STM and STS on monolayer MoS_2/BP towards ultraclean open-face graphene/BN moiré devices

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Moiré superlattices in two-dimensional van der Waals heterostructures generate minibands in which strongly correlated and topologically protected electronic states can arise. While twisted heterostructures with hexagonal C_3/C_6-symmetry, such as graphene and most transition metal dichalcogenides (TMDs), have already been studied to some extent, the formation of moiré superlattices out of crystal from distinct symmetric classes has been barely explored. Here, rotational symmetry may be broken, leading to enhanced anisotropic electronic properties.[1,2] Monolayer molybdenum disulfide (MoS_2) on orthorhombic black phosphorus (BP) represent such a novel candidate, in which hybridisation of the bands in momentum space and a breaking of C_3-symmetry have recently been demonstrated using micro-ARPES.[3] However, to date, there has been no direct scanning tunnelling microscopy and spectroscopy (STM/STS) characterisation of these moiré flatbands and local potential modulations in real space.

Here we present the first STM/STS study at room temperature, 77 K and 4.2 K on a monolayer of MoS_2 on BP. Fourier analysis of the topography maps at 77 K resolves both the atomic lattices and a moiré superlattice with a long period of ~4.4 nm and twist angle of Φ~3.1°. Comparison with a rigid two-scale model shows agreement for two additional moiré components, one short and one longer, the latter of which is sensitive to twist and strain. STS measurements reveal a renormalised bandgap of E_g ~1.6-1.7 eV, likely caused by the dielectric screening of the polarisable BP substrate, as well as a spatially periodic, energy-selective modulation of the valence band edge at -0.74 eV, tracking the moiré period.

Furthermore, with the future aim of investigating minibands in graphene/hBN stacks, we have adapted the *sliding disassembly*[4] method at C2N to produce moiré-deterministic, resist-free fabrication process of open-face devices. Preliminary AFM measurements of a device based on a Bernal bilayer graphene (BBG) on hBN confirm the formation of a clean moiré superlattice approaching the maximum wavelength limit.

This work provides both local validation of minibands with mixed symmetry in real space and a path towards ultra-clean open-face graphene/hBN devices, as required for scanning probe investigations and photoemission measurements.

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