Master’s project: Probing single atoms or molecules on top of two-dimensional semiconductors

Project description:

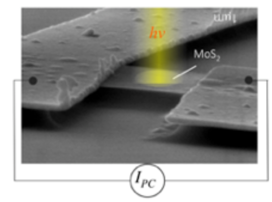

Figure 1: Photocurrent spectroscopy setup

Transition Metal Dichalcogenides (TMDCs) are atomically-thick materials related to graphene. TMDCs are semiconductors featuring strong electron/electron interactions leading to formation of excitons, tightly-bound hydrogen-like electron/hole pairs. Excitonic physics in TMDC has recently been a subject of intense study [1]. The aim of the current project is to explore more complex three-body excitonic “molecules”: electron/hole pairs inside a TMDC that are electrostatically bound to a charge on *an external molecule or an atom on the surface of the TMDC*. Such excitonic molecules are expected to have large binding energy dependent on the type of atom or molecule they are bound to. The motivation of the project is twofold: First, we want to explore and engineer complex quantum-mechanical excitonic molecules. Second, by detecting signatures of new excitonic states, we may be able to approach detection of *individual* atoms and molecules on top of TMDCs.

To detect excitons bound to atoms/molecules, we will use photocurrent spectroscopy (PCS). PCS has recently emerged as an interesting alternative to traditional optical spectroscopies. In PCS, electrical current across an electrically conductive sample is detected as a function of the wavelength of the light illuminating the sample (Fig. 1). In a sense, the sample acts as its own photodetector. The potential advantage of PC is that it is an extremely sensitive and local technique that can probe solid/light interactions even in samples with atomic dimensions. For example, we recently shown that PCS can be used to study excitons inside a two-dimensional TMDCs [2]. We expect that PCS should be able to resolve the signatures of excitons bounds to atoms/molecules.

During the project the student will acquire the following skills:

- **Exfoliation, growth, and transfer of two-dimensional materials.** The student will learn to deposit and characterize various types of two-dimensional materials using optical and Raman spectroscopies.
- N**anofabrication,** including electron beam lithography, metal evaporation, etching. The student will fabricate nanoscale TMDC devices with electrical contacts.
- **Optoelectronic measurements and cryogenics.** The student will help to develop the low-temperature scanning photocurrent spectroscopy setup currently operating in the Bolotin lab.
- **Data analysis, programming, preparing a scientific publication**

After the completion of the project, it will likely be possible to continue towards a PhD in the same research area in the Bolotin group under the auspices of the new Collaborative Research Center “Ultrafast spin dynamics”.

References

[1] Mak et al., Nature Photonics 10, 216 (2016)
[2] Klots et al., Scientific Reports 4, 6608 (2014)