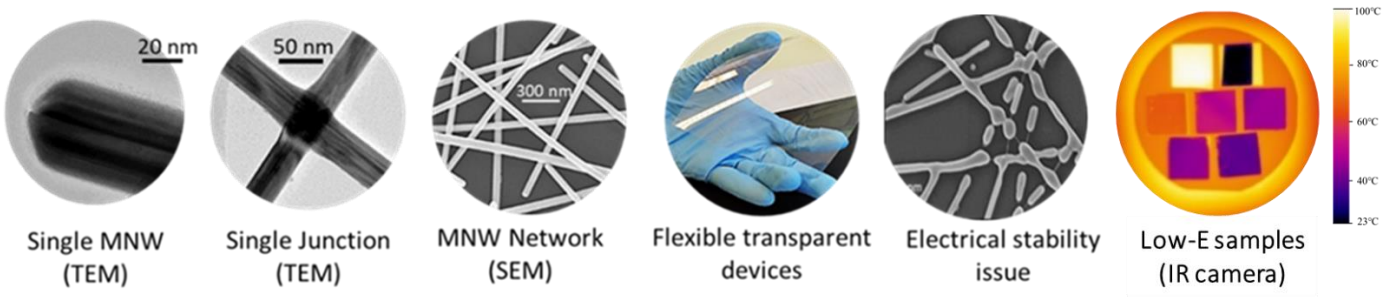
2024-2025

Internship proposal (Master 2, final project engineering school) at LMGP

Investigation of silver nanowire (AgNW) networks as low-emissivity films: exploring the dependence of the IR emissivity with AgNW dimensions, network density and coating

Investigating low-emissivity coatings is crucial for minimizing heat transfer in buildings, reducing energy consumption for heating and/or cooling, in buildings but also for many devices. Such coatings help maintain comfortable indoor temperatures regardless of external conditions. Silver nanowire (AgNW) networks, known for their transparency and mechanical resilience, offer a sustainable solution for energy conservation[1]. The optical properties of silver nanowire networks make them ideal for transparent conductive films, ensuring minimal visual obstruction[2]. These networks can be produced at a large scale, making them suitable for widespread implementation in architectural settings.

With their outstanding electrical and optical properties, AgNW-based percolating networks appear promising for many applications[3,4]. Although the properties of these transparent electrodes are already remarkable, many problems remain to be understood, such as the network defects, the electrical homogeneity and their stability[5–8]. Silver nanowire networks can be deposited onto various surface textures and substrates, enhancing their versatility[9].



Electronic or optical pictures of AgNW networks showing the different length scales that play a role, up to the low-emissivity applications

The goal of this internship is to better understand and optimize properties of AgNW networks, aiming for integration of these electrodes in low-emissivity coatings. The focus will be on both experimental and (possibly) simple physical modelling approaches. As well, the effects of metal oxide or nitride coating silver nanowires on their infrared (IR) low-emissivity properties and stability will be carefully studied. The metal oxide or nitride-based coating will be deposited either by Atomic Layer Deposition (ALD) or by Spatial ALD.

The approach could be, depending on the skills/wishes of the trainee, based on:

(i) **Experimental approaches**

→ Deposition of AgNWs by spray-coating technique on glass and flexible/bendable polymeric substrates

→ Optimization of bare and/or coated AgNW networks through their optical, electrical and structural properties, with a specific emphasis on their IR-emissivity and VIS-transparency.

(ii) **Fundamental aspects**

→ Better understanding of the physical properties thanks to **simple physical modelling;** namely we would like to better understand the relationship between the IR-emissivity of AgNW networks and other features (AgNW dimensions, coating nature and thickness…) or properties of AgNW networks (electrical resistance, optical transmittance…)

(iii) **Integration into devices**

→ Integration as low-emissivity coating (for energy saving and/or thermal management)

This internship offers a good trade-off between fundamental, experimental and applied aspects. The candidate will get precious knowledge and skills in physics and nanomaterial sciences. The Laboratoire des Matériaux et du Génie Physique (LMGP) houses state of the art experimental equipment to fabricate Ag nanowire networks with many characterization tools (such as IR-camera, electronic microscopes, X-Ray Diffraction…) and including also in-situ electrical resistance measurement set-up[10]. A special

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attention will also be devoted to the optimization and stability enhancement of the obtained transparent electrodes and the integration of these transparent electrodes as low-emissivity films. A collaboration between CEA Grenoble and LMGP has shown already some interesting results[1]. Moreover we have shown at LMGP that the conformal coating of AgNW by thin oxide layers leads to a much enhanced stability[11], but the effects of such coatings on IR-emissivity of AgNW networks are still unexplored. Simple physical models can also be developed to better understand the physical properties and stability enhancement[9].

References (all are from LMGP except reference n°2):

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Scientific environment: Located in the heart of an exceptional scientific environment, LMGP offers the applicant a rewarding place to work. The applicant will be integrated within a close collaboration between several scientists of LMGP and other labs (SIMAP, LTM at Grenoble, ICMCB in Bordeaux and Physics Department in Liège University).

Laboratory website: http://www.lmgp.grenoble-inp.fr/

Profile: We are looking for a highly motivated student who is interested to work in an inter-disciplinary project. Interpersonal skills, dynamism, rigor and teamwork abilities will be appreciated. Candidates should be fluent in English.
Subject could be continued with a **PhD thesis** (only for M2 training): Yes/~~No~~. We should get two Thesis grants opened in October 2025 on this thematic.

Stipend: an internship stipend will be provided (≈600€/month for a training longer than 10 weeks)

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