

MASTER 2

Proposition de stage 2026-2027 - Internship Proposal 2026-2027

Laboratoire d'accueil / Host Institution

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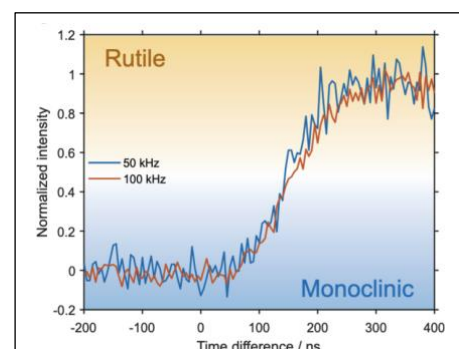
Titre / Title : Asynchronous ultrafast Raman imaging of reactions and phase transitions in energy materials

Projet scientifique (1 page maximum) / Scientific Project (maximum 1 page):

Raman spectroscopy is a workhorse of chemistry and materials science for tracking phase changes, chemical reactions and local structure. Compressive Raman imaging exploits concepts from single-pixel imaging [1]: it uses programmable spectral filters based on a digital micromirror device (DMD) and a quantum-enabled single-photon detector, which has led to the fastest spectral imaging acquisitions to date [2]. With this approach, we recently imaged, in operando, how ions move through battery and electrocatalyst particles [3,4]. For example, we showed that an oxygen-evolution catalyst switches between bulk and surface charge-compensation pathways depending on the applied potential [4]. However, even these experiments were ultimately limited by how fast a Raman image can be recorded. Electrochemical sweeps had to be kept slow so that the imaging could follow, and faster processes remained out of reach.

We have now developed a new strategy, asynchronous Raman imaging. Rather than trying to record images faster, we exploit the picosecond timing resolution of our single-photon avalanche diode (SPAD). Each detected Raman photon is time-stamped against a controllable, repeated perturbation of the sample, such as a voltage or current step, a light pulse or a temperature change. The dynamics are then reconstructed from the photon arrival times, so the time resolution is no longer set by the imaging speed. As a proof of concept, we applied this method to vanadium dioxide (VO_2), a model material whose insulator-metal phase transition can be triggered on demand, and followed the transition through its Raman signatures [5].

In this internship, the candidate will extend the method to other chemical and physical transformations of interest for energy applications. Several candidate systems are available. They range from halide perovskites for solar cells, where illumination drives ion migration and phase segregation, to supercapacitors electrodes, where charging involves fast ion adsorption and intercalation. Battery and electrocatalyst materials can also be revisited at the fast cycling rates previously out of reach [3,4]. The project is carried out in close collaboration with chemists and material scientists. The work will mainly be experimental: sample and cell preparation, synchronization of the Raman microscope with the external stimulus, and imaging experiments. There will also be computational tasks in data processing and analysis, so basic experience with a programming language (Python, MATLAB or similar) is expected. We welcome candidates with a background in physical chemistry, electrochemistry or materials science who are curious about optics and instrumentation. Depending on the outcome, the internship could be followed by a PhD project. Informal queries are welcome.



Ultrafast transient Raman response from the two possible phases of VO_2 .

[1] Edgar et al., Nat. Photonics 13, 13 (2019).

[2] Gentner et al, Opt. Lett. 49, 6573 (2024); Soldevila et al., Optica 6, 341 (2019); Sturm et al., ACS Photonics 6, 1409 (2019).

[3] Degoulangue et al., PNAS 120, e2220662120 (2023); Pandya et al., Nat. Nanotechnol. 18, 1185 (2023).

[4] Pandya et al., Nat. Commun. 15, 8362 (2024).

[5] Yang et al, in preparation (2026)