Optical Study of a Spectrum Splitting Solar Concentrator based on a Combination of a Diffraction grating and a Fresnel lens

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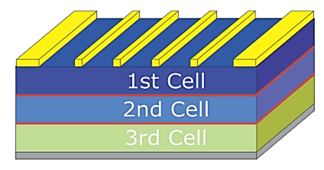
There are two solutions in order to reduce satellites high cost and space environment degradation

(1) Solar concentration : # solar cells/m² ↓ → cost ↓

Space environment
→ specific thermal conditions
→ desired solar concentration <10x

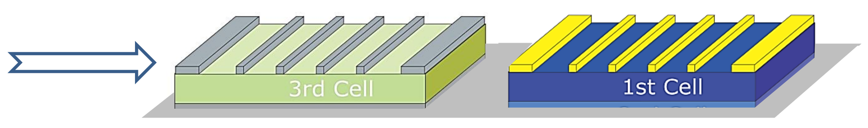
(2) Spectrum splitting



Current matching condition
→ power limited by the worst cell

Lattice matching condition at the interfaces

Total power = Σ powers
→ less sensitive to ageing, incident spectral changes, etc.

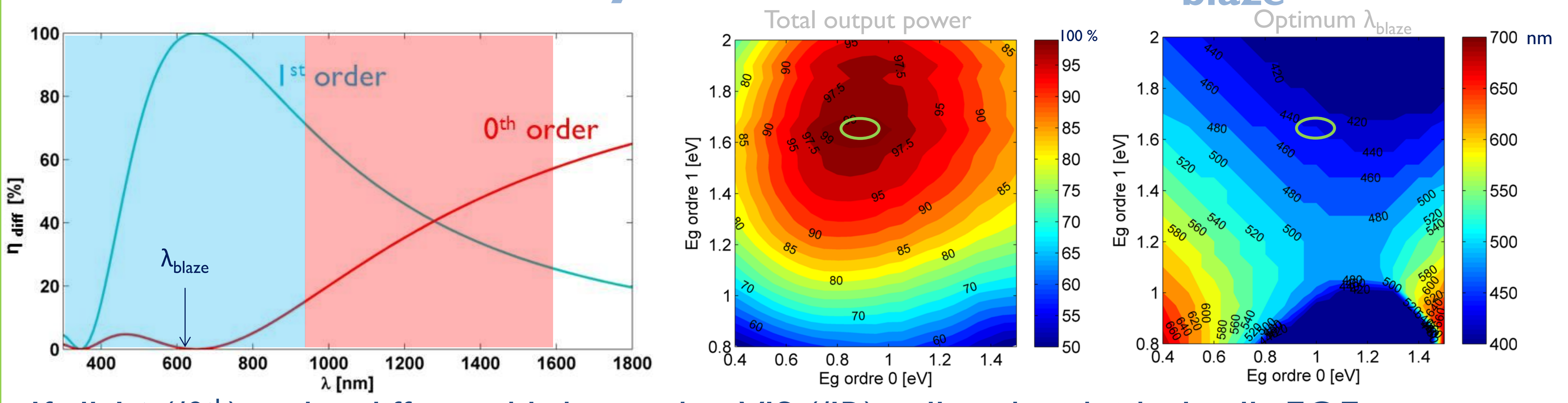


Free choice of materials

Two designs based on a diffraction grating/Fresnel lens combination are proposed:

(1) With a blazed grating

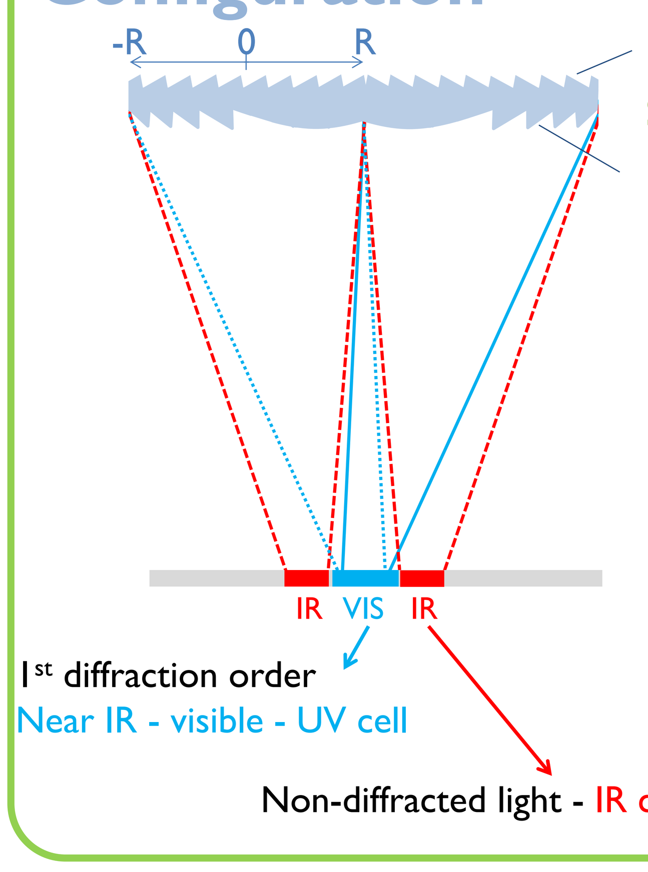
Diffraction efficiency → Ideal PV cell/ λ_{blaze} combination

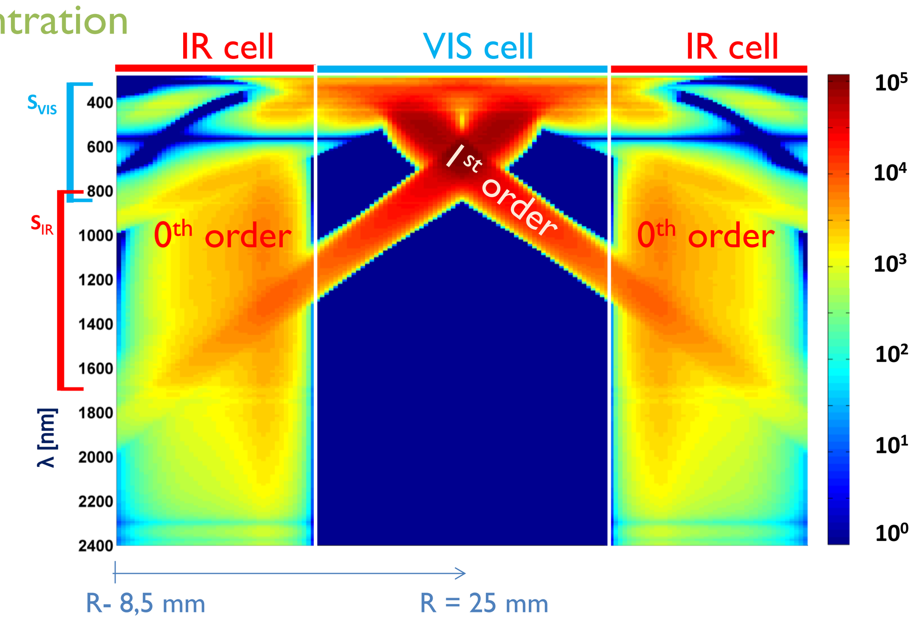


If all 1st (/0th) order diffracted light reaches VIS (/IR) cell, and with ideal cells EQEs (all photon with energy larger than the Eg is converted), we found the optimum combination of cells and λ_{blaze} : Eg_0 = 0,95eV and Eg_1 = 1,65 eV, λ_{blaze} = 450nm.

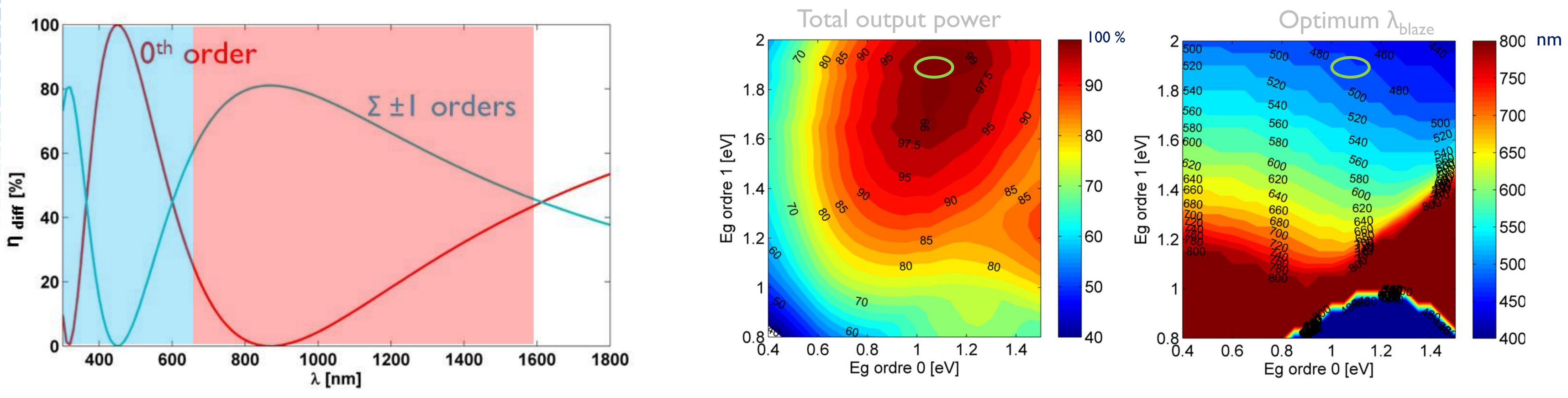
Configuration

For more information about optimization method see « C. Michel & al., *Sol. Energy Mat. Sol. Cells* **120** (2014) »

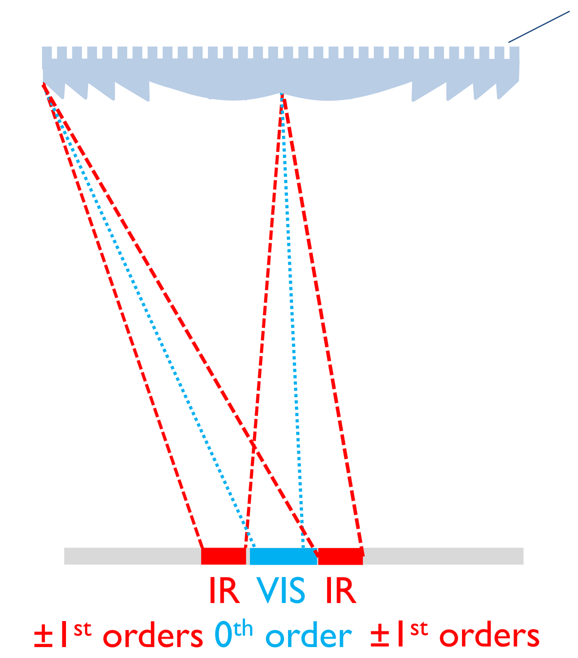


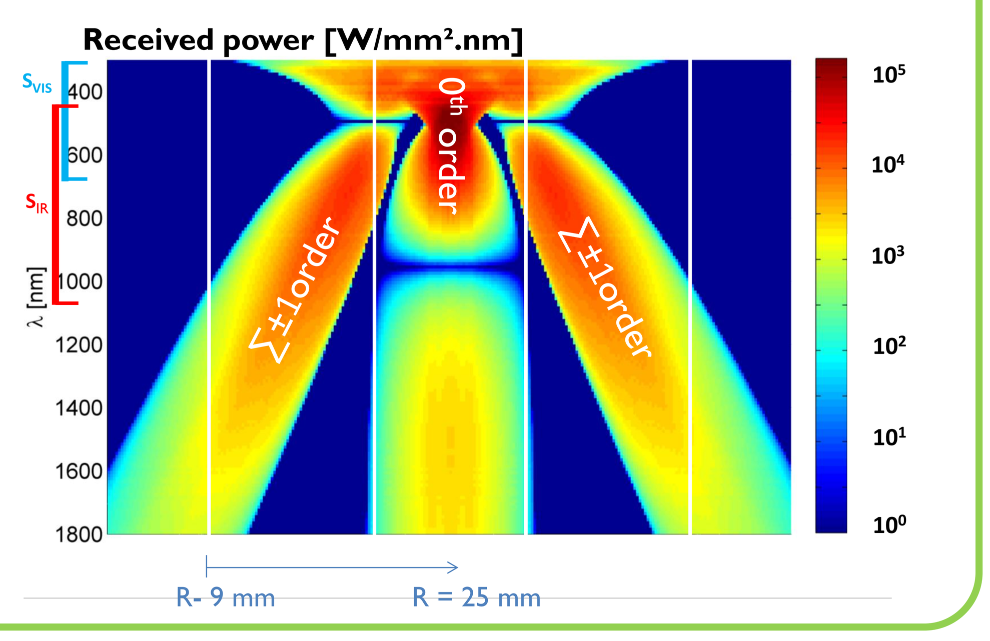


(2) With a lamellar grating



We found the optimum combination of cells and λ_{blaze}: Eg_0 = 1,05eV and Eg_1 = 1,9 eV, λ_{blaze} = 490nm.





IR C_{geo} increase through a variation of grating period along the lens

From 1st order optimized lens, the distribution of grating period along the lens is reoptimized in order to focus 1st order diffracted light in the same focal plane as the non-diffracted light, see adjacent picture

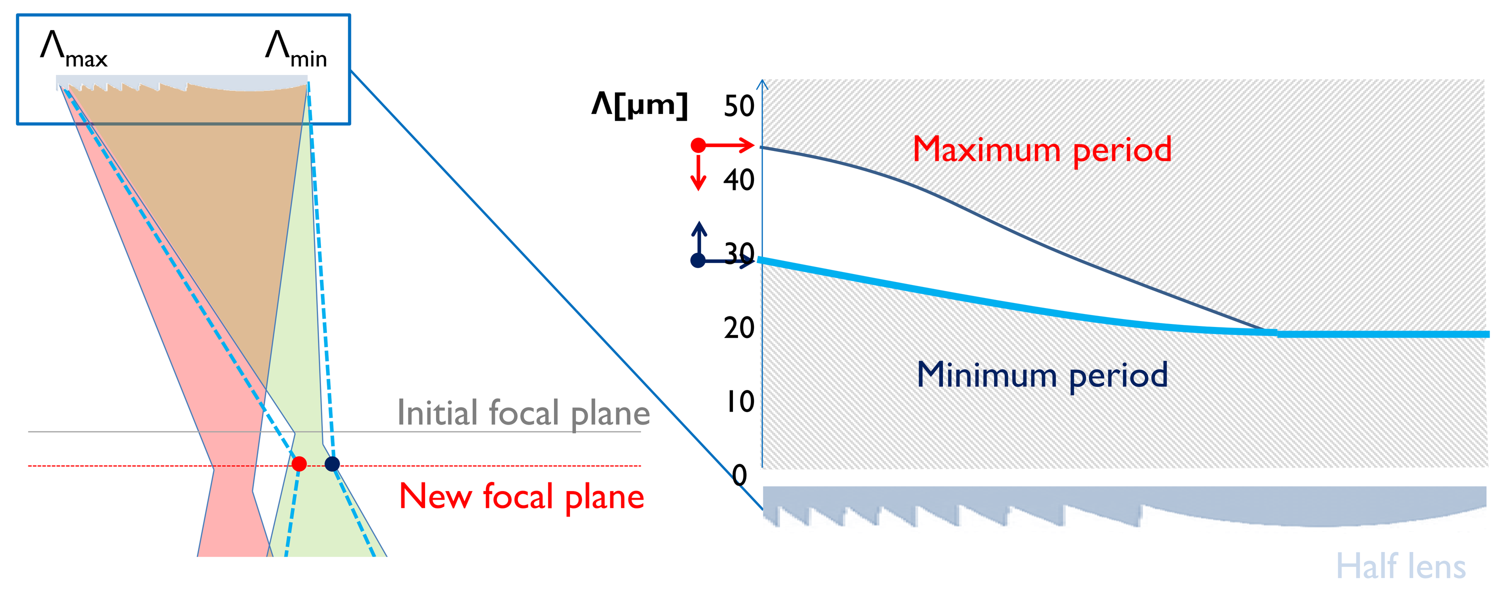
Blazed configuration

→ IR C_{geo} increases from 10x to 16x, without reducing VIS C_{geo} nor output power. Tracking tolerance is reduced from ±0.9° to ±0.85°.

Lamellar configuration

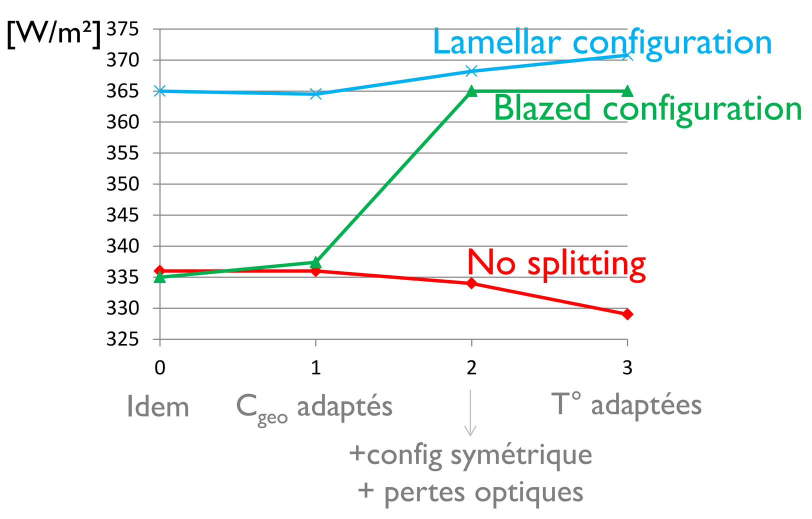
→ IR C_{geo} increases from 3x to >8x and VIS C_{geo} increases from 11x to >16x increasing also output power.

→ This method is essential for the lamellar configuration to reach interesting C_{geo}



Results with perfect EQEs

Configurations with light splitting are theoretically more performing than a concentrator focusing on a simple SJ cell



Results with more realistic EQEs

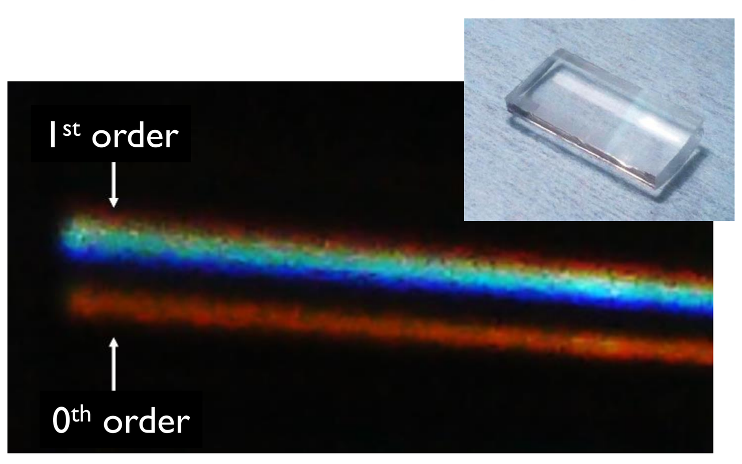
	No splitting	Blazed configuration	Lamellar configuration
	GaAs	3 Mono-Junctions	3 Mono-Junctions
Band-gaps [eV]	GaAs	1 GaAs (1.4) & 2 InGaAs (0.7)	2 Si (1.11) & 1 $In_{0.49}Ga_{0.51}P$ (1.83)
C_{geo} [×]	11	12 and 16 (global 6.85)	8.3 and 16.3 (global 5.49)
Average T_{cells} [°C]	80	70	65
P_{outmax} [W/m²]	282	287 (2×16.7+253.5)	299 (2×58+183)
λ_{blaze} [nm]	/	650	450
$\Theta_{90\%}$ [°]	0.85	0.8	0.7

Results can be improved by cells combination closer to the optimum found from ideal optimization.

The spectrum splitting light concentrator with two types of cells is theoretically advantageous compared to a classical concentrator focusing on a SJ. But, output power is still lower than a TJ cell. Advantages are then to be found in EOL output power, since the spectral splitting allows the use of SJ having a lower sensitivity to ageing or spectral change due to contamination etc. than MJ (cf. current matching condition). Moreover, the choice of cell is free: lighter, more radiation resistance, or cheaper cells can be chosen, specific coating to enhance performance can also been used on each cell. EOL output power can then be larger thanks to the light splitting! The panel cost is decreased thanks to the C_{geo}.

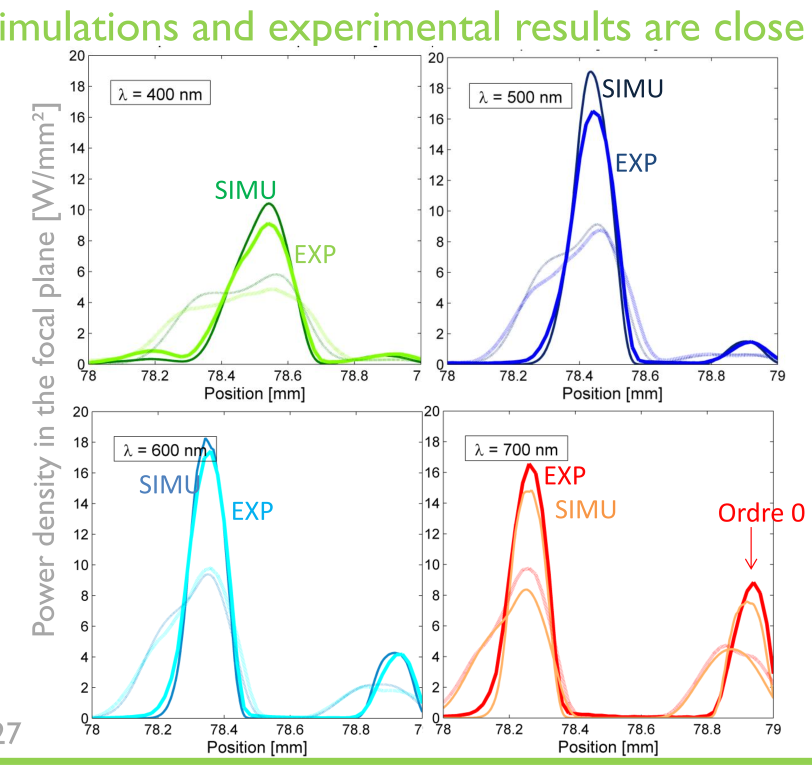
Experimental results

PMMA lens/NOA76 grating

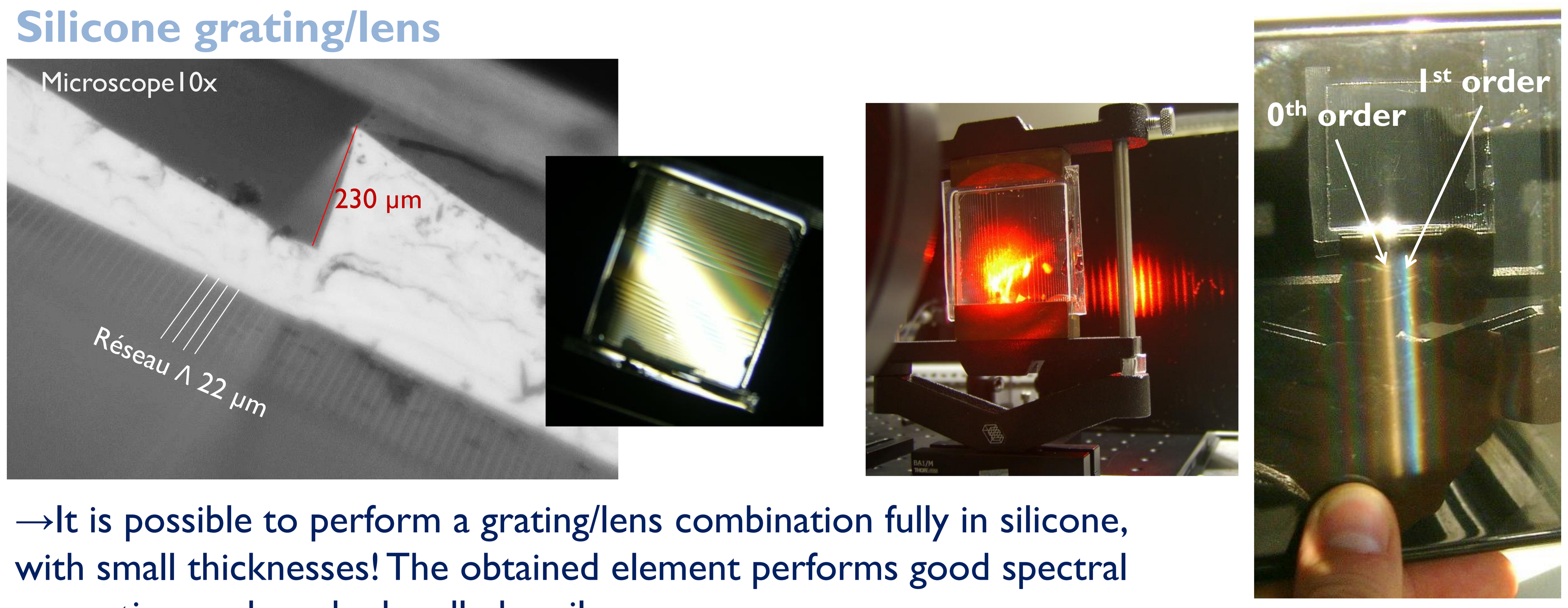


P. Blain *et al.*, Proc. SPIE, Brussels, 14-17 April 2014, Paper 9140-27

Simulations and experimental results are close



Silicone grating/lens



→It is possible to perform a grating/lens combination fully in silicone, with small thicknesses! The obtained element performs good spectral separation, and can be handled easily