Solar Energy

the great promise of renewable source of energy serving mankind in 2nd millenium, but requires:

- large areas (a 1-km^2 at η=10% gives only 100 M W_p)
- cost reduction (target cost of 1$/W hardly met)
- big effort in semiconductor mass production (yearly world-wide Si devices production covers just 1-km^2 of cell)

However, SE is already viable for:

- space applications (electrical supply of satellites)
- small utilities (radio repeaters, developing countries, etc.)
- small equipment in alternative to battery supply (watches, hand-held computers, toys, etc.)

Solar cells vs solar panels

- **Solar cells** are those converting sun radiation into electrical energy - efficiency is low (typ. η=10-15%), but energy produced is valued - it is *free* energy (as if is at T=∞)
- **Solar panels** are widely used to convert sun radiation into a heat quantity with high efficiency (typ. 90-95%) - but energy has low value - it is *heat* with small ΔT (typ. ΔT=30°C)

Exergetic efficiency establishes a firm base for comparing cell value from a thermodynamic point of view: $\eta_{exerg} = \Delta T/T \, \eta_{syst}$. This puts solar cell first: a solar cell operating a heat pump generates more energy than a solar panel

Electrical parameters

From basic diode Shockley's equation

$$I = I_o\,[\exp(V/nV_T) - 1] - I_{ph}$$

cell short-circuit current is :

$$I_{cc} = -\,I\,_{V=0} = I_{ph}$$

and open-circuit voltage is:

$$V_{oc} = V|_{I=0} = \mathcal{E}_g + V_T \ln(1 + I_{ph}/I_{oo}) \approx \mathcal{E}_g + V_T \ln(I_{ph}/I_{oo})$$

where $E_g = e\mathcal{E}_g$, and reverse current is

$$I_o = I_{oo} \exp{-\mathcal{E}_g/V_T}$$

electrical power supplied to the load, $P_e = |V \cdot I|$, is written with V_{oc} and I_{cc} by introducing the *fill-factor* FF of the I/V characteristic:

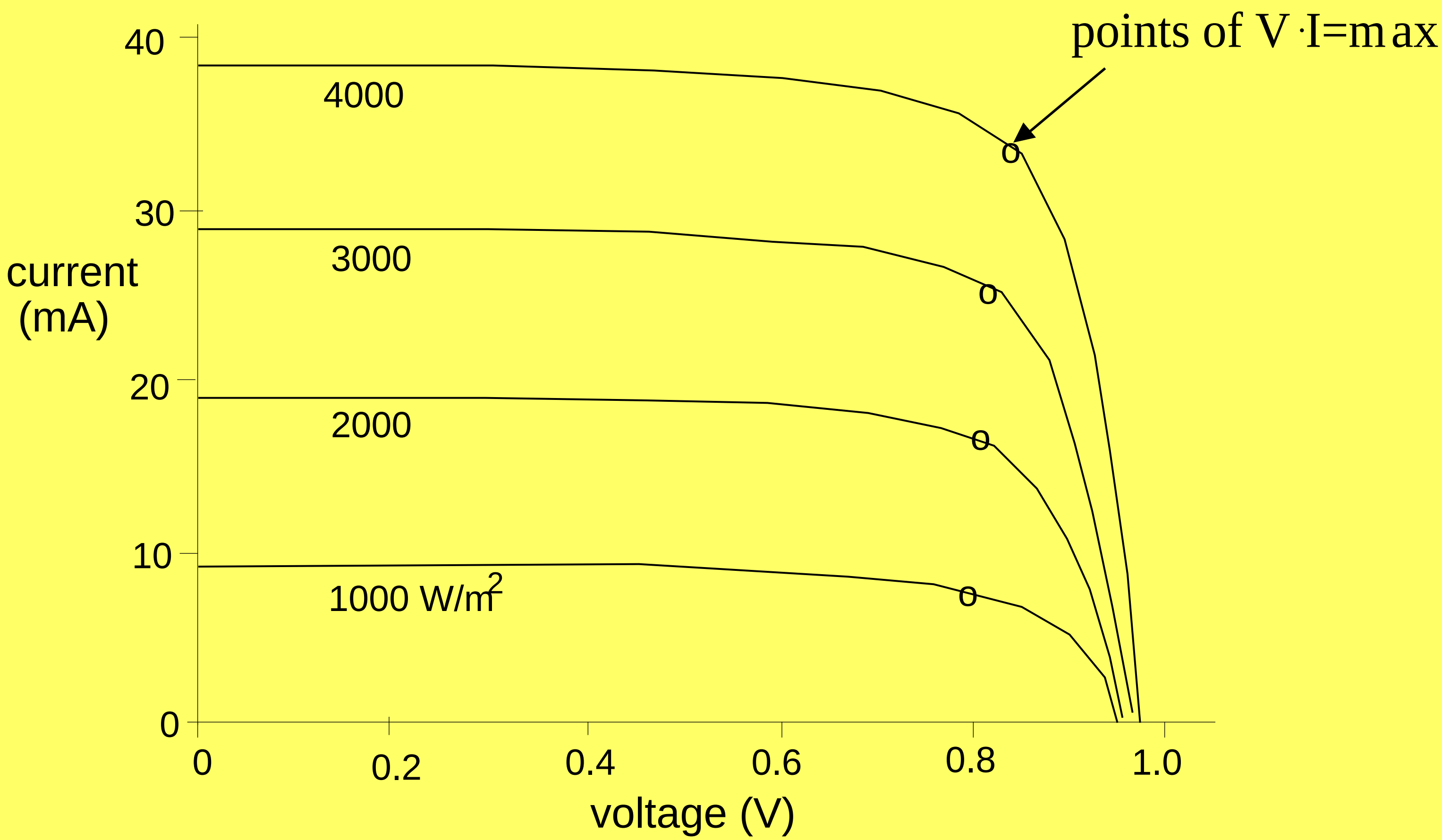
$$FF = V \cdot I \,/\, V_{oc} \cdot I_{cc}$$

so that

$$P_e = V_{oc} \cdot I_{cc}\, FF$$

from:"Photodetectors", by S.Donati, Prentice Hall 2000

V/I characteristics of a solar cell



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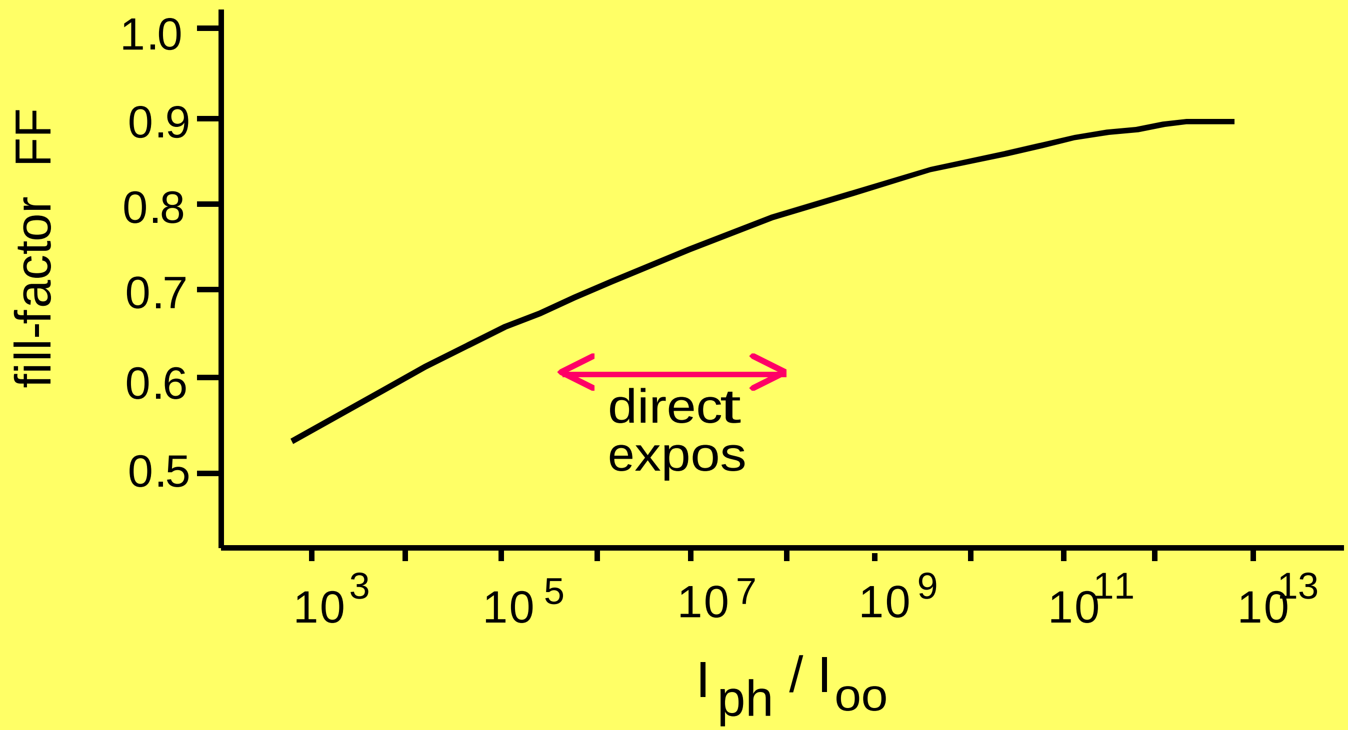
Fill factor



Fill-factor FF vs the photogenerated current (E_g=1eV, T=300 K).
In concentration systems, I_{ph}/I_{00} is proportional to C

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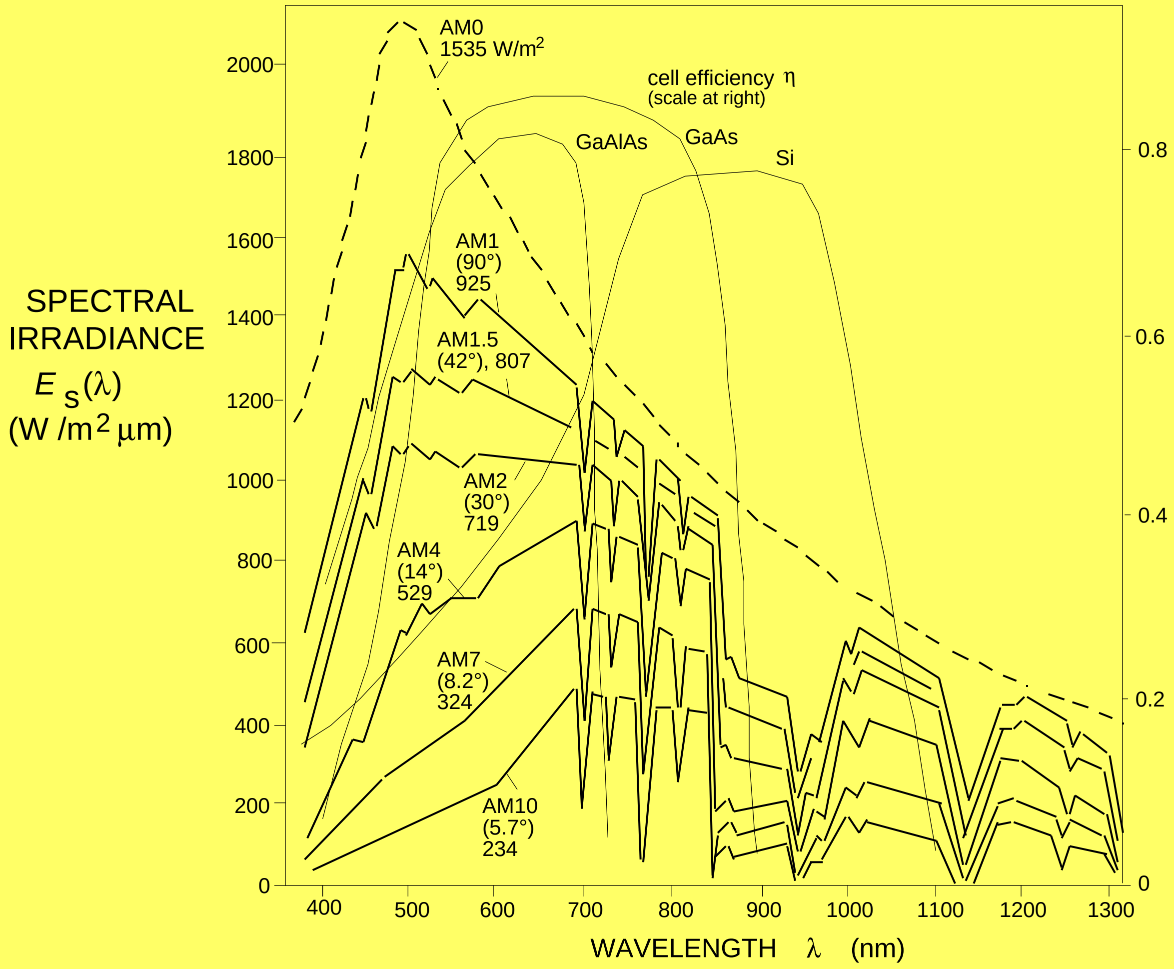
Solar spectrum



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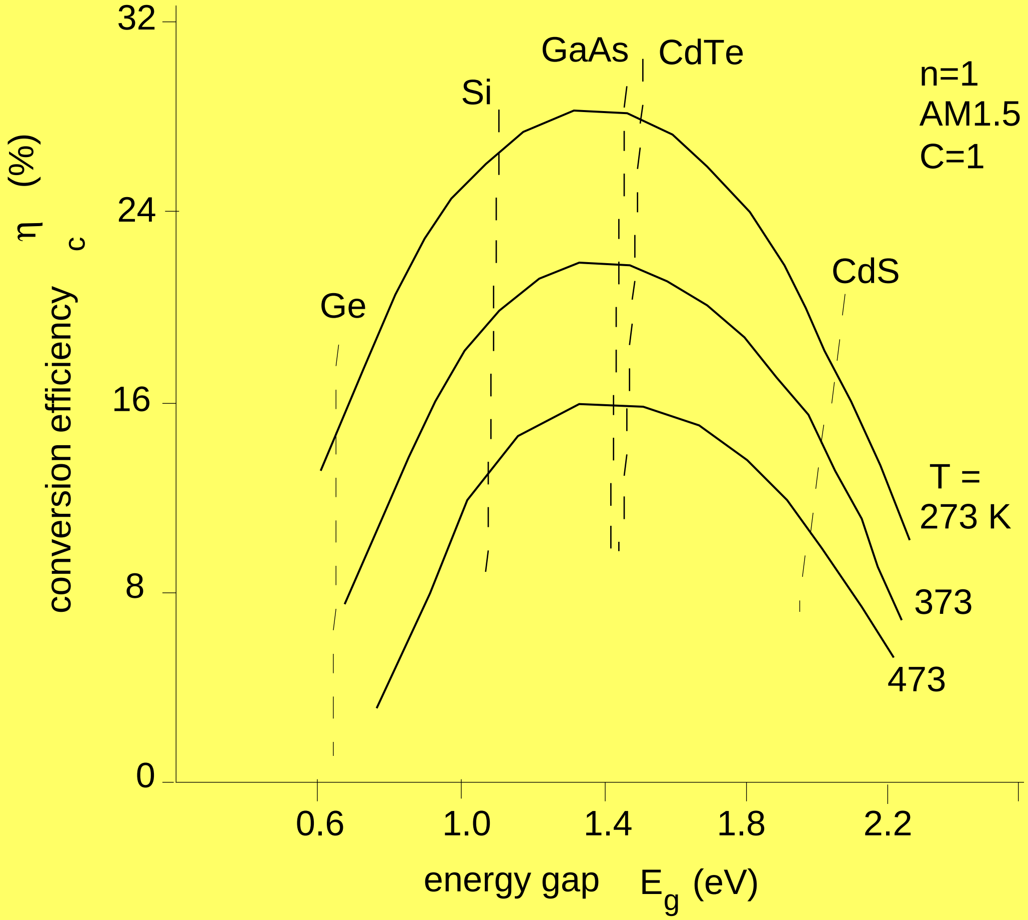
Efficiency vs bandgap



typ. Si-cell η: 15-18%

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Intrinsic and extrinsic losses

intrinsic:

- reflection loss at input interface, decreased by ARC but still causing a reduction factor of $\eta_r = 0.7\text{-}0.9$
- incomplete photon dissipation in the depletion region, with a typical value $\eta_d = 0.8\text{-}0.9$
- voltage drop loss across the junction and contacts resistance, usually $\eta_s = 0.7\text{-}0.9$ at C=1

extrinsic:

- incomplete filling of available area A, when cells are assembled in a panel ($\eta_a = 0.78$ for round cells)
- series/parallel electrical interconnection, where the cell with the lowest η dictates the module I_{cc} (typ. $\eta_e = 0.6\text{-}0.9$)
- electrical load conditioning by means of a dc/ac converter or a battery to store energy produced during peak hours ($\eta_{ext} = 0.7\text{-}0.8$)

total system efficiency seen by the user: $\eta_{sys} \approx$ 8-9% for Si cells

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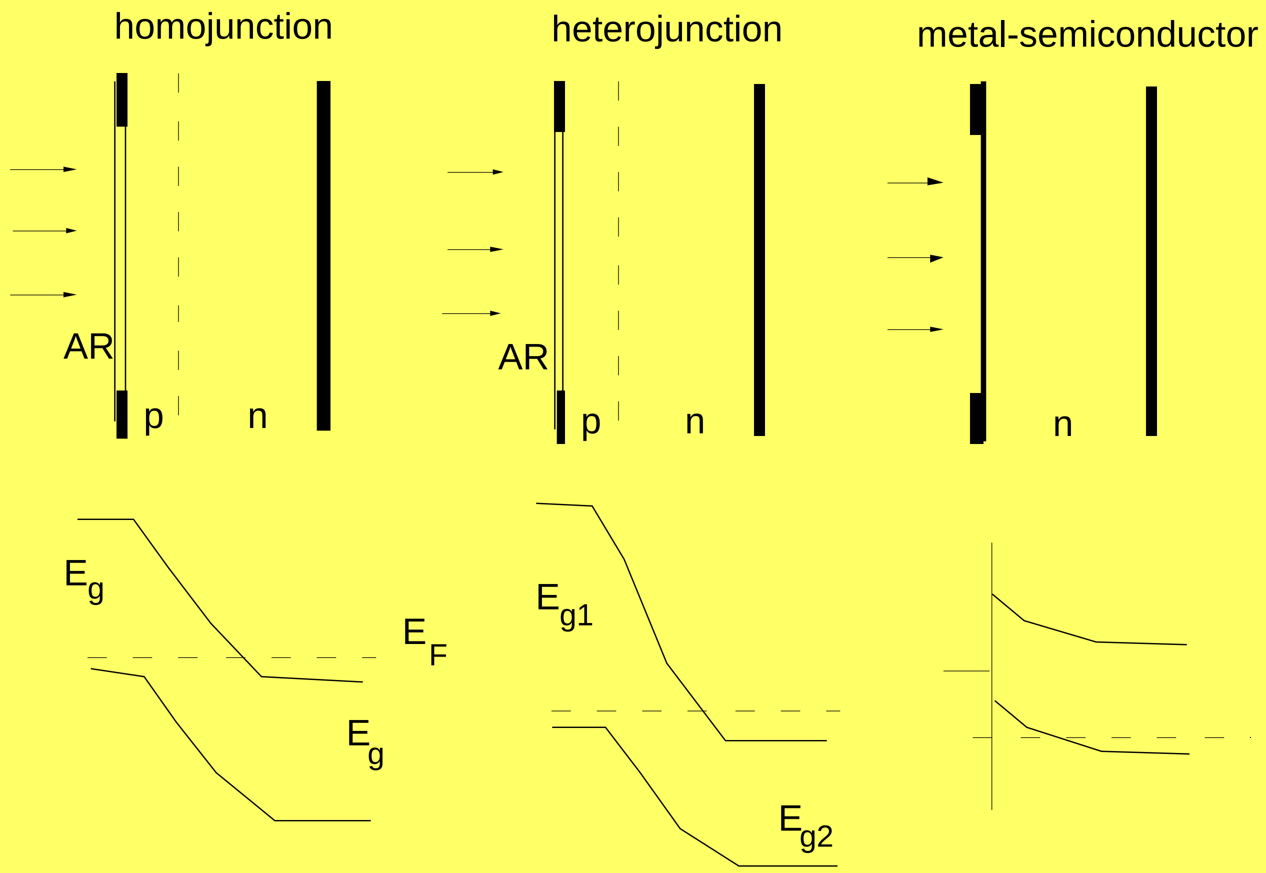
Structures



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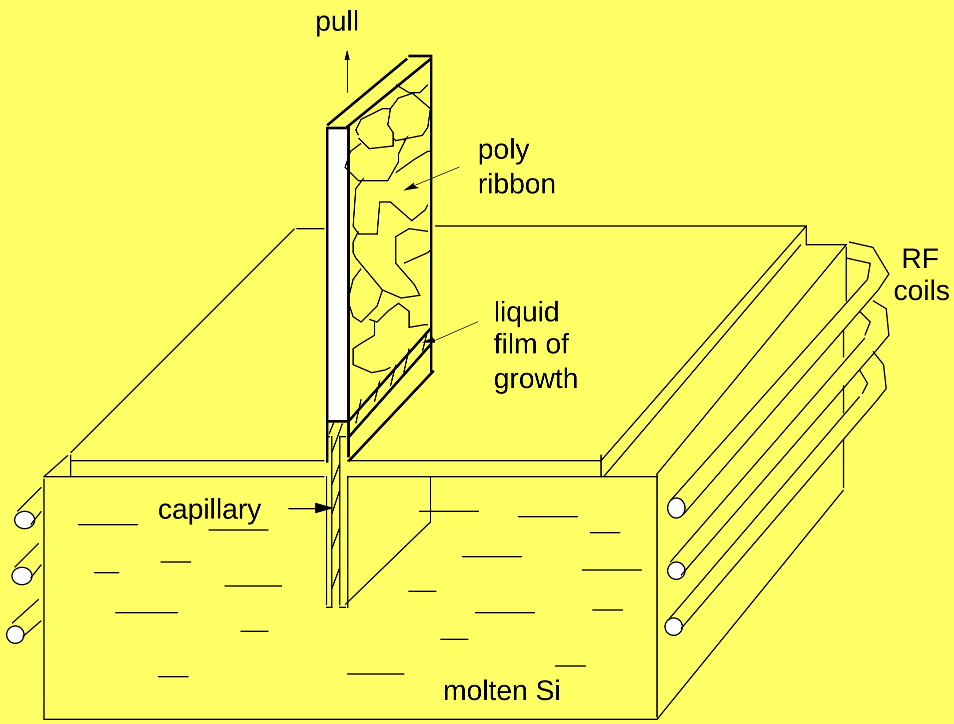
Materials

- Si: monocrystalline
- Si: polycrystalline (poly-Si solar-grade)
- Si: amorphous hydrogenated (a-Si:H)
- GaAs/GaAlAs: monocrystalline
- ZnS, PbS: thin film, quasi-polycrystalline
- Polymer (?)

Poly-Si ribbon pulling



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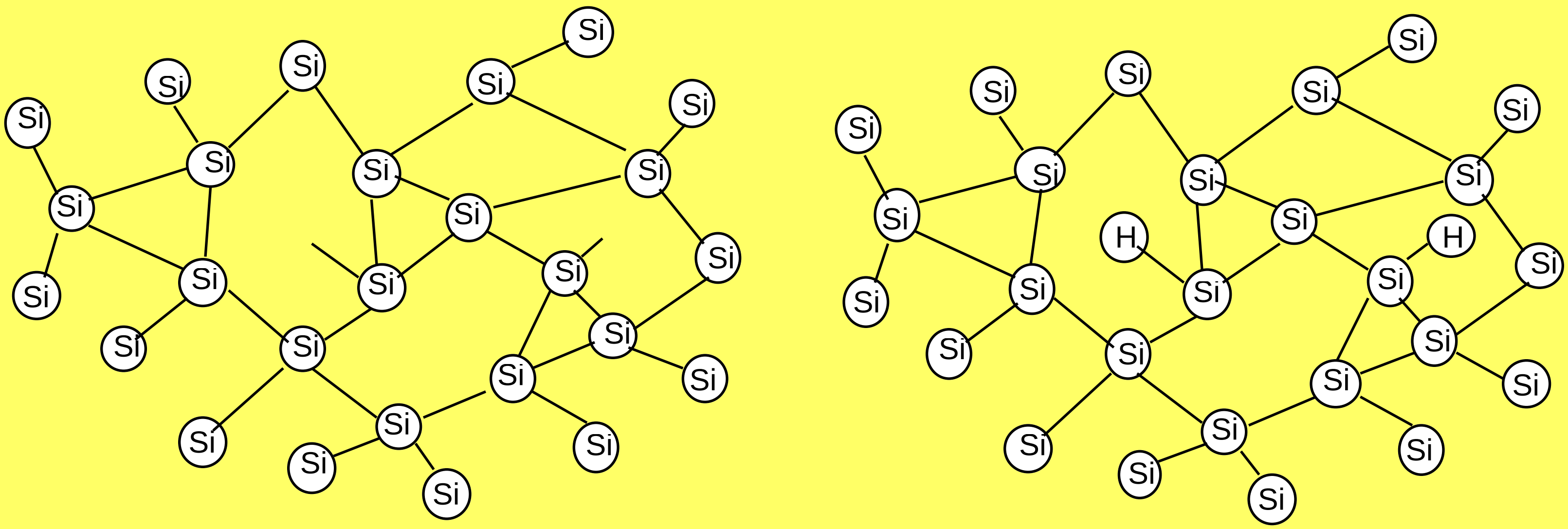
a-Si structure



effect of hydrogenation on dangling bonds

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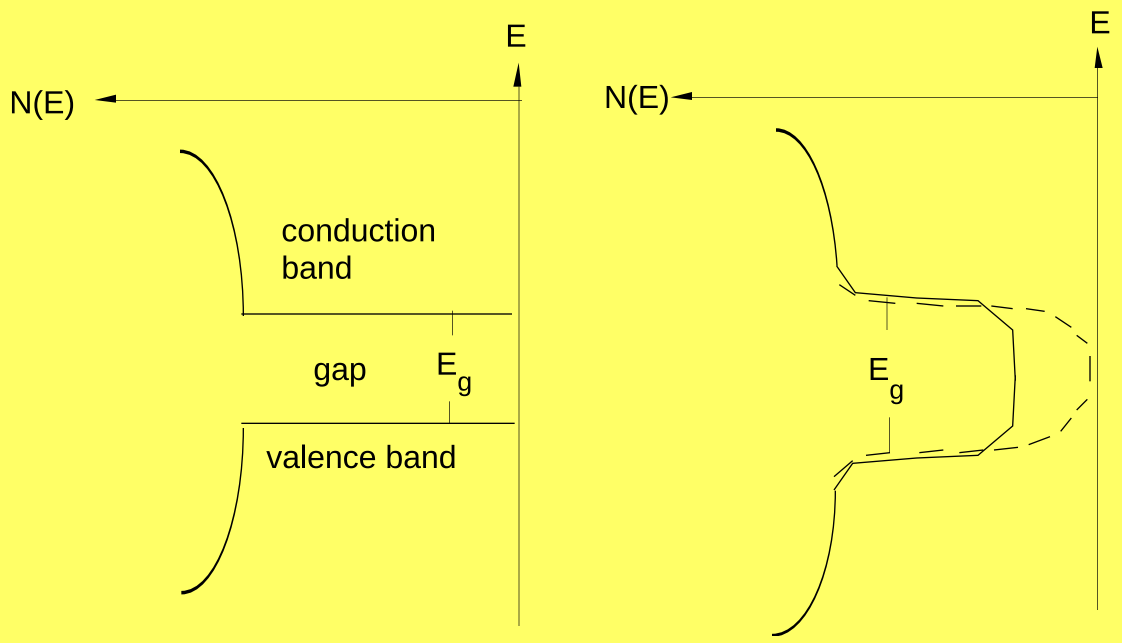
a-Si bands



crystalline amorphous

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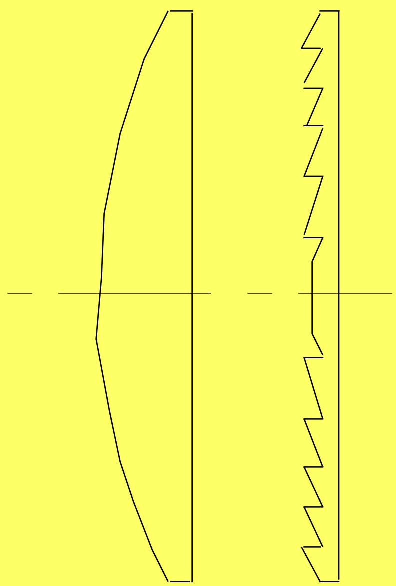
Systems

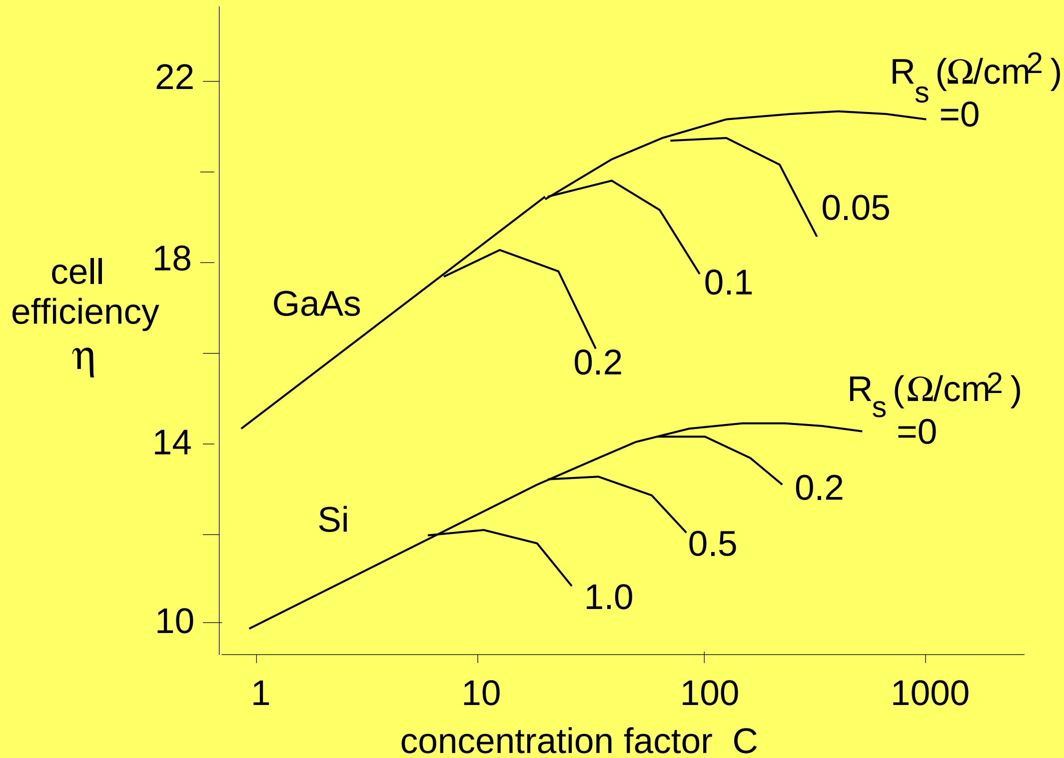
- direct-exposure systems
- systems with concentrator optics
- tandem and multispectral-cell systems

In *direct -exposure* systems, cell module is aimed to south with an azimuth angle θ_p to maximize collected energy E_{dc} during the time period T of interest (day, season or year):

$$E_{dc} = A \int_T E_S(\lambda, AM)\, R_a(t)\, \eta(\lambda) \cos\theta(t)\, dt$$

Concentration systems





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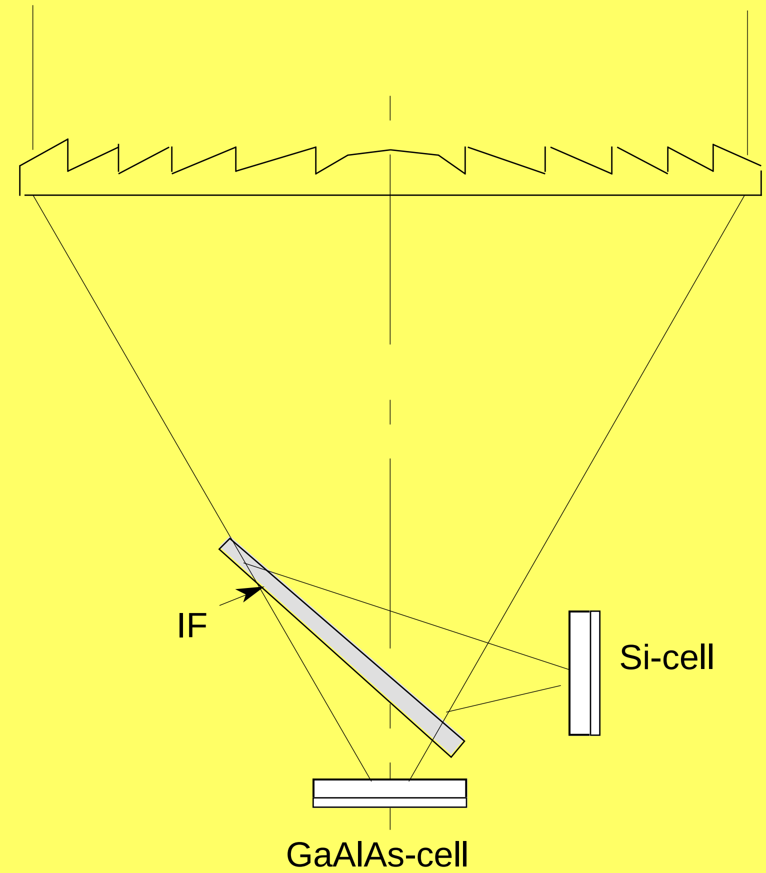
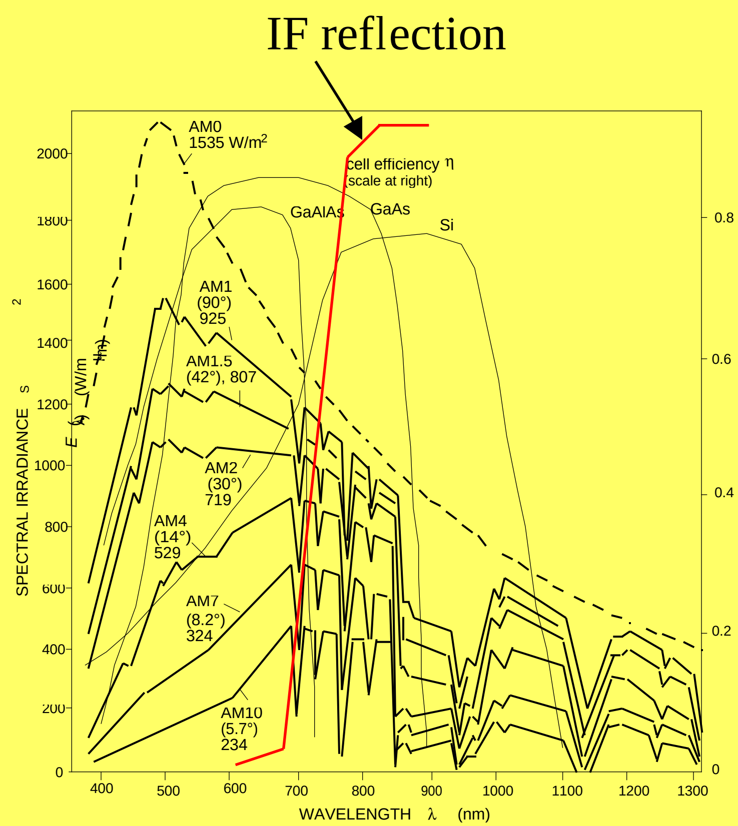
Tandem cells





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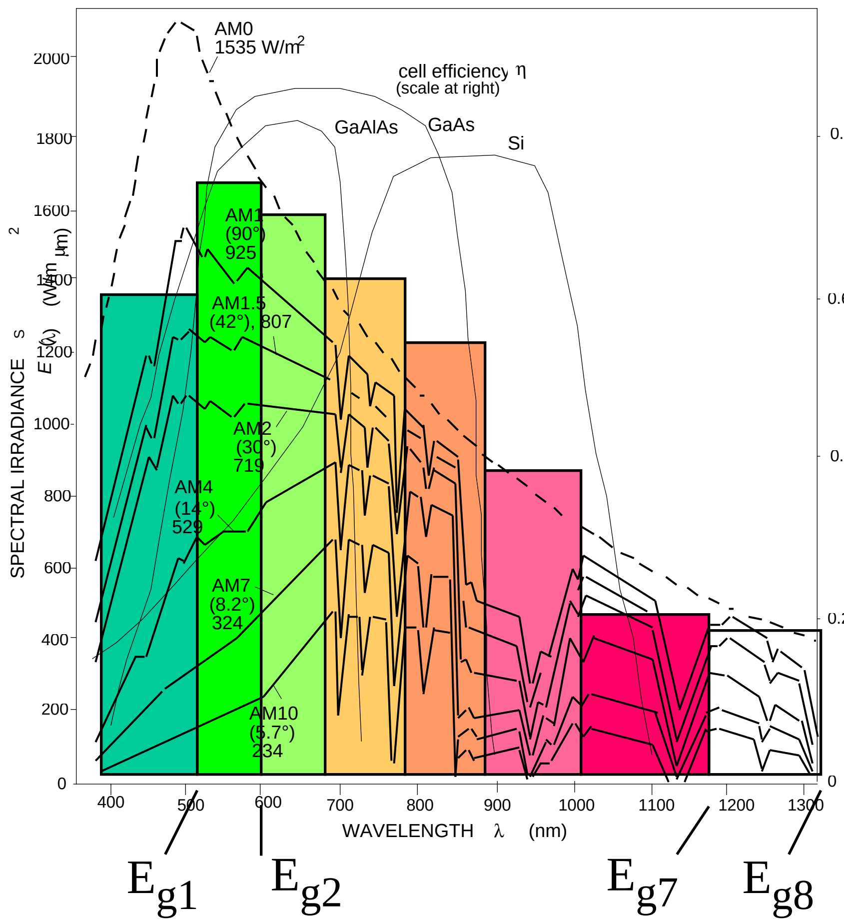
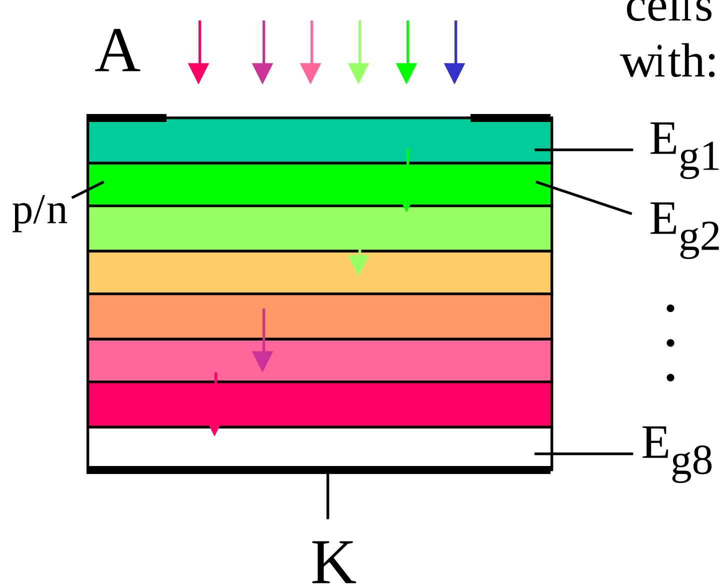
Multi-spectral cells



example:
n=8 cells

pn cells with:



Theoretically, η=60% for n=6 and 95% for n=16 cells

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