Ph.D offer

Title: Development of thin film based on metallic nanowire networks and functional oxides for energy-efficient smart windows

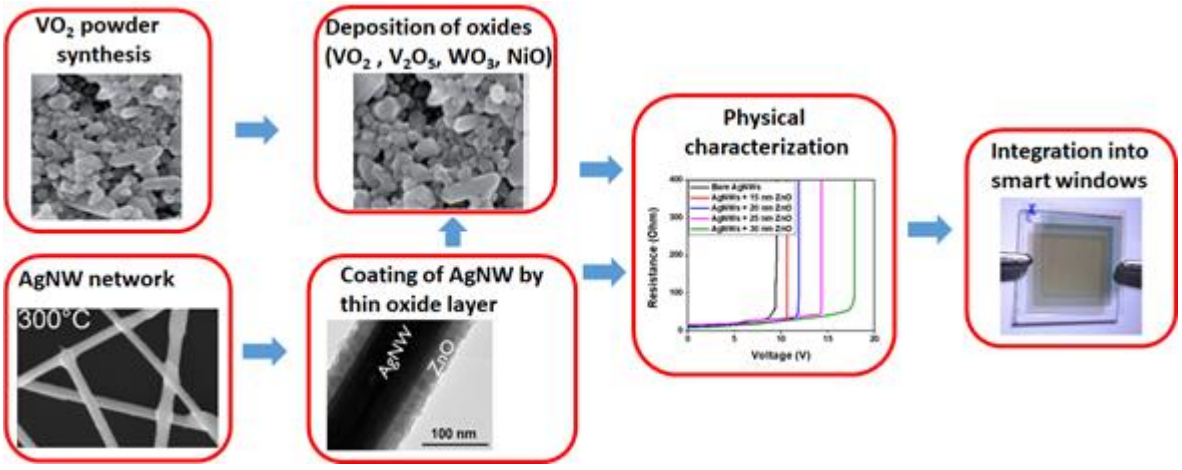
Project description and working program: Functional materials are key components for industrial development. Smart windows create climate adaptive building shells and play a prevailing role for energy consumption reduction within buildings. There is a clear need to conceive and fabricate functional low-cost and abundant raw material based thin layers with the aim of integrating them in smart windows. The Thesis concerns the development of eco-friendly functional materials for efficient, low-cost and stable thermo- and electrochromic devices. More precisely the work will imply the fabrication and optimization of metallic nanowire nanocomposites and active oxide layers. Their integration will be tackled in thermo- and electrochromic devices for smart windows; with the goals of increasing stability and efficiency, as well as lowering cost.

The PhD thesis is proposed within the framework of a European project (2021-2024), INSTEAD, which proposes an interdisciplinary approach. The main aims of the PhD will be the following (as illustrated briefly in the figure below):

1/ Fabrication and optimization of metallic nanowire networks (mainly with silver nanowires (AgNW) or copper nanowires (CuNW)), by studying the relation between metallic nanowires dimensions and network density on one side and the physical properties on the other side. The coating of AgNW or CuNW by a very thin oxide layer (few tens of nm) ensures a much enhanced stability; the obtained benefits will be used for fabricating very stable transparent electrodes

2/ Synthesis of thin layers and their interfaces to conceive efficient, low-cost and stable thermo- and electrochromic devices. The oxide materials used as the active layer in thermochromic (working in IR range) and/or electrochromic (working in visible range) devices will be mainly: VO_2, V_2O_5, WO_3 and NiO. These obtained new functional active materials and their associated interfaces will be thoroughly investigated thanks to several methods

3/ Integration of thermo- and electrochromic devices into smart windows and tests of the latter.



During the PhD, the candidate will use several synthesis growth methods (spray, spatial atomic layer deposition, sputtering, bar coater) and characterization tools (electrical, optical, structural…) with a wide range of operative *in-situ* or *ex-situ* experimental methods (thermal ramps, electrical ramps, follow with infrared camera etc). In short, the Thesis aim is to investigate systemic ways to efficiently

integrate metallic nanowire networks and functional oxides into thermo- and electrochromic devices with improved stability and optimized interfaces. The candidate will benefit from the expertise of two leading research groups in LMGP (AgNW networks properties[1], stability[2] and modelling[3]) and ICMCB (Electrochromic and Thermochromic materials synthesis[4] and integration[5,6]). She/he will also have access to state-of-the-art film metrology in order to thoroughly characterize the materials deposited. Depending on the progress of the thesis and the desire of the doctoral student, the better understanding of these layers and their integration may also rely on physical modeling.

Location: The candidate will be based at the Materials and Physical Engineering Laboratory (LMGP) at Grenoble and Institute of Condensed Matter Chemistry of Bordeaux (ICMCB) at Bordeaux. These two leading research laboratories are joint Research Units between Grenoble Institute of Technology (G-INP) and CNRS for LMGP, and Bordeaux University, Bordeaux INP and CNRS for ICMCB.

Requirements: We look for a highly motivated materials scientist, chemist, physicist or engineer with a strong scientific background and aptitude for teamwork. Candidates interested and with expertise/background in functional materials science, nanoscience and/or energy will be favored. Candidates must be fluent in English, and have excellent presentation and writing skills, in addition to human qualities allowing efficient teamwork.

Allowance: The research will be carried out in the framework of M-Era-Net project INSTEAD (Study of InNovative compoSite Thin films based on metallic nanowire nEtworks and functional oxides for application in smArt winDows), following the successful application of a consortium of 4 partners (including LMGP and ICMCB). The Thesis allowance is issued from INSTEAD project. The Thesis will be conducted between (LMGP) at Grenoble INP and ICMCB (Bordeaux). These both labs belong as well to CNRS. Travel expenditures between Grenoble and Bordeaux will be paid by the two laboratories. We foresee the PhD student to start in October 2021. The net salary will be approximatively 1688 euros/months (plus possible extra salary for teaching activities if wished).

Application: Please send your application to Daniel Bellet (daniel.bellet@grenoble-inp.fr) and to Aline Rougier (Aline.Rougier@icmcb.cnrs.fr) including an updated CV, motivation letter, a copy of your undergrad and Master marks and two references (contact details).

Website of LMGP: https://lmgp.grenoble-inp.fr/

Website of ICMCB: https://www.icmcb-bordeaux.cnrs.fr/en/

References :

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2. Nguyen, V.H.; Resende, J.; Papanastasiou, D.T.; Fontanals, N.; Jiménez, C.; Muñoz-Rojas, D.; Bellet, D. Low-Cost Fabrication of Flexible Transparent Electrodes Based on Al Doped ZnO and Silver Nanowire Nanocomposites: Impact of the Network Density. *Nanoscale* **2019**, *11*, 12097–12107, doi:10.1039/C9NR02664A.
3. Langley, D.P.; Lagrange, M.; Nguyen, N.D.; Bellet, D. Percolation in Networks of 1-Dimensional Objects: Comparison between Monte Carlo Simulations and Experimental Observations. *Nanoscale Horizons* **2018**, *3*, 545–550, doi:10.1039/C8NH00066B.
4. Mjejri, I.; Rougier, A.; Gaudon, M. Low-Cost and Facile Synthesis of the Vanadium Oxides V_2O_3, VO_2, and V_2O_5 and Their Magnetic, Thermochromic and Electrochromic Properties. *Inorg. Chem.* **2017**, *56*, 1734–1741, doi:10.1021/acs.inorgchem.6b02880.
5. Da Rocha, M.; He, Y.; Diao, X.; Rougier, A. Influence of Cycling Temperature on the Electrochromic Properties of WO3//NiO Devices Built with Various Thicknesses. *Solar Energy Materials and Solar Cells* **2018**, *177*, 57–65, doi:10.1016/j.solmat.2017.05.070.
6. Futsch, R.; Mjejri, I.; Rakotozafy, H.; Rougier, A. PEDOT:PSS-V2O5 Hybrid for Color Adjustement in Electrochromic Systems. *Frontiers in Materials* **2020**, *7*, doi:10.3389/fmats.2020.00078.