Aktuelle Fragen
der Nanophysik

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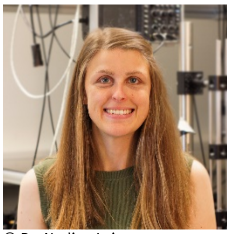
Electrical control of excitons in a gated two-dimensional semiconductor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The emergence of two-dimensional (2D) materials, such as graphene and transition metal dichalcogenides (TMDs), and the ability to build artificial van der Waals heterostructures (vdWHs) by stacking different combinations of materials, has opened a new route for engineering quantum systems. 2D TMDs support bound electron-hole pairs, or excitons, that have particularly large binding energies, such that excitons dominate their optical properties, even at room temperature. The ability to electrically tune their properties via external electric gates is essential for various interesting opto-electronic applications.
A crucial feature of semiconductor nanostructures is the quantum confined Stark effect (QCSE), the change in optical energy on applying an electric field perpendicular to the layers. Using a gated vdWH, we demonstrated, that in monolayer MoS_2 the optical absorption is strong, but the transition energy is not tunable as the neutral exciton has essentially no permanent out-of-plane electric dipole and is only slightly polarizable [1]. The electrical control of excitons via the QCSE requires larger polarizabilities or a non-zero dipole moment as observed in heterobilayers where the bound electrons and holes reside in different layers. However, the coupling to light in these systems is considerably reduced. To combine best of both worlds, a polarizable yet strong optical dipole, we integrated homobilayer MoS_2 in a dual-gate device structure. In its natural bilayer form, we discovered interlayer excitons which exhibit both a high oscillator strength and highly tunable energies in an applied electric field. Owing to their very large dipole moments, we were able to bring these interlayer excitons energetically close to resonance with the excitons confined to the single layers, and study exciton-exciton interactions in these systems [2].
Equipping MoS_2 with gates allows electrons to be injected, creating a 2D electron gas. By probing the electronic ground state at various electron densities, we presented experimental evidence for a spontaneous spin-polarization in monolayer MoS_2 [3]. Significantly, its extremely small Bohr-radius suggests that Coulomb effects play an important role at experimental relevant electron densities.
The ability to control the properties of thin semiconductors by electrical means makes these systems a versatile platform for rich exciton physics and unique opto-electronic applications.

[1] J. G. Roch, N. Leisgang *et al.*, Nano Letters **18**, 1070–1074 (2018).
[2] N. Leisgang *et al.*, Nature Nanotechnology **15**, 901–907 (2020).
[3] J. G. Roch, G. Froehlicher, N. Leisgang *et al.*, Nature Nanotechnology **14**, 432-436 (2019).