Study of the thermophysical properties of silicon-based metamaterials for applications in thermophotovoltaic devices

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Filière: Energy, Electronic

Context and motivations:

Recent studies [1] prove that approximately all of the world's energy consumption involves the 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 from a hot body, which can be removed from the recuperator, via a photovoltaic cell that operates in the infrared spectral range (cf. figure 1). Multiple sources of heat (vehicle engines, factories, etc.) could be put to use.

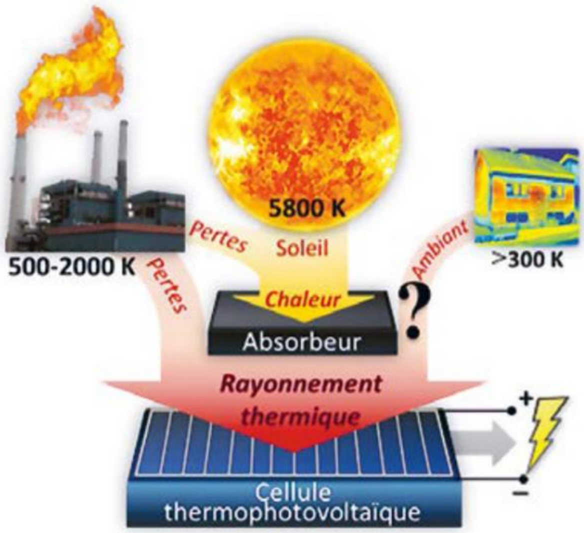

Figure 1 : Principle of thermophotovoltaic conversion [5]

Unlike the case of solar photovoltaics, it is possible to control, at least partially, the radiative (optical) properties of the hot source for the TPV device or, if the source and the cell are close enough, to return the radiation not converted by the cell to the source to avoid yield losses. In Figure 2, only part of the maximum radiation that can be received (black body, in orange), the "emission window", is emitted by the hot body. This makes it possible in principle to optimize the radiation emitted by the source in order to convert a large part of it, for example by concentrating the power emitted just below the gap wavelength. The theoretical maximum efficiency is then close to 100%. But this also means that the electrical power generated is

lower, since the emission window is reduced. Contrary to the case of PV, efficiency and power generated are not systematically proportional for the TPV.
The other key element is the TPV cell. Materials whose gap energy is located in the infrared are few in number and some, notably InSb, must even be cooled to operate (as are IR detectors). One of the important challenges is to design TPV cells that operate at temperatures close to ambient without cooling.

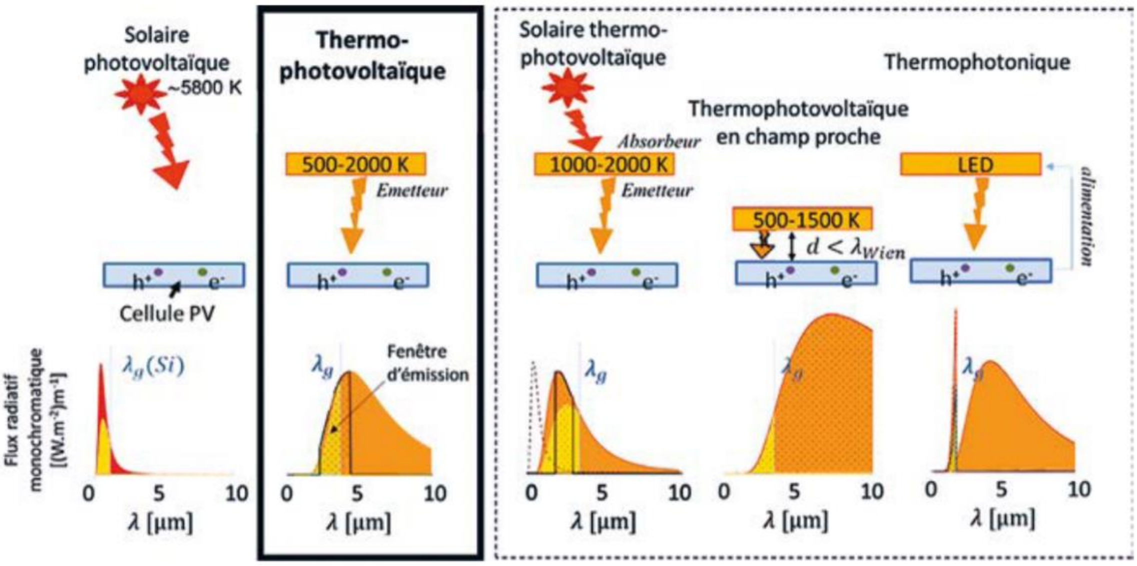

Figure 2 : The family of thermophotovoltaic concepts [6].

Objectives:

This project aims to understand the IR properties of a new Silicon based metamaterials, called Black Silicon (BSi), and its possible usage in TPV devices. This so called BSi metamaterial was chosen to be studied because recent studies have shown that the BSi has solar photothermal conversion properties [7] and antireflection properties in both the visible and infrared [8,9].
The first step is to be able to measure the IR emission and establish radiative properties (mainly the emissivity) of BSi in function of the temperature. Where, the emissivity of materials is an important radiative thermal property that finds numerous applications in energy management, including radiative cooling, solar cells, infrared photodetectors, and broad-spectrum optical sources.

The research student will first help with the optimization of the experimental direct emissivity's measurement setup. Then, alongside our PhD student, check if the BSi metamaterial can be used efficiently as a TPV cell. One should know that the properties of the BSi samples depend on the fabrication process, hence can be tuned. The fabricated BSi will be tested under real life TPV usage in our collaborator laboratory.
This work will help us to better understand the BSi radiative properties, and hopefully find a way to use it in TPV applications.

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