Thermophotovoltaic cells for the conversion of energy stored at very high temperatures

PhD supervision : Alexis Vossier (PROMES)/ Guilhem Almuneau (LAAS)

Collaboration : Inès Massiot (LAAS)/ Rodolphe Vaillon (IES)

Context : The deployment of electricity production technologies based on so-called "variable" renewable energies (RE) is currently constrained by their limited dispatchability. Among the many storage solutions currently being studied to increase the dispatchability of renewable energies and promote a better match between production and demand, thermophotovoltaic (TPV) conversion of high-temperature heat is undeniably one of the most promising options, both technologically and economically. This technology for the thermal storage of concentrated solar energy, or even electrical energy (called "power-to-heat"), followed by conversion into electricity, is based on the combination of two key components: 1) a thermal radiation emitter based on silicon or tin, heated to very high temperatures by means of resistive heating; 2) a thermophotovoltaic conversion module, inserted in close vicinity of the thermal emitter, and enabling the radiation emitted by the latter to be converted into electricity. While this concept of energy storage in thermal form at high temperature has been the subject of several theoretical evaluations in recent years [1], [2], the experimental demonstration of its efficient conversion has been the subject of a recent publication that has received considerable attention: a conversion efficiency of 40% has been measured on tandem cell architectures exposed to radiation emitted by a heat source whose temperature is between 2000 and 2400°C [3].

The technical and economical interest of this storage method is largely constrained by the temperature level of the thermal emission source. A high emission temperature is indeed an important lever to ensure simultaneously:

- ✓ A high power density radiated by the emitter.
- ✓ A spectral distribution of the emitted radiation compatible with the use of solar cells characterized by bandgaps ≥ 1 eV.
- ✓ A low cost of the stored electricity (the relative cost of the cells being all the lower as the electrical power density supplied by them is high).

In this objective, a number of scientific and technological locks will necessarily have to be overcome, since TPV cells for high-temperature radiation conversion will operate in a very specific environment and conditions (non-standard: strong illumination from a thermal source) and will have to guarantee:

- ✓ A backside reflectivity of the cell close to 100% over a wide spectral range: an efficient reflection of the photons not absorbed by the cell towards the emitter being imperative in order to guarantee minimal optical losses and maximum efficiency.
- ✓ High conversion efficiency: the cell should be adapted to the radiation of the thermal emitter and may strongly depend on the optoelectronic properties of the semiconductor materials used.
- ✓ Minimal resistive losses: the exposure of TPV cells to high-temperature radiation will necessarily cause an increase in the current carried by them, as well as resistive losses.

This thesis project aims at developing optimized TPV cell technologies for the conversion of stored energy at very high temperatures. It will essentially be based on three complementary and interconnected axes:

1. *Theoretical evaluation of TPV cell architectures for high-temperature radiation conversion*: in particular, the performance of tandem cell architectures (based on a multi-junction *pn* stack [4] or thin III-V cells [5]) will be evaluated and compared. We will quantify how the different limiting mechanisms, such as resistive losses, parasitic absorptions, or non-radiative recombinations, are likely to affect the performances of the different cell architectures studied.

2. *Cell modeling*: based on the results of the theoretical evaluation work, the most promising cell architecture potentially meeting a number of performance and cost criteria will be selected and modeled in order to determine the optimal characteristics (in terms of doping, thickness, characteristics of the reflective structuring on the back side...). This work will be based on specific tools for optical and electrical modeling of components.

3. *TPV cell fabrication and characterization*: the last part of this work will be dedicated to the fabrication and characterization of a TPV cell architecture identified as particularly promising after the modeling work. A specific study will be conducted on the fabrication and characterization of the broadband reflector based on multilayers or/and nanophotonic structures. On the other hand, its technological integration to the cell based on III-As(N) semiconductors of adequate band gap (1-1.4eV) will also be studied.

Required profile: Engineer or Master 2 (physics/energy/materials).

Skills in physics, optics, material science and semiconductor physics, knowledge in the field of photovoltaic conversion will be appreciated.

Bibliography :

[1] C. Amy, H. R. Seyf, M. A. Steiner, D. J. Friedman, et A. Henry, « Thermal energy grid storage using multi-junction photovoltaics », *Energy & Environmental Science*, vol. 12, nº 1, p. 334-343, 2019, doi: 10.1039/C8EE02341G.

[2] A. Datas, *Ultra-High Temperature Thermal Energy Storage, Transfer and Conversion*. Woodhead Publishing, 2020.

[3] A. LaPotin *et al.*, « Thermophotovoltaic efficiency of 40% », *Nature*, vol. 604, nº 7905, p. 287-291, avr. 2022, doi: 10.1038/s41586-022-04473-y.

[4] M. El-Gahouchi, M. R. Aziziyan, R. Arès, S. Fafard, et A. Boucherif, « Cost-effective energy harvesting at ultra-high concentration with duplicated concentrated photovoltaic solar cells », *Energy Science & Engineering*, vol. 8, nº 8, p. 2760-2770, 2020, doi: 10.1002/ese3.692.

[5] H.-L. Chen *et al.*, « A 19.9%-efficient ultrathin solar cell based on a 205-nm-thick GaAs absorber and a silver nanostructured back mirror », *Nat Energy*, vol. 4, nº 9, p. 761-767, sept. 2019, doi: 10.1038/s41560-019-0434-y.