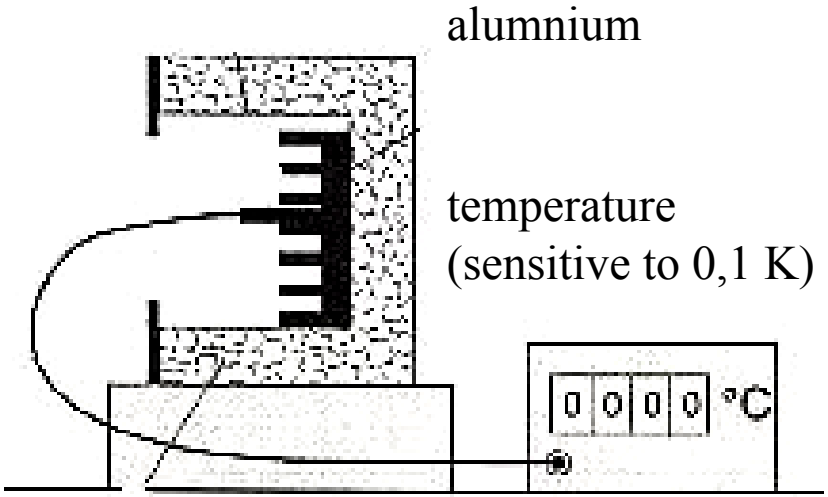
Solar Cells for providing buildings with electricity.

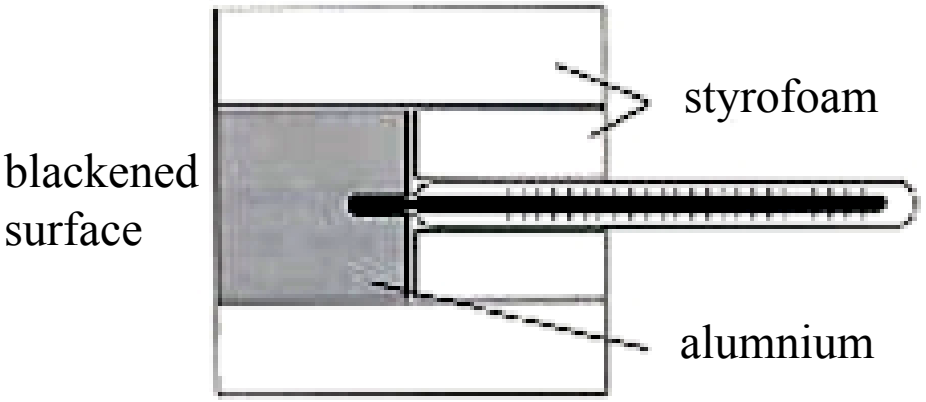

*Die stromaufwärts Photovoltaik GmbH sorgt für hauseigenen Solarstrom.*

# Solar Hydrogene System



# Measuring the Sun´s Radiation




$\alpha \sim 0{,}98$, $c_{Al} = 0{,}896$ J/m².K

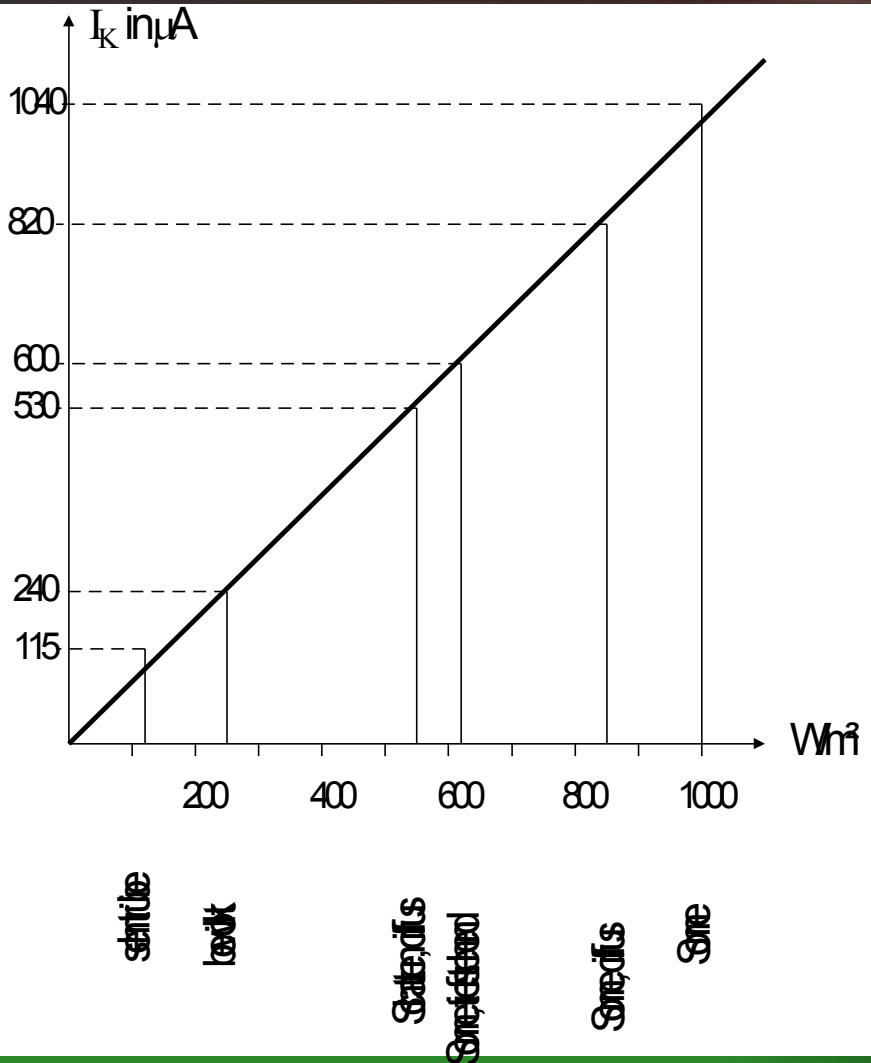
$$P_{rad} = \frac{dQ}{dt} = c_{Al} m \frac{d\vartheta}{dt}$$

$$S = \frac{P_{rad}}{A} = \alpha \cdot c_{Al} \frac{m}{A} \frac{d\vartheta}{dt}$$

# Calibration of a Solar Cell

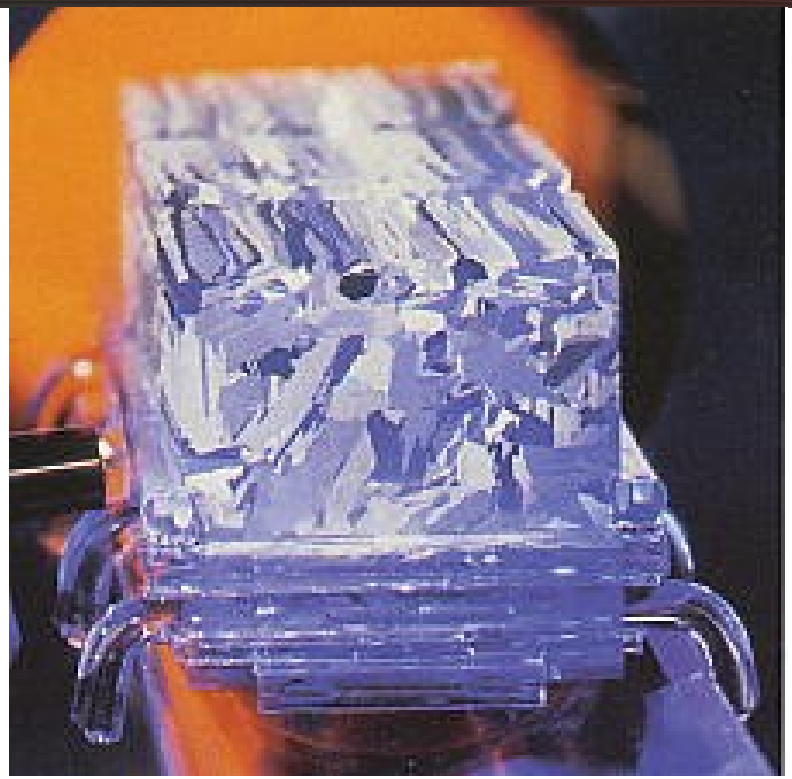
| OBSERVATION | CURRENT | IRRADIANCE |
|---|---|---|
| | | |
| Sunshine | 1040 µA | 1000 W/m² |
| Sun, a bit diffuse | 850 µA | 820 W/m² |
| Sun, before dawn | 620 µA | 600 W/m² |
| shadow, diffusely illuminated | 550 µA | 530 W/m² |
| clouded | 200 - 300 µA | 240 W/m² |
| room, bright | 130 µA | 125 W/m² |
| very dull | 120 µA | 115 W/m² |
| room close to the window, shadow | 60 µA | 60 W/m² |
| room dark | 13 µA | 13 W/m² |

# Calibration / Diagram



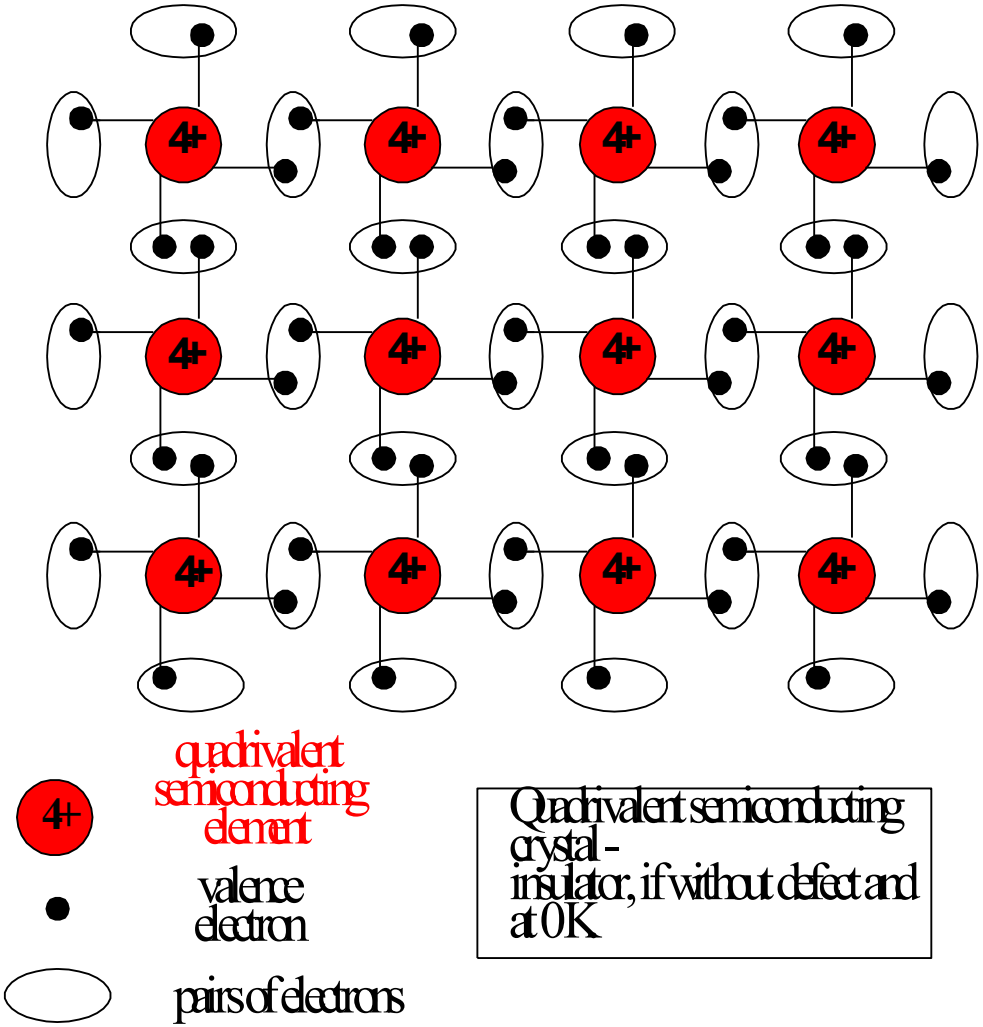

**Solar Cell d = 1 cm**

# Solar Cells



This silicon-cube
is cut into wafers,
this wafers being
doped.

The solar cell,
one wafer of
thickness 0,3 mm.

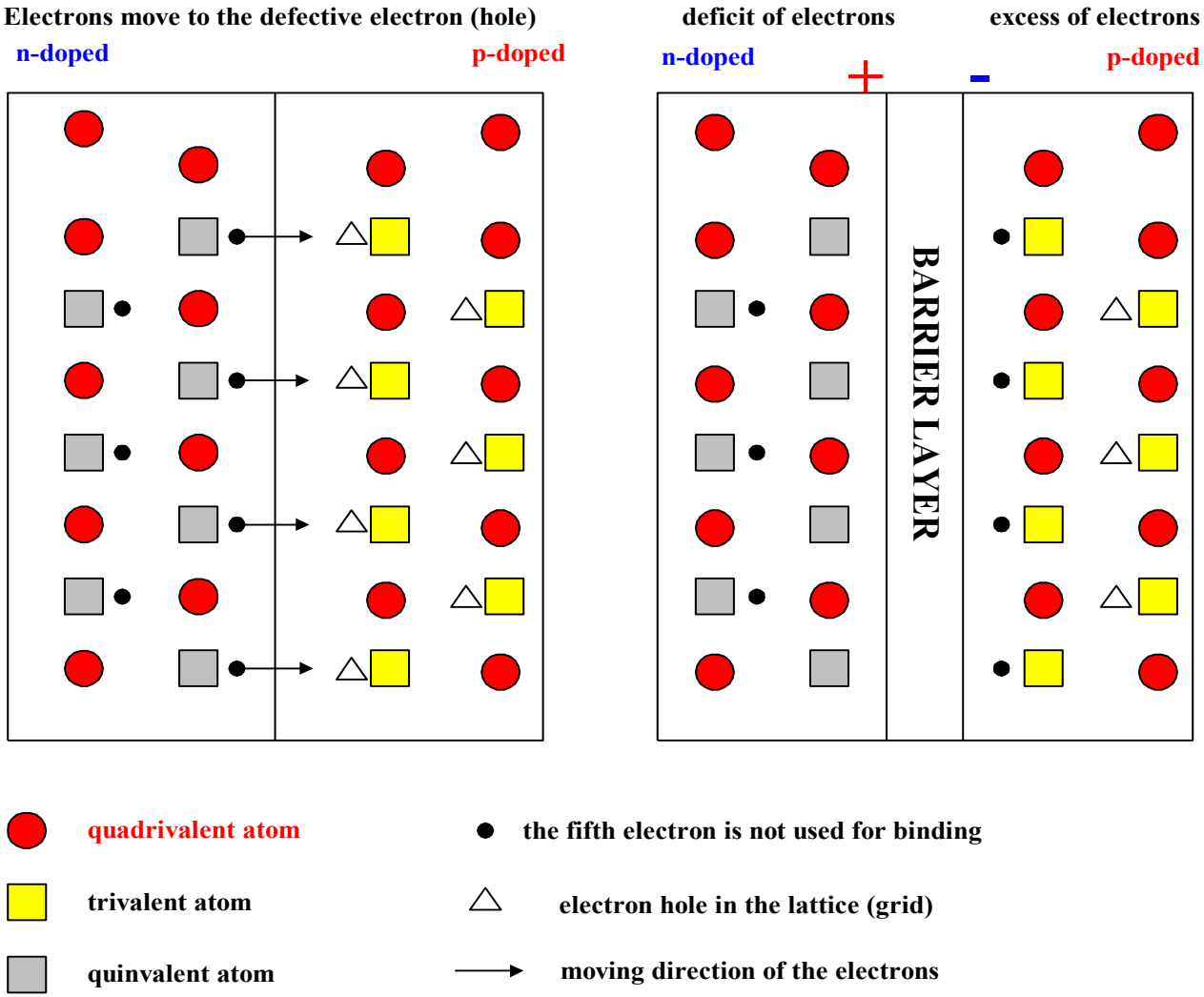



**intrinsic conduction**

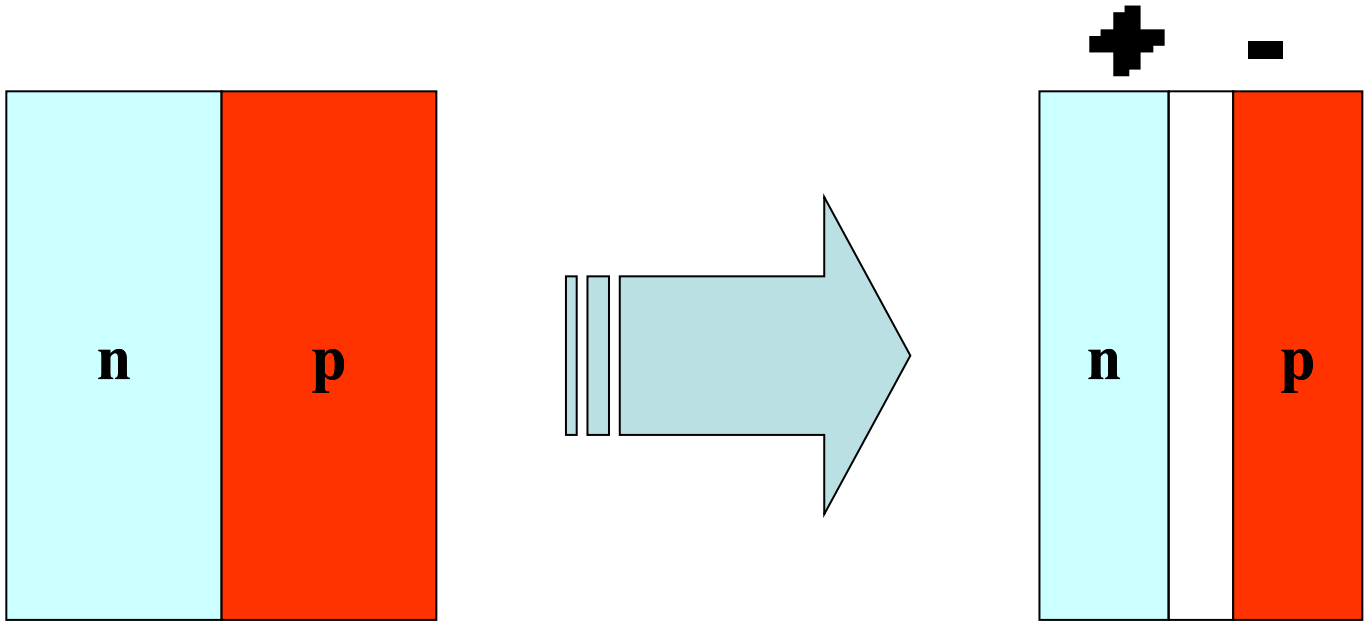
Lattice of the diamond-type
Because of defects in the crystal and at rising temperature - input of caloric energy -
some electrons are set free
the crystal shows intrinsic conduction.

Matter:
Silicon,
Indiumphosphide,
Galliumarsenide,
Cadmiumtelluride

# Doped Semiconductors

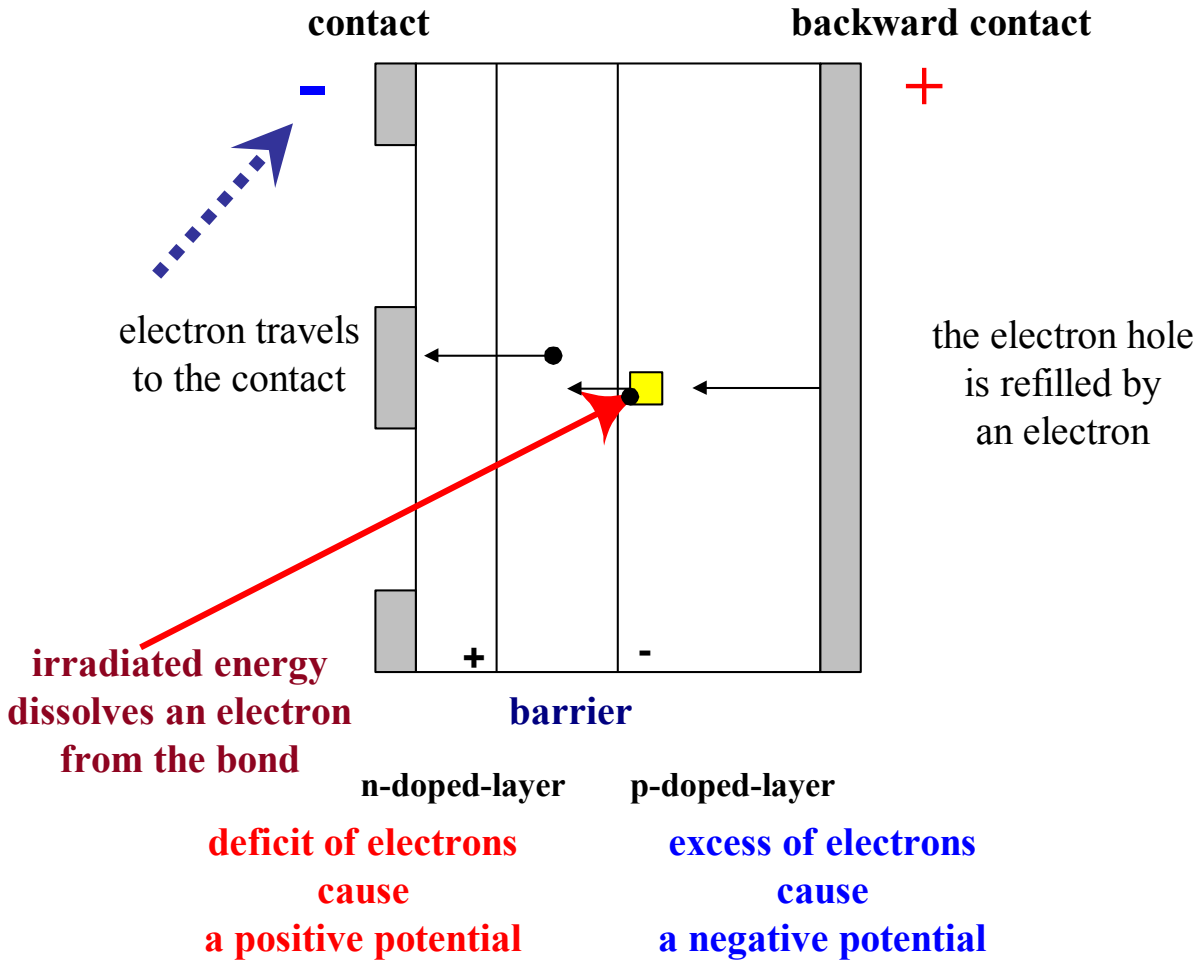


# Doped Semiconductor




**intrinsic (reverse) voltage**

# Generation of Photovoltage

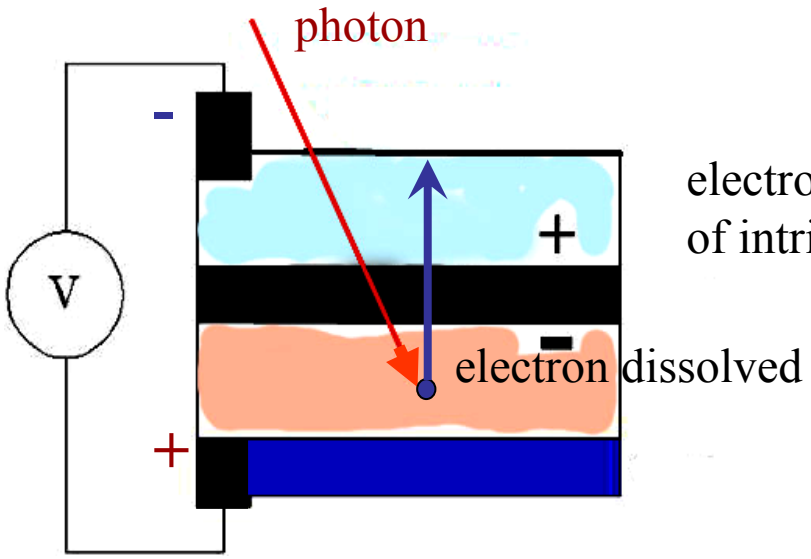


# Generation of Voltage

For generating photovoltage, you need:

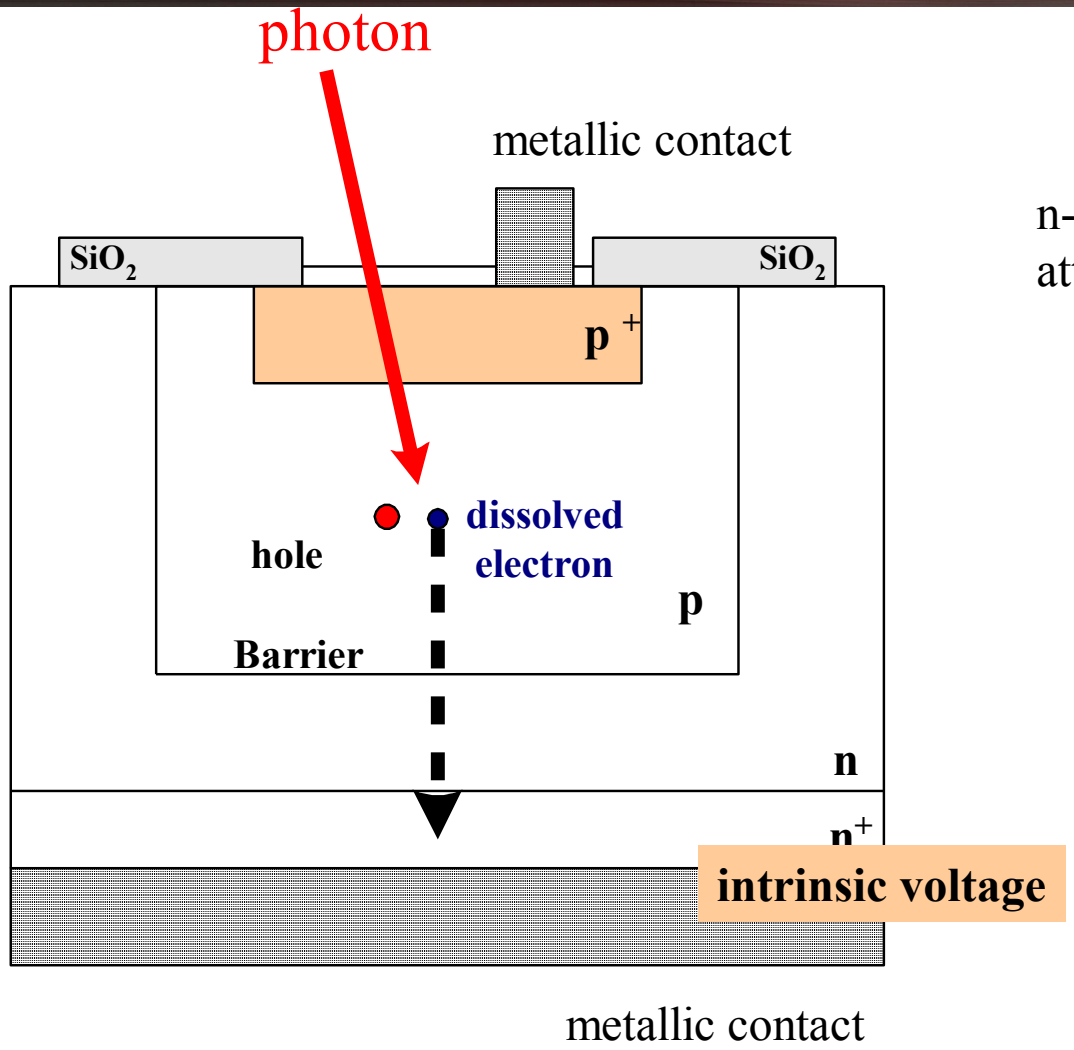
↳ matter, from which photons are able to dissolve electrons: Si, Ge, semiconducting compounds (InSb, InP, GaAs, CdS, CdTe).

↳ Intrinsic potential difference being able to separate the electrons from the positive defective electrons.




electron travels by influence of intrinsic voltage

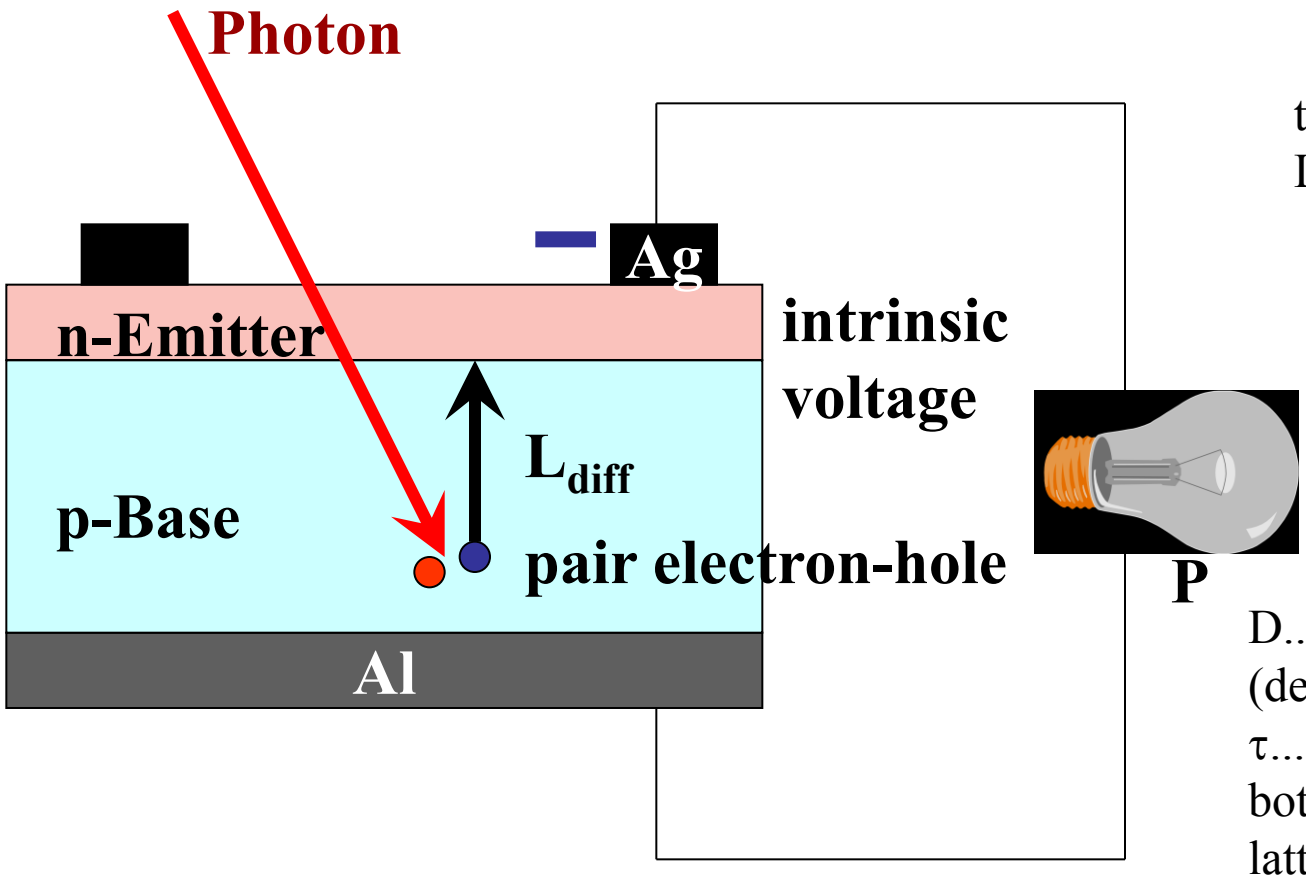
# Generation of Photovoltage




n-n$^+$/p-p$^+$ ...enlarging the attractive potential

**400 mA/lm**

# Generation of Photovoltage

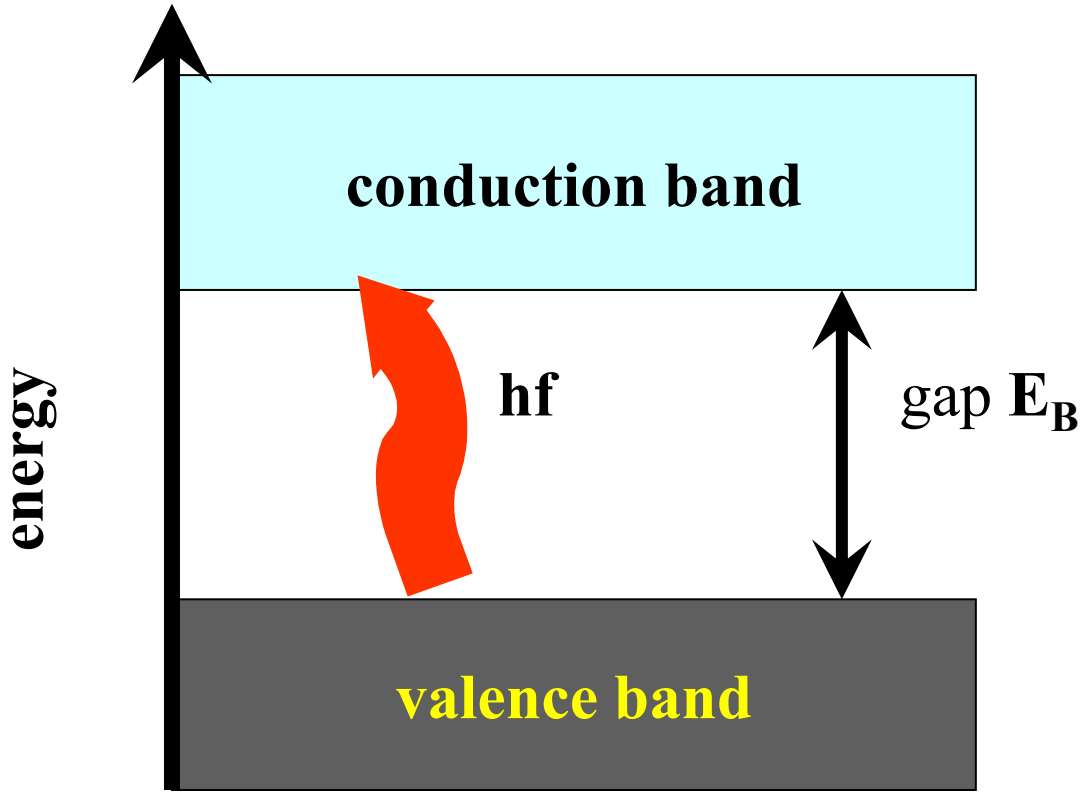



thickness 300 µm
$L_{diff}$...diffusion length

$$L_{diff}=\sqrt{D\tau}$$

D...diffusion constant (depending on matter)
τ...life time
both depending on lattice impurity and atomic defect

# Generation of Photovoltage

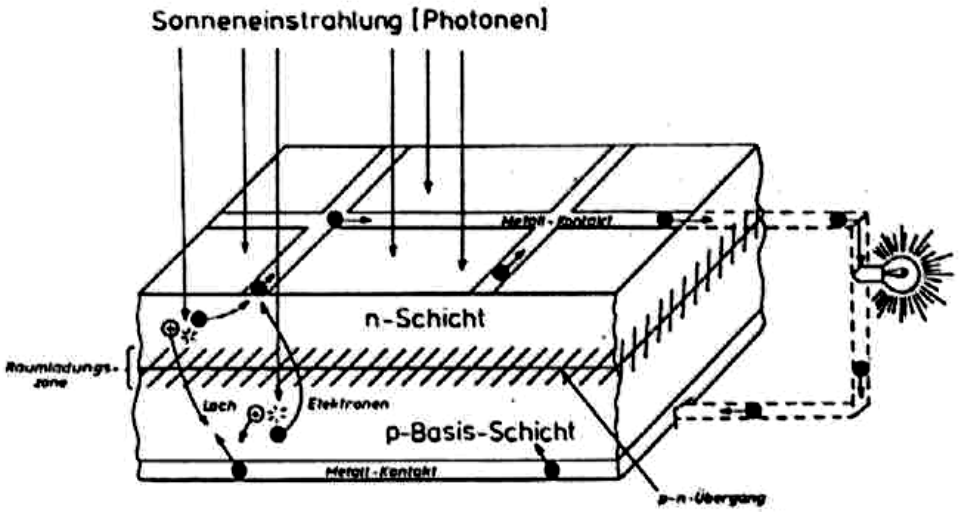


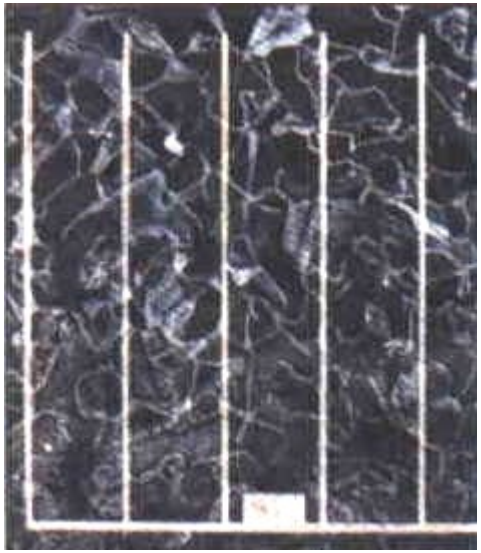

$hf > E_B$

$E_B - hf$...
caloric energy to the grating

theoretical efficiency: 43%

# Generation of Photovoltage



silicon
polycrystalline

The band gaps are:
Si...1,12 eV
maximum of sensitivity: red
long wave limit: IR 1,1 mm
above translucent
Ge...0,7 eV
GaAs...1,42 eV
CdTe...1,5 eV
GeS.....1,5 eV
InSb...0,2 eV (IR)

# Generation of Photovoltage


Efficiencies at 1 kW/m²:
c-Si (crystal Si).....max 28 %
practically 18 %
mc-Si (multicrystal-Si)...16 %
a-Si (amorphous Si)...13-17 %
CdTe.....11% (15% lab)

# Open Circuit Voltage

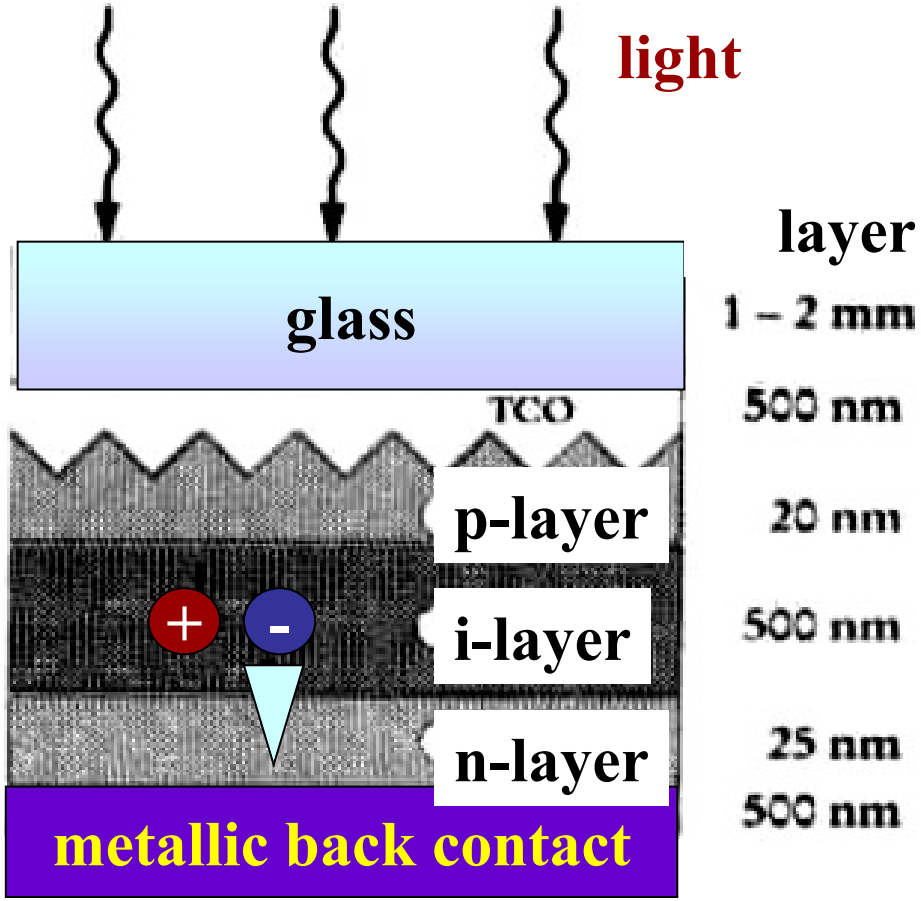
$$U_0 = \frac{k \cdot T}{e} \cdot \ln\left( \frac{q}{n_0 \frac{D_E \cdot t}{L_E^2} + p_0 \frac{D_L}{L_L}} + 1 \right)$$

in case:
$D_E = D_L$
$L_E = L_L$
$n_0 = p_0$:

$$U_0 = \frac{k \cdot T}{e} \cdot \ln\left( \frac{q \cdot t}{n_0 \cdot L} + 1 \right)$$

$j\ [A/m^2] = q.e$

T...temperature in K
q...number of electron-hole pairs generated per second and unit of area
L...diffusion length
D...diffusion constant
$n_0$,$p_0$...concentration of electrons, holes
t...life-time of electron-hole pairs
index E responds to the electron
index L responds to the hole




i-layer: not doped, generation of electron-hole-pairs

# Efficiency

$$\eta = F \cdot A \cdot Q$$

**fill factor...share of energy being transfered from the solar cell to the appliance.**

**absorption ability, depends on material and frequency of radiation**

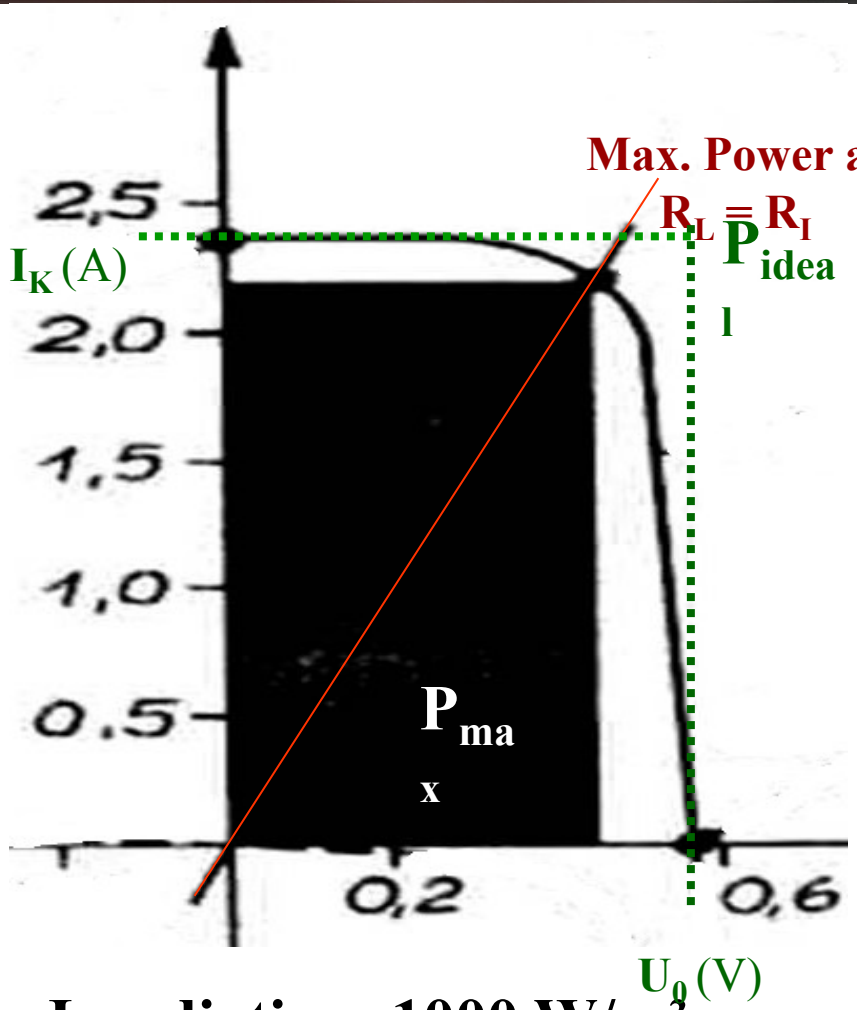
**yield of quanta energy, abundance, to which photons solve electrons.**

For Si it is: $\eta = 0{,}8 \cdot 0{,}7 \cdot 0{,}21 = 0{,}12$ (12%)

# Efficiency

| matter | | efficiency theor. | efficiency pract. |
|---|---|---|---|
| Si | monocryst. | 15% | 11-16% |
| | polycryst. | 10-15% | 9-12% |
| | amorphous | 20% | 11% (4-7%) |
| GaAs, CdTe, GeS, CdS, ZnSe | | up to 20% | up to 16% |
| | technics | | 16% |
| | high-efficiency cells | | 24% |
| | Tandem-, sandwich | | up to 32% |

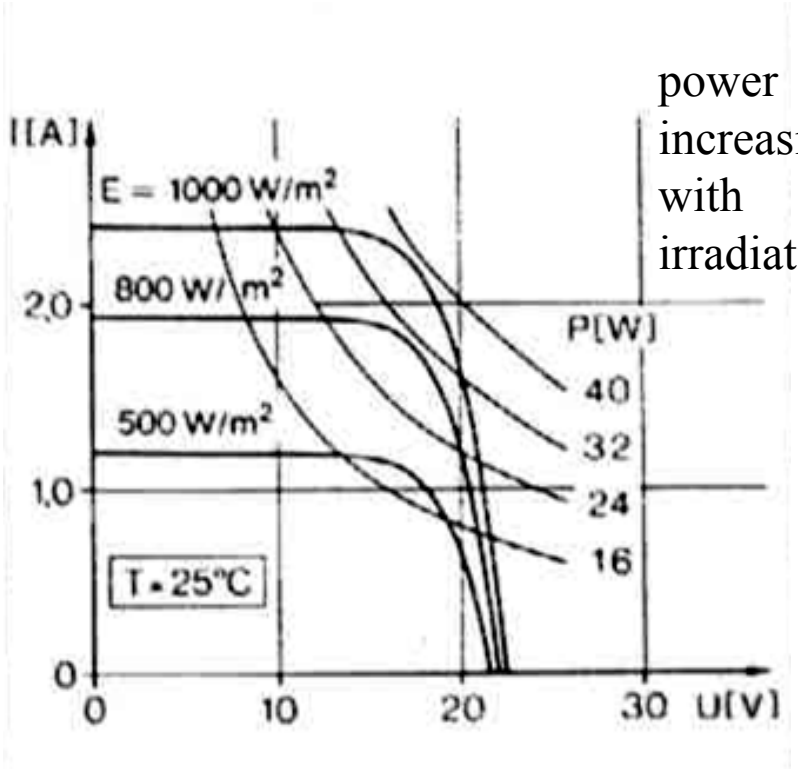
# Power Characteristic of a Solar Cell




**Irradiation: 1000 W/m²**

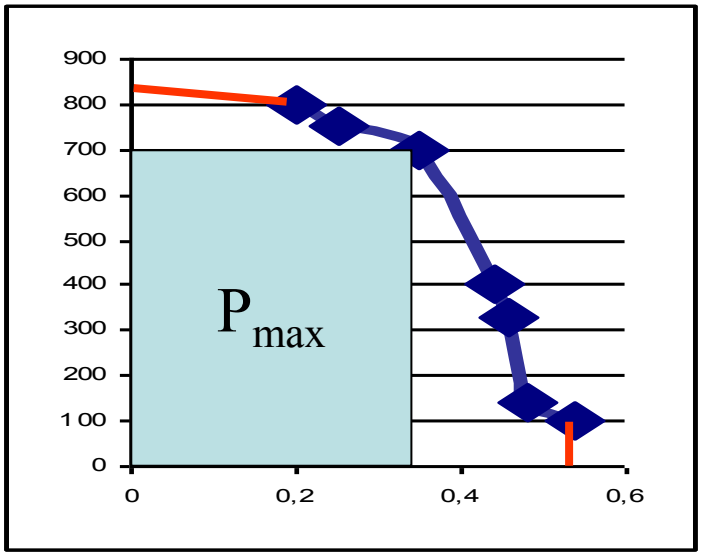
# Power Characteristic of a Solar Cell

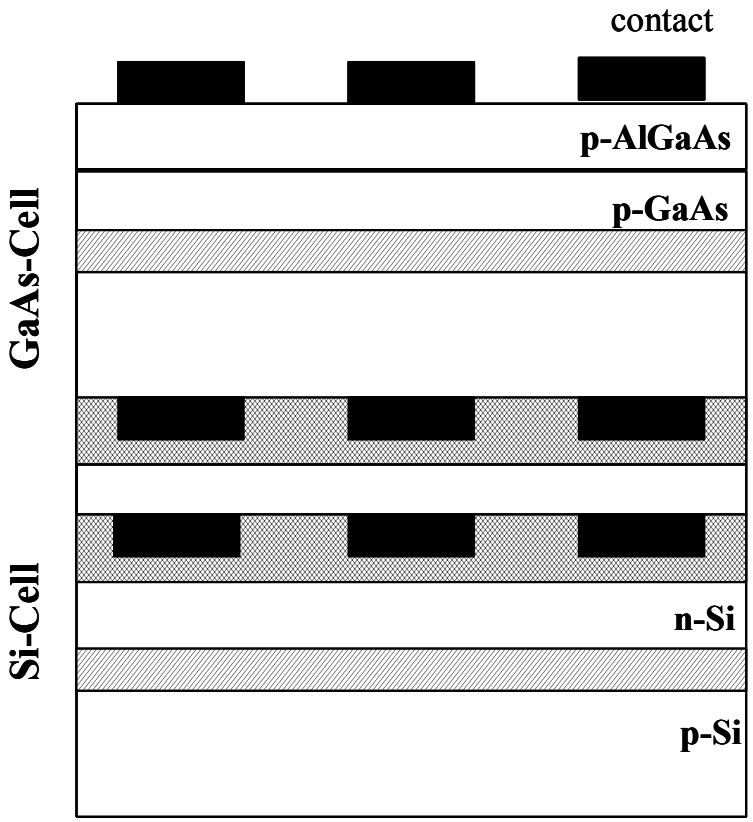
Max. power, if external resistance equals the internal resistance of the solar cell.



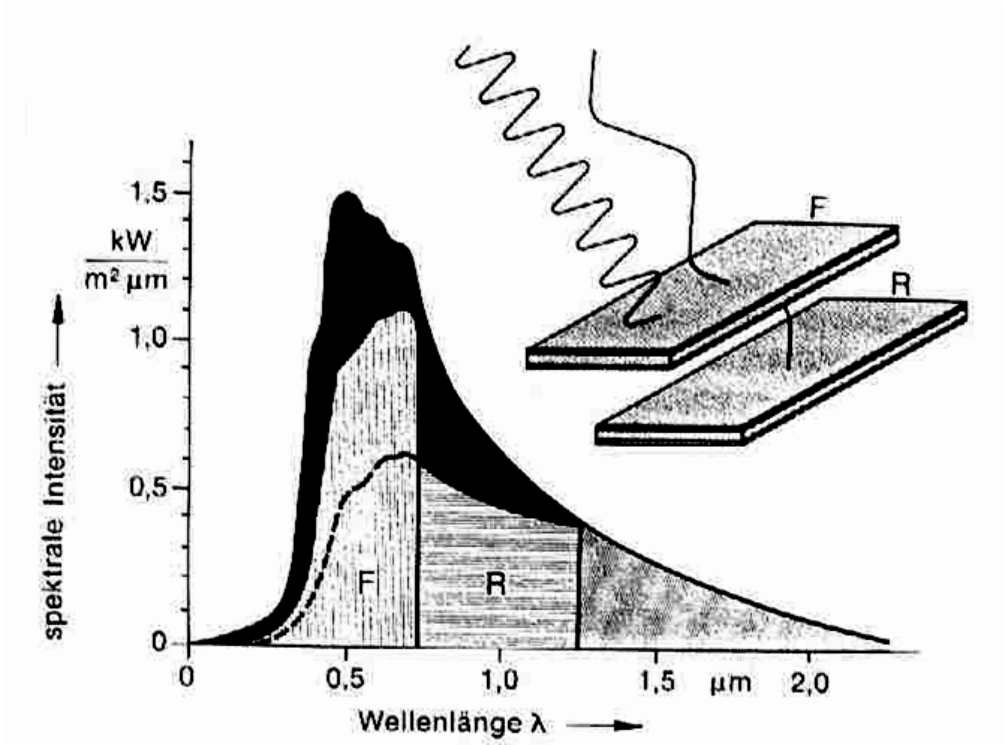

power increasing with irradiation

measured values

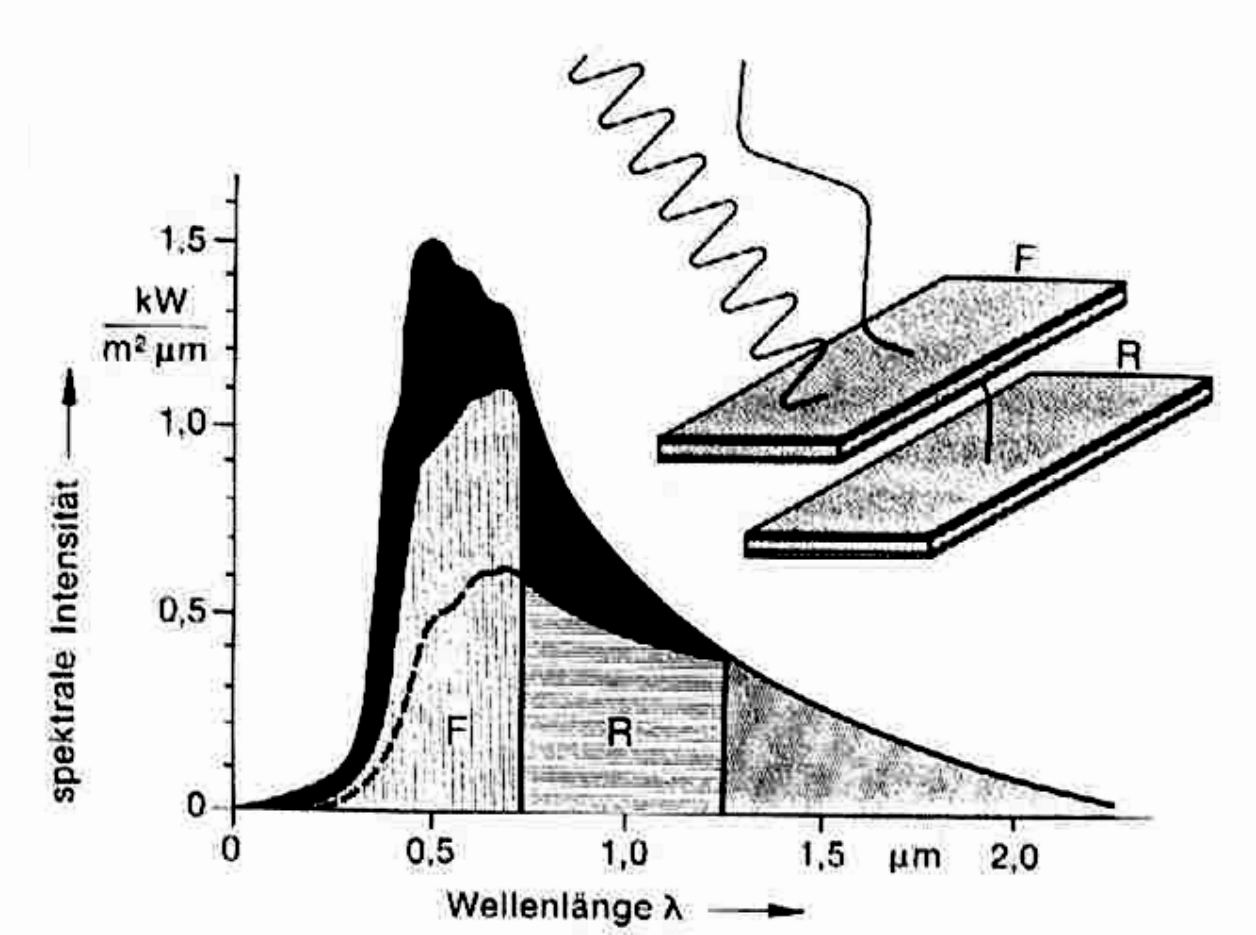





**sensitive for blue light**

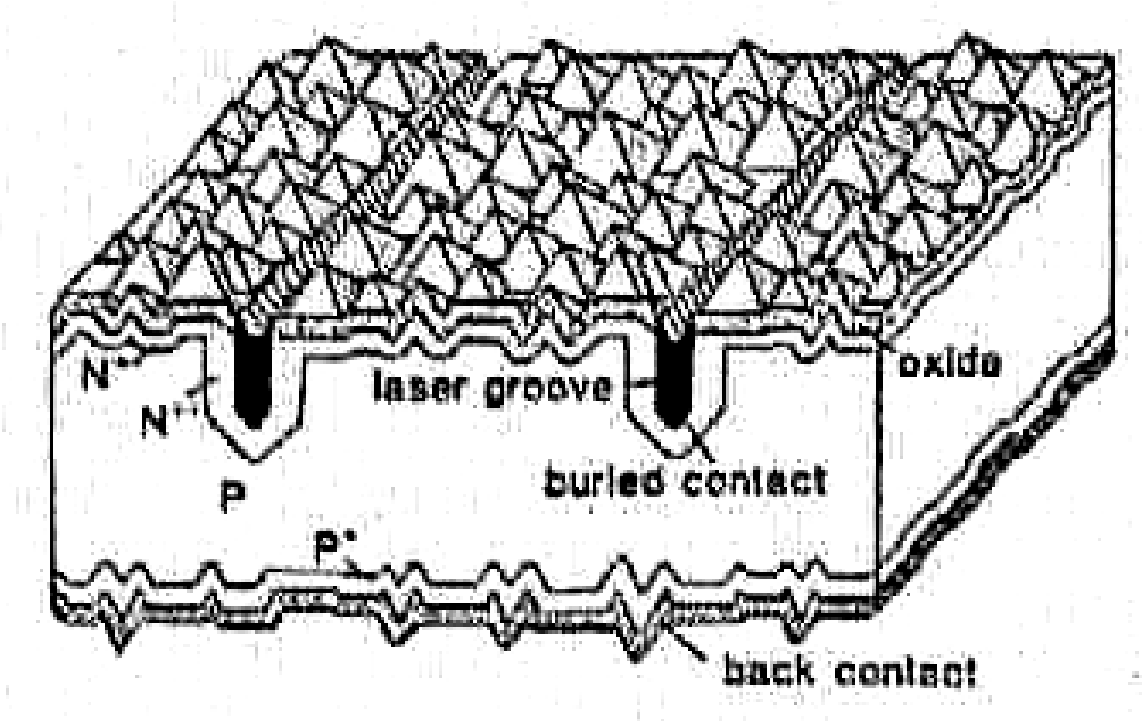


# Tandem Cells



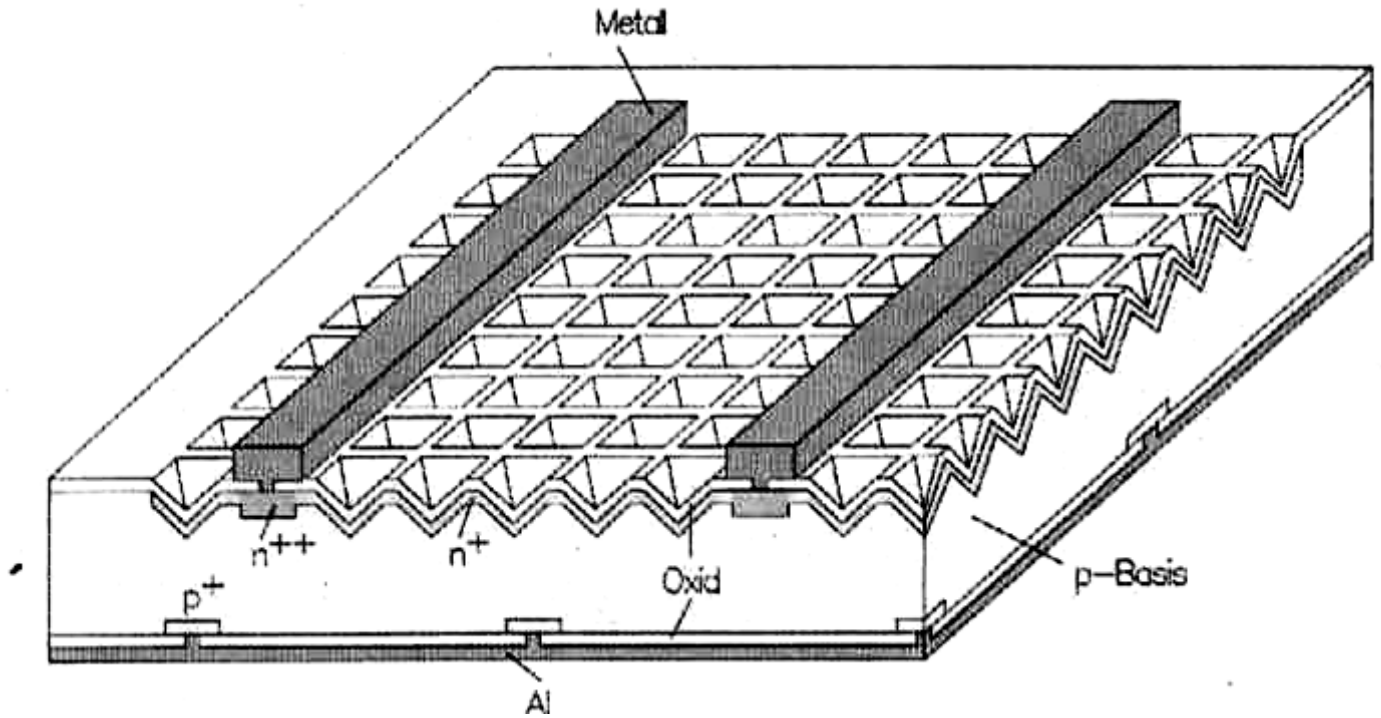
# Further Development

surface structure avoids reflection

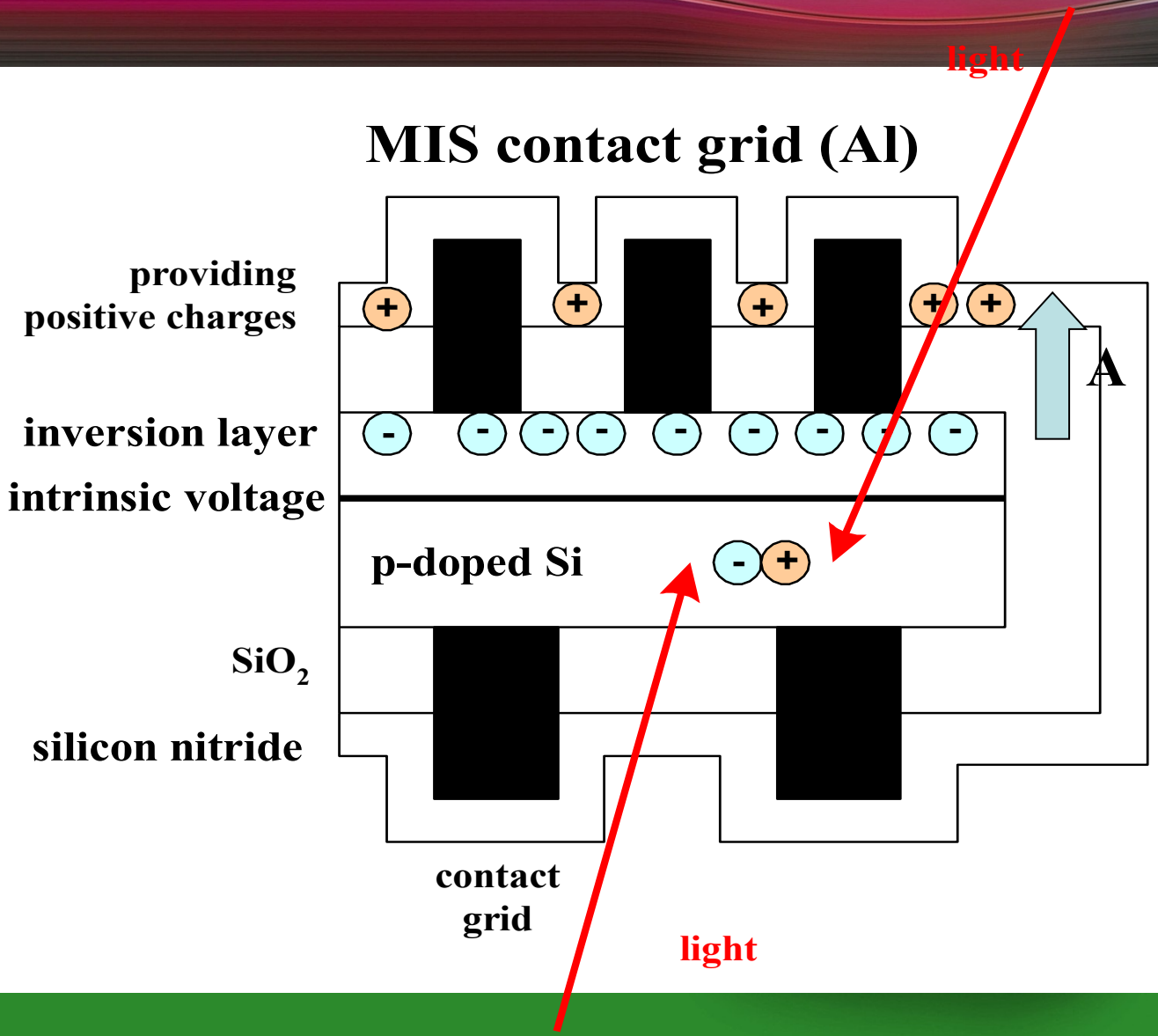



$n^+$, $n^{++}$, $p^+$....highly doped – causing a higher concentration of electron-hole-pairs and a higher intrinsic voltage

# Further Development

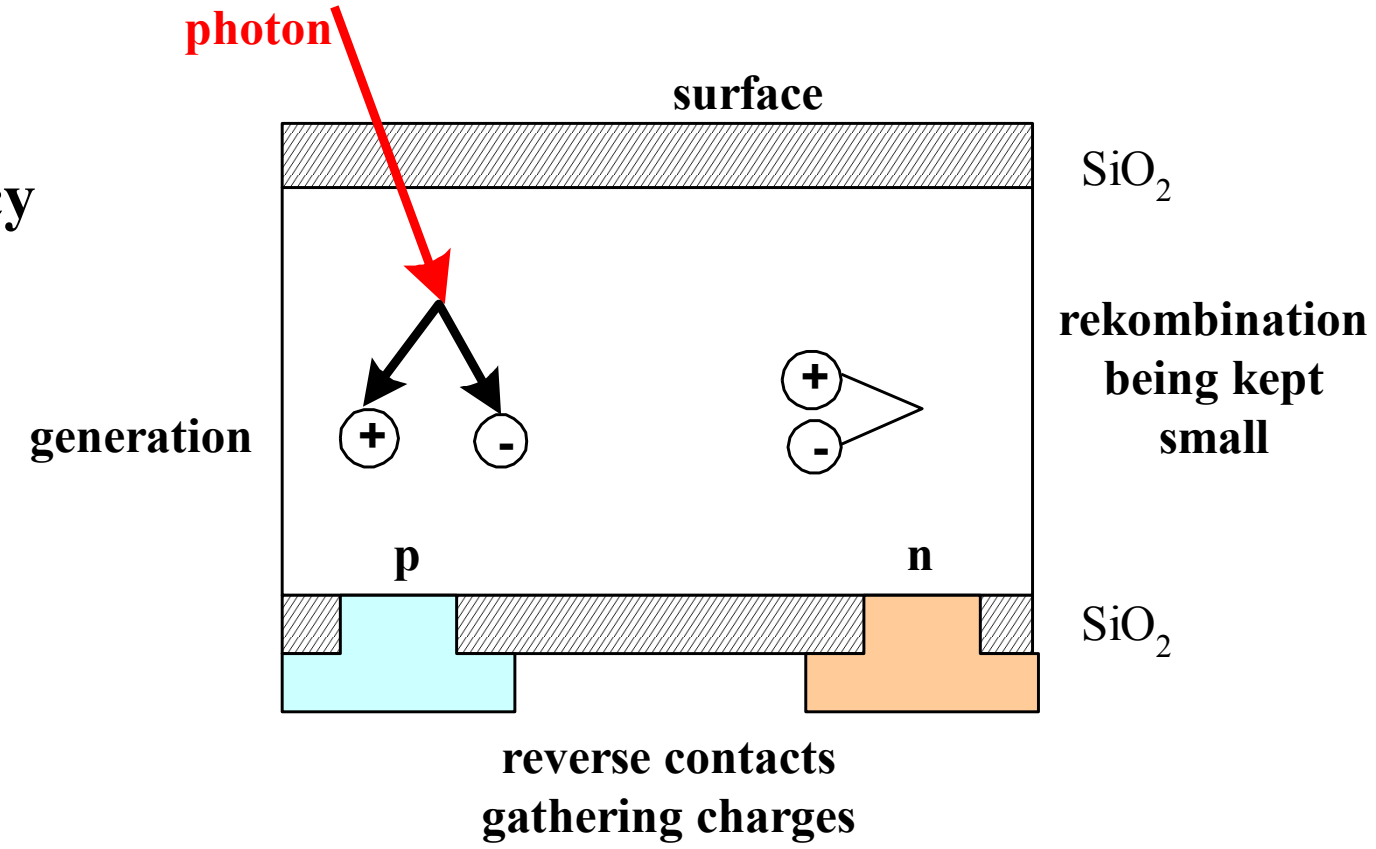


# Further Development



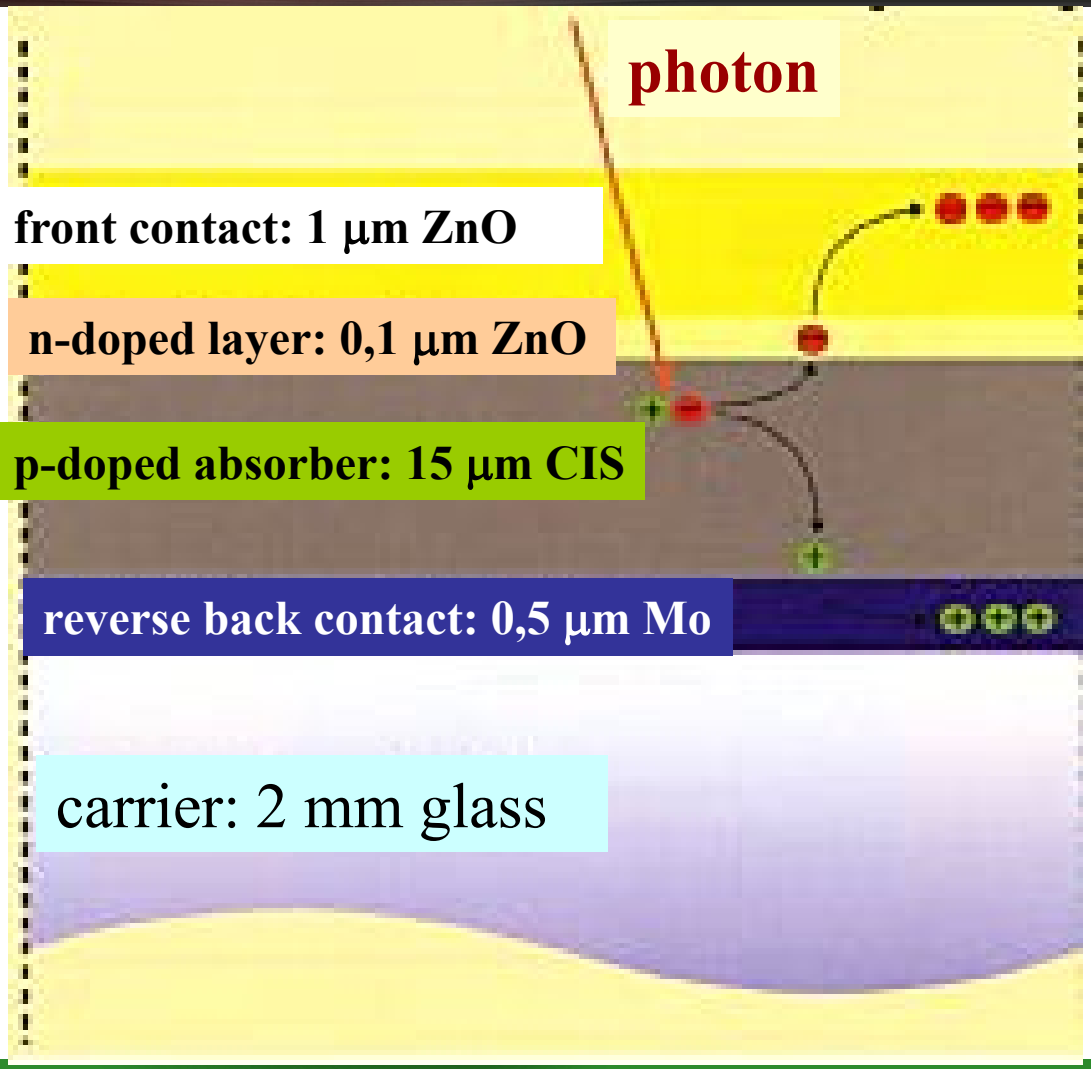

in silicon nitride positive charges are fixed
they attract electrons – causing the intrinsic voltage
light releases electrons by this generating electron-hole-pairs
electrons travel to the inversion layer
by this: less recombination, higher efficiency (~ 20%).

**high efficiency solar cell**



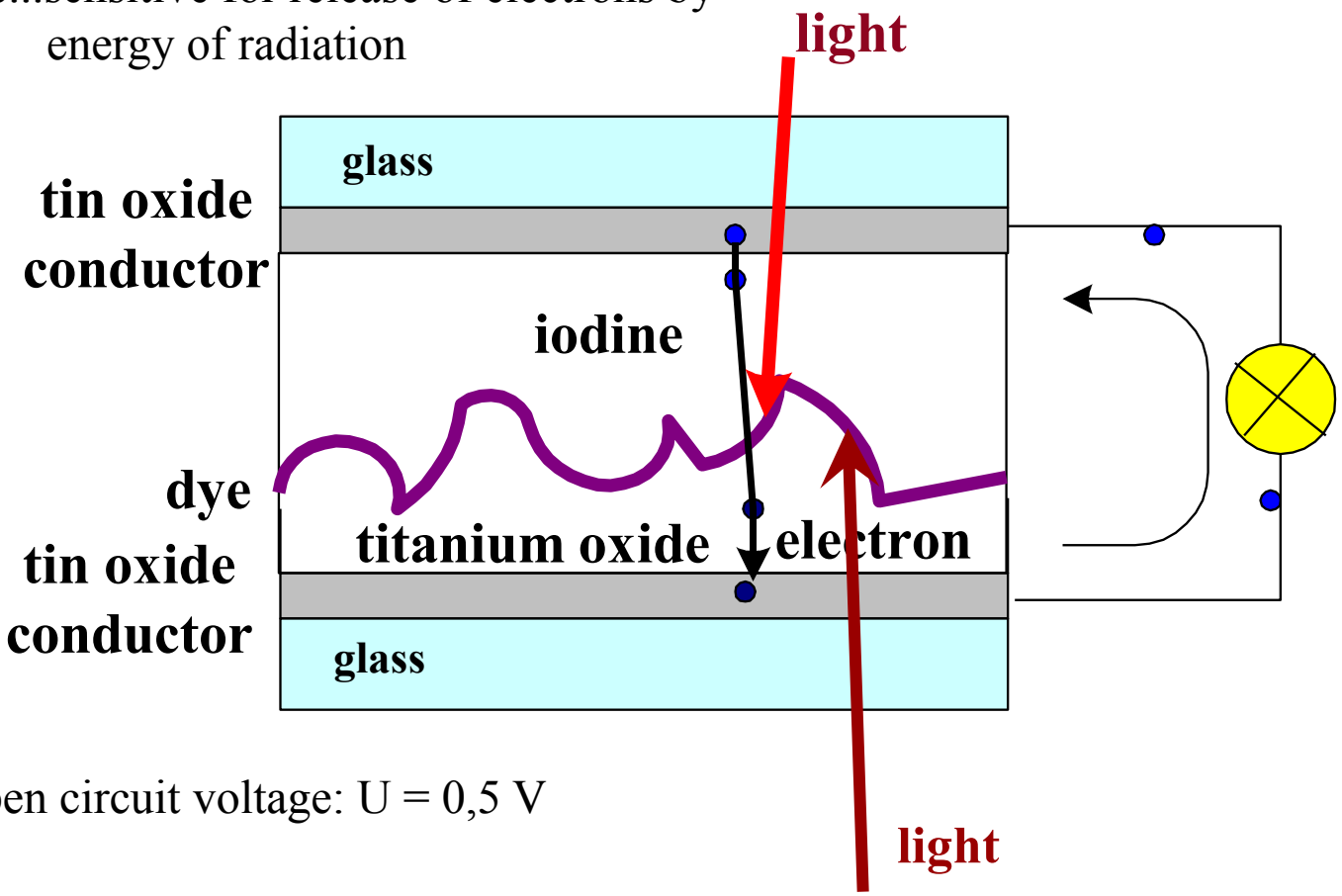
# CIS-Cells

CIS...$CuInS_2$
Layer: 1 µm
Gap: 1,5 eV (suitable for sun´s spectrum)
P = 1000 W/m²....$P_{el}$~ 13 mW/cm²



# Dye-Cells

iodine...carrier for electrons
dye...sensitive for release of electrons by
energy of radiation




Open circuit voltage: U = 0,5 V