Combined MFM/KPFM at the Ultimate Sensitivity Limit for Probing Curvature-Engineered Micromagnetic States

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Curved substrates offer a promising route for tailoring the magnetic properties of multilayer systems, potentially stabilizing topologically non-trivial spin textures such as skyrmions. However, local variations in surface inclination can significantly affect growth conditions, altering crystallographic orientation or even disrupting the multilayer architecture.

In this study, we investigate a Pt/Co/Ru multilayer deposited on a polymer substrate patterned with nanoscale semispherical bumps using a combined single-pass Magnetic Force Microscopy (MFM) and Frequency-Modulated Kelvin Probe Force Microscopy (FM-KPFM) technique. By employing cantilevers with quality factors exceeding one million, our system achieves unprecedented sensitivity to both magnetic and electrostatic interactions.

We find that steep, near-vertical walls at the perimeter of hemispherical features (dashed line in Fig. 1**g**) locally disorder the multilayer stack, resulting in distinct changes in the contact potential difference (dashed line in Fig. 1**h**). This disruption facilitates magnetic flux return and enables the formation of circular magnetic domains aligned with the external magnetic field on the dome tops (Fig. 1**i**). Notably, smaller hillocks (dotted circle in Fig. 1**j** and **k**) act as nucleation sites for isolated skyrmions with magnetization cores antiparallel to the applied field (Fig. 1**l**), suggesting a curvature-induced enhancement of the Dzyaloshinskii–Moriya interaction.

Our results position high-Q combined MFM/KPFM as a powerful nc-AFM-compatible platform for resolving and understanding curvature-driven micromagnetic phenomena, paving the way for the design and characterization of future spintronic devices.

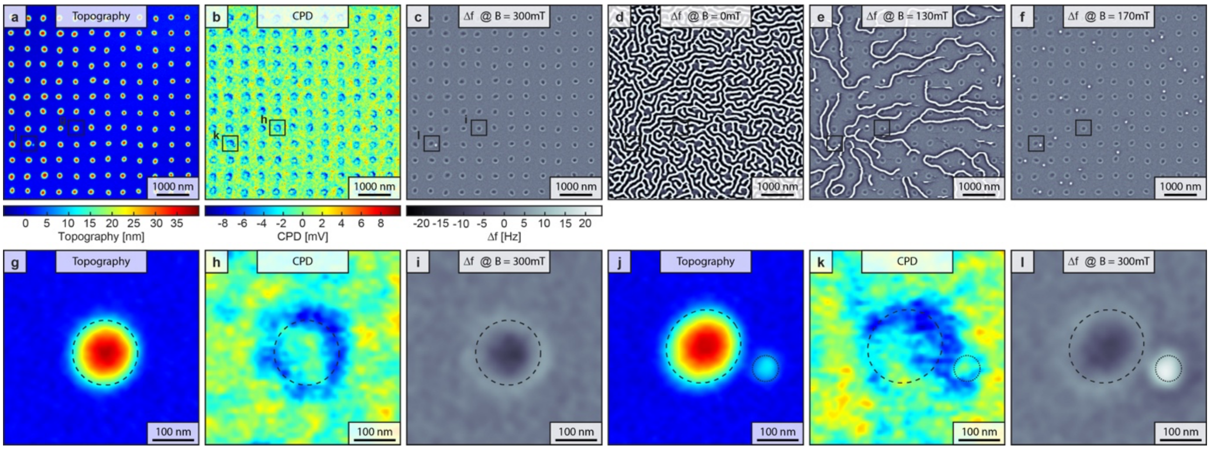

Figure 1. **a**–**c**: Simultaneously recorded topography, contact potential difference (CPD), and frequency-shift magnetic signal of a Pt/Co/Ru multilayer deposited on a locally curved polymer substrate. **d**–**f**: Evolution of the micromagnetic state as a function of applied magnetic field. **g**–**i** and **j**–**l**: Zoomed-in views of the topography, CPD, and magnetic signal, respectively. The dashed line in **g**–**i** indicates a perimeter region with near-vertical walls where the multilayer structure breaks down. The dotted circle in **j** highlights a smaller topographic feature stabilizing a skyrmion, marked by a dotted line in **l**.