Study of a solar concentrator for space based on a diffractive/refractive optical combination

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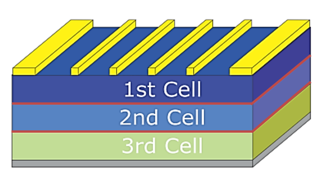
Context : satellites needs

Solar concentration : # solar cells/m² ↓ → cost ↓

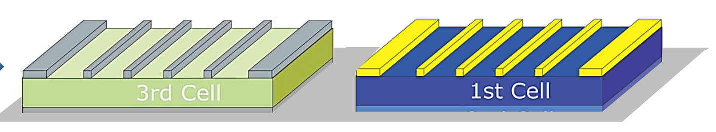
Space environment → specific thermal conditions → desired solar concentration about 10×

Spectrum splitting



Current matching condition → power limited by the worst cell

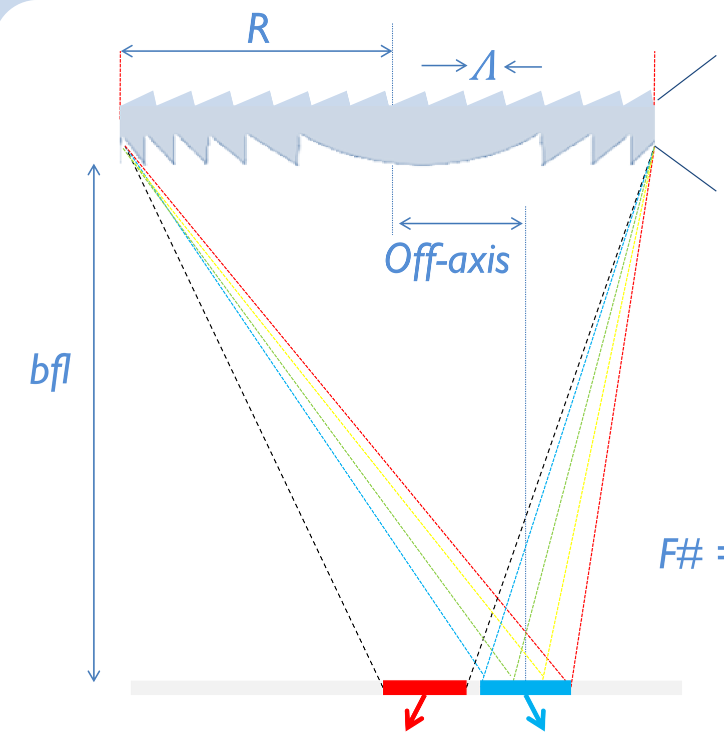
Lattice matching condition at the interfaces



Total power = Σ powers

Free choice of materials

Combination



Blazed diffraction grating — Splitting

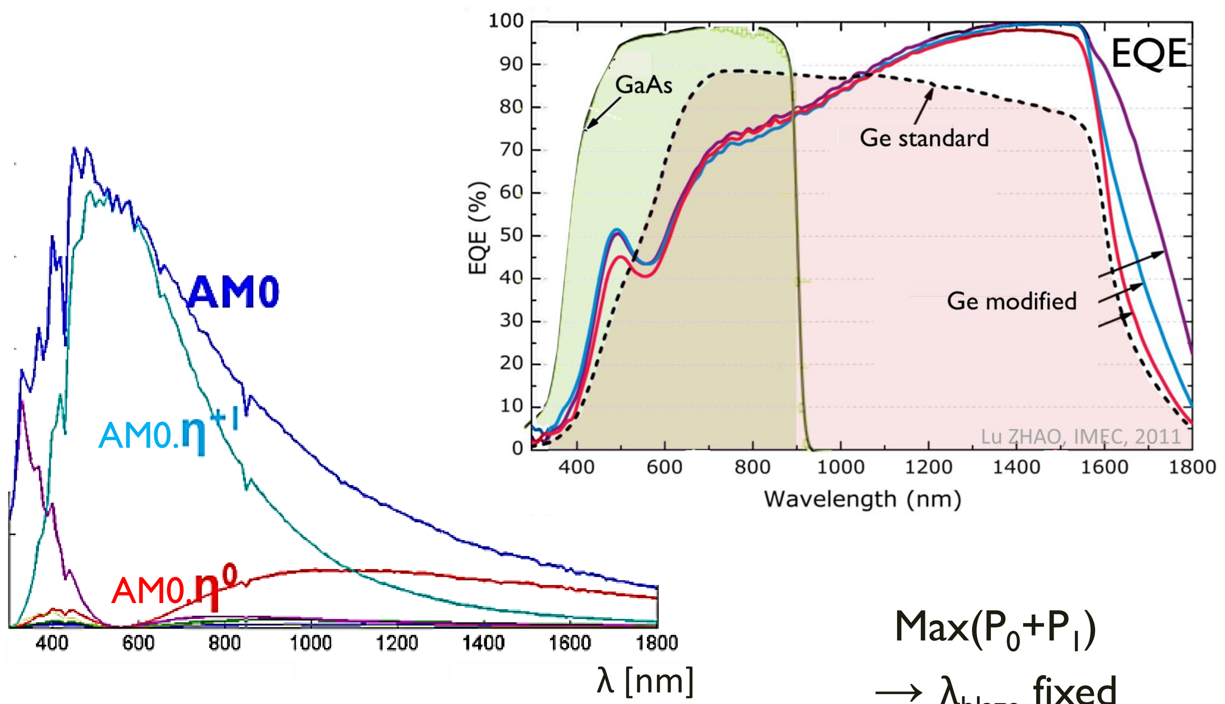
Cylindrical refractive Fresnel lens — Concentration

0^{th} diffraction order — IR cell

1^{st} diffraction order — Near IR - visible - UV cell

Design and optimization : a lot of constraints → a compromise must be found

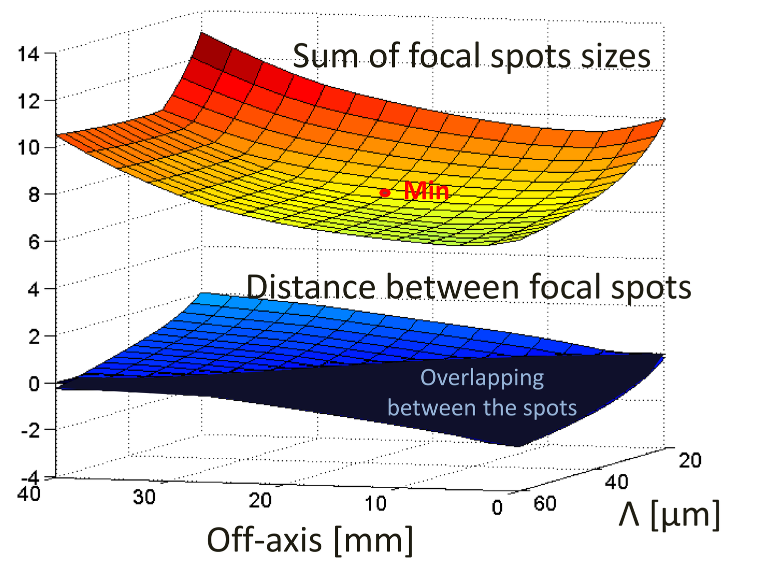
Maximum total output power



Max(P_0+P_1) → λ_{blaze} fixed

$$P_0+P_1 = \int AM0.\eta^0_{diff}(\lambda_{blaze}).\frac{\lambda.q}{h.c}.EQE_{Ge}\,d\lambda + \int AM0.\eta^1_{diff}(\lambda_{blaze}).\frac{\lambda.q}{h.c}.EQE_{GaAs}\,d\lambda$$

Maximum geometrical concentration ratio

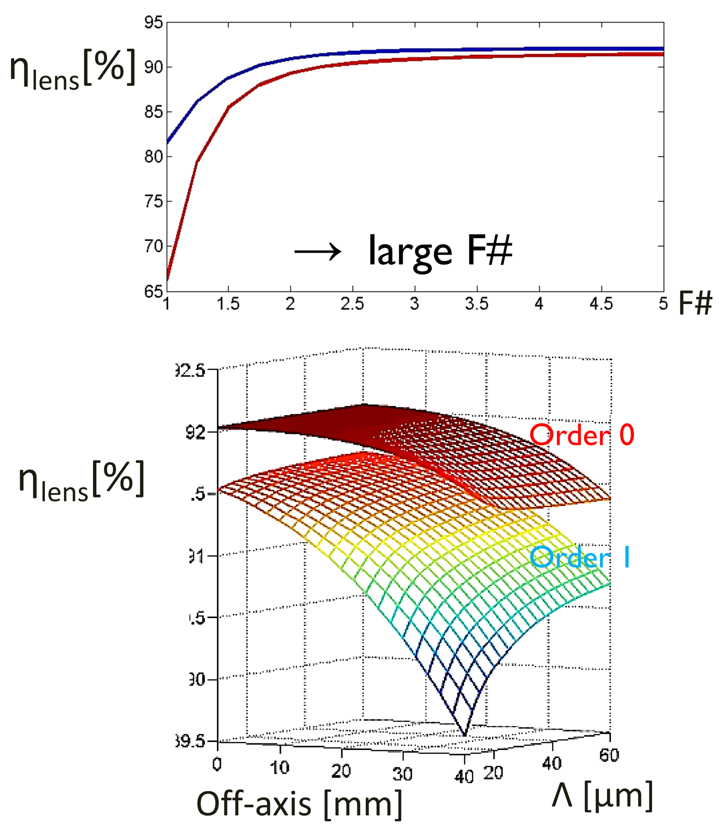


→ (Λ, off-axis, F#) are related
→ minimum encountered for distance = 0

Max 2^{nd} order diffracted light collection recovery → large Λ

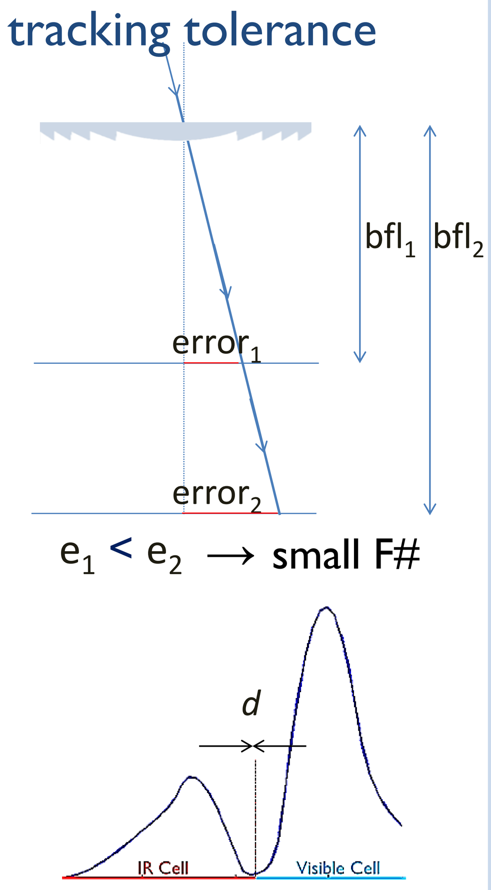
Thermal constraints → C_{geo} is limited

Maximum lens transmission efficiency



→ large Λ and small off-axis

The best tracking tolerance

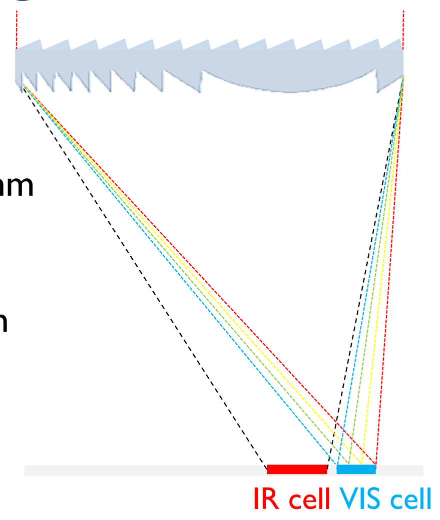


$e_1 < e_2$ → small F#

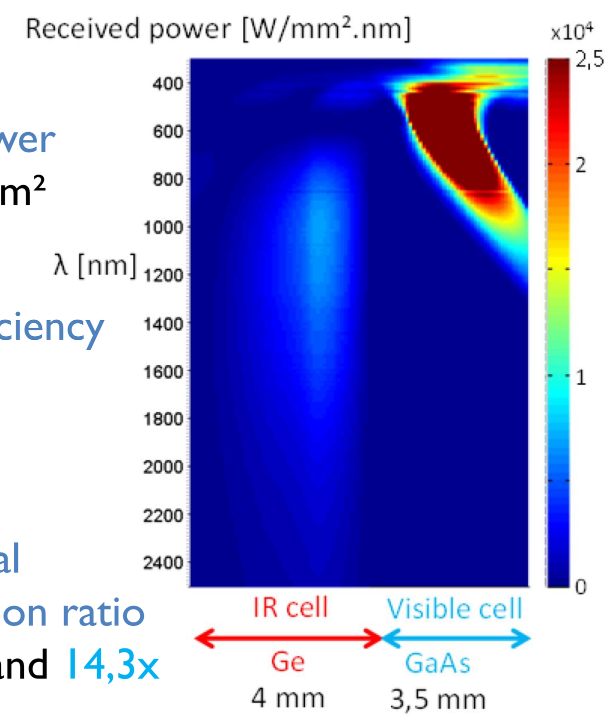
→ distance > 0

Different configurations have been studied : the results are promising

First configuration



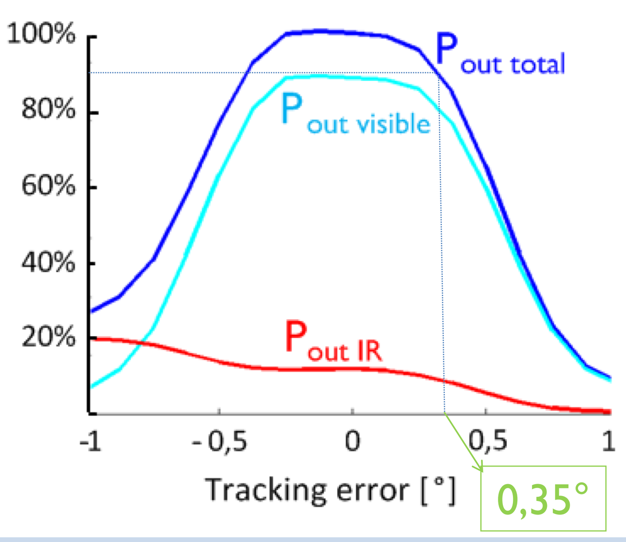
Diameter = 50mm
F# = 3
Λ = 38,7µm
Off-axis = 24mm



Output power 290W/m²

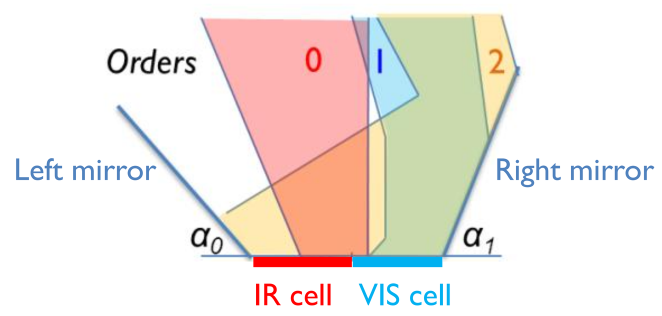
Optical efficiency > 70%

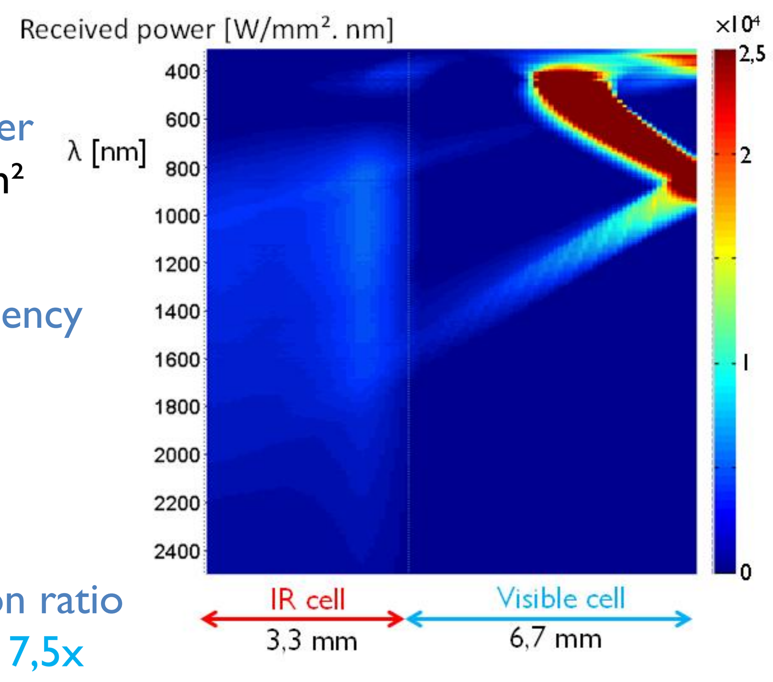
Geometrical concentration ratio 12,5x and 14,3x



With secondary concentrators

Diameter = 50mm
F# = 3
Λ = 20µm
Off-axis = 32mm
α_0 = 62,8
α_1 = 85,2

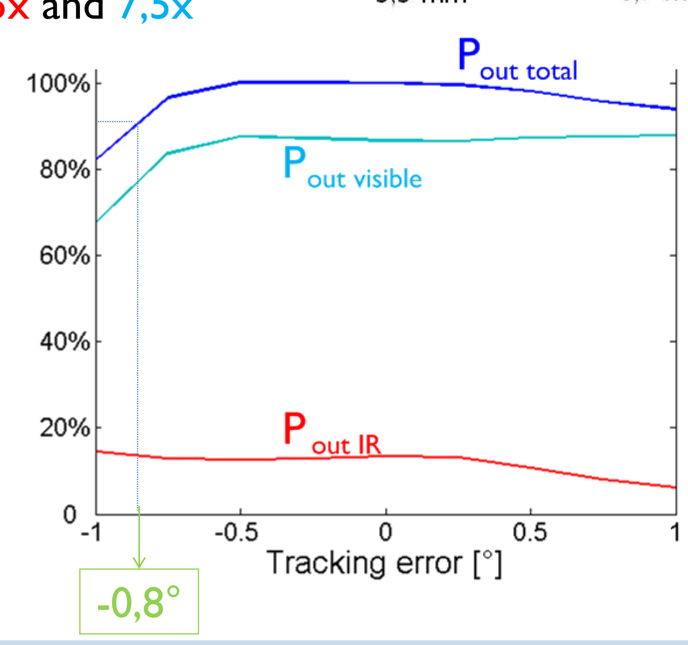




Output power 290W/m²

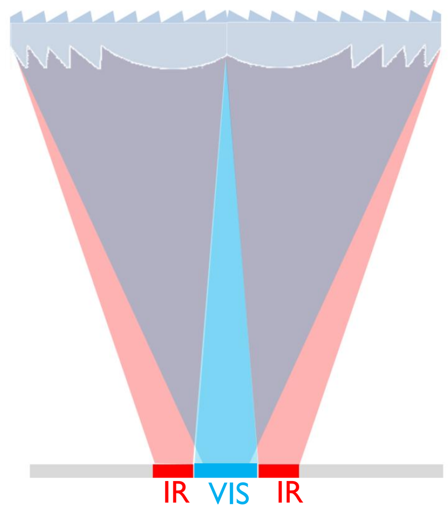
Optical efficiency > 70%

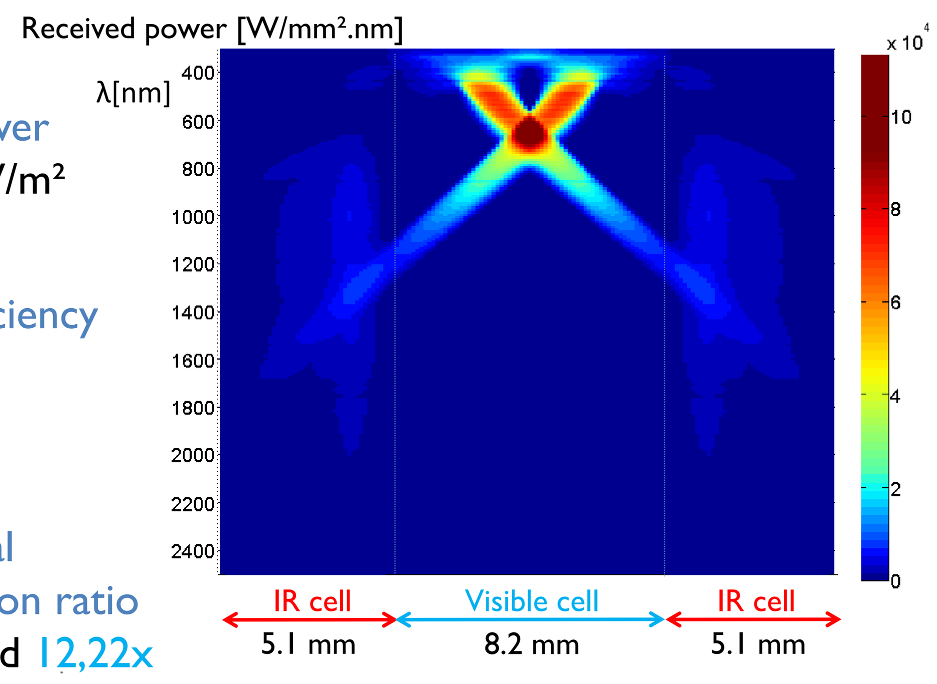
Geometrical concentration ratio 15x and 7,5x



Symmetrical design

Diameter of each lens = 50mm
F# = 3
Λ = 20µm
Off-axis of each lens = 25mm

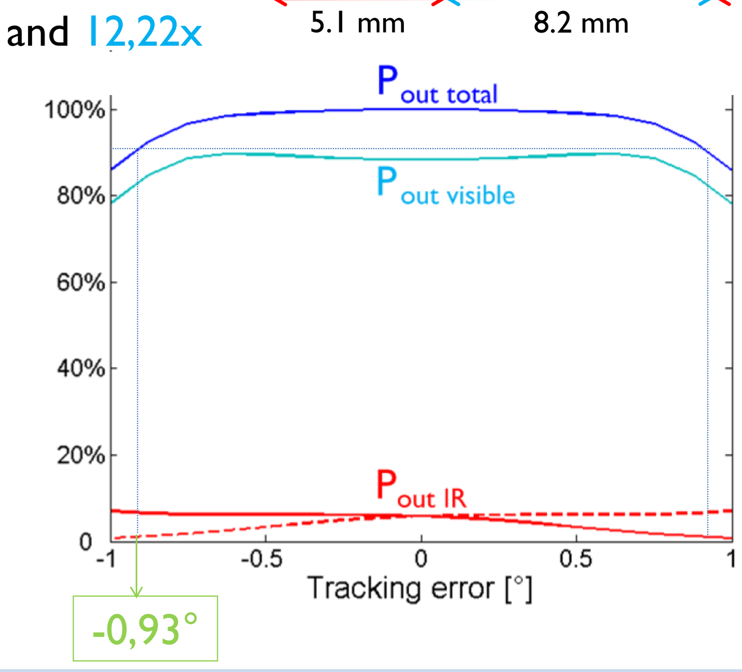




Output power >300W/m²

Optical efficiency > 75%

Geometrical concentration ratio 9,8x and 12,22x



Next steps : thermal simulation and validation

- Cell efficiency ↓ when the temperature ↑
- Space: no convection → heat transfer is difficult
  → hot spots appear on solar cells

⟹ A thermal simulation is necessary to know the maximal concentration that can be achieved without damaging the cells

Hypothesis : Sun divergence (±0,26°), AM0 spectrum, cell temperature = 65°C. Fresnel reflections and shadowing of the grooves are taken into account, diffraction efficiencies of the grating are computed from the scalar diffraction theory. The shapes of the Fresnel lens (in DC93-500 silicone) and of the diffraction grating are ideal (no draft angles, no rugosity, …). Light scattering is not included in the model.