Fast, Stable Vacuum-Compatible Kelvin Probe Force Microscopy for Moiré Electric Potential Imaging

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Kelvin Probe Force Microscopy (KPFM) has emerged as a critical tool for probing moiré electric potential in twisted stacks of two-dimensional materials. Specifically, the periodic electric potential generated by twisted hexagonal boron nitride (t-hBN) multilayer can modulate optoelectronic properties in overlaid materials [1,2]. However, identifying suitable multilayer flakes from exfoliated flakes remains challenging and time-consuming.

We introduce a vacuum-compatible KPFM operating mode that integrates amplitude modulation mode with active cantilever quality-factor damping and phase detection for frequency modulation KPFM [3]. This approach enables rapid, stable imaging of moiré electric potential across large scan areas (>10 µm) even with the topographic variations up to ~100 nm. Figure 1 demonstrates topography and contact potential difference (CPD) images of a t-hBN multilayer produced by the self-folding technique [1,2].

We will present the details of the experimental technique and discuss the impact of operating parameters including tip oscillation amplitude, effective quality factor and amplitude setpoint on CPD imaging resolution and stability.

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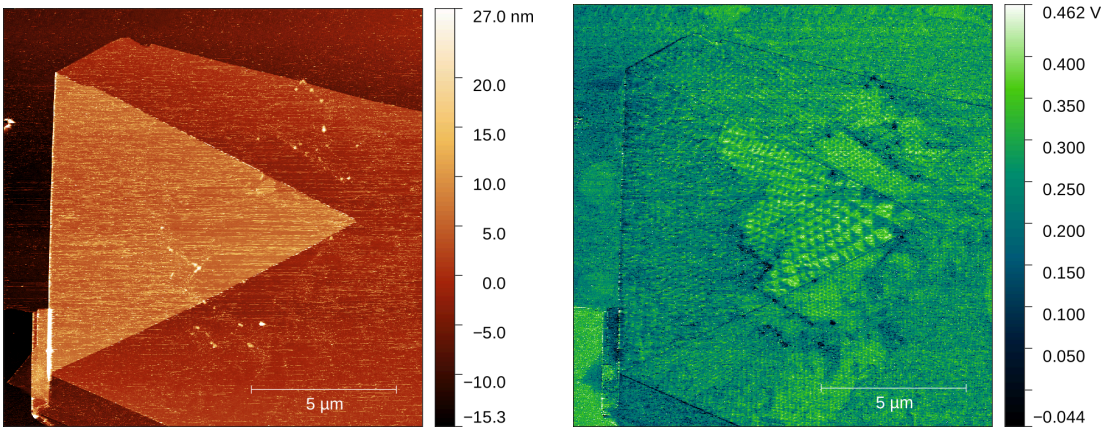

Fig. 1 (Left) Topography and (Right) CPD images of t-hBN multilayers.

References

[1] D.S. Kim, R.C. Dominguez, R. Mayorga-Luna et al., "Electrostatic moire potential from twisted hexagonal boron nitride layers", *Nat. Mater.*. **23**, 65-70 (2024).

[2] D.S. Kim, C. Xiao, R.C. Dominguez, et al., "Moire ferroelectricity modulates light emission from a semiconductor layer", *Sci. Adv.* **11**, eadt7789 (2025).

[3] Y. Miyahara, N. Austin-Bingamon and Md M. Hasan, *in preparation*.