

Thermal radiation to electric energy conversion using silicon meta-materials based TPV systems

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Introduction and context

According to recent studies [1], 90% of the world's energy consumption involves production or manipulation of heat over a wide temperature range. As a result, thermal energy and heat management is a central point in our energy production/consumption. Thermal energy can also be converted into other forms of energy such as electricity. It can be done by thermoelectric conversion, for example, but this requires maintaining a temperature difference between the two faces of a solid component. A promising alternative is thermophotovoltaic conversion (TPV) [2–6], which converts the radiative heat flux emitted by a hot body into electricity using a photovoltaic cell that operates in the infrared spectral range (Figure 1). Multiple sources of heat (thermal engines, industrial heat waste, solar heat, etc.) could be used for this purpose. The operating principle of a TPV system is illustrated in Figure 1.

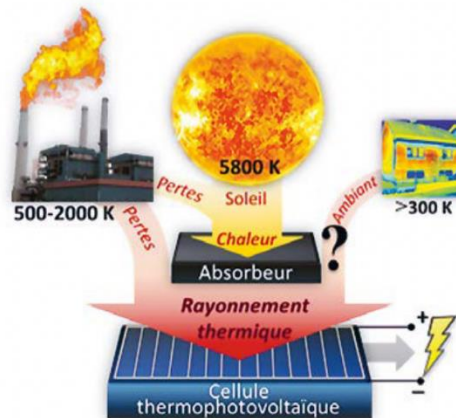


Figure 1: Principle of thermophotovoltaic conversion [5].

In the case of solar photovoltaics (PV), the radiation spectrum (sun radiation in this case) is given and cannot be controlled. It is the main source of efficiency limitations in PV since all radiation with energy smaller than the cell bandgap is not converted into electricity and is lost. Contrarily, in TPV, it is possible to control, at least partially, the radiative properties of the radiation source, to match the used TPV cell efficiency spectrum and improve the system overall efficiency by maximizing the part of thermal radiation with energy larger than the cell bandgap ($E > E_g$ or $\lambda < \lambda_g$). Spectral radiation control is one of the key strategies to reach high efficiency TPV systems. As shown in Figure 2-a, only a part of the emitted radiation (total black body radiation, in orange), with wavelengths shorter than the gap wavelength λ_g , can be converted by a given PV or TPV cell. An optimal system therefore requires the concentration of the emitted radiation in the so-called "emission window" ($\lambda < \lambda_g$) which can be achieved using different IR photonics techniques for radiation spectral control.

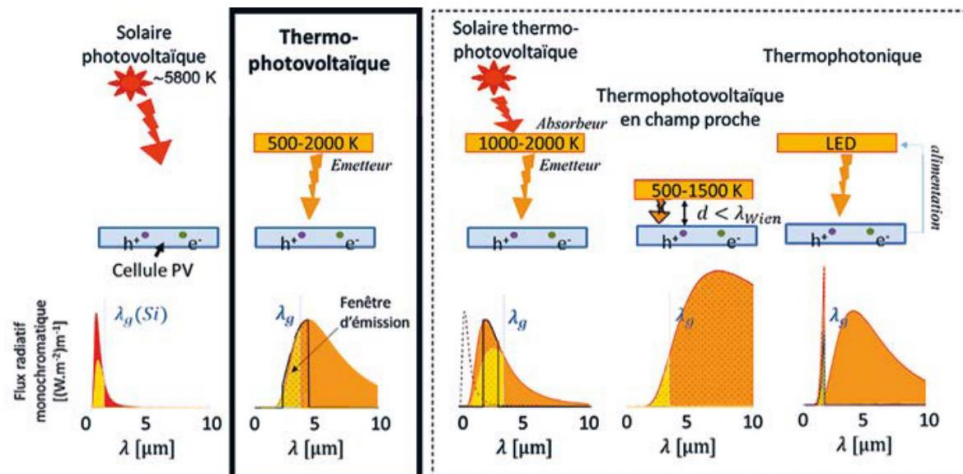


Figure 2: The family of thermophotovoltaic concepts [5].

Many IR meta-materials have been studied at ESYCOM Lab during the past decade to tune the spectral range of thermal radiative properties [10]. These materials can be tuned and used as selective emitters for high efficiency TPV applications. An ongoing PhD project currently focuses on the numerical optimization and tuning of silicon selective emitters to match specific TPV cells [11]. The present project will benefit from the laboratory expertise and recent results in such meta-materials design, optimization, and fabrication to integrate them into a high efficiency TPV system.

Workplan:

This project aims to:

- Design and build an experimental setup for the characterization of far field TPV systems
- Design, Optimize and Fabricate selective emitters for TPV based on the specifications of commercial TPV cells,
- Model the whole TPV system including the heat source, the selective emitter, the cavity and the cell to predict the system performances using specific emitter and cell,
- Integrate the fabricated selective emitters in the TPV system,
- Experimentally assess the performances of the whole system,
- Study the effect of operating conditions (temperature, time, aging) on different components and the whole system's performance.

Candidate profile:

We are seeking candidates with an MSc in Engineering, specializing in mechanical engineering, electrical engineering, or solid-state physics. A strong background in heat transfer—particularly radiative heat transfer—physics of photovoltaic devices, micro- and nano-materials, and photonics is highly desirable. Candidates with a demonstrated interest in both experimental work and modeling are especially encouraged to apply. Proficiency in English is essential. The ideal candidate will be self-motivated, scientifically curious, and possess excellent communication skills along with a strong ability to work collaboratively within a team.

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The ESYCOM laboratory specializes in the engineering of communication systems, sensors and microsystems for the city, the environment and the individual.

More specifically, the topics addressed are:

- antennas and propagation in complex environments, photonic - microwave components.
- microsystems for environmental analysis and depollution, for health and the interface with living organisms.
- Energy Harvesting, including micro-devices for recovering ambient mechanical, thermal or electromagnetic energy.