Universität Münster

Aktuelle Fragen der Nanophysik

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The rich world of two-dimensional semiconductors: On lattice reconstruction in $MoSe_2$-WSe_2 heterobilayers and doping-control of excitons and magnetism in few-layer CrSBr

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Since the discovery of graphene in 2004, a plethora of two-dimensional (2D) materials has been investigated. Among 2D semiconductors, transition metal dichalcogenides have been of particular interest due to their direct band gap in the monolayer, large exciton binding energies, and rich valley physics. Within the class of 2D magnets, air-stable CrSBr stands out as an antiferromagnetic semiconductor with a high Néel temperature, excitons coupled to the magnetic order [1], and exciton-magnon coupling [2].

Combining two monolayers of transition metal dichalcogenides with a twist angle or different lattice constants gives rise to rich moiré physics or atomic reconstruction into energetically favorable registries with strong signatures of interlayer excitons. In the first part of this talk, I will present our work on lattice reconstruction in $MoSe_2$-WSe_2 heterobilayers grown by chemical vapor deposition (CVD) [3]. We observe reconstruction into moiré-free extended domains enclosing micron-scale regions of periodic nanoscale reconstruction giving rise to dipolar excitons with and without confining potential landscapes. We unambiguously identify the dominant atomic registries in both high-symmetry stacking configurations, consistent with theoretical modelling. In H-type stacking, we observe extended domains of the H_h^h registry, while R-type heterostacks reconstruct into the R_h^M registry with z-polarized interlayer excitons (Fig. 1 a,b), which are not observed in stamping-assembled heterostructures [4] where R_h^X dominates the photoluminescence. Our work highlights the potential of CVD for applications requiring laterally extended heterosystems of one atomic registry or exciton-confining heterostack arrays.

In 2D magnets, phenomena distinct from bulk magnetism have been revealed, such as sensitivity to charge doping and electric field in few-layer CrI_3 [5]. In the second part of this talk, I will present our work on doping-control of excitons and magnetism in few-layer CrSBr [6]. We demonstrate that both exciton and magnetic transitions are sensitive to field-effect charging, exhibiting bound exciton-charge complexes (Fig. 1 c) and doping-induced metamagnetic transitions. We further visualize magnetic domain formation induced by magnetic field or charge-doping at the metamagnetic transition all-optically by raster-scan reflectance imaging (Fig. 1 d). Our work identifies few-layer CrSBr as a rich platform for exploring collaborative effects of charge, optical excitations, and magnetism.

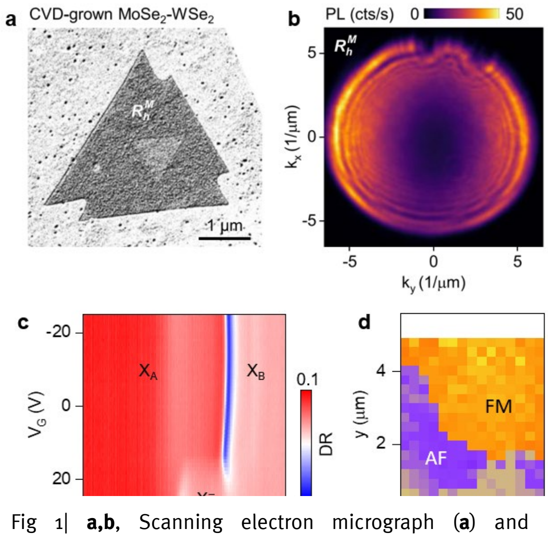

Fig 1| **a,b**, Scanning electron micrograph (**a**) and momentum-space photoluminescence (PL) image (**b**) of a $MoSe_2$-WSe_2 heterobilayer with large area R_h^M reconstruction. **c**, Voltage sweep in differential reflectance (DR) of bilayer CrSBr. **d**, Optical imaging of magnetic domains in bilayer CrSBr, AF: antiferromagnetic, FM: ferromagnetic. **a,b**, reproduced from ref. [3], **c,d**, reproduced from ref. [6].

References:
[1] N. Wilson et al., Nat. Materials **20**, 1657-1662 (2021)
[2] Y. J. Bae et al., Nature **609**, 282 (2022).
[3] Z. Li*, F. Tabataba-Vakili*, S. Zhao* et al., Nano Lett. **23**, 4160 (2023).
[4] S. Zhao et al., Nat. Nanotechnol. **18**, 572 (2023).
[5] S. Jiang et al., Nat. Nanotechnol. **13**, 549 (2018).
[6] F. Tabataba-Vakili et al., arXiv:2312.11041 (2023).