# Mapping Strain in van der Waals Nanostructures with Nanoscale Resolution Using 4D STEM

**Maarten Bolhuis**
Sabrya van Heijst, Sonia Conesa-Boj

*Delft University of Technology, Lorentzweg 1, Delft, The Netherlands*

m.bolhuis@tudelft.nl

Abstract

Strain is known to induce changes in the properties of quantum materials, and the emerging field of Straintronics [1] aims to leverage strain in nanomaterials, such as graphene or transition metal dichalcogenides (TMDs), to precisely tune their band structure [2]. While methods like Raman spectroscopy have been used to probe changes in the electronic structure of graphene at the macroscopic scale [3], mapping the local strain and rotation at the nanoscale in complex van der Waals nanostructures, such as twisted flakes and nanotubes, remains challenging due to their intricate geometry, small size, and sensitivity limitations.

In this study, we present a new approach for mapping strain in entire nanostructures with nanoscale resolution, using 4D scanning transmission electron microscopy (STEM) imaging with an Electron Microscope Pixel Array Detector. The method combines electron wave power cepstrum [4] (EWPC) with tracking and clustering of various crystal symmetries [5][6], enabling high accuracy and precision measurements of strain. Our results offer new opportunities for investigating the mechanical behaviour of twisted flake nanostructures and have potential implications for materials science and the bandgap engineering of quantum materials. By enabling precise mapping at the nanoscale, our approach has the potential to advance the field of Straintronics and open new avenues for the development of novel quantum devices.

References

[1] Miao, F., Liang, SJ. & Cheng, B. npj Quantum Mater. 6, 59 (2021)
[2] M. L. Teague, A. P. Lai, J. Velasco, et al., Nano Letters 9 (7) (2009)
[3] Mingyuan Huang, Hugen Yan, Tony F. Heinz, and James Hone, Nano Letters 10 (10) (2010)
[4] Elliot Padgett, Megan E. Holtz, Paul Cueva, et al., Ultramicroscopy, Volume 214, (2020)
[5] Lowe, D.G. International Journal of Computer Vision 60, 91–110 (2004)
[6] Sculley, D. WWW '10: (2010)

Figures

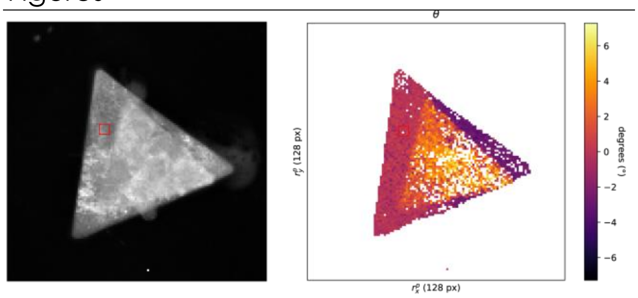

**Figure 1:** (left) Annular Darkfield 4D STEM image of a Twisted $WS_2$ nanostructure. (Right) Rotation map of the same $WS_2$ nanostructure, computed with the same 4D STEM dataset.