Twisted van der Waals Heterostructures from Advanced Transmission Electron Microscopy

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Twisted van der Waals (vdW) homo- and heterostructures enable unprecedented opportunities for the fine-tuning of nanoscale electronic properties. The main drivers of this flexibility are the Moiré patterns that arise from either lattice mismatches or from rotational misalignments. These intricate patterns critically influence the electronic band structure, leading to remarkable effects such as Moiré excitons and spatial variability in the band gap [1]. Such modifications are further linked to strain fields [2] generated within the twisted structures [3]. While several spectroscopic methods have successfully identified Moiré excitons in transition metal dichalcogenide (TMD) heterostructures, pinpointing their spatial distribution with the required resolution remains a challenge. In this study, we fingerprint twisted TMD nanostructures (WS_2 and WSe_2) through advanced Scanning Transmission Electron Microscopy techniques achieving the atomic-level imaging of the Moiré superlattice's structure. Employing Electron Energy Loss Spectroscopy and leveraging Machine Learning techniques [4], we scrutinise the resulting modulation of their electronic functionalities [5]. This strategy successfully identifies local band gap variations across the specimen, reveals the characteristic Moiré-related periodicity of spatially localised excitons. The same strategy can also be deployed to other morphologies such as one-dimensional MoS_2 nanotubes [1] highlighting exciton localisation in highly strained regions of the material. Our synergistic methodology enables novel insights in our understanding of the rich interplay between crystal structure, strain, and electronic properties at the nanoscale in vdW materials, facilitating their potential impact on a wide spectrum of nanotechnology applications, spanning from nanoelectronics to nanophotonics.

References

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