Thermal radiation from structured materials: can macroscopic surfaces emit beyond the planar blackbody limit?

ESIEE Paris coordinator: Georges HAMAOUI
Laboratory: ESYCOM, ESIEE Paris – Université Gustave Eiffel
Level: Master 1 – E4 / Master 2 – E5 Research Internship program

A. Master internship proposal

Context and motivation

A blackbody represents the conventional reference for thermal radiation: at a given temperature, it defines the maximum thermal emission of an ideal planar surface. However, this description is usually expressed relative to the **projected area** of the emitter.

For a strongly structured three-dimensional surface, this definition raises an important question: **is projected area still sufficient to describe the thermal radiation emitted by the material?**

Recent experiments performed at ESYCOM and the University of Tokyo on micro- and nanostructured silicon (black silicon) suggest that some structured surfaces may exhibit an apparent far-field thermal emission larger than that of a planar blackbody occupying the same projected area. This observation does not imply a violation of Planck's law. Instead, it raises the possibility that morphology, optical cross-section and thermally excited electromagnetic modes must be considered when describing radiation from structured materials.

This research work will perform exploratory experiments and simulations to investigate this question on new structured materials, with particular interest in **silicon carbide (SiC)**. SiC is especially attractive because it supports surface phonon polaritons in the infrared and therefore provides a fundamentally different material platform from highly doped silicon.

Objectives

The main objective is to investigate whether **macroscopic structured surfaces can exhibit projected-area super-Planckian far-field thermal emission**, and to begin identifying the physical mechanisms responsible for this behavior.

The student will investigate structured SiC and/or silicon samples and compare their thermal emission with appropriate planar references. Depending on the progress of the internship, the experimental work will be complemented by electromagnetic simulations to study how morphology and surface electromagnetic modes affect absorption and thermal emission.

Three main questions will guide the work:

- **Can structured SiC exhibit enhanced far-field thermal emission compared with a planar reference?**
- **How does the morphology of the surface influence the measured thermal emission?**
- **Can electromagnetic simulations help identify the physical origin of the observed behavior, particularly the contribution of surface phonon-polariton modes?**

The objective is not necessarily to demonstrate super-Planckian emission during the internship. A rigorous demonstration that a given structure **does not** exceed the conventional projected-area reference, together with an understanding of why, would also constitute an important scientific result.

B. Master internship program

The work will be organized around four main steps:

1. Bibliographic study and theoretical foundations. The student will first become familiar with Planck's law, emissivity, blackbody radiation, Kirchhoff's law and thermal radiation from structured materials. Particular attention will be given to surface phonon polaritons in SiC and their possible interaction with structured surfaces.

2. Experimental characterization. The student will learn to use the FTIR thermal-radiation platforms available at ESYCOM. Thermal emission from structured samples will be measured as a function of wavelength and temperature and compared with planar SiC/Si references and calibrated blackbody references.

3. Electromagnetic simulations. Simple electromagnetic simulations will be performed to investigate the optical response of representative structures. Depending on the student's background and progress, these simulations may include absorption/emissivity calculations, electromagnetic-field distributions and the influence of geometrical parameters.

4. Experiment–simulation comparison. The experimental and numerical results will be combined to determine whether the measured emission can be explained by conventional surface-area effects or whether electromagnetic resonances and surface modes play a significant role.

C. Expected results

The research work will provide a first experimental and numerical assessment of far-field thermal emission from structured SiC or related materials. The results will contribute to a broader research programme at ESYCOM aimed at understanding the fundamental limits of thermal radiation from structured matter.

Depending on the results, the work may lead to further Master/PhD research and contribute to scientific publications.

D. Student profile

This is an ambitious fundamental-research project intended for a highly motivated student with an excellent academic record. The subject combines thermal physics, optics/electromagnetism, experiments and numerical modelling and therefore requires strong scientific curiosity and autonomy. A good background in heat transfer, electromagnetism, optics or condensed-matter physics is highly desirable. Previous experience with Python, MATLAB, COMSOL or experimental spectroscopy would be an advantage but is not mandatory.

I am particularly looking for a student interested in pursuing research beyond the internship (PhD level).