PhD thesis proposal

Thermal radiation at the nanoscale and implications for energy-conversion applications

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Context: Thermal radiation is one of the main heat transfer mechanisms with heat conduction and heat convection, which exists even in absence of matter. It allows to harvest power, for instance from the sun by photovoltaic means. At usual macroscopic scale, one can neglect many electromagnetic features of the thermal-radiation carriers (photons) which are considered as particles, but this is not possible at nanoscale, where interference and sub-wavelength effects, including photon tunneling, enter into play. In particular, the heat exchanged between two bodies becomes huge when they are brought very close, in what is known as near-field thermal radiation exchange. Predicted 50 years ago, these effects have been demonstrated experimentally in the last ten years. Since important quantity of energy is exchanged, it is interesting to try to convert it in electricity, in energy-harvesting devices. We have demonstrated experimentally that devices with 15% efficiency can be used to harvest power as high as 10 kW.m-2 in near-field thermophotovoltaic devices [1]. We therefore measure in the same time the energy exchange between hot and cold bodies, and the power converted into electricity in a photovoltaic cell placed at the sample location. Such experimental work is backed by advanced numerical modelling based on electromagnetism and thermodynamics [2].

Objective: The goal of the PhD thesis is to develop new technologies of radiative energy harvesting accompanying thermophotovoltaics and thermophotonics, which resonate with the current need for improved energy management at the global scale. Both numerical and experimental works can be performed. On the numerical side, we aim at generalizing the existing work on samples consisting of flat layers (See Figure (b)) to structured surfaces allowing to optimize further the energy conversion performances. On the experimental side the candidate will work with an AFM-based setup (see Figure (b)) to measure the conversion power and efficiencies of devices. Sample characterization will be performed using advanced infrared spectroscopy techniques.

(a)

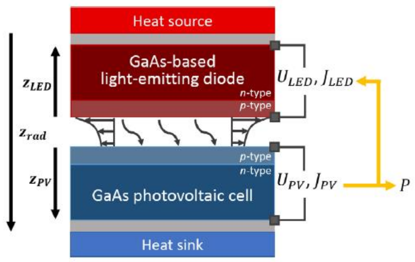

Figure (a)
Theoretical configuration for thermophotonic (TPX) energy conversion. The radiative energy emitted by high quality LEDs can, in theory, be higher than the electric energy supplied to them. The energy difference is obtained by extracting heat from the heat source (electroluminescent cooling). The emitted radiation is converted back to electricity using a PV cell of similar characteristics as the LED. Part of the produced power is used to feed the LED , the remaining power can then be harvested [3].

(b)

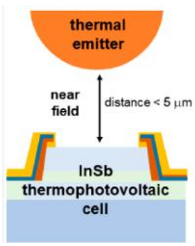

Figure (b)
Schematic of a near-field harvesting device. The thermal radiation emitted by the sphere is converted to electricity using an InSb thermophotovoltaic cell. By bringing the thermal emitter in close vicinity of the cell, power conversion can be enhanced by exploiting the exponentially decaying electromagnetic modes [1].

References:

[1] Near-Field Thermophotovoltaic Conversion with High Electrical Power Density and Cell Efficiency above 14%, Lucchesi et al., Nano Letters, 11, 4524 (2021)

[2] Operating conditions and thermodynamic bounds of dual radiative heat engines, Legendre et al., arXiv:2402.07527, (2024)

[3] GaAs-based near-field thermophotonic devices: Approaching the idealized case with one-dimensional PN junctions, Legendre et al., Solar Energy Materials and Solar Cells Volume 238, 111594 (2022)

Hosting group: Micro and nanoscale heat transfer (MiNT) group at CETHIL - https://cethil.insa-lyon.fr/en/node/52.
The group is expert in nanoscale heat transfer and thermal-energy conversion, from atomic scale to macroscopic scale, and addresses topics related to heat conduction, thermal radiation and their applications energy-conversion devices such as thermophotovoltaics and thermoelectrics.

Collaboration: Collaborations with colleagues expert in nanophotonics, PV-cell technology and micro- and nanofabrication are expected.

Required background: Electrical or Mechanical engineering or Physics. Numerical simulations. Experimental work. Experience with electromagnetism would be highly desirable. The student will be able to learn many novel concepts and is not expected to be an expert of the field at the beginning.

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