Colloidal two-dimensional heterostructures

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

Context

Monolayers of lamellar materials such as transition metal dichalcogenides (TMDCs: MoS_2 and WS_2 for example) possess a direct band-gap tunable over the whole visible-near-infrared spectrum, have extraordinary high absorption cross-sections,[1] and can present optimal fluorescence efficiency in the absence of trap states.[2] 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, and particularly fluorescence. Obtaining fluorescent monolayers necessitate to efficiently passivate recombination centers, preferentially located at the nanostructure interface. One way to suppress these defects is to grow another material on the nanosheet edges, moving away the interfaces. The aim of this internship is then to develop colloidal synthetic strategies to prepare fluorescent TMDCs heterostructures. By combining colloidal synthesis exploration with systematic characterization 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 heterostructures.

Methodology

Some successful colloidal synthesis strategies have already been developed, allowing for the preparation of freestanding TMDCs monolayers. For example, we developed the first colloidal synthesis of WS_2 monolayers.[3] More recently, we also developed syntheses allowing shape control of the nanosheets, yielding triangular layers (figure 1).

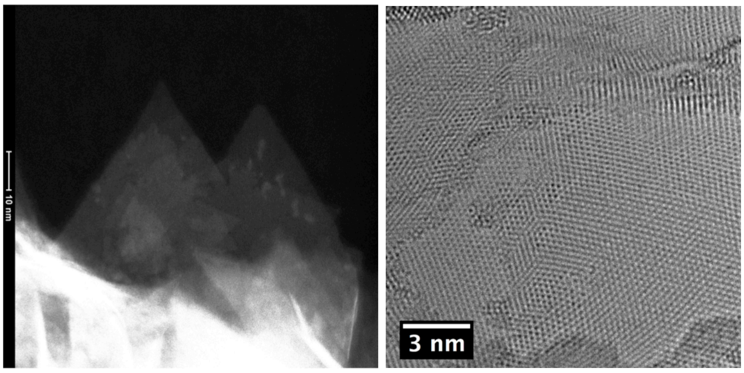

Figure 1: left: *HAADF-HRSTEM picture of triangular shaped WS_2 nanosheets.* **Right:** *HRTEM picture of a crystalline WS_2 nanosheet.*

This demonstrates the possibility to synthesize colloidal monolayers and to tune at the same time the nanosheets morphology. Using controlled introduction of precursors into the reaction medium, it should be possible to create heterostructures of different geometries. Furthermore, depending on the materials used and their relative band alignment, such heterostructures could act as excitation concentrators or could separate efficiently the photogenerated charge carriers. The strong electronic differences between homogeneous layers and heterostructured nanosheets should allow us to follow the heterostructures formation spectroscopically, using absorbance and fluorescence measurements.

Internship program

The student will first develop new TMDC colloidal syntheses, with a particular effort focused on the heterostructures production. 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 and interfaces, using the FEI Titan TEM at MATEIS laboratory.

References

1. Bernardi, M., Palummo, 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).