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

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Context and motivations:

Recent studies [1] prove that a large part 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 transforms the radiative heat flux from a hot body to electricity via a photovoltaic cell that operates in the infrared spectral range (cf. figure 1), by the intermediate of an absorber, which convert global heat flux to a selective infrared heat flux. Multiple sources of heat (vehicle engines, factories, etc.) could be put to use.

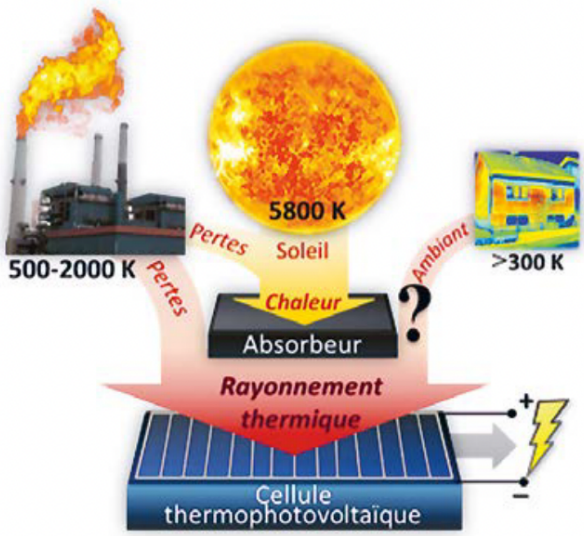

Figure 1 : Principle of thermophotovoltaic conversion [5]

Unlike the case of solar photovoltaics, it is possible to control, at least partially, the radiative (optical) properties from the hot source to 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 converted by the cell. 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.

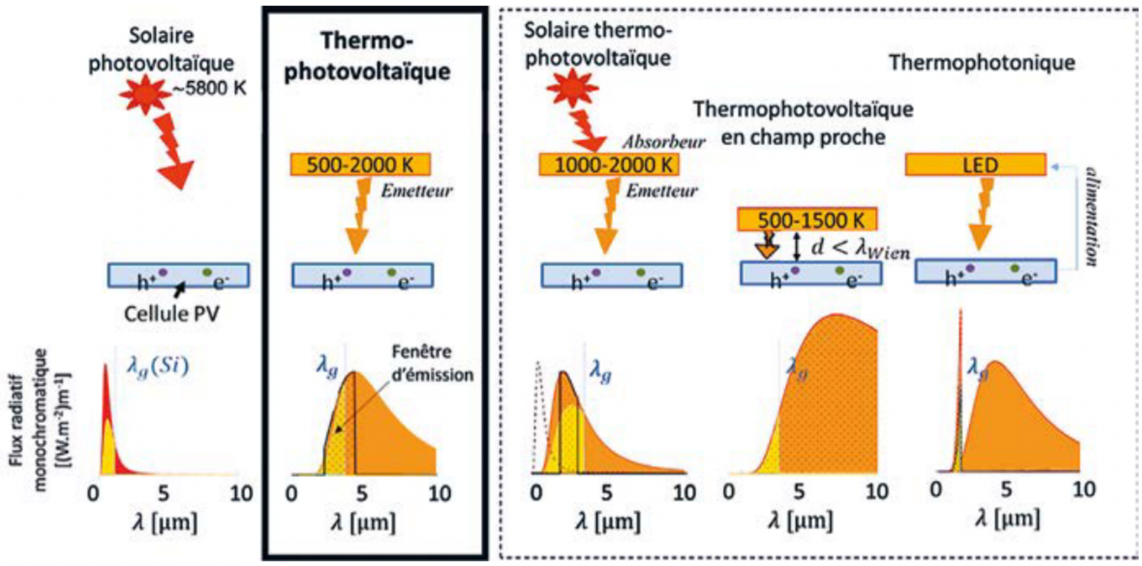

Figure 2 : The family of thermophotovoltaic concepts [6].

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. 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 initially focus on optimizing the experimental setup for direct emissivity measurements. Following this, the student will investigate the potential of using BSi metamaterial effectively as a TPV cell and/or emitter. This will involve developing a new bench setup to assess BSi's performance as an emitter when paired with commercial TPV cells. BSi samples will be heated using a 4" Bach ceramic heater capable of reaching temperatures up to 500℃. Notably, the properties of BSi samples are fabrication-dependent, allowing for potential tuning to achieve desired characteristics. The fabricated BSi will undergo testing under real-life TPV conditions in our collaborator’s laboratory, with the goal of advancing our understanding of BSi's radiative properties and its possible applications in TPV technology.

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