Black Silicon-based meta-materials: characterization of thermal and energy exchanges at interfaces

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Context

Heat management efforts aiming at controlling and reducing thermal losses in new electronic components require the development of new micro/nano-structured materials whose properties such as thermal diffusivity, thermal effusivity or the interfacial thermal resistance/conductance can be controlled[1,2] in order to improve the performance and reliability of systems.[3,4] The aim is to improve the performance of electronic systems by intervening at the nano- and micrometric scales, where the levels of heat dissipation at these small scales can be extremely high. In addition, applications such a thermal energy harvesting or cooling also require energy management at the nanoscale.[5] The development of appropriate experimental techniques[6] is therefore essential to measure, understand and control the thermophysical properties of these new materials, as well as their couplings.

Black Silicon (BSi), the material at the heart of this thesis, is the result of a "bottom-up" structuring of silicon at the sub-micron scale on which the ESYCOM laboratory has been working for many years.[7–9] In particular, due to its specific morphology, it is well known for its excellent absorption of almost 100% of incident visible light.[8,9] BSi also has solar photothermal conversion properties [10,14] and anti-reflective properties in both the visible and infrared spectra[11,12] which can provide rectification possibilities in innovative systems for heat dissipation applications. Its fascinating optical properties[10,13,14] allow it to be a privileged target for optimizing radiative heat transfer.[7,13] It has also attracted attention in thermoelectricity.[15] In addition, the original properties of this material can be controlled by varying several morphological (etching depth, aspect ratio of nanostructures) and electronic (doping) parameters in particular.[7–9]

Thesis subject

While the scientific literature has so far mainly focused on the optical properties of BSi, in this exploratory thesis we will focus on its thermophysical properties for heat management in electronic components. Two scientific and technological objectives should be addressed:

1) Fabrication and experimental characterization of new types of metamaterials based either on i) thin layers (from a few nanometers to a few micrometers) of BSi on substrates based on semiconductors, polymers or phase change materials; or on ii) nanocomposites of BSi with nano-inclusions of carbon nanotubes and graphene. This type of functionalization has already been shown to be suitable for improving optical properties.[16] For thermal applications (rectification, cooling, etc.), the temperature dependence of the considered materials physical properties is of paramount importance. Since these properties have so far been mainly studied at room temperature, a systematic characterization of their temperature dependence will be performed.

2) Design of new systems benefiting from the meta-materials manufactured and characterized in phase 1 and with potential for innovative thermal energy management, such as rectification for example. Finite element simulations will enable the design and numerical optimization of these systems before experimental validation

The fabrication of BSi-based materials will mainly be carried out in the clean rooms of University Gustave Eiffel - ESIEE Paris - ESYCOM Laboratory. The study of their thermophysical properties will be done by the 3-omega method for thermal conductivity measurement and FTIR spectroscopy for radiative properties measurement. The experimental results will then be combined to numerical simulations to provide solutions improve and control heat transport at interfaces.

The expected results will assess the application potential of these BSi-based meta-materials in different multi-scale heat conversion and management systems such as thermal rectification,[17] thermal energy harvesting or the cooling of base stations.

Required profile

The candidate must have a physicist profile and knowledge in materials science, optics, thermodynamics and heat/energy transfers. Knowledge of signal processing, Matlab / Python language, Labview software, as well as experience in numerical simulation with the *COMSOL multiphysics* finite element method will be a plus. He (she) must be motivated to carry out both theoretical and experimental work. A good command of written / spoken English is essential, as well as a good aptitude for teamwork in an international environment.

Contact

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Prospective applicants are encouraged to contact Georges Hamaoui (contact details above) for more information. Applications (a cover letter, a CV, Master's grades and recommendation letters) have to be sent to Georges Hamaoui.

Practical information

Starting date and duration

The PhD is expected to start on October 1st 2021 for an exact duration of three years (36 months).

Compensation

The funding for this thesis has not yet been secured. The candidate will apply for a ministerial scholarship through the MSTIC doctoral school. This kind of scholarship will fully fund the thesis for its entire duration, with a monthly compensation of about 1350 euro per month net salary. This salary can be increased by about 300 euros per month if the PhD candidate is additionally recruited for a teaching assistant position (64 hours per year teaching duty). Note however that the availability of teaching vacancies varies each year, and that they remain usually limited for non-French speaking PhD candidates.

Geographical location

The PhD candidate will work at the ESYCOM laboratory location, in Champs-sur-Marne, Paris metropolitan area. The center of Paris is at about 20 minutes using public transportation.

Housing

The university can help foreign PhD students to find housing at an affordable price.

The ESYCOM Laboratory works mainly in the fields of engineering of communication systems, sensors and microsystems for the city, the environment and the person.
The topics covered are more specifically:
- Antennas and propagation in complex media, photonic components - microwaves;
- Microsystems for environmental analysis and pollution control, for health and the interface with living organisms;
- Micro-devices for recovering ambient mechanical, thermal or electromagnetic energy.

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