

# Colloidal synthesis and structural characterization of semiconducting monolayers

**Supervision:** Benoit Mahler ([benoit.mahler@univ-lyon1.fr](mailto:benoit.mahler@univ-lyon1.fr), ILM) and Matthieu Bugnet ([matthieu.bugnet@insa-lyon.fr](mailto:matthieu.bugnet@insa-lyon.fr), MATEIS)

## Context

Monolayers of lamellar materials such as transition metal dichalcogenides (TMDCs: MoS<sub>2</sub> or WS<sub>2</sub> for example) possess a direct band gap tunable over the whole visible-near-infrared spectrum, have extraordinary high absorption cross-sections<sup>1</sup>, and can present optimal fluorescence efficiency in the absence of trap states<sup>2</sup>. Moreover, they are *stable, cheap, earth abundant and possess low toxicity*. These properties make them promising candidates for the development of *new nanomaterials for light conversion applications*.

The aim of this internship is to develop colloidal synthetic strategies to prepare highly fluorescent TMDCs nanosheets. By combining colloidal synthesis exploration with systematic characterization of their trap states and trap density through spectroscopic measurements and of their structure down to the atomic scale through high-resolution transmission electron microscopy (HRTEM), it will be possible to identify the adequate synthetic parameters to obtain highly crystalline, size-controlled, fluorescent colloidal TMDCs monolayers.

## Methodology

Some successful colloidal synthesis strategies have already been developed, allowing for the preparation of freestanding TMDCs monolayers. We recently developed the first colloidal synthesis of WS<sub>2</sub> monolayers (figure 1).<sup>4</sup> By controlling the reaction conditions, we were able to prepare either WS<sub>2</sub> monolayers or aggregated nanosheets with different crystal structures. This demonstrates the possibility to synthesize colloidal monolayers, but this proof of principle still leads to highly defected structures (figure 1b). It should be possible to acquire a much better control of the synthesis, through the use of specially designed precursors, more adequate ligands and reaction conditions.

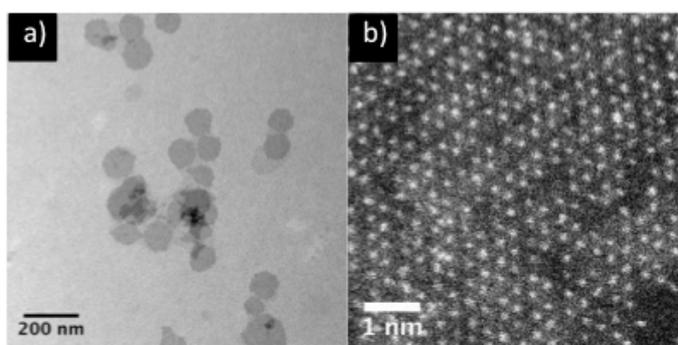
This synthesis exploration is indissociably linked to the use of characterization techniques able to give quantifiable information about the defects density into the sheets. In the case of monolayers, usual crystal structure monitoring such as X-ray diffraction is useless. Therefore, we will rely on HRTEM to acquire insight about the crystallinity of the monolayers. First, nanoscale imaging will be carried out in the analytical Jeol 2100F TEM available at ILM (CTμ) to ensure the successful synthesis of TMDC nanosheets. Then, subsequent high-resolution analysis will be performed on the FEI Titan TEM, instrument of the CNRS Federation CLYM, recently installed on the campus La Doua. It is equipped with a corrector of geometrical aberrations of the objective lens for improved spatial resolution, an electron energy loss spectrometer for nanoscale elemental imaging, and ultrafast camera with enhanced signal/noise, which allows improved high-resolution imaging of electron beam sensitive materials such as the 2D TMDC.

## Internship program

The student will first develop new TMDC colloidal syntheses, with a particular effort focused on the crystallinity improvement. The as-synthesized nanosheets will be routinely analysed using absorbance and fluorescence spectroscopy, Raman spectroscopy and Transmission Electron Microscopy at the ILM. The best samples will then be studied in depth to characterize their crystallinity, trap states and trap density, using the FEI Titan TEM at MATEIS laboratory.

## References

1. Bernardi, M., Palumbo, M. & Grossman, J. C. *Nano Lett.* **13**, 3664–70 (2013).
2. Amani, M. *et al. Science.* **350**, 1065–1068 (2015).
3. Mahler, B., Hoepfner, V., Liao, K. & Ozin, G. A. *J. Am. Chem. Soc.* **136**, 14121–14127 (2014).



**Figure 1:** a) TEM image of 1T-WS<sub>2</sub> monolayers obtained by colloidal synthesis. b) HAADF-HRSTEM picture of the monolayers revealing the defective crystal structure, (Mahler *et al*, 2014)<sup>4</sup>