Folds and buckles at the nanoscale: experimental and theoretical investigation of the bending properties of graphene membranes

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While the unique elastic properties of monolayer graphene (under either stretching or bending loading conditions, as well as both in the linear and nonlinear regimes) have been extensively investigated [1-4], comparatively less knowledge has been developed so far on folded graphene ribbons. Nevertheless, it has been recently suggested that fold-induced curvature (occurring without in-plane strain) could possibly affect the local chemical reactivity [5], the mechanical properties [6] and the electron transport of graphene membranes [7]. This is indeed an intriguing perspective, since a proper engineering of the folding and/or bending could enable a materials-by-design approach where tailored ribbons are used as enhanced nano-resonators or nano-electro-mechanical devices.

In this work we will review an ongoing effort to understand the combined folding and bending properties of graphene, where high-resolution transmission electron microscopy (HREM), continuum elasticity theory, and tight-binding atomistic simulations are concurrently combined to provide a complete nano-scale geometrical and physical picture. In particular, we will focus on the edge curvature and topography of folded graphene membranes, with different crystalline orientations. Figure 1 shows the equilibrium shape for a closed bi-layered edges graphene nanoribbon predicted by atomistic simulations. Theoretical predictions were validated by applying a novel experimental methodology for the transmission electron microscope, capable of recovering the 3D topography of the folded membrane. Figure 2-a shows the experimental HREM image of a folded monolayer. Apparent strains in the graphene lattice (Fig. 2-b) can be used to recover the 3D shape of the folded edge (Fig. 3-d), with sub-nanometre lateral resolution and height precision.

References

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Figures

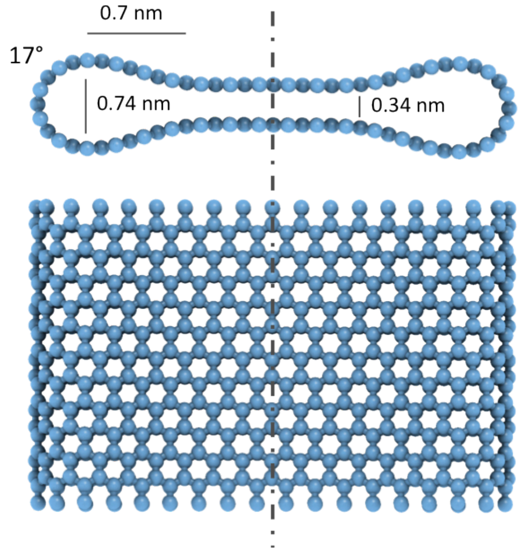

Figure 1: Modeled closed bi-layer edge graphene nanoribbon, with the folded border parallel to the armchair direction.

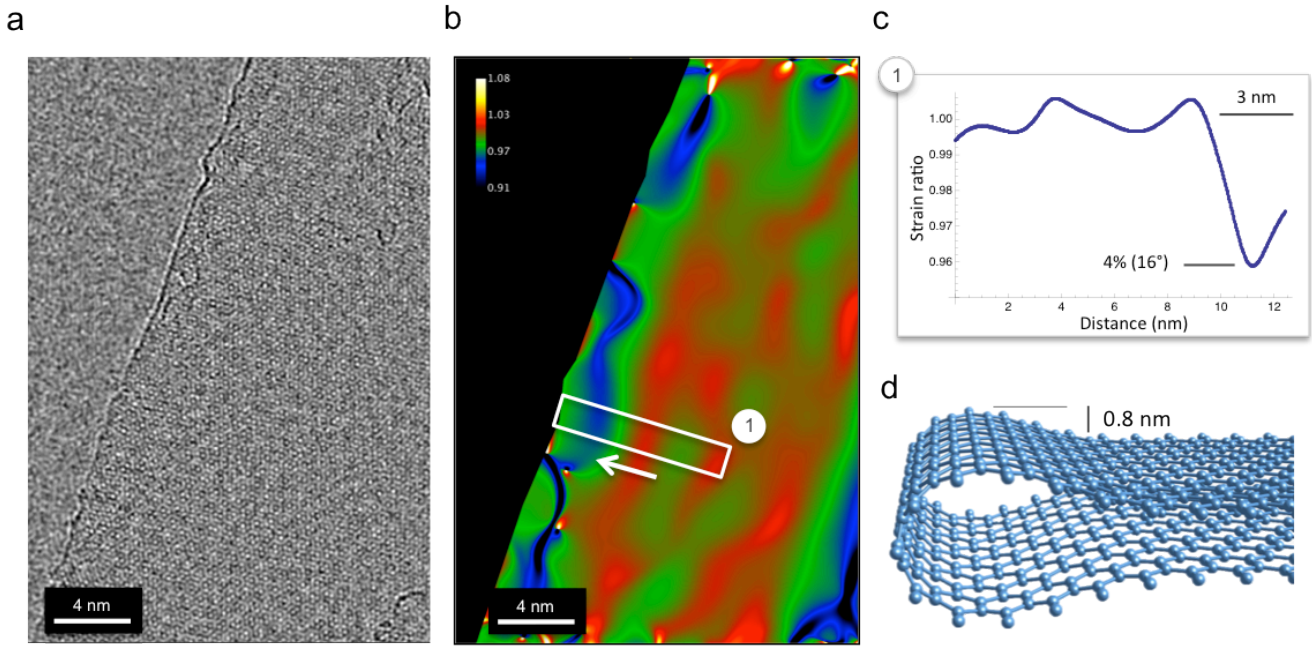

Figure 2: a) HREM image of a folded graphene membrane. b) Strain component along the direction perpendicular to the border, as reconstructed from a. c) Strain profile over region 1 in b. The compression of 4% close to the edge corresponds to a slope of 16% over a region of 3nm. d) 3D structure of the folded edge reconstructed from the strain profile.