3-year PhD position at Institut Pprime

CNRS – University of Poitiers, France

Real-time growth monitoring of ultrathin Ag layers: impact of interface chemistry and additives on morphological evolution and opto-electronic properties

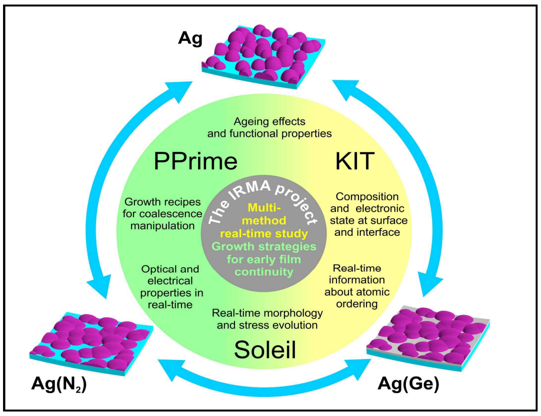
Starting period: 1st October 2022 **Deadline for application**: **15 April, 2022**

Gross Salary: 2135 € / month, funded by ANR (IRMA project)

Keywords

Ag ultrathin layer; thin film growth; real-time monitoring; reactivity; opto-electronic properties; X-ray synchrotron experiments

Scientific context



Noble-metal ultrathin films, with nominal thickness smaller than ~ 15 nm, are ubiquitous in a wide range of plasmonic devices and other optoelectronic applications. At present, there is much interest to produce metal-based transparent conductive electrode (TCE) ultrathin metal layers as potential alternative to currently used indium tin oxide, which suffers from high cost and poor sustainability, is faced with recyclability issues, and is prone to cracking upon bending. However, Ag films obtained by conventional deposition process have the natural tendency to grow in granular, 3D layer forms on weakly interacting substrates (dielectrics or insulating oxides) resulting in the formation of rough surface layers. The proposed **research strategy** is to use additives (N_2 and Ge), either at the growth front (acting like surfactants) or using a seed layer, to improve wetting of Ag layers [1,2] and obtain a conductive layer at sufficiently low thickness to ensure optical transparency. This is illustrated in the above schematics.

The IRMA project, funded by ANR in the frame of international collaborative projects, seeks to develop efficient and non-invasive strategies for **manipulating morphology** and **opto-electronic properties** of vapor-deposited Ag nanostructures (i.e., 3D nanoparticles and ultra-thin continuous layers). This will be achieved via selective **deployment of additives** (i.e., gaseous species and solute metals) to target key nanostructure formation stages, whereby complex dynamic synthesis processes will be studied in **real-time** by leveraging the strengths of lab-scale *in situ* probes [3] and synchrotron X-ray tools [4].

Work program

Three main objectives are foreseen within the proposed PhD thesis:

1) To gain fundamental understanding on the impact of additives on the early-growth stages of Ag ultrathin films, in terms of interface chemistry, growth morphology, crystal structure, and surface roughness.
2) To study relaxation processes after short-time growth interruptions as well as long-term and thermal stability of the investigated systems.
3) To propose guidelines for efficient design strategies for achieving ultrathin metal layers with optimal optical transmittance, electrical conductivity, and improved durability for use as TCEs

To this end, the PhD student will be involved both in the growth by magnetron sputtering and structural/morphological characterization of Ag ultra-thin layers. Different Ag layers will be critically examined and benchmarked against reference Ag films grown at room temperature on SiO_2: i) the use of gas additives by performing Ag growth in $Ar+N_2$ plasma discharge, and ii) the growth of Ag on amorphous Ge (a-Ge) seed layers. Additionally, the intelligent deployment of these surfactants, such as the use of $Ag_{1-x}Ge_x$ seed layers ($0 \leq x \leq 1$) grown by co-deposition or the addition of N_2 at specific growth stages (before and after film percolation) will be explored.

He/she will use complementary ***in situ*** and **real-time diagnostics** available at Pprime Institute, namely surface differential reflectance spectroscopy (SDRS), wafer curvature and electrical resistance measurements (see Fig. 1) to determine the morphological transition thicknesses (percolation-h_p and continuity-h_c), as preparatory study for real-time synchrotron experiments. He/she will characterize the **film morphology** using *ex situ* transmission electron microscopy (TEM) and atomic force microscopy (AFM) imaging. He/she will also participate to the characterization of interface/surface chemistry using X-ray photoelectron spectroscopy (XPS) during short research stays at KIT (Germany), and be also actively involved in **synchrotron experiments** at SOLEIL (France) to study the structure formation, stress evolution and morphological evolution using simultaneous X-ray diffraction (XRD), X-ray reflectivity (XRR), and grazing incidence small-angle X-ray scattering (GISAXS) measurements.

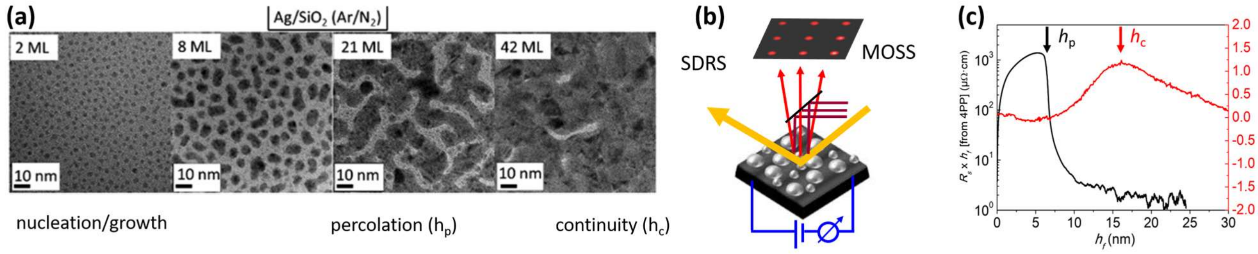


Figure 1: a) plan-view TEM images showing evolutionary morphology of Ag ultrathin layer, b) schematic of in situ and real-time diagnostics employed to monitor Ag growth: wafer curvature (MOSS), surface differential reflectance spectroscopy (SDRS) and electrical measurement, c) evolution of stress-thickness and resistivity vs. film thickness h_f during growth of Ag, and determination of percolation (h_p) and film continuity (h_c) thicknesses.

References

1. Yun, J. Ultrathin Metal films for Transparent Electrodes of Flexible Optoelectronic Devices. *Adv. Funct. Mater.* **27,** 1606641 (2017).
2. Jamnig, A. *et al.* 3D-to-2D Morphology Manipulation of Sputter-Deposited Nanoscale Silver Films on Weakly Interacting Substrates via Selective Nitrogen Deployment for Multifunctional Metal Contacts. *ACS Appl. Nano Mater.* **3,** 4728–4738 (2020).
3. Colin, J. *et al.* In situ and real-time nanoscale monitoring of ultra-thin metal film growth using optical and electrical diagnostic tools. *Nanomaterials* **10,** 2225 (2020).
4. Krause, B. *et al.* Interfacial Silicide Formation and Stress Evolution during Sputter Deposition of Ultrathin Pd Layers on a-Si. *ACS Appl. Mater. Interfaces* **11,** 39315–39323 (2019).

Framework and collaborations

The PhD student will work in an international consortium composed of three academic partners, Pprime Institute and SOLEIL in France, and Karlsruhe Institute of Technology (KIT) in Germany, which offer unique research facilities to reach the scientific objectives of the IRMA project funded by ANR and DFG.

Candidate profile

Applicant should hold a degree (M.Sc. or equivalent) in Materials Science or Condensed Matter Physics, must be fluent in English or French (both written and spoken), have a taste for experimental work, and ability to team working. Laboratory skills or prior experience in PVD growth and/or structural characterization will be appreciated.

Application procedure

Interested candidates should submit their application on the CNRS job portal at https://bit.ly/3I5MLHL (CV, cover letter and at least one recommendation letter) **before 15 April 2022**.

PhD advisors/Contact

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