Job title: Postdoctoral position

Electric-field-activated metal/insulator transitions in Cr-V_2O_3 investigated by in situ electron spectromicroscopy techniques

A 2 year post-doctoral position is available in the framework of the ANR project IMPULSE in the STEM group at the Laboratoire de Physique des Solides, CNRS & Université Paris-Saclay (Orsay, France)

Planned start for the position : June 2023

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Scientific context

Mott insulators and strongly correlated systems such as $(V_{1-x}Cr_x)_2O_3$ can undergo various metal/insulator transitions (MITs) in response to external perturbations such as pressure, electronic doping or temperature [McWhan, PRB 2, (1970) 3734]. However, such properties remain difficult to exploit technologically. Recently, electrically activated resistive switching has shown promise in Mott insulators by inducing metallic nano-filament formation in $(V_{1-x}Cr_x)_2O_3$ (e.g. x = 0.3) systems, providing real potential capabilities at room temperature for non-volatile memory and neuromorphic applications [Janod et *al.*, Adv.Funct. Mat. 25 (2015) 6287].

More generally, at the fundamental level, $(V_{1-x}Cr_x)_2O_3$ is considered as a prototypical MIT system in which local competitive structural and/or electronic mechanisms associated with temperature-driven transitions have been extensively studied at the macroscopic scale [McWhan, PRB, 2, 3734 (1970)] and highlighted in recent years at spatial resolutions ranging from micrometers to tens of nanometers [Lupi et *al*., Nat. Commun.,**1** (2010),105; Ronchi et *al.*. PRB 100 (2019); McLeod et *al.* Nature Physics 13 (2017); Kalcheim *et al. PRL* 122 (2019) 057601]. These latest investigations also demonstrate the problems and experimental limitations inherent in combining results from different instruments to map accurately the dynamics of mechanisms within regions of interest of a few tens of nm; hence the need to perform structural and electronic experiments within a single instrument. Moreover, all these electronic transitions rely on the relationship between their structural and electronic degrees of freedom. These MITs thus provide a perfect arena in which to probe *in situ* the $(V_{1-x}Cr_x)_2O_3$ structural and electronic changes at the finest scale. Advanced monochromated electron spectromicroscopes emerged over the last decade as real game-changers for nanomaterials characterization. For instance, *in situ* electron spectromicroscopy techniques can probe and map structural and electronic features down to the nm scale under thermal cycling ranging from 120K to 300K, as already demonstrated in the group within the thesis work of I. Koita [Koita et al. Microscopy and Microanalysis 27 (2021) 1482] in the IMPULSE project.

This postdoctoral project will aim to investigate experimentally at the nm scale how electric-field-activated MITs take place within Cr-doped V_2O_3 systems. The Mott-Hubbard transition between a paramagnetic metallic phase and a paramagnetic insulator phase takes place when $(V_{1-x}Cr_x)_2O_3$ is submitted to electrical pulses above a certain threshold voltage; metallic conducting filaments are created across the insulating matrix. The nm-scale metallic filament can be dissolved or stabilized depending on the competition between the avalanche breakdown caused by the electric field and the Joule-effect relaxation mechanisms, yielding volatile or non-volatile resistive switching, respectively [Janod et *al.*, Adv.Funct. Mat. 25 (2015) 6287]. Recent investigations led by our IMN collaborators have already revealed by µ-Raman with µ-X-Ray diffraction mapping that applying successive electric pulses leads to resistive switching, inducing a direct lattice contraction in the metallic filament [Babich et *al.* arXiv:2105.05093, 2021].

Project description

The aim of this project will be to develop, perform and optimize *in situ* experiments under electrical pulses in Cr-V_2O_3 to probe at the nm scale the local relationship between structural evolution and emergence of the metallic state during non-volatile resistive switching. Under “operando” conditions, the successful candidate will associate (1) mapping of relevant spectroscopic electronic excitations (from IR to soft X-ray) with an ultra-high EELS energy resolution with (2) the local structural features (symmetry and lattice parameters) determined by 4D STEM nano- and microdiffraction techniques.

These *in situ* monochromated STEM/EELS experiments will be carried out on the NION CHROMATEM 200 MC (national project: TEMPOS EquipeX) coupled with a double-tilt HennyZ cryo-holder, using MEMS to apply successive electrical pulses yielding the MIT. They will require the instrumental optimization of the electrical bias system and the use of original acquisition modes, and will yield data requiring advanced analyses.

Amongst the specific issues to be addressed are the investigation at the nm scale and better understanding of:
- the nucleation and percolation mechanisms of the conductive filament created under electrical pulses
- the precursor role of a possible intermediate phase
- the critical role of local strains at insulating/metallic interface domains
- the impact and role of low chromium doping
- the critical size required to stabilize the conductive filament

The successful candidate will also interact strongly with our collaborators who are producing the samples and characterizing their physical properties at the macroscopic scale (Etienne Janod, et *al.*, PMN group at IMN laboratory, Nantes, FR).

Working environment

The STEM group at the Laboratoire de Physique des Solides is a world-leading electron microscopy and spectroscopy team well recognized for its expertise in investigating the structural, chemical, optical and electronic properties of nanomaterials. The successful candidate will have access to the two NION scanning transmission electron microscopes (STEMs) including the unique microscope CHROMATEM with which the UHR-STEM/EELS *in situ* experiments will be performed. The project will be carried out in the framework of the ANR JCJC project "IMPULSE" and she/he will benefit from the strong interaction with our IMN collaborators.

Profile of the candidate

The project will mainly involve experimental work and may include instrumental developments upon depending on the successful applicant's skills. We are seeking for a candidate with a strong taste for experimental work, a sharp curiosity and creativity for advanced experiments, together with good organizational skills.

The candidate must hold a Ph.D. in materials science or condensed matter physics. She/he will be expected to show initiative and creativity, as well as have the appropriate skills and knowledge necessary to achieve the project objectives. Expertise with *in situ* (biasing, thermal), transmission electron microscopy, EELS or FIB techniques will be an asset for this application.

How to apply

Qualified candidates should send a CV, a motivation letter, and contact details of at least two referees to Laura Bocher (laura.bocher@universite-paris-saclay.fr) and Odile Stéphan (odile.stephan@universite-paris-saclay.fr).

More information on :

https://equipes2.lps.u-psud.fr/stem/
https://equipes2.lps.u-psud.fr/stem/impulse/

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