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MULTISCALE ANALYSIS OF EPITAXIALLY GROWN 2D MATERIALS USING 4D-STEM

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Two-dimensional materials exhibit remarkable physical properties that are highly sensitive to the presence of structural defects. Understanding the correlation between growth processes, structural order, and electronic behavior is essential for their technological integration. This work develops four-dimensional scanning transmission electron microscopy (4D-STEM) as a quantitative tool for the multiscale characterization of epitaxially grown transition metal dichalcogenides. In the nanobeam acquisition condition, 4D-STEM enables the measurement of crystallographic orientation and polarity, allowing the spatial mapping of detrimental grain boundary defects, as demonstrated on MOCVD-grown semiconducting WS2 and MBE-grown semimetallic

PtSe2 layers. Additionally, convergent-beam 4D-STEM provides access to projected electric field and potential distributions at the atomic scale, enabling identification of single-dopant charge states in vanadium-doped WSe2. The developed methodology establishes 4D-STEM as a powerful approach for probing structural and electronic features in synthesized 2D materials, providing insights that can guide the targeted optimization of growth processes.