WWU MÜNSTER

FACHBEREICH PHYSIK

Allgemeines Physikalisches Kolloquium

Donnerstag, 11.05.2023 um 16 Uhr c.t.

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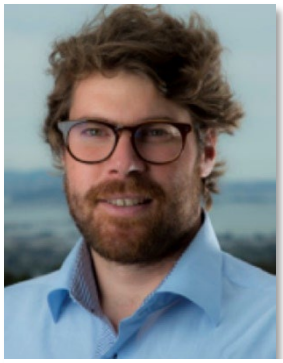

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Controlling Quasiparticle Excitations in 2D Solids through Atomically Precise Heterostructures

In this presentation, we investigate how atomically defined heterostructures, such as 2D stacks, 1D boundaries within a 2D material, and 0D vacancies and substitutes in 2D materials, localize new protected states that host quasiparticle excitations. Quasiparticles are emergent excitations in condensed matter systems that behave like particles, but are not elementary particles like electrons or protons. In 2D solids, a wide variety of quasiparticle excitations can be experimentally accessed, including localized electrons, excitons, superconducting states, and polaritons, as well as more exotic systems like Tomonaga Luttinger liquid. Each specific quasiparticle excitation is a result of a specific crystalline symmetry. By inducing atomically defined 0D, 1D, and 2D heterostructures, it is possible to localize, protect, and create novel quasiparticle excitations.

We demonstrate how to engineer heterostructures into 2D Transition Metal Dichalcogenides and visualize the resulting electronic structure using Scanning Tunneling Microscopy. We discuss the resulting quasiparticle excitations that we directly capture using Scanning Tunneling Microscopy, as well as Time Resolved optical Spectroscopy. We show how 0D heterostructures or defects in 2D MoSe2 and 2D WS2 carry intrinsic point defects that substantially modify electronic properties. For instance, individual S vacancies create two-level systems within the band gap with extremely high spin-orbit coupling, and can mediate single photon emission via optical or electric stimulation. We also demonstrate how C-H for S or Se substitutes in 2D WS2 and 2D WSe2 form locally charged hydrogen-like states. Upon deprotonation, the localized carbon radical hosts a deep in-gap state with a net spin and electron-phonon coupling that is similar to NV color centers in diamond, but with atomistic control. Furthermore, individual Chalcogen Vacancies can be decorated with a variety of different adatoms, creating new types of 0D heterostructures, such as Co-S substitutes that could become relevant for Quantum Information Science.

In 1D heterostructures, such as Mirror Twin Boundaries in MoSe2 or WS2, we discovered atomically thin metallic conductors that undergo a quantum phase transition at low temperature to form a Tomonaga Luttinger Liquid (TTL).

TTLs are correlated electron systems, where electrons couple to form a bosonic system, and that can foster partial electron and spin transport.

As a 2D heterostructure, we explore WS2/WSE2 stacks, where we study the formation and recombination channels of interlayer excitons formed in WS2/WSE2 stacks, which may relate to the recently reported formation of excitonic Bose-Einstein condensates. Another fascinating area of research is coupling quasiparticles to form new quasiparticles. By stacking 2D WSe on linear plasmonic cavities, we were able to couple excitons to plasmons, creating plexcitons. We use techniques such as photo low-temperature Scanning Tunneling Microscopy, near-field optical microscopy, and low-temperature time-resolved optical spectroscopy to investigate the properties and behavior of these quasiparticle excitations.