

# PHILIPS

sense and simplicity

## Optimising phosphors and filters for Luminescent Solar Concentrators

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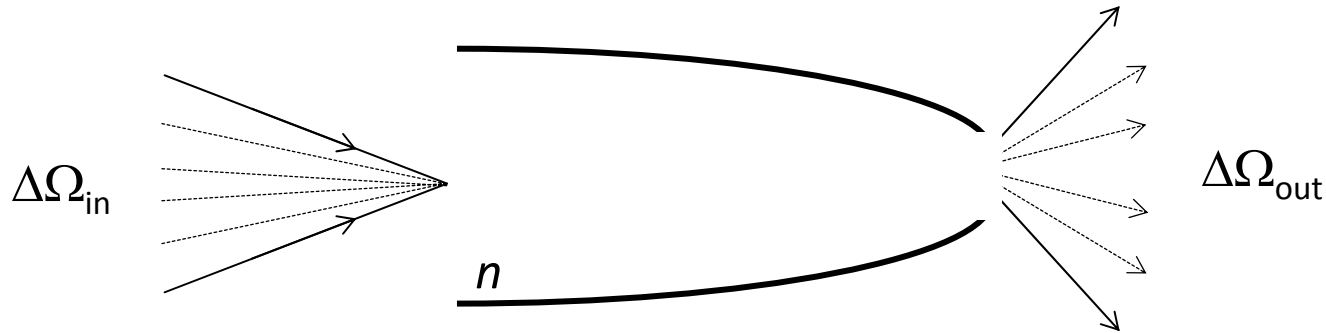
solar cells are attractive, but expensive →  
**concentrators** for reducing use of expensive PV material

concentration:

$$c_p = \text{irradiance on PV cell} / \text{irradiance on concentrator}$$

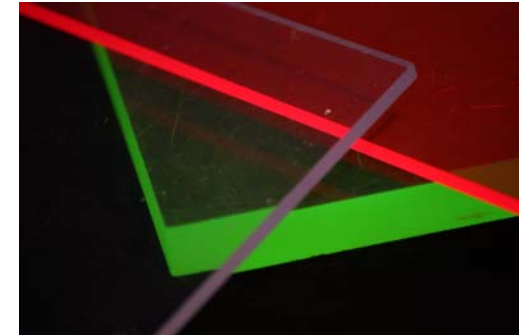
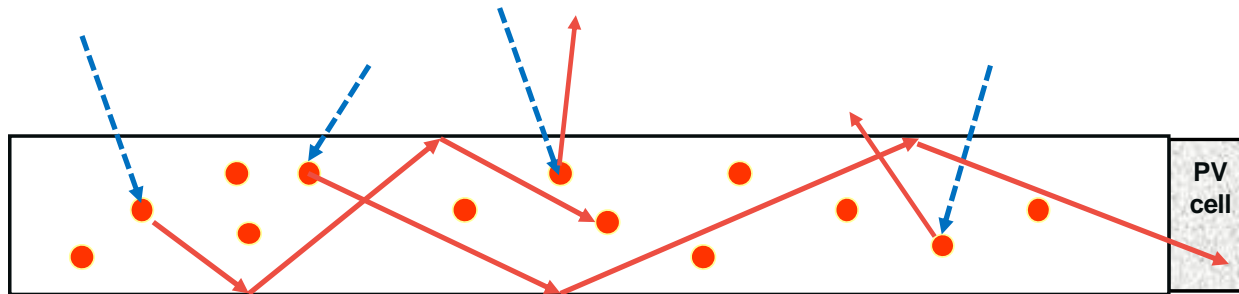
thermodynamics:

$$c_p^{\text{max}} = n^2 \Delta\Omega_{\text{out}} / \Delta\Omega_{\text{in}}$$



large  $c_p$  → small  $\Delta\Omega_{\text{in}}$  → tracking needed,  
 not suitable for diffuse light

# luminescent solar concentrator (LSC)



- low cost
- design freedom

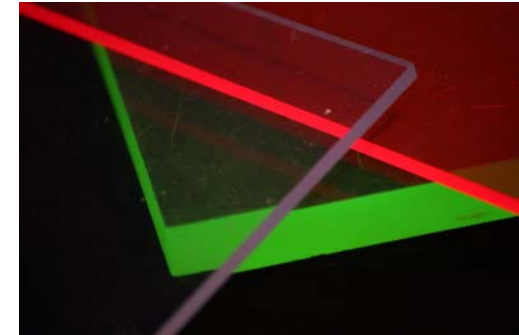
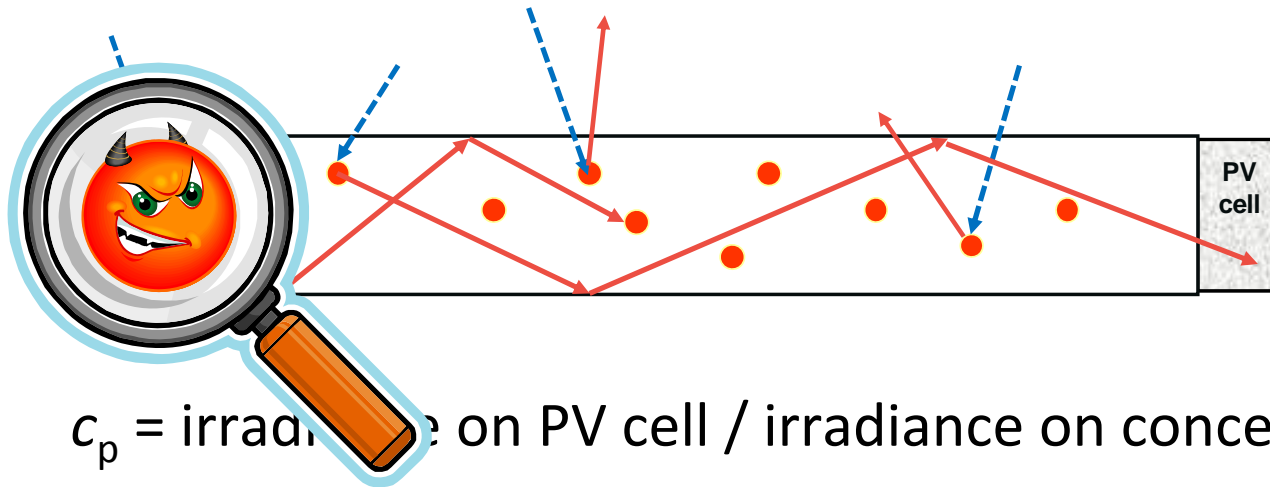
$c_p$  = irradiance on PV cell / irradiance on concentrator

thermodynamics:

$$c_p^{\max} = n^2 \Delta\Omega_{\text{out}} / \Delta\Omega_{\text{in}} \frac{E_{\text{em}}^2}{E_{\text{abs}}^2} \exp(\Delta E/kT) \approx 3000 \text{ for } \Delta E = 0.2 \text{ eV}$$

Stokes shift:  $\Delta E = E_{\text{abs}} - E_{\text{em}}$

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Stokes shift:  $\Delta E = E_{\text{abs}} - E_{\text{em}}$

Stokes shift converted to heat → entropy is decreased

# short history of LSC

1976 invention (Goetzberger and Greubel)

1979 thorough study (Batchelder et al.)

1980 thermodynamic limits (Yablanovitch)

2008 record efficiency: 7.1 % @ 2.5 geometric gain (Slooff et al.)

new luminescent materials:

2000 quantum dots (Barnham et al.)

2006 oriented dyes (Debije et al.)

2008 new organic dyes (Currie et al.)

2008 organometallic rare-earth compounds (Rowan et al.)

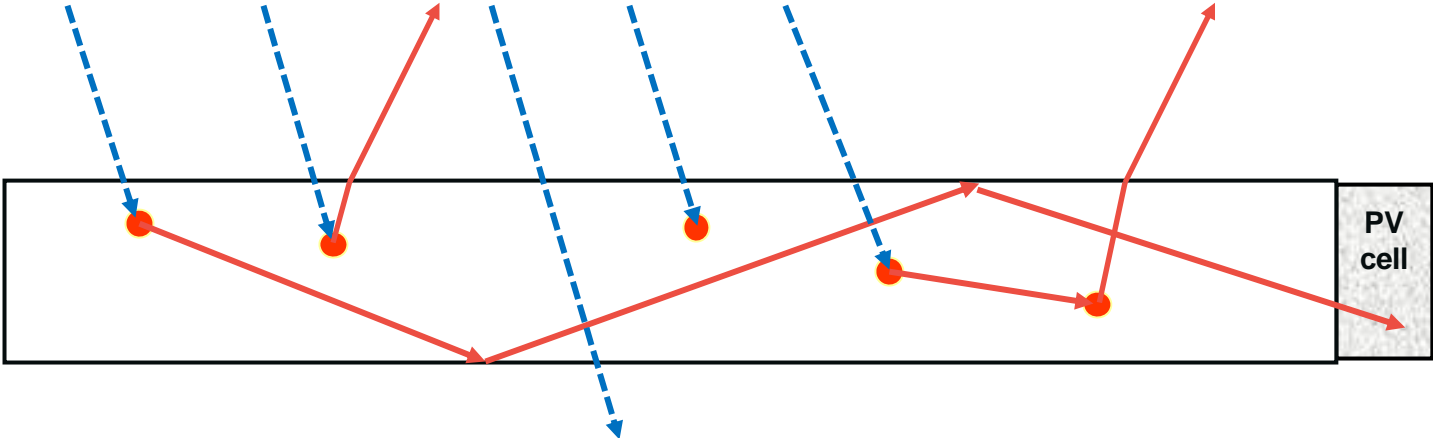
wavelength-selective filters:

1990 principle (Smestad et al.)

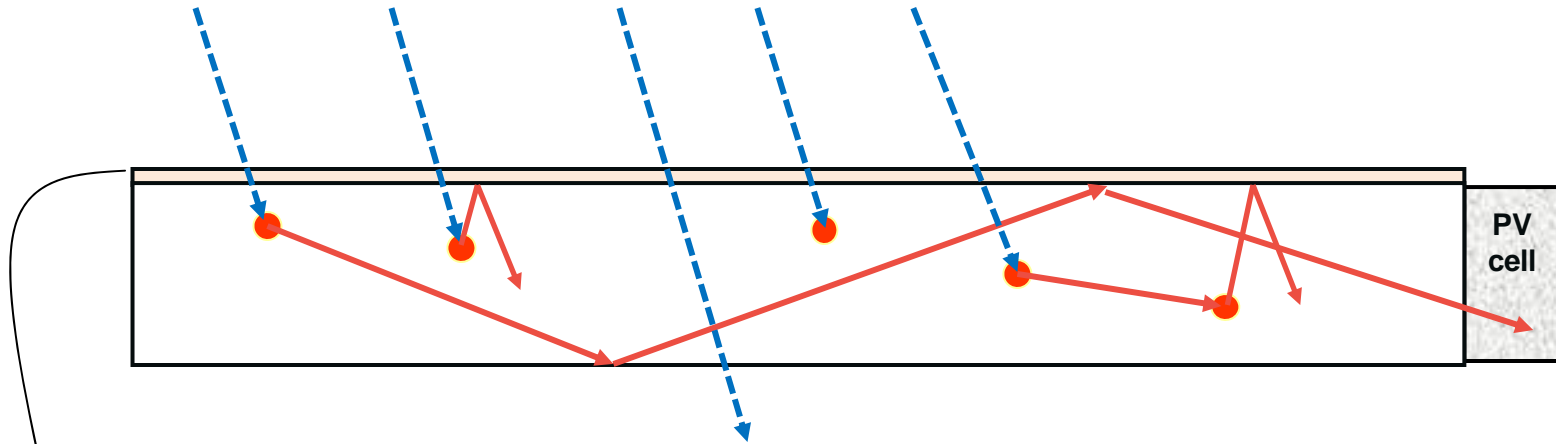
2005 dielectric mirrors (Rau et al.)

2006 cholesteric mirrors (Debije et al.)

# loss processes

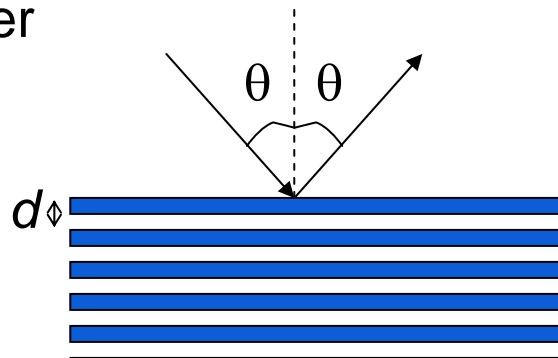


# loss processes

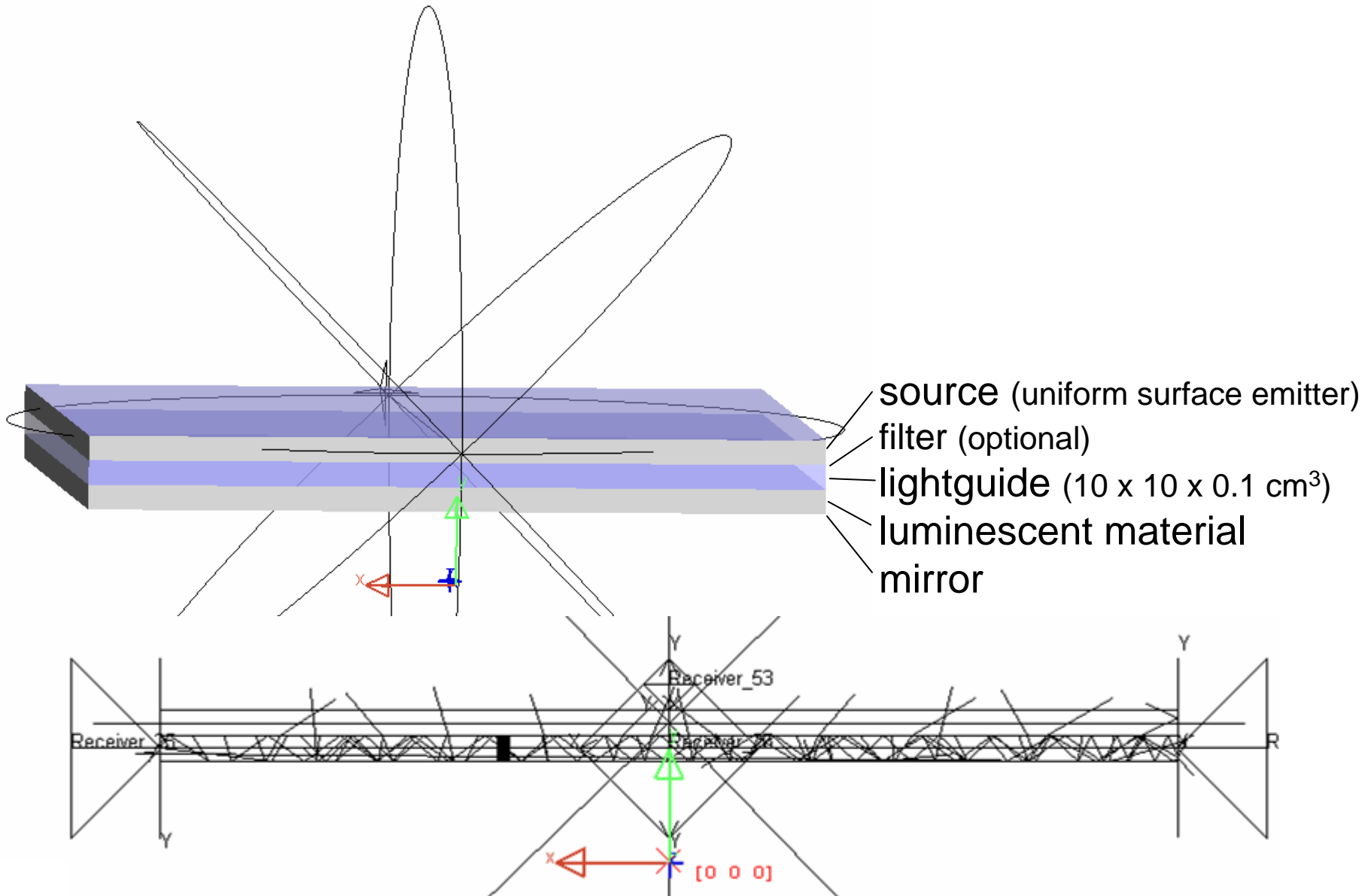


wavelength-selective filter

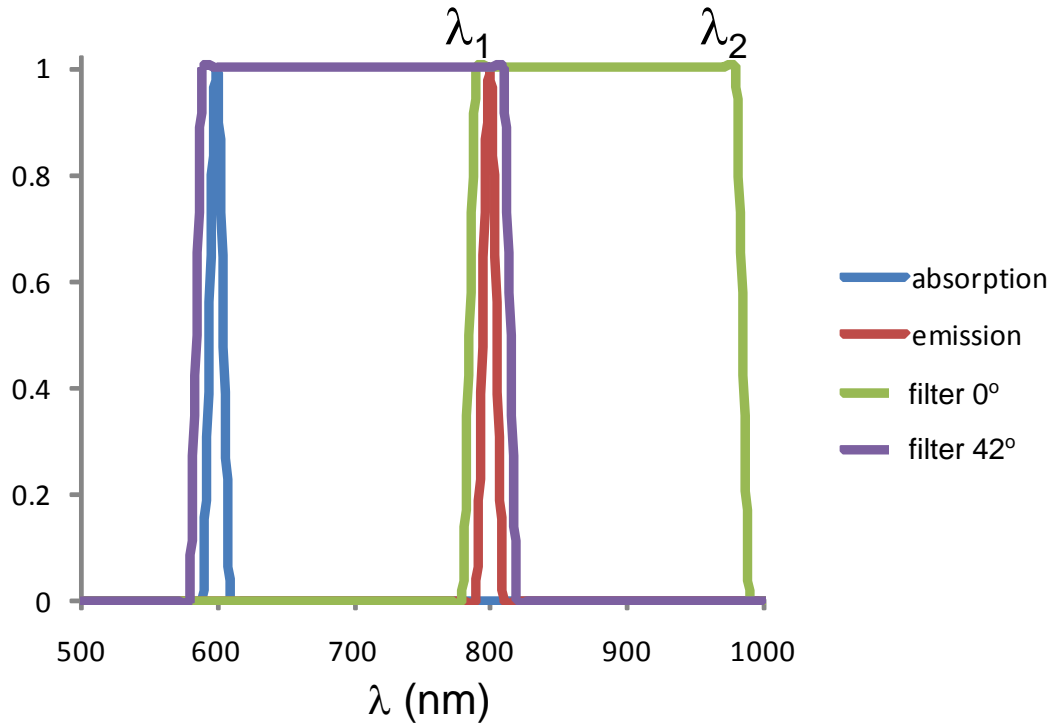
Bragg:  $\lambda = 2n d \cos \theta$



# ray-trace simulations (LightTools)

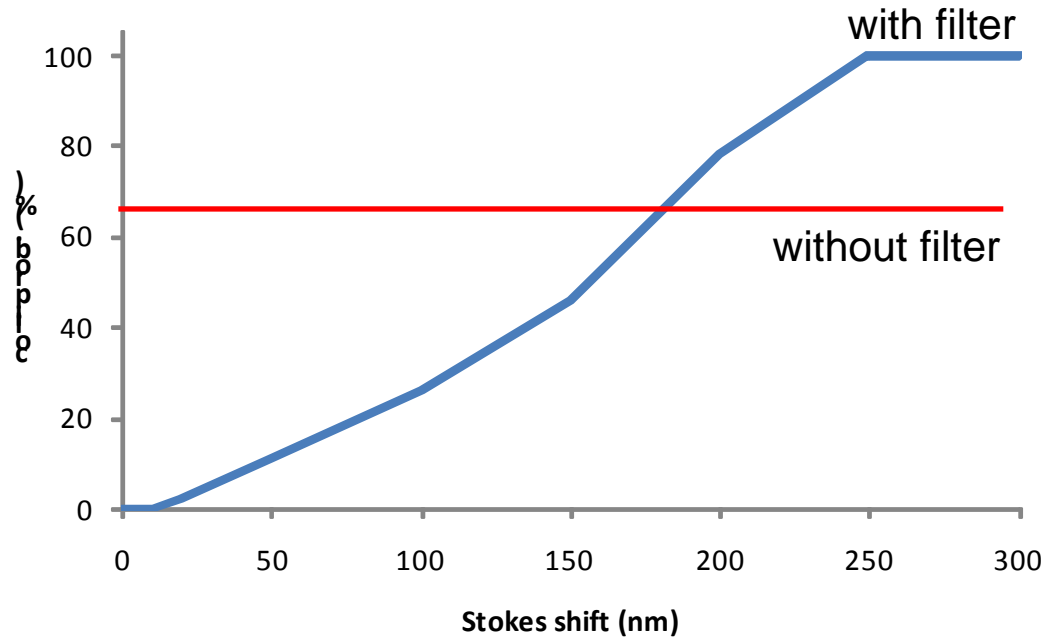


# effect of wavelength-selective filter



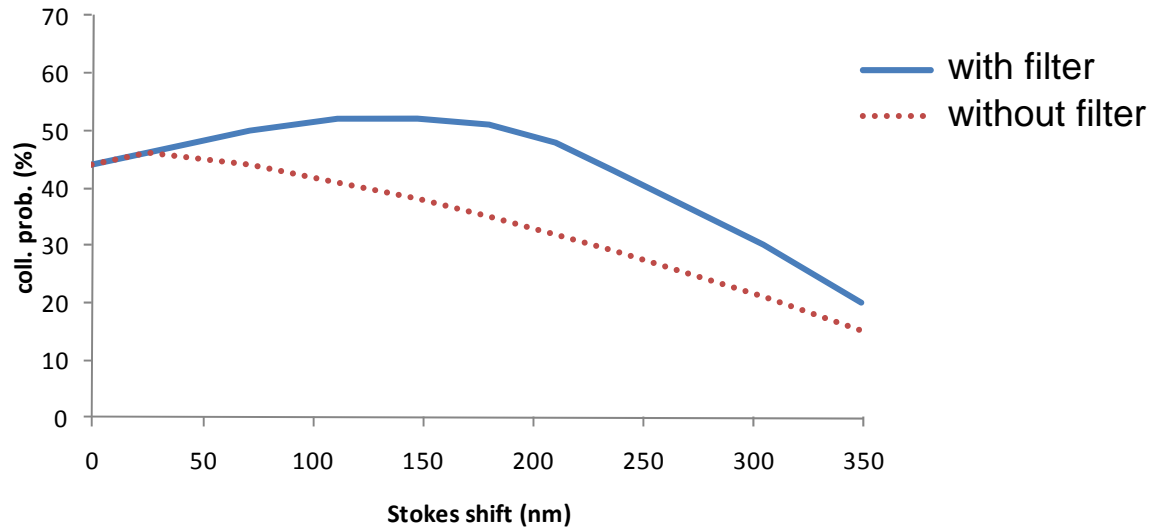
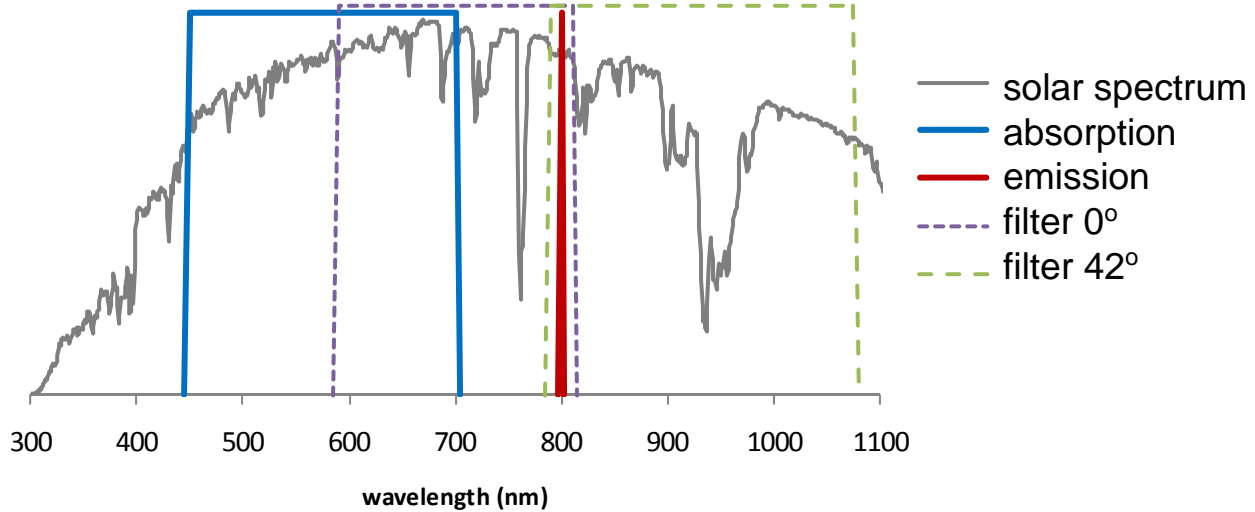
$$\lambda_{1,2} = (n d)_{1,2} \cos\theta$$

# collection probability vs Stokes shift



line emitter is favourable!

# collection probability vs Stokes shift

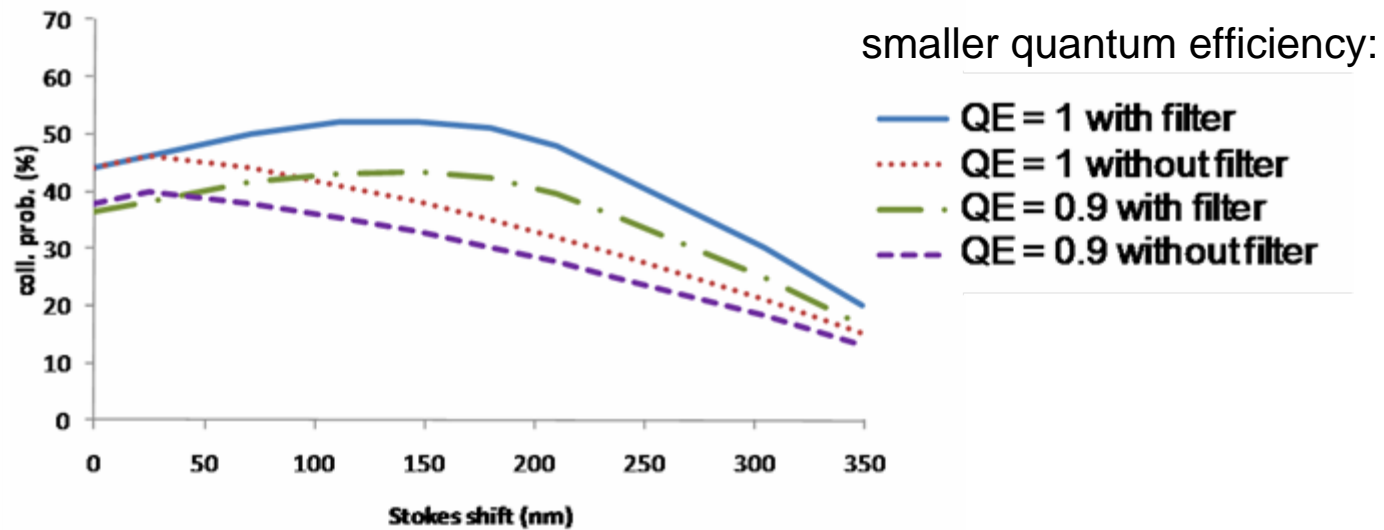
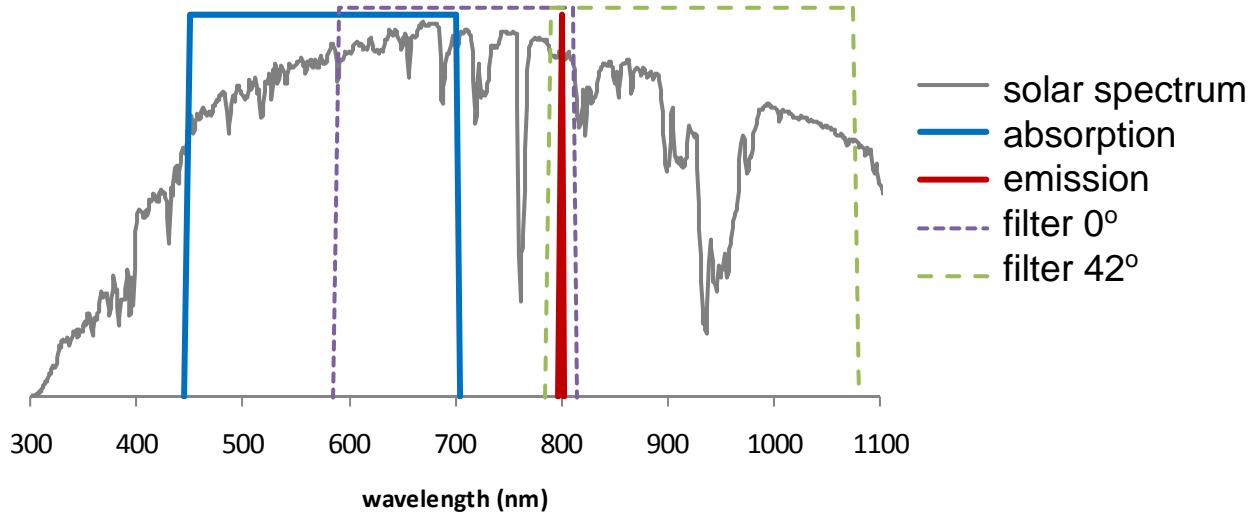


collection probability: up to 800 nm

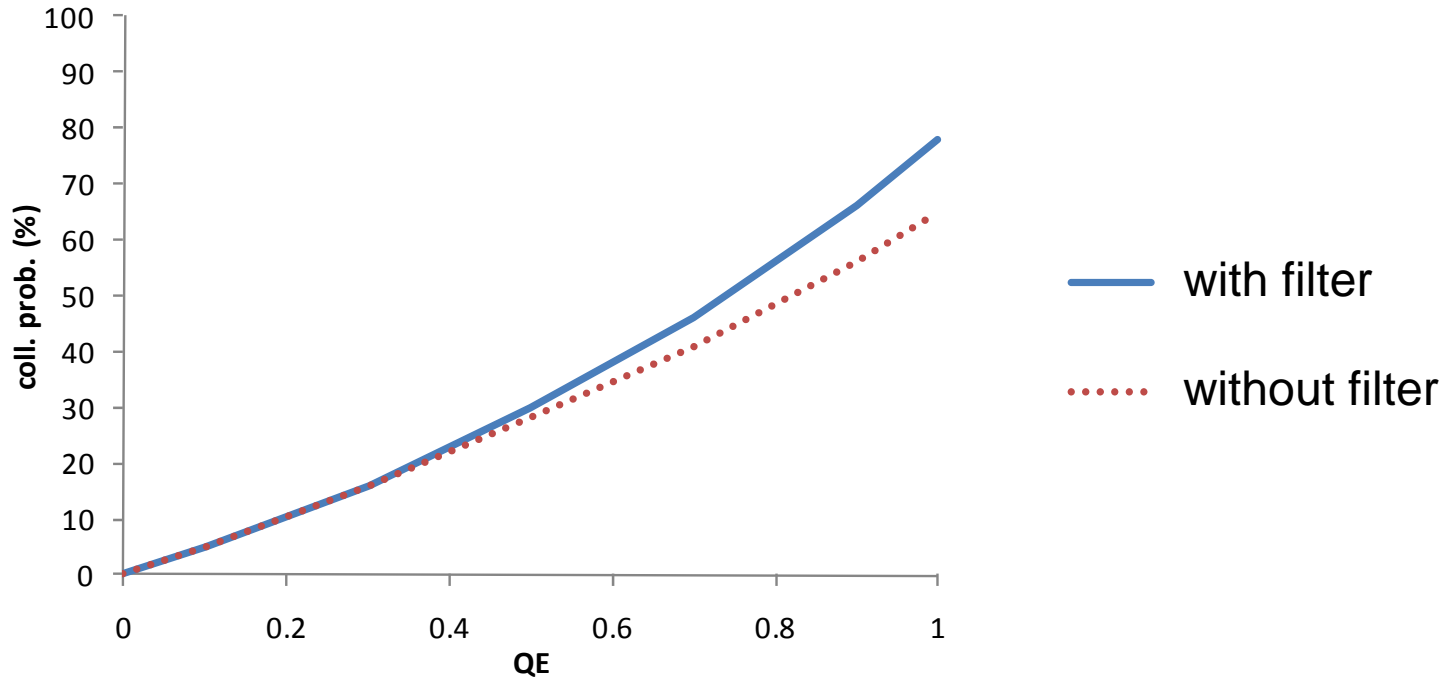
Si: x 0.63

GaAs: x 0.86

# collection probability vs Stokes shift

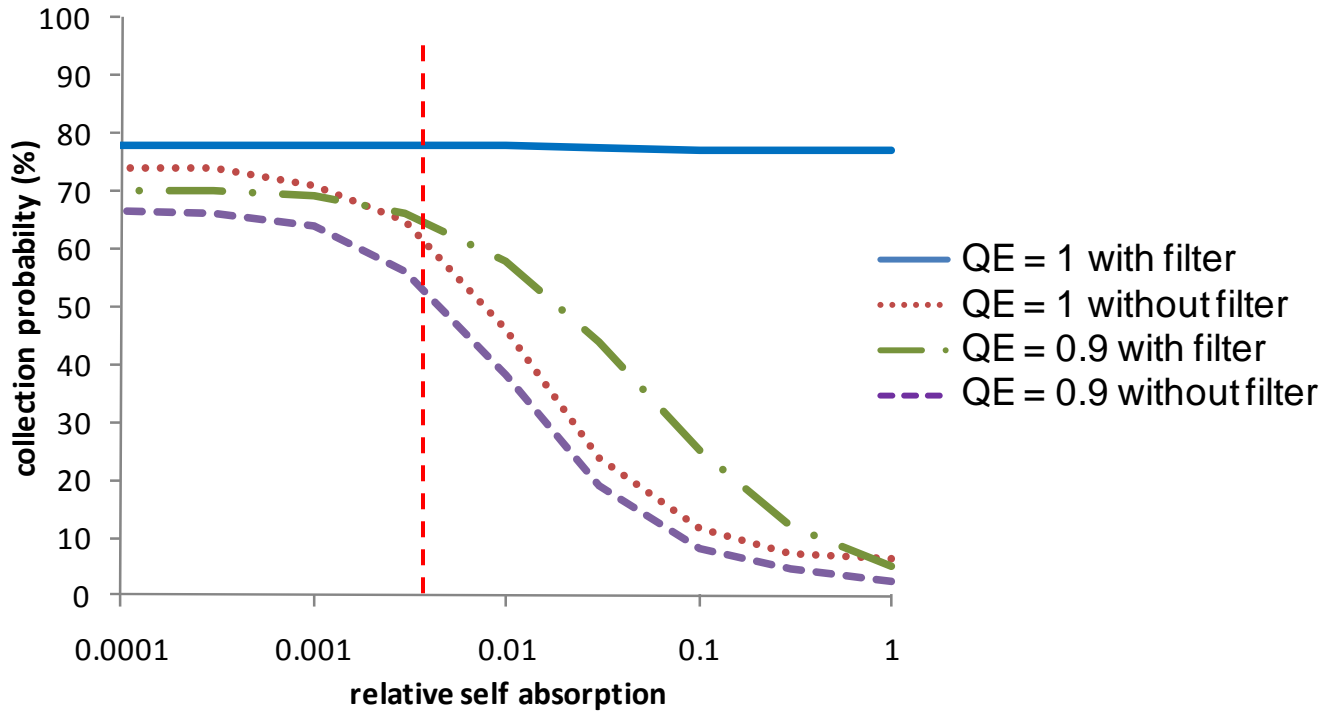


# collection probability vs quantum efficiency



# collection probability vs self absorption

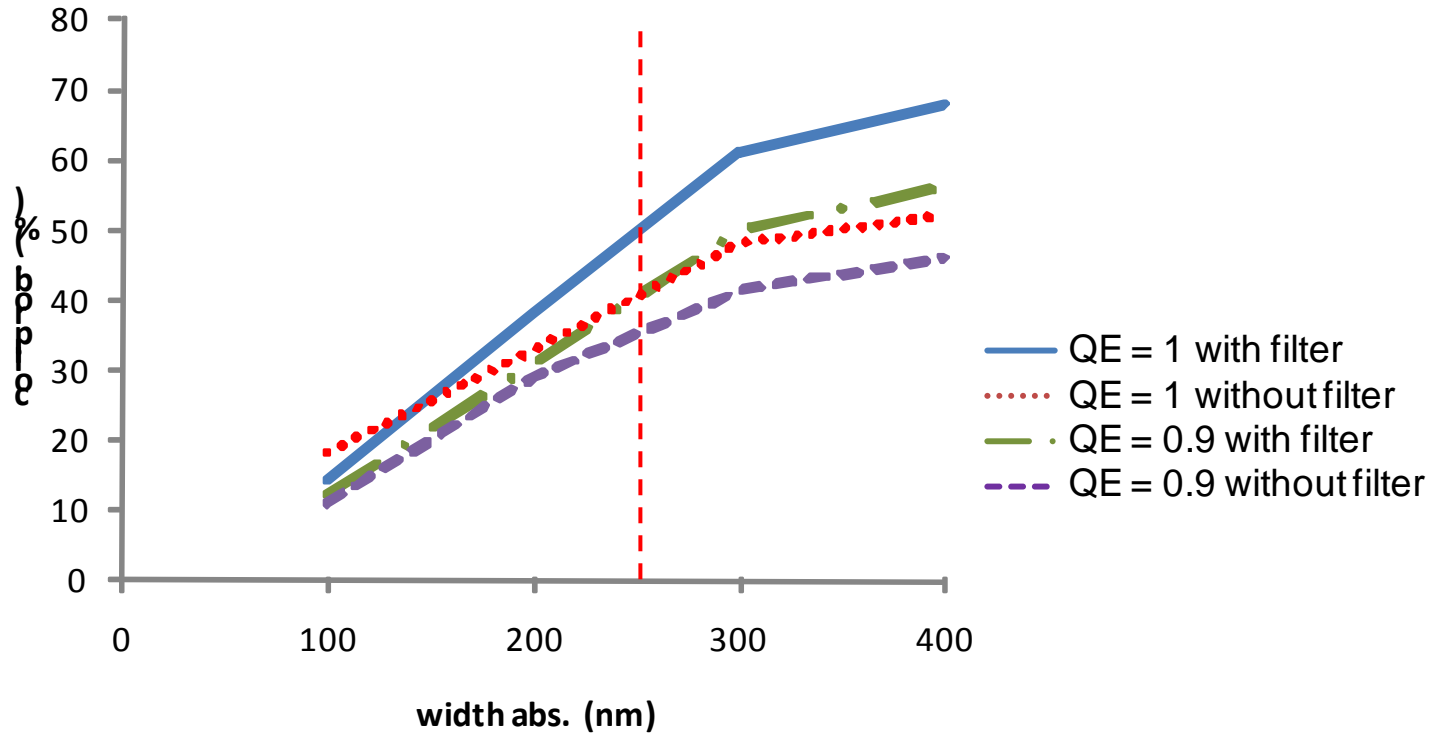
= absorption of emitted radiation / absorption of incident sunlight



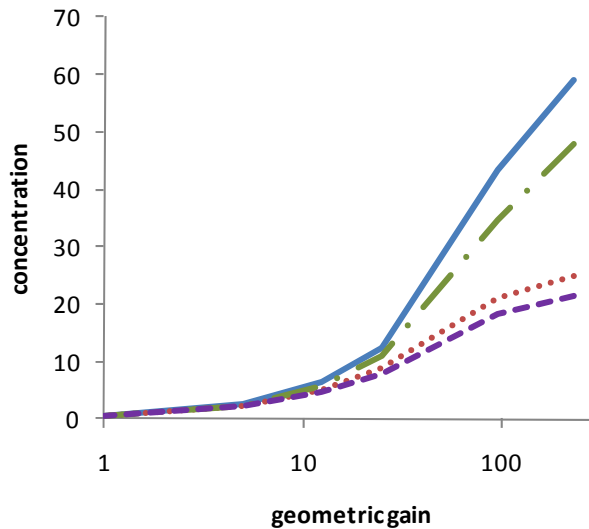
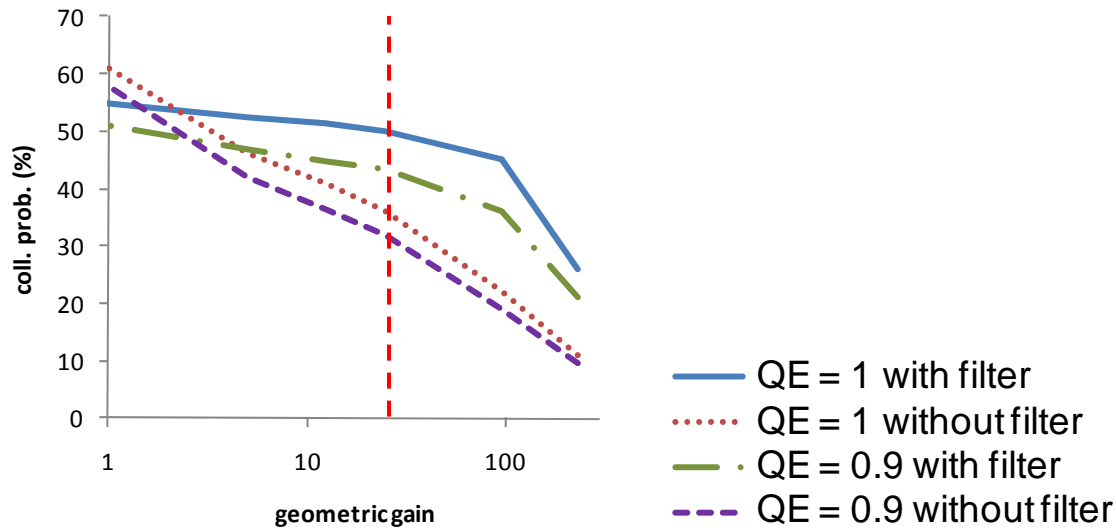
organic dyes: relative self absorption  $\approx 0.01 - 0.05$

# collection probability vs width absorption spectrum

@ Stokes shift = 100 nm



# collection probability vs geometric gain

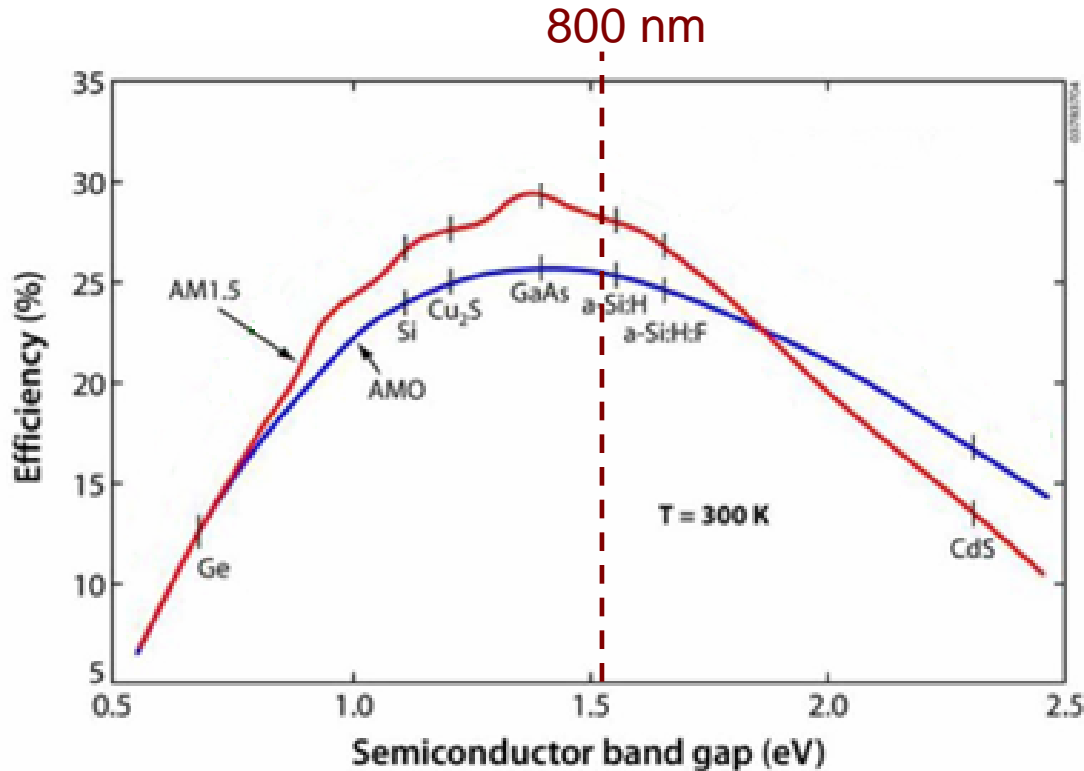


concentration = geometric gain x collection probability

# discussion

- solar cell efficiencies
- polymer matrix
- luminescent materials
- filters

solar-cell (system) efficiency  
 = electrical energy out / solar energy in



solar-cell efficiency

@ 100% coll. prob.

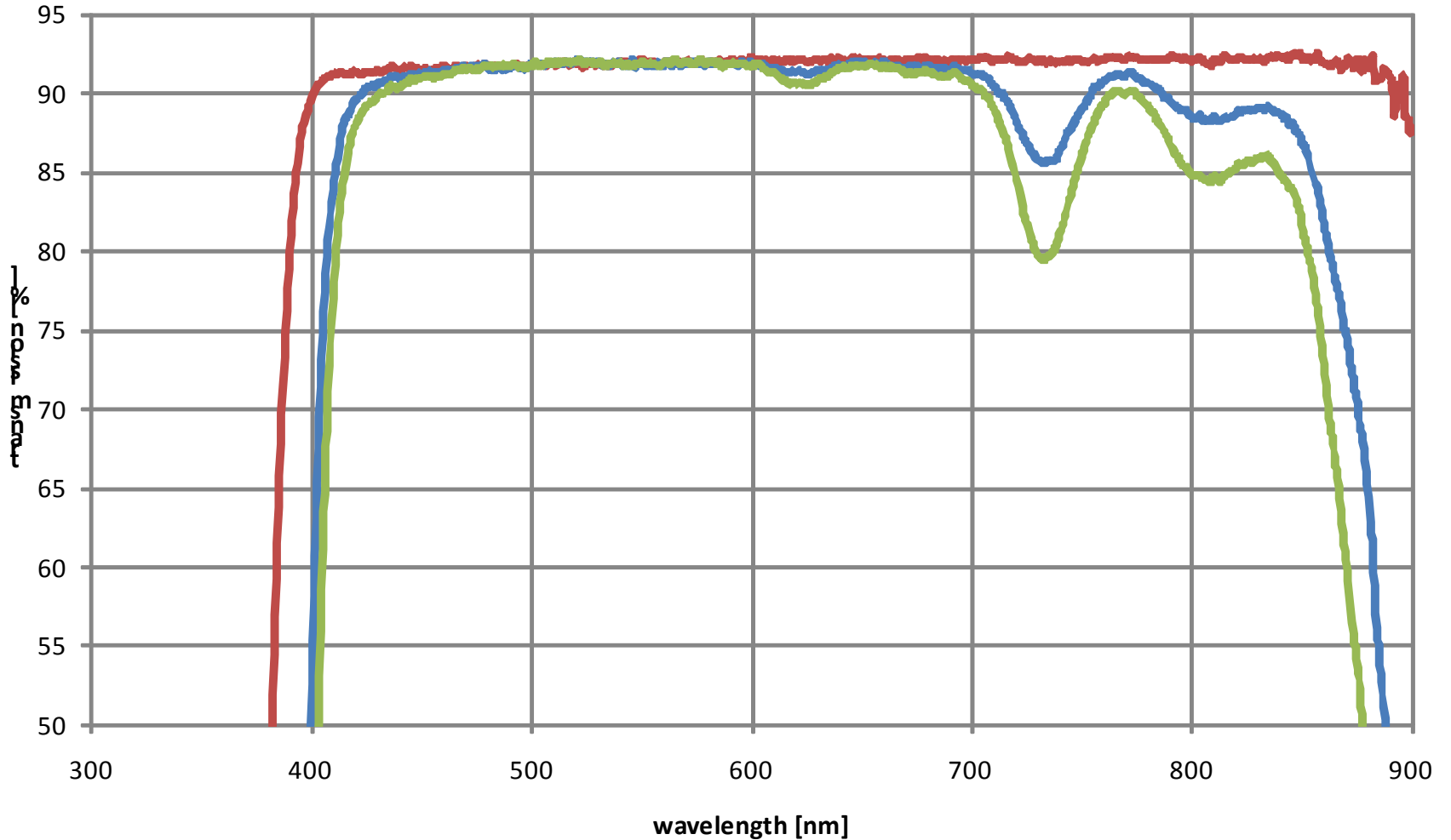
Si: x 0.63 → 16 %

GaAs: x 0.86 → 24 %

# transmission of matrix materials

## transmission of PMMA

thickness: — 3mm — 100mm — 200mm



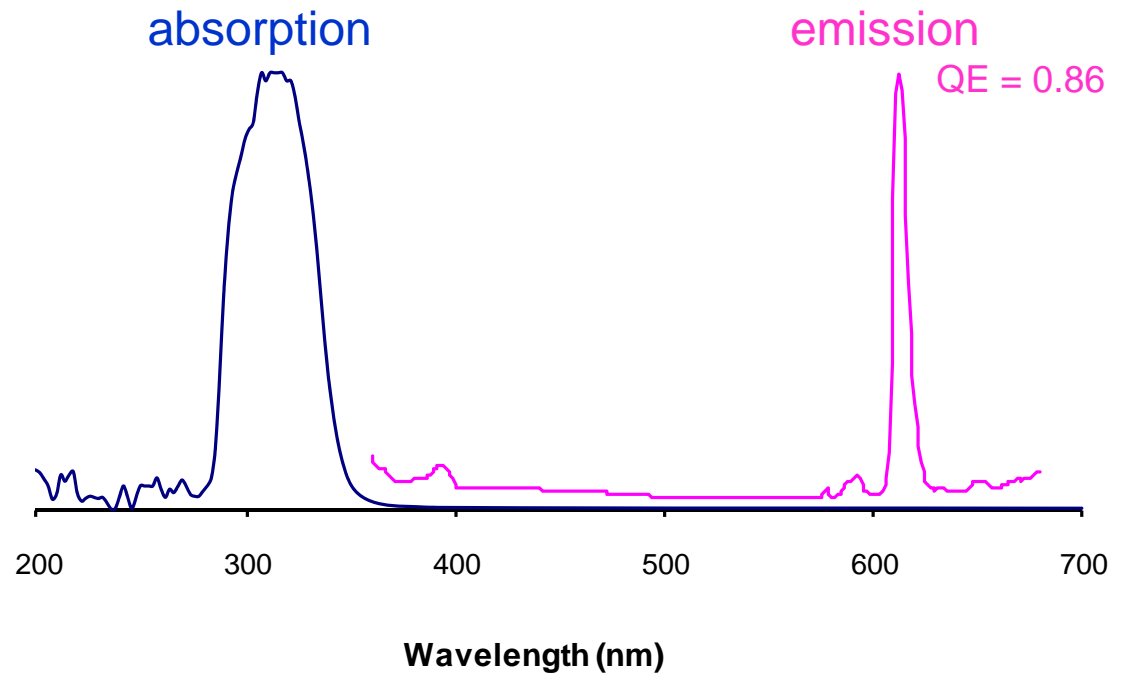
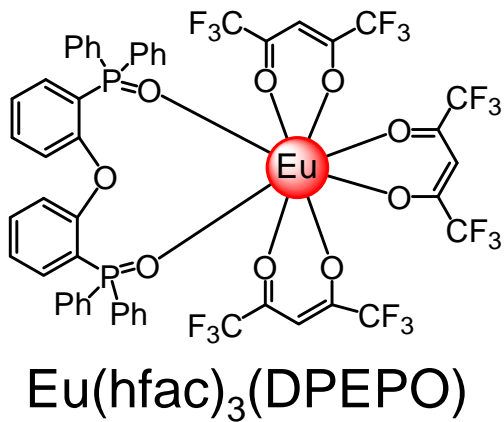
## line emitters with large Stokes shift

- small self absorption
- compatible with wavelength-selective filter

# line emitters with large Stokes shift:

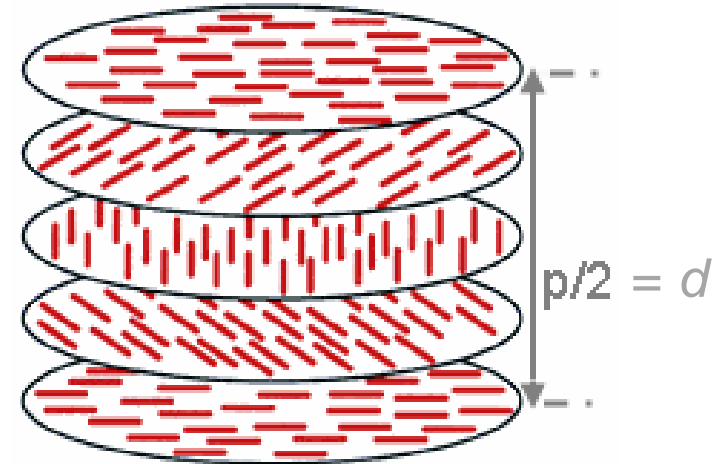
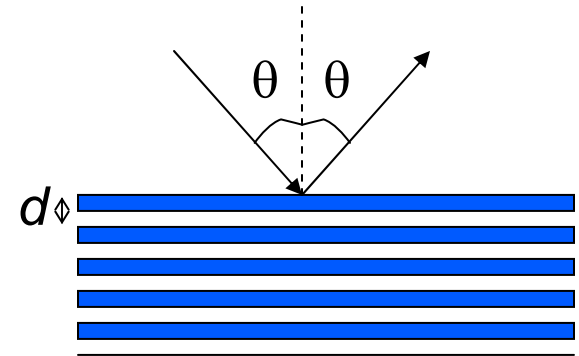
## Lanthanide complexes

Wilson et al. 2010



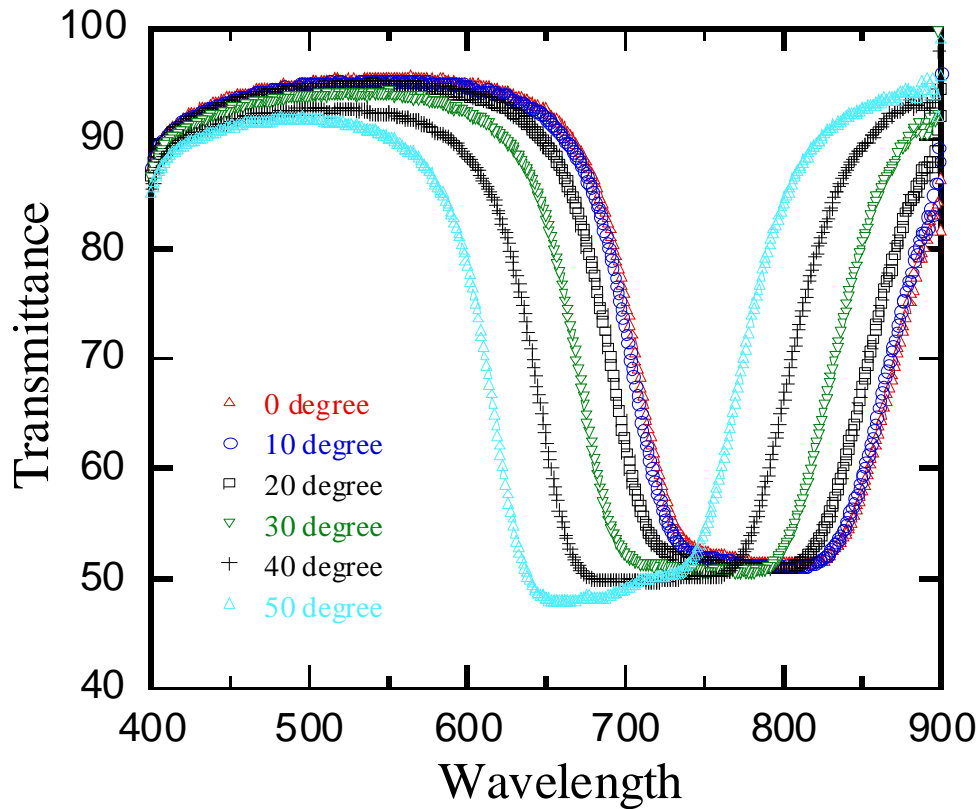
# wavelength-selective filters:

- dielectric filters (Goldschmidt 2008)
- photonic crystals
- cholesteric-liquid-crystal polymers (Debije 2006)

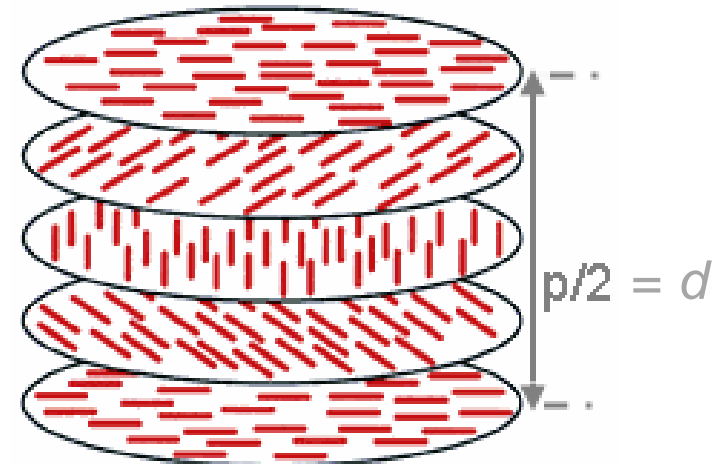


# wavelength-selective filters: gradient-pitch cholesteric-liquid-crystal polymers

(Broer 1995)



(Chi-Wen Lin 2010)



# conclusions

- collection probabilities  $> 50\%$  (solar-cell efficiencies  $> 10\%$ ) are feasible @ geometric gain  $> 10$
- luminescent materials should have:
  - broad absorption spectrum
  - small self absorption
  - Stokes shift  $\approx 100 - 150$  nm
  - preferably line emission
- wavelength-selective filters should be:
  - tuned to luminescent spectrum
  - wide-band filters



# transmission of matrix materials

