

2026-2027

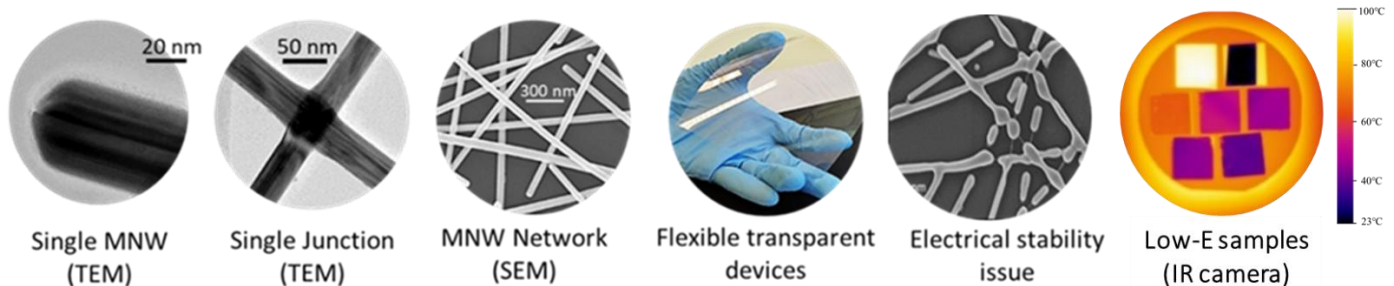
Internship proposal (Master 2, final project engineering school) at LMGP

In collaboration with LGP2

Investigation of silver nanowire (AgNW)/Nanocellulose networks: improving their physical properties and stability for efficient integration into electrochromic devices

Internship as part of the collaborative ANR EC-LIPSE project

Silver nanowire (AgNW) networks, are known for being efficient transparent electrodes^[1]. Their optical transparency, good electrical properties and mechanical resilience, offer a sustainable solution for many applications, such as solar cells, transparent heaters^[2], low-emissivity films^[3,4] etc. These networks can be produced at a large scale, making them suitable for widespread implementation^[5,6]. Although the properties of these transparent electrodes are already remarkable, many problems remain to be understood, such as the relationship between electrical and optical properties, the influence of network defects, the electrical homogeneity and their stability^[7,8]. Silver nanowire networks can be deposited onto various surface textures and substrates, especially flexible substrate enhancing their versatility^[9].



Electronic or optical pictures of AgNW networks at different and key length scales, up to the device applications

This internship aims to develop a better understanding and optimize the properties and stability of hybrid transparent electrodes based on silver nanowire (AgNW) networks embedded in a nanocellulose matrix, with the aim of integrating these electrodes into printed electrochromic devices^[10]. The focus will be on experimental investigations and, where relevant, simple physical modelling approaches^[11]. In particular, the influence of nanocellulose content, AgNW network density and nanowire dimensions on the electrical conductivity, optical transparency, haze and stability towards stress (thermal, electrical, mechanical) of the electrodes will be investigated. Special attention will be paid to understanding how the nanocellulose matrix affects the formation and stability of the AgNW network, and to identifying the optimal balance between electrical and optical performances. The work will also explore how the hybrid AgNW/nanocellulose architecture can improve the processability by printing and long-term stability of the transparent electrodes, providing a deeper understanding of the relationships between formulation, network structure and final electrode properties. The approach could be, depending on the skills/wishes of the trainee, based on:

(i) Experimental approaches

- Deposition of AgNWs by different deposition technique (spray / coating / printing) on glass and flexible/bendable polymeric substrates
- Observation of the optical transmittance, IR-emissivity and sheet resistance of AgNW networks
- Exploration of transparent electrode protecting strategies (SALD coating for instance)

(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 optical transmittance of AgNW networks and electrical resistance.

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(iii) Integration into devices

→ Integration as transparent electrodes in Electrochromic system (collaboration with LGP2 (Grenoble) and ICMCB (Bordeaux))

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), located at Grenoble, houses state of the art experimental equipment to fabricate Ag nanowire networks with many characterization tools (such as UV-VIS-NIR spectrophotometer, IR-camera, electronic microscopes, X-Ray Diffraction...) and including also in-situ electrical resistance measurement set-up^[12]. A special attention will also be devoted to the optimization and stability enhancement of the obtained transparent electrodes and the integration of these transparent electrodes in devices^[3,10]. Moreover we have shown at LMGP that the conformal coating of AgNW by thin oxide layers leads to a much enhanced stability^[13,14], 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].

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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 (LGP2 in Grenoble, ICMCB in Bordeaux). **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.

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

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