

# Automated atomic force microscopy for the manipulation and metrology of layered materials heterostructures

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One aspect of AFM that has increasingly been exploited of late in layered materials research is using the probe to manipulate samples deterministically [1]. In this talk, we will demonstrate how the use of in-situ heating during contact mode AFM cleaning [2,3] leads to clean interfaces within layered materials heterostructures. By forming marginally twisted homostructures of monolayer molybdenum disulphide (1L-MoS<sub>2</sub>) on graphite using PDMS stamps, we show a dramatic increase in the efficacy of the removal of trapped interfacial contamination when we do contact mode in-situ cleaning versus ambient temperature contact mode cleaning or annealing. The effectiveness of cleaning is determined by both the absence of trapped interfacial contamination in topographic images and the observation of moiré patterns between layers after cleaning.

In the second part of the talk, we will review the different modes that can be used to routinely measure moiré patterns in layered materials heterostructures, including topography, lateral force microscopy (LFM), torsional force microscopy (TFM) and electrical modes including conductive AFM (C-AFM) and Kelvin probe force microscopy (KPFM). We will also present a method to electrically contact isolated heterostructures on both polymeric and polymer free stamps to enable electrical AFM characterisation of partially assembled heterostructures and interfaces that go on to be buried upon further fabrication steps.

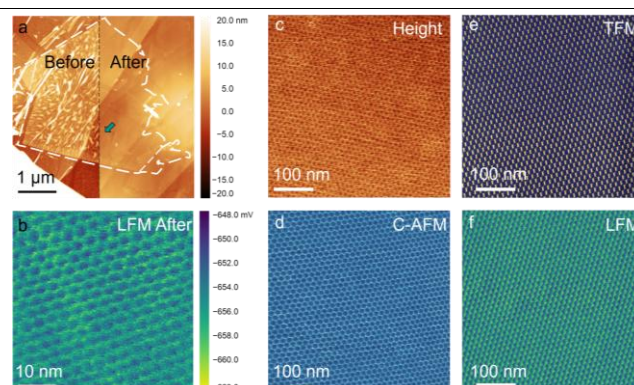
## References

[1] R. Ribeiro-Palau et al. *Science* 361,690-693 (2018).

[2] M. Rosenberger et al. *ACS Appl. Mater. Interfaces* 10, 12, 10379–10387 (2018)

[3] Y. Kim et al. *ACS Nano* 13, 12, 14182–14190 (2019)

## Figures



**Figure 1:** Comparing the surface morphology of a ~0° twisted 2L-MoS<sub>2</sub> homostructure on graphite before and after in-situ AFM cleaning at 125 °C (a) with an LFM image (b) of a moiré pattern from a cleaned area. AFM also enables moiré metrology through a range of imaging modalities. Here we show moiré patterns between few layer graphene and hBN acquired using non-contact mode (c), C-AFM (d), TFM (e) and LFM (f).