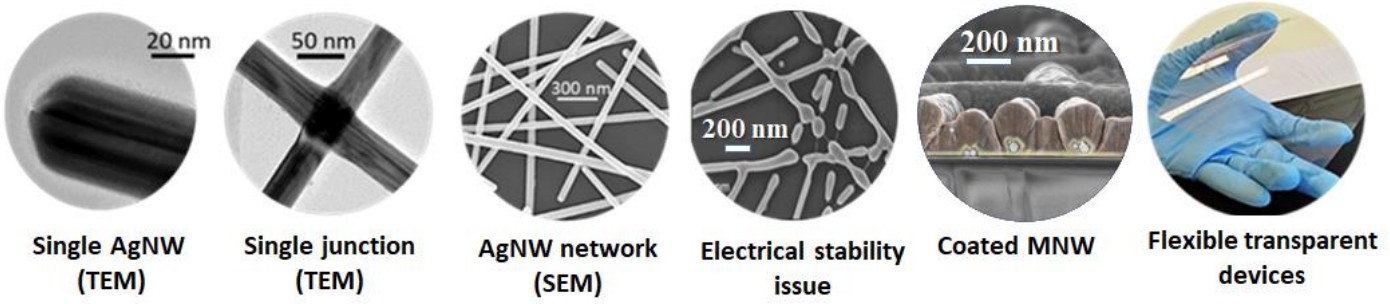
2024-2025

Internship proposal (Master or final project engineering school) at LMGP

Silver Nanowire Networks:

Effects of thin coating on their properties, stability and integration into efficient energy applications (low-emissivity, electrochromic and solar cells)

Transparent electrodes attract intense attention in many technological fields, including solar cells, OLEDs, touch screens, transparent film heaters, and smart windows. New-generation transparent electrodes are expected to have three main physical properties: high electrical conductivity, optical transparency and mechanical flexibility[1]. The most efficient and widely used transparent conducting material is indium tin oxide (ITO). However, the scarcity of indium, associated with ITO's lack of flexibility and the relatively high manufacturing costs, has prompted a search for alternative materials. With their outstanding electrical and optical properties, silver nanowire (AgNW)-based percolating networks appear to be one of the most promising alternatives to ITO for many applications[2,3]. Although the properties of these transparent electrodes are already remarkable, many problems remain to be understood, such as network defects, electrical homogeneity, and stability[4–7].



Electronic or optical pictures of AgNW, AgNW networks showing the different length scales that play a role, up to the transparent electrode devices (on the extreme right)

The goal of this internship is to better understand and optimize the stability enhancement effect of coating the AgNWs, aiming for integration of these electrodes in low-emissivity coating, electrochromic or photovoltaic devices. The focus will be on the effects of the type and thickness of the metal oxide or nitride coating, which will be deposited by selective Area Selective Deposition by ALD (ASD) and/or Spatial ALD.

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

(i) **Experimental approach**

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

→ Optimization of coated AgNW networks through their optical, electrical and structural properties. The coating of AgNWs will be thoroughly investigated (in collaboration between LMGP, LTM and SIMAP) since it drastically enhances the stability of AgNW networks[8,9].

→ Comparison of the studied coating on the energy efficiency of the device will be assessed.

(ii) **Fundamental aspects**

→ Better understanding of the physical properties thanks to **physical modelling** and also multiscale **characterizations**

(iii) **Integration into devices** (specifically promising since this is compatible with roll-to-roll technology)

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

→ Integration as transparent electrodes in solar cells

This internship offers a good trade-off between fundamental and experimental aspects. The candidate will get precious knowledge and skills in physics, material and nanomaterial sciences. The Laboratoire des Matériaux et du Génie Physique (LMGP) houses state-of-the-art experimental equipment to fabricate AgNW networks and characterize their main properties, including an in-situ

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electrical resistance measurement set-up[10]. Special attention will also be devoted to the optimization and stability enhancement of the obtained transparent electrodes and the integration of these transparent electrodes into devices will be performed[1,11,12]. For instance, we have shown at LMGP that the conformal coating of AgNW by thin oxide layers leads to a much-enhanced stability[8]. Simple models, as well as numerical simulations, can also be developed to better understand the physical properties and stability enhancement of the AgNW networks[13].

Related references from the LMGP laboratory:

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[3] D. T. Papanastasiou, A. Schultheiss, D. Muñoz-Rojas, C. Celle, A. Carella, J. Simonato, D. Bellet, *Adv. Funct. Mater.* **2020**, *30*, 1910225.
[4] D. P. Langley, M. Lagrange, G. Giusti, C. Jiménez, Y. Bréchet, N. D. Nguyen, D. Bellet, *Nanoscale* **2014**, *6*, 13535.
[5] M. Lagrange, D. P. Langley, G. Giusti, C. Jiménez, Y. Bréchet, D. Bellet, *Nanoscale* **2015**, *7*, 17410.
[6] S. Aghazadehchors, V. H. Nguyen, D. Muñoz-Rojas, C. Jiménez, L. Rapenne, N. D. Nguyen, D. Bellet, *Nanoscale* **2019**, *11*, 19969.
[7] V. H. Nguyen, J. Resende, D. T. Papanastasiou, N. Fontanals, C. Jiménez, D. Muñoz-Rojas, D. Bellet, *Nanoscale* **2019**, *11*, 12097.
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[9] L. Bardet, D. T. Papanastasiou, C. Crivello, M. Akbari, J. Resende, A. Sekkat, C. Sanchez-Velasquez, L. Rapenne, C. Jiménez, D. Muñoz-Rojas, A. Denneulin, D. Bellet, *Nanomaterials* **2021**, *11*, 2785.
[10] D. T. Papanastasiou, N. Charvin, J. Resende, V. H. Nguyen, A. Sekkat, D. Muñoz-Rojas, C. Jiménez, L. Flandin, D. Bellet, *Nanotechnology* **2021**, *32*, 445702.
[11] A. Khan, B. Faceira, L. Bardet, C. Sanchez-Velasquez, S. S. Nayak, C. Jiménez, D. Muñoz-Rojas, A. Rougier, D. Bellet, *ACS Appl. Mater. Interfaces* **2024**, *16*, 10439.
[12] L. Bardet, M. Akbari, C. Crivello, L. Rapenne, M. Weber, V. H. Nguyen, C. Jiménez, D. Muñoz-Rojas, A. Denneulin, D. Bellet, *ACS Appl. Nano Mater.* **2023**, *6*, 15234.
[13] D. P. Langley, M. Lagrange, N. D. Nguyen, D. Bellet, *Nanoscale Horizons* **2018**, *3*, 545.

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 (LTM, SIMAP). The LMGP works in close collaboration with LTM and SIMAP in Grenoble, and 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.
Subject could be continued with a **PhD thesis** : 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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