Ultrafast dynamics in 2D materials and heterostructures visualized with time- and angle-resolved photoemission

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The optical and electronic properties of two-dimensional (2D) materials make them attractive for a variety of applications in quantum information processing, solar-energy harvesting, and catalysis. However, the dynamics of electrons, holes, and excitons formed after photo-excitation are often complex and involve many states that are optically dark, making their characterization with optical spectroscopy alone difficult. We will present our recent work imaging the quantum states of 2D materials and their heterostructures in momentum space using time- and angle-resolved photoemission. A unique combination of tunable ultrashort extreme ultraviolet (XUV) pulses with 61 MHz repetition rate and timeof-flight momentum microscopy (ToF k-mic) enables the parallel recording of electron dynamics in all states across the full Brillouin zone after perturbative excitation, while systematically varying many parameters. We will present recent results resolving the mixture of interlayer and intralayer excitons created after above band-gap excitation of MoSe2/WS2 bilayers due to spatially varying type I and type II band alignment[1], and dark states in type II WS2/WSe2 bilayers. We will also present recent progress towards time-resolved momentum microscopy at arbitrary (0-61 MHz) repetition rate with tunable pump and probe photon energies.

Keywords: 2D materials, momentum microscopy.

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[1]Guo et al., “Moiré-Tunable Localization of Simultaneous Type I and Type II Band Alignment in MoSe 2 /WS2 Heterobilayer.” arXiv:2502.14138 (2025).