Achromatization of solar concentrator using diffractive optics

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1. Objective

Our objective is to find a way to
- reduce chromatic aberration
- increase concentrating ratio
- make it easily replicable with a cost-efficient technology.

Thus the aim of our research is to find an alternative to doublets in order to improve -at low cost- the efficiency of solar concentrators. This will be done with a hybrid (refractive-diffractive) lens.

2. Theory : ideal diffractive lens

Equating OPL's until the desired focal point, we find the ideal profile.

Fig. 1: monolayer diffractive lens

Each zone introduces a 2π phase shift without discontinuity for the designed wavelength λ_o so that the scalar diffraction efficiency $\eta(\lambda_o)$ is 100%. The efficiency at the 1st order is given by

$$\eta_1 = \left| \frac{\sin[\pi(\alpha-1)]}{\pi(\alpha-1)} \right|^2 \quad \text{with} \quad \alpha(\lambda) = \frac{n(\lambda)-1}{n(\lambda_0)-1}\frac{\lambda_0}{\lambda}$$

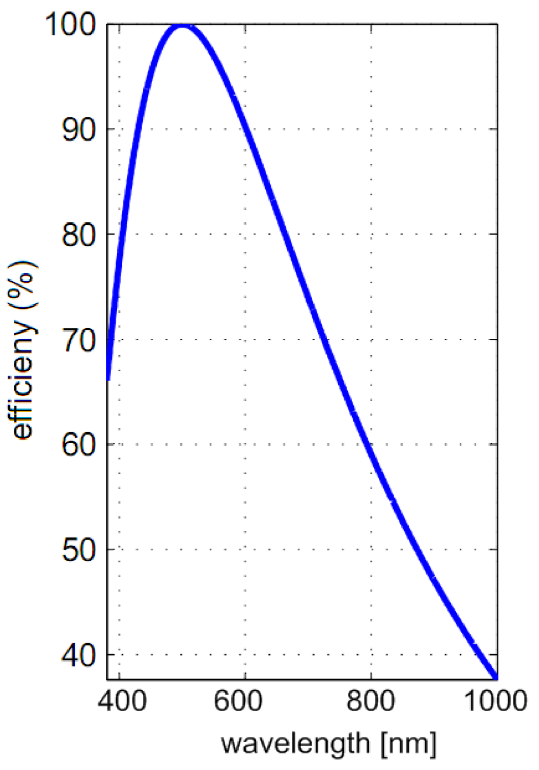


Fig. 2: diffraction efficiency for PMMA

Unfortunately the efficiency drops rapidly by illuminating the lens with another wavelength than λ_o [see Fig. 2]

Hopefully Adding layers of other material could reduce the wavelength dependence:

$$\alpha(\lambda) = \sum_i \frac{[n_i(\lambda) - n_{i+1}(\lambda)]\, d_i}{\lambda}$$

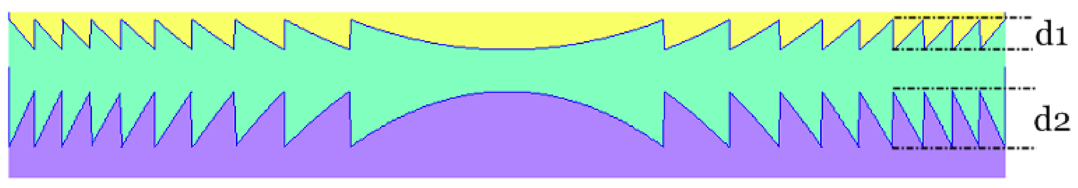


Fig. 3: multilayer diffractive lens

Not only the efficiency depends on the wavelength but also the focal length:

$$f(\lambda) = f(\lambda_0)\frac{\lambda_0}{\lambda}$$

so that the Abbe number is negative and independent of the material being used.

The use of a diffractive lens and a refractive one could thus easily lead to an achromatic system over a wide wavelength range.

3. Optimization on solar spectrum

With two layers (or more) we can easily reach 100% efficiency for two chosen wavelengths.

We can then integrate the energy coming from the sun and transmitted at the first diffraction order and optimize the energy transmitted by moving the maxima (= changing d_1 and d_2)

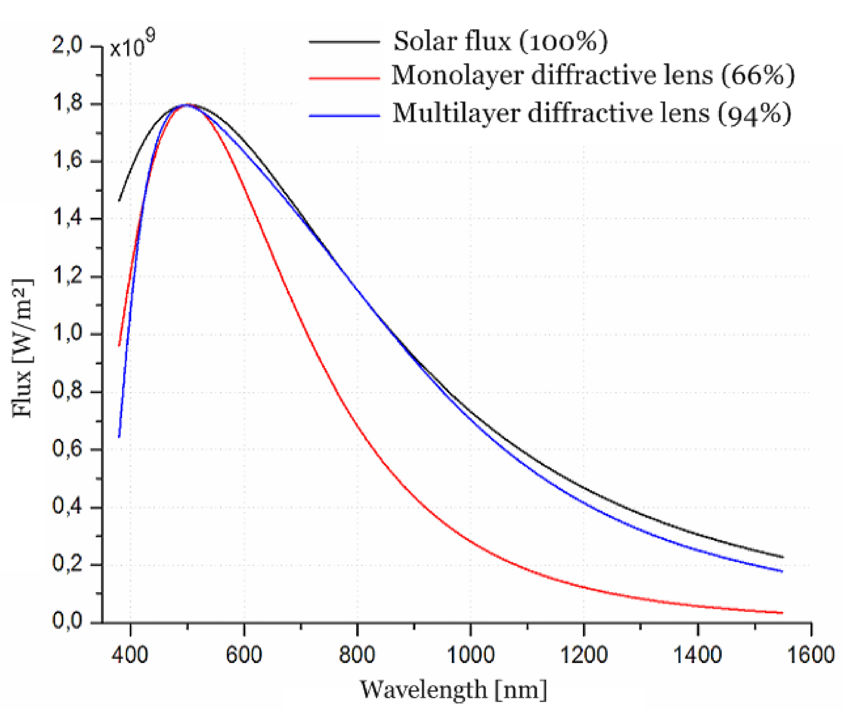


Fig. 4: flux at first order compared with solar flux

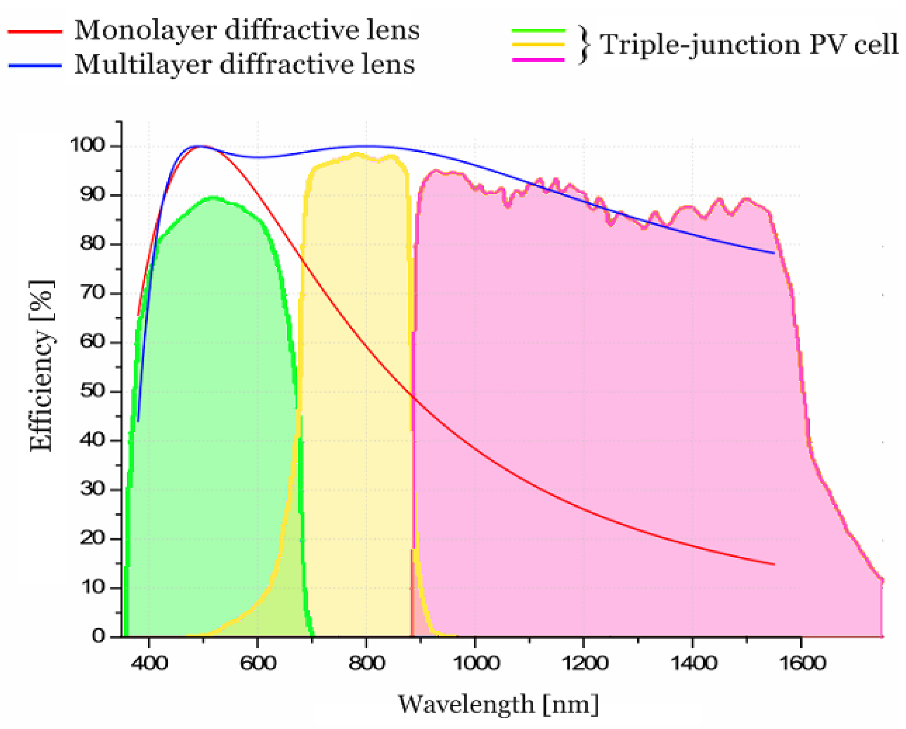


Fig. 5: 1st order diffraction efficiency compared with a triple junction PV cell

4. Hybrid lens vs refractive lens

With a lower chromatic aberration, higher concentrating ratio can be reached. Let's compare the amount of light reaching the cell with a hybrid lens and with a refractive lens for a geometrical ratio of 2500

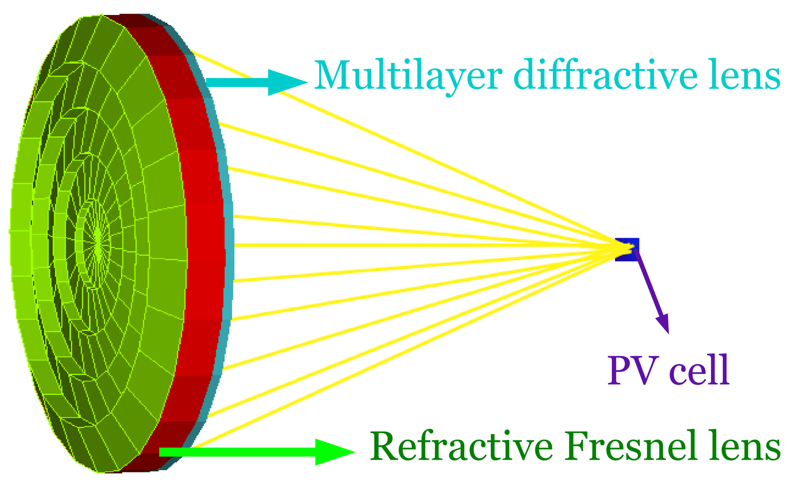


Fig. 6: schematic representation of a hybrid (refractive-diffractive) lens

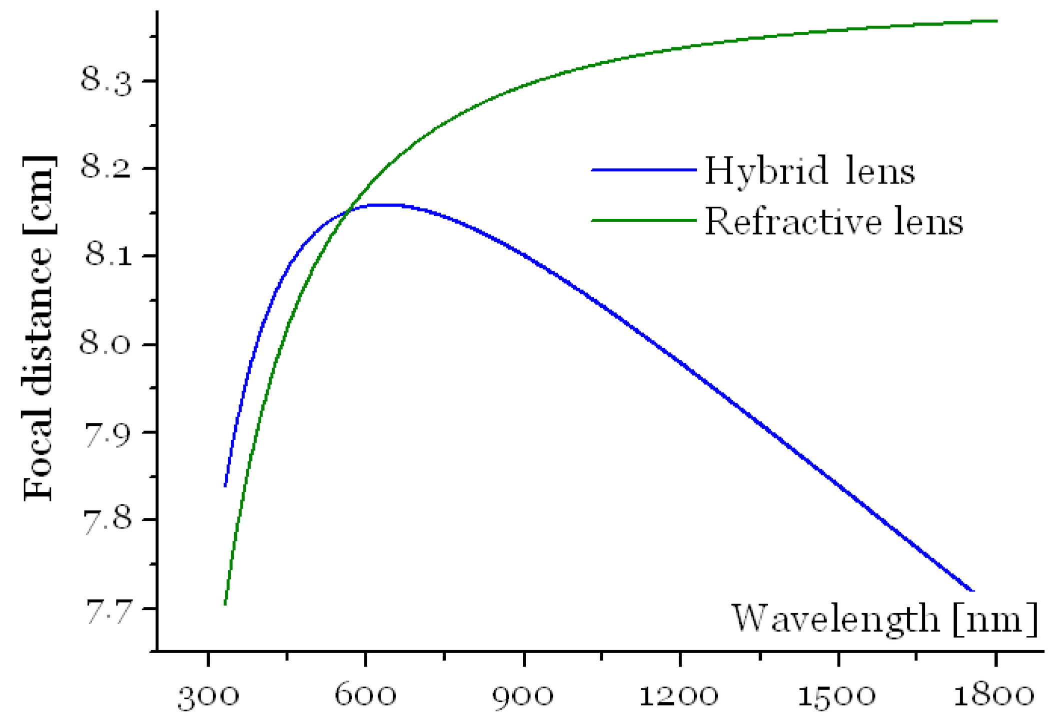


Fig. 7: focal distance in function of the wavelength for a refractive and a hybrid lens

Although the difference may seem small, the next picture compares two kinds of refractive lenses with a hybrid lens

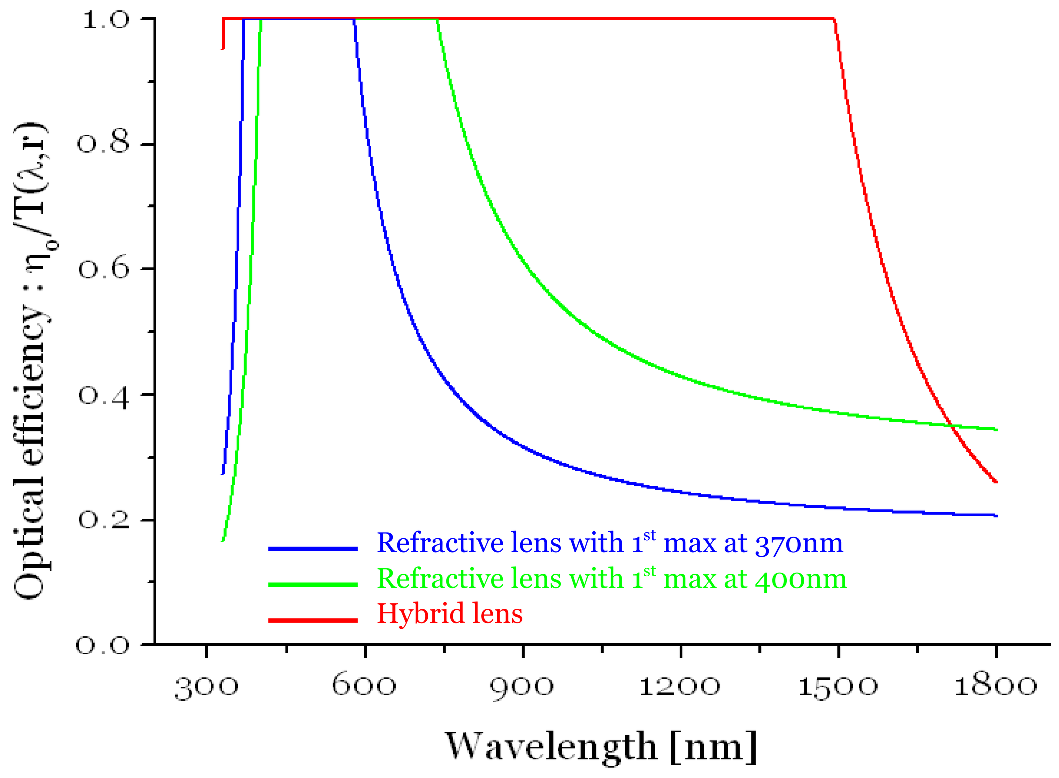


Fig. 8: optical efficiency for two refractive lenses and a hybrid lens in the case of a 2500 concentrating ratio

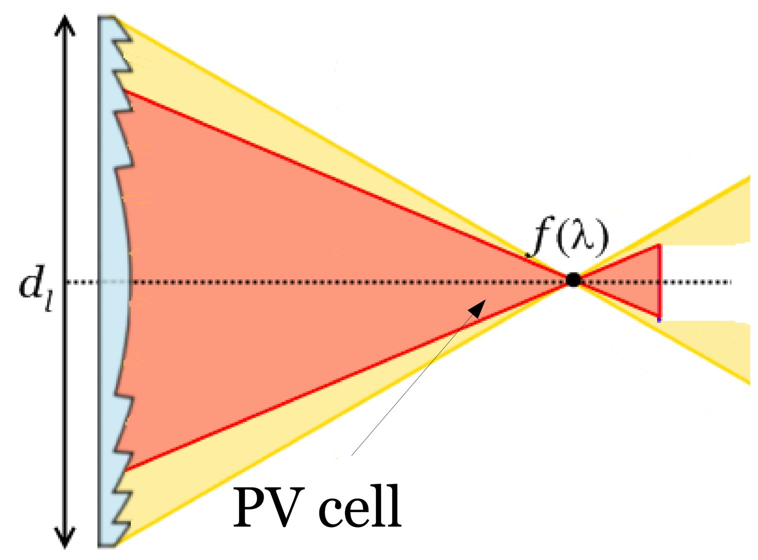
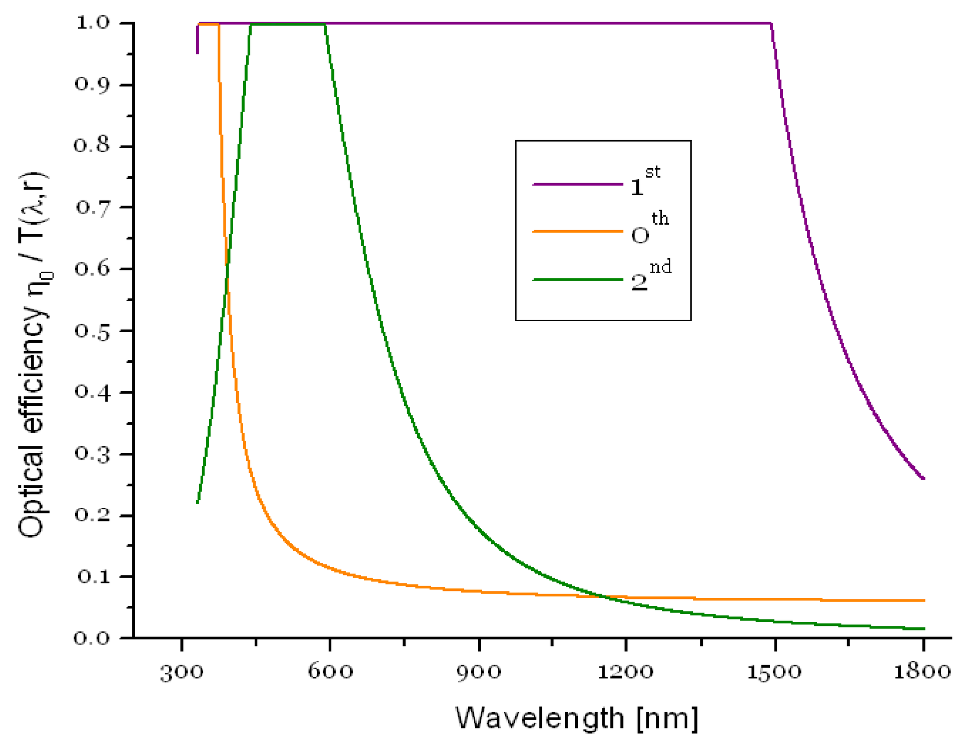


Fig. 9: the light reaching the cell (red part) depends on the focal distance

Moreover not only the 1st order but also a non negligible part of the 0th and 2nd order will reach the cell as shown on the following picture



5. First diamond turning tests

Fig. 10: 1st result of the diamond turning of the refractive part

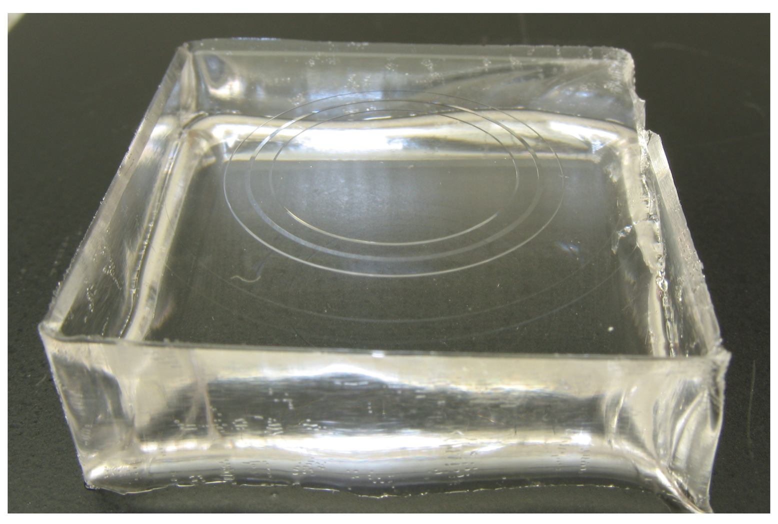


Fig. 11: silicone replica

6. Conclusions

Hybrid lenses represent a serious alternative to refractive doublets: they are thinner, lighter and cheaper if made by mass production.

The very first experimental results should be available soon.

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