Atomic-scale quantum photonics of moiré superlattices

Host Institution: Université de Strasbourg and CNRS, Institut de Physique et Chimie des Matériaux de Strasbourg **(IPCMS, UMR 7504)** - 23 rue du Lœss, BP 43, 67034 Strasbourg - France
Supervisors: Stéphane BERCIAUD, Professor at Unistra and Guillaume SCHULL, CNRS Research Director
Contact: stephane.berciaud@ipcms.unistra.fr | guillaume.schull@ipcms.unistra.fr

The quest for low-dimensional heterostructures with novel quantum properties is one of the most active research directions in condensed matter physics. In this context, the broad palette of 2D materials and the "twist" degree of freedom between 2D layers offer endless possibilities to design **van der Waals (vdW) heterostructures** [1]. These systems exhibit **moiré superlattices** (Fig. 1a), wherein the Coulomb potential is spatially modulated at twist-tunable moiré wavelengths (up to ~ 10 nm) that largely exceed the Bohr radius (~ 1 nm) of Coulomb-bound electron-hole pairs (*i.e.*, excitons). The resulting **moiré superpotential** may be harnessed to tailor the electronic and optical properties of these materials and, in particular, to trap excitons [2]. The exciton Bohr radius and the moiré wavelength set the scales at which the physics of vdW heterostructures should be probed and correlated to the nanoscale environment. These scales are, however, two to three orders of magnitude below the resolution of conventional diffraction-limited optical techniques, which is a major experimental obstacle.

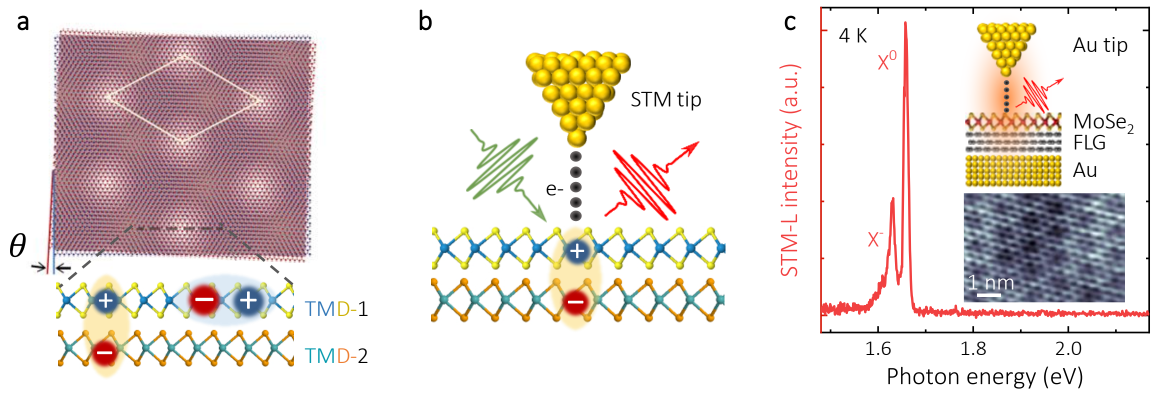

*Figure 1 | **a** - Illustration of a moiré superlattice in a 2D semiconductor heterobilayer twisted by an adjustable angle θ [2]. Inter and intra-layer excitons are illustrated in real space. **b** - Our approach: STM-induced luminescence (STML) and tip-enhanced optical spectroscopy of moiré excitons will be performed with ultimate spatial resolution. **c** - First 4K STML measurement on a 2D semiconductor (here, $MoSe_2$)/few-layer graphene (FLG) heterostructure. Two narrow emission lines are assigned to the neutral (X^0) and negatively charged exciton (X^-) in $MoSe_2$. A moiré superlattice is clearly visible on the STM topography image (lower inset). Data from IPCMS, see Ref. [3] for more details.*

This research project takes up the challenge highlighted above and aims at understanding and controlling quantum light-matter interactions in vdW heterostructures with ultimate spatial resolution. For this purpose, twist-engineered vdW heterostructures (Fig. 1a,b) will be fabricated in house (STnano facility) and studied using a state-of-the-art setup that combines low temperature scanning tunneling microscopy (STM) and optical spectroscopy ([3] and Fig. 1c). **We are looking for a candidate with a solid background in fundamental physics and a strong taste for experimental research at the interface between condensed matter physics, optical spectroscopy and quantum photonics.** The candidate will assemble and characterize vdW heterostructures and perform STM-based measurements, data analysis and modelling. He/She will join a dynamic collaboration between two teams at IPCMS. We will consider applications from Master students looking for a research internship or from prospective PhD students. **Funding for a PhD is already secured.**

Selected references:

[1] N. Wilson *et al.*, *Nature* **599**, 383 (2021) - doi: 10.1038/s41586-021-03979-1
[2] K. Seyler *et al.*, Nature **567**, 66 (2019) - doi:10.1038/s41586-019-0957-1
[3] L.E. Parra Lopez *et al.*, Nature Materials **22**, 482 (2023) - doi:10.1038/s41563-023-01494-4 | Unistra and CNRS press release | news and views (doi:10.1038/s41563-023-01514-3) | preprint: arXiv:2204.14022