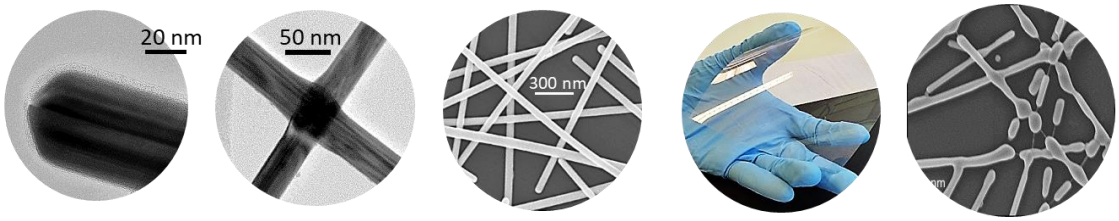
2021-2022

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

Transparent Electrodes based on Silver Nanowire Networks: Fundamental properties, stability and integration into devices

Transparent electrodes attract intense attention in many technological fields, including solar cells, OLEDs, touch screens, transparent film heaters or smart windows. New generation transparent electrodes are expected to have three main physical properties: high electrical conductivity and optical transparency and mechanical flexibility. The most efficient and widely used transparent conducting material is currently indium tin oxide (ITO). However the scarcity of indium, associated with ITO's lack of flexibility and the relatively high manufacturing costs have prompted a search into 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 [1,2,3]. 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 [4,5].



Single MNW (TEM) | Single Junction (TEM) | MNW Network (SEM) | Flexible transparent devices | Electrical stability issue

The goal of this internship is to couple experiments and modelling to deeply understand the physical phenomena occurring at the scales of the network and also at the nanowire junctions aiming for integration of these electrodes in optoelectronic devices.

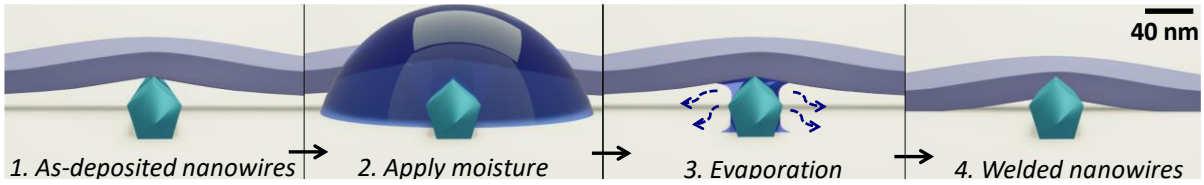
The approach could be, depending on the skills/wishes of the trainee, based on:

(i) **Experimental approach**

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

→ Optimization of AgNW networks through cold-welding post-deposition treatment, this is achieved by sparying some water droplets on AgNW networks. This leads to an electrical resistance reduction, called capillary force-induced cold welding.

→ Comparison with thermal annealing treatment.



Principle of capillary force induced cold-welding

(ii) **Fundamental aspects**

→ Better understanding of the mechanisms occurring during capillary force-induced cold-welding thanks to **physical modelling** and also multiscale **characterizations** including Atomic Force Microscopy, Infra-red Emissivity, X-Ray Diffraction, Transmission Electron Microscopy, Scanning Electron Microscopy, X-ray photoelectron spectroscopy…

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

→ Integration into organic solar cells

→ Layers of low-emissivity for energy saving

→ Flexible transparent heaters (for defrosting/defogging)

This internship offers a good trade-off between fundamental and experimental 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 in-situ electrical resistance measurement set-up

2021-2022

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

[4,5,6]. 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 into devices will be performed. For instance we have shown in the lab that the conformal coating of AgNW by thin oxide layers leads to a much enhanced stability [7,8,9]. Simple models as well as numerical simulations will be developed to better understand the physical properties and stability enhancement.

Related references:

[1] D.P. Langley, G. Giusti, C. Mayousse, C. Celle, D. Bellet, J.-P. Simonato, ***Nanotechnology*** 24 (2013) 452001
[2] T. Sannicolo, M. Lagrange, A. Cabos, C. Celle, J.-P. Simonato, D. Bellet, ***Small***, 12 (2016) 6052-6075
[3] D. T. Papanastasiou, A. Schultheiss, D. Muñoz-Rojas, C. Celle, A. Carella, J.-P. Simonato, D. Bellet, *Advanced Functional Materials* **2020**, *30*, 1910225.
[4] T. Sannicolo, N. Charvin, L. Flandin, S. Kraus, D. T. Papanastasiou, C. Celle, J. Simonato, D. M. Rojas, C. Jiménez, D. Bellet, ***ACS Nano*** (2018), 12, 4648
[5] A. Khan, V. H. Nguyen, D. Muñoz-Rojas, S. Aghazadehchors, C. Jiménez, N. D. Nguyen, D. Bellet, ***ACS Appl. Mater. Interfaces*** (2018), 10, 19208−19217.
[6] M. Lagrange, D.P. Langley, G. Giusti, C. Jimenez, Y. Bréchet, D. Bellet, ***Nanoscale*** 7 (2015) 17410-17423.
[7] T. Sannicolo, D. Muñoz-Rojas, N. Nguyen, S. Moreau, C. Celle, Caroline, J.P. Simonato, Y. Bréchet, D. Bellet, ***Nano Letters*** 16 (2016) 7046-7053
[8] N.V. Nguyen, J. Resende, D.T. Papanastasiou, N. Fontanals, C. Jiménez, D. Muñoz-Rojas, D. Bellet, ***Nanoscale*** 11 (2019) 12097
[9] S. Aghazadehchors, V. H. Nguyen, D. Muñoz-Rojas, C. Jiménez, L. Rapenne, N. D. Nguyen, D. Bellet ***Nanoscale*** 11 (2019) 19969

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.

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 can be fluent either in English and/or in French. Subject could be continued with a **PhD thesis** : Yes/~~No~~.

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

Contacts : Laetitia Bardet: laetitia.bardet@grenoble-inp.fr
Daniel Bellet: daniel.bellet@grenoble-inp.fr;