Observing electronic structure of two-dimensional materials in real space and ultrafast time domains

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Two-dimensional (2D) semiconducting transition metal dichalcogenides (TMDs) exhibit a diverse collection of intriguing electronic phenomena. These include single-particle effects related to new spin and valley physics, as well as exotic many-body interactions. The latter are exemplified by the presence of tunable band gaps and tightly bound excitons and trions.

Here, I will discuss our recent efforts to synthesize single-layer TMDs such as MoS_2 and WS_2 using a variety of methods ranging from van der Waals epitaxy [1] to manual exfoliation, transfer and assembly of TMD-based heterostructures with other 2D materials [2,3]. Characterization of the electronic properties of such materials is carried out using a combination of angle-resolved photoemission (ARPES) experiments that incorporate either ultrafast time-resolution (TR-ARPES) or micro- to nano-scale spatial resolution (microARPES/nanoARPES). I will show how ultrafast band gap tuning and control of the spin- and valley-degrees of freedom in TMDs can be achieved and observed in pump-probe experiments [4]. Finally, I will address how the substrate material influences the band structure and many-body interactions in 2D heterostructures based on spatially-resolved photoemission experiments [2,3].

[1] J. A. Miwa, M. Dendzik *et al.*: *Van der Waals Epitaxy of Two-Dimensional MoS_2-Graphene Heterostructures in Ultrahigh Vacuum*. ACS Nano **9**, 6502 (2015)

[2] S. Ulstrup, J. Katoch *et al.*: *Spatially Resolved Electronic Properties of Single-Layer WS_2 on Transition Metal* Oxides. ACS Nano 10, 10058 (2016).

[3] J. Katoch, S. Ulstrup *et al.*: *Giant spin-splitting and gap renormalization driven by trions in single-layer WS_2/hBN heterostructures*. Nature Physics 14, 355 (2018).

[4] S. Ulstrup, A. G. Cabo *et al.*: *Spin and Valley Control of Free Carriers in Single-Layer WS_2.* Physical Review B: Rapid Communications 95, 041405(R) (2017).