Ultrafast Momentum-Resolved Carrier Dynamics in 1D Wires and 2D Heterostructures

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Low-dimensional materials exhibit strong electronic correlations due carrier confinement and reduced screening. In this talk I will introduce Indium wires epitaxially grown on Si(111), a quasi 1D system that undergoes a metal-to-insulator transition at low temperatures, and epitaxial van der Waals heterostructures made out of monolayer WS_2 (a direct-gap semiconductor with strong spin-orbit coupling) and monolayer graphene (a semimetal with conical band structure and extremely high carrier mobility). We photo-doped both material systems with femtosecond laser pulses and investigated the resulting carrier dynamics with time- and angle-resolved photoemission spectroscopy (tr-ARPES) at extreme ultra-violet (XUV) wavelengths.

Indium wires grown on Si(111) exhibit an unconventional multiband Peierls instability with strong interband coupling. This charge density wave ground state is readily destroyed with femtosecond laser pulses resulting in a light-induced insulator-to-metal phase transition. The current understanding of this transition remains incomplete, requiring measurements of the transient electronic structure to complement previous investigations of the lattice dynamics [1]. Using tr-ARPES, we find that the transition from the insulating to the metallic band structure occurs within ~660fs [2] that is a fraction of the amplitude mode period. The long life time of the transient state (>100ps) is attributed to trapping in a metastable state [2] in accordance with previous work [1].

In the WS_2/graphene heterostructure we find evidence for ultrafast charge transfer between the individual layers after photoexcitation of the heterostructure with 2eV pump pulses resonant to the A exciton in WS_2. In agreement with previous work [3] we find ultrafast charge transfer between WS_2 and graphene on the picoseconds time scale. In addition, we clearly show that this charge transfer is asymmetric: the transfer of electrons from the conduction band of WS_2 into the pi-bands of graphene takes 1.1ps whereas the corresponding hole transfer is at least ten times faster. Hence, in the transient state, electrons and holes are localized in the conduction band of WS_2 and the valence band of graphene, respectively. Further, the angular spread of the photoelectrons emitted from this charge transfer exciton allows us to estimate the size of the wave function of the exciton as suggested in [4].

References:
[1] S. Wall, et al., Phys. Rev. Lett. **109**, 186101 (2012); T. Frigge, et al., Nature **544**, 207 (2017).
[2] M. Chavez-Cervantes et al., arXiv:1803.05189 (2018), Phys. Rev. B accepted.
[3] J. He, et al., Nat. Commun. **5**, 5622 (2014); N. Huo, et al., J. Mater. Chem. C, **3**, 5467 (2015); H. M. Hill, et al., Phys. Rev. B **96**, 205401 (2017); L. Yuan, et al., Sci. Adv. **4**, 1700324 (2018).
[4] A. Rustagi, et al., arXiv:1802.07270 (2018).