

Supporting Information

3D Mapping of the Structural Transitions in Wrinkled 2D Membranes: Implications for Reconfigurable Electronics, Memristors, and Bioelectronic Interfaces

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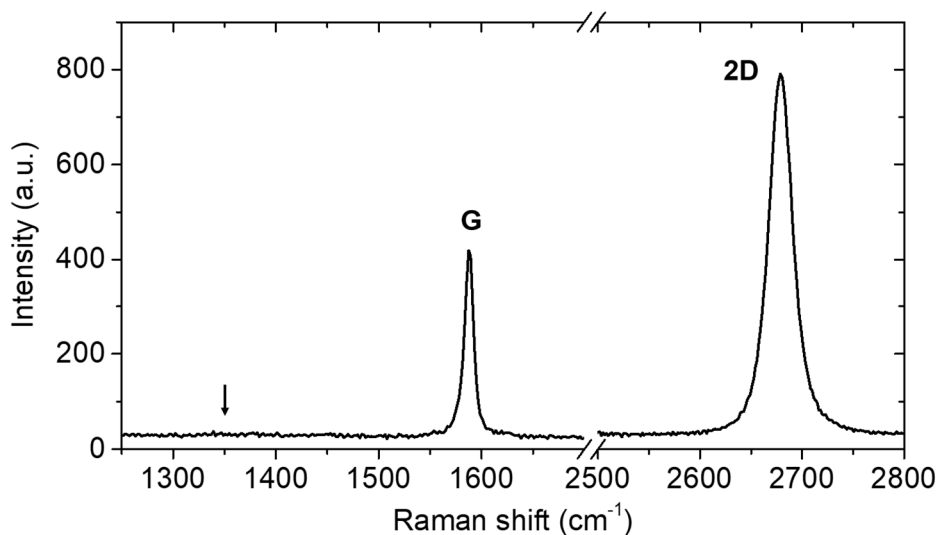


Figure S1. Raman spectroscopy of graphene on flat SiO₂ substrate. The presence of single peaks at ~1580 cm⁻¹ (G band) and ~2700 cm⁻¹ (2D band) confirms the presence of monolayer graphene, while the absence of D band at ~1350 cm⁻¹ reveals that the graphene is defect-free within the spectral resolution limit.¹

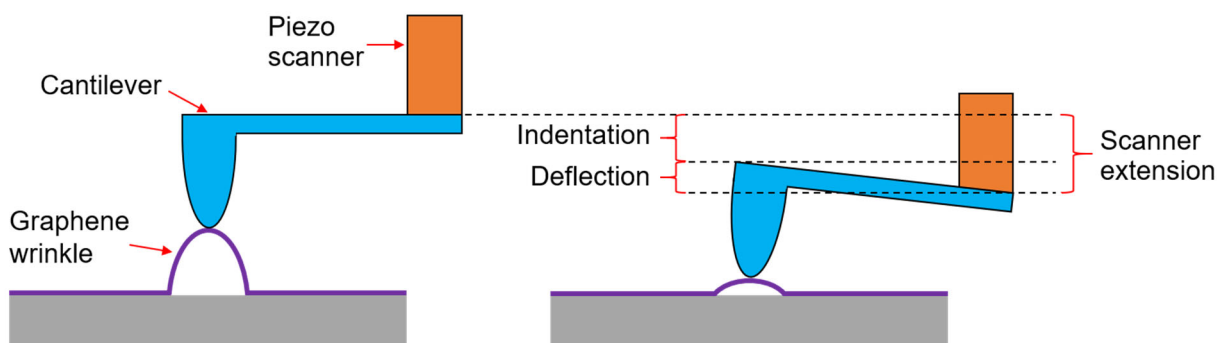


Figure S2. Schematic of the force-indentation measurement. The left and right figures correspond to the cantilever and sample configuration right before and during indentation, respectively. The raw signals measured are the cantilever deflection (Def) and scanner extension (Ext). The force is obtained as $F = k \cdot Def$ (where k is the spring constant of the cantilever), and the indentation is obtained as $Ind = Ext - Def$.

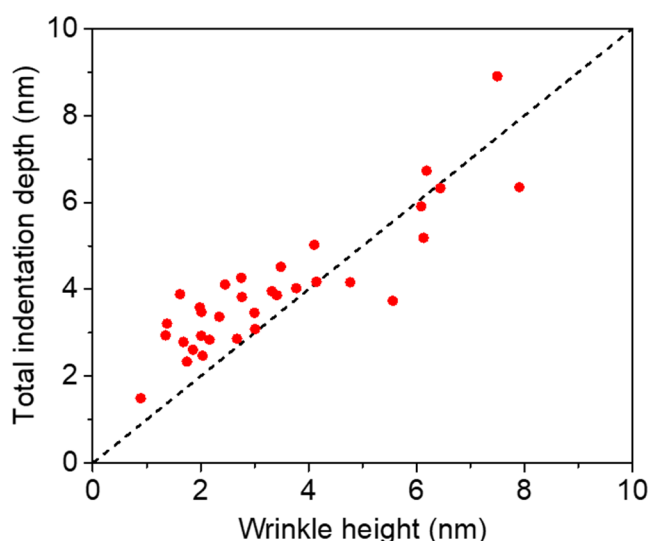


Figure S3. Correlation plot of the total indentation depth (determined from the FFM curves) and the wrinkle height (determined from tapping mode AFM image of the same area) of a series of spots on different wrinkles. Red dots are experimental data. To guide the eye of the readers, we also draw the black dashed line with a slope of 1, representing the condition that the total indentation depth is identical to the wrinkle height.

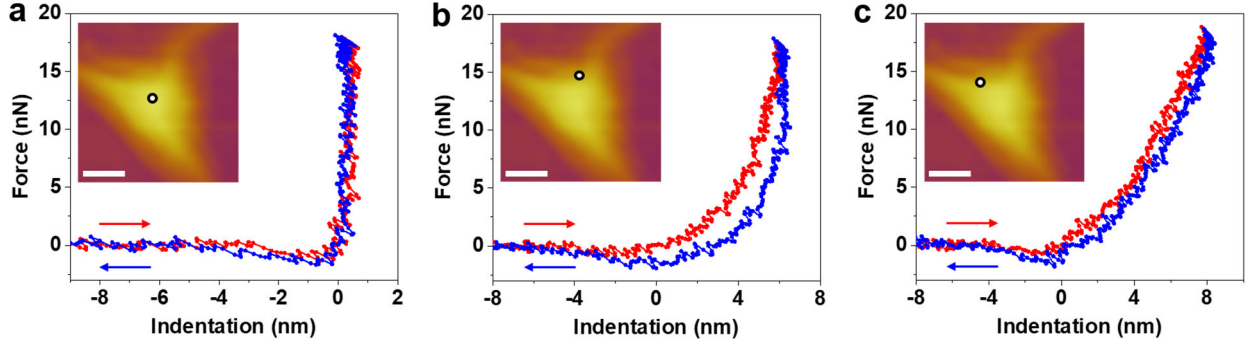


Figure S4. Force-indentation curves of graphene wrapped on top of a SiO₂ nanosphere. Insets are AFM height images, where the circles mark the positions on which the curves are measured. Scale bars: 20 nm. Note that the zero point of the indentation is chosen as the point where the force starts to increase. In (c) the maximum indentation is still not achieved at the force setpoint of ~18 nN.

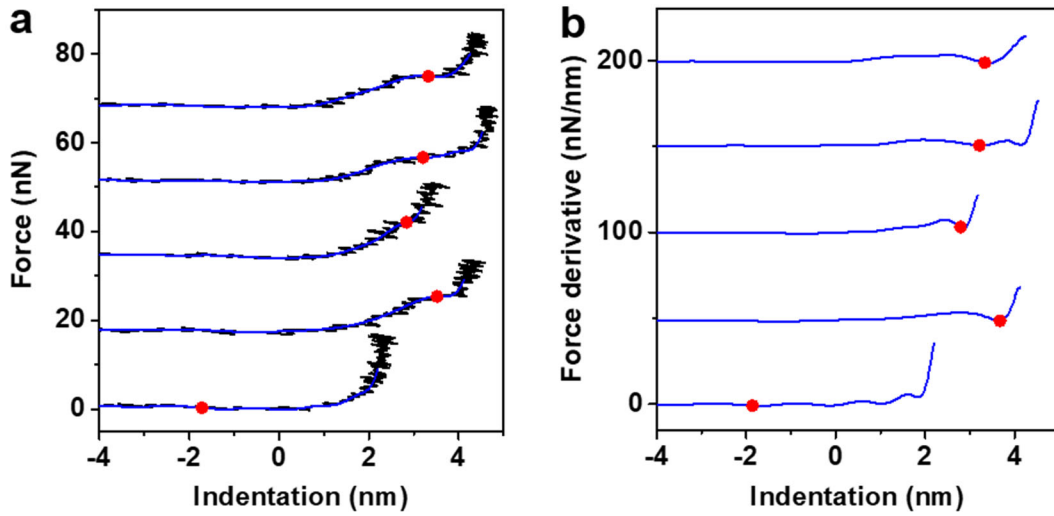


Figure S5. Examples illustrating the automatic tracking process of the threshold force for snapping transition. (a) The raw (black) and smoothened (blue) force vs indentation curve. (b) The derivative of force vs indentation, where the local minimum with the largest prominence is identified as the threshold transition point, labeled as red dots. Here the prominence of a local minimum (or valley) is defined as the smaller vertical distance from the valley to its two neighboring peaks. After identifying the threshold indentation values, we extract the corresponding force values (red dots in (a)). Among the five example curves shown here, our tracking code returns finite, non-zero threshold forces for the first four curves (measured on wrinkles) and zero threshold force for the last curve (measured on a flat graphene area). For clarity, vertical offsets are applied to the top four curves in both (a) and (b).

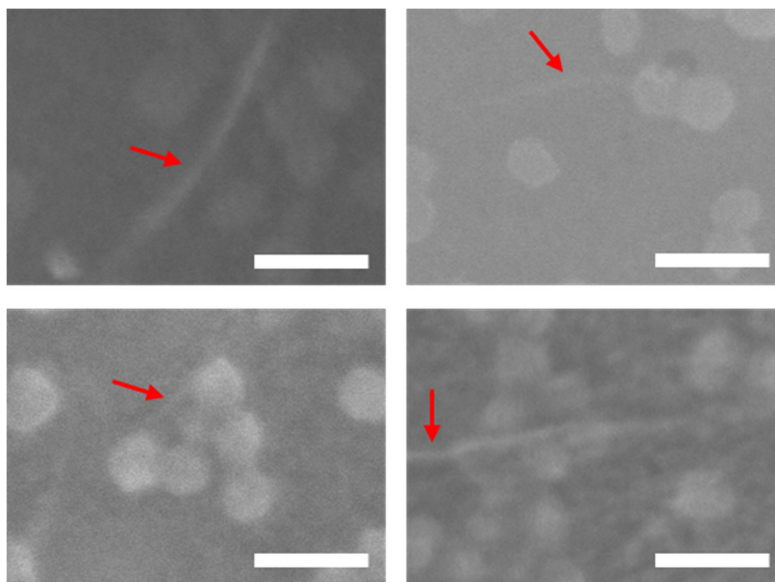


Figure S6. Scanning electron microscopy (SEM) images of graphene wrinkles. In all the imaged areas, graphene covers everywhere, including the nanospheres and flat substrate. The wrinkles that show a clear contrast are marked by red arrows. From these images, we estimate a wrinkle width of ~ 4 nm. Scale bars: 50 nm.

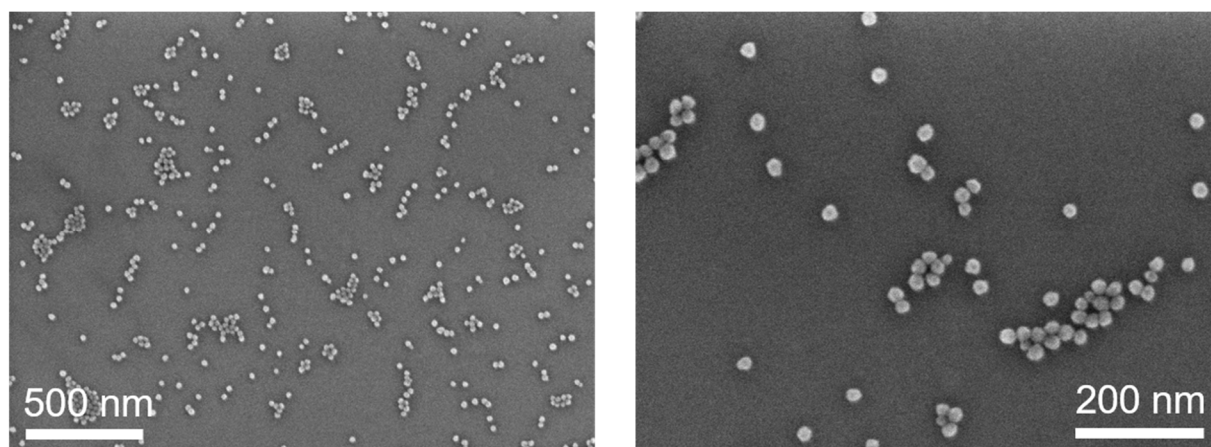


Figure S7. SEM images of SiO_2 nanospheres (~ 20 nm diameter) on SiO_2/Si substrate.

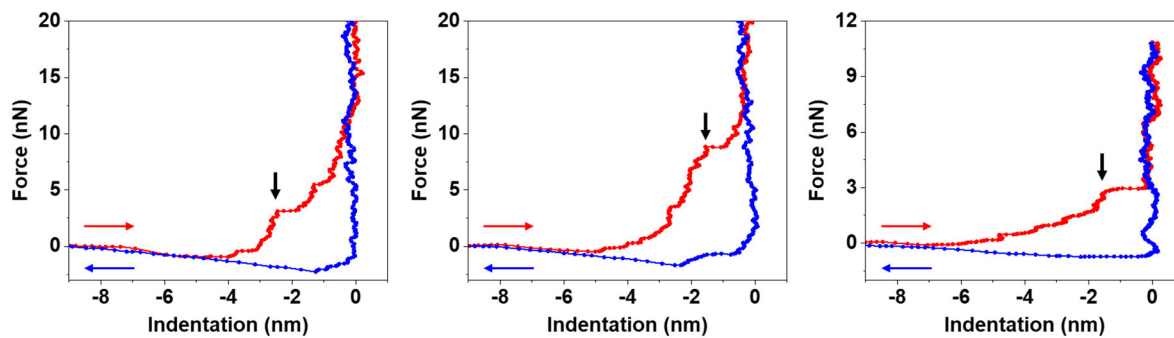


Figure S8. Individual force curves measured at 1 Hz at different graphene wrinkle spots. The black arrows mark the snapping transition points.

References

1. Ferrari, A. C.; Meyer, J. C.; Scardaci, V.; Casiraghi, C.; Lazzeri, M.; Mauri, F.; Piscanec, S.; Jiang, D.; Novoselov, K. S.; Roth, S.; Geim, A. K. Raman Spectrum of Graphene and Graphene Layers. *Phys. Rev. Lett.* **2006**, 97, 187401.