Dislocations represent one of the most fascinating and fundamental concepts in materials science. First and foremost, they are the main carriers of plastic deformation in crystalline materials. Furthermore, they can strongly affect the local electronic and optical properties of semiconductors and ionic crystals. In materials with small dimensions they experience extensive image forces, which attract them to the surface in order to release strain energy. However, in layered crystals like graphite dislocation movement is mainly restricted to the basal plane. Thus the dislocations cannot escape enabling their confinement in crystals as thin as only two monolayers. To explore the nature of dislocations under such extreme boundary conditions, the material of choice is bilayer graphene, the thinnest imaginable quasi-2D crystal, in which such linear defects can be confined. Homogeneous and robust graphene membranes (Figure 1a, b) derived from high-quality epitaxial graphene on SiC [1] provide an ideal platform for their investigation.

Here we report on the direct observation of basal-plane partial dislocations (Burgers vector $\frac{1}{3}\langle 1-100 \rangle$) in freestanding bilayer graphene (Fig. 1a, b) by transmission electron microscopy and their detailed investigation by diffraction contrast analysis (Figure 1c, Burgers vector analysis 2c) and atomistic simulations (Figure 2a, b, and e) [2]. Our investigation reveals striking size effects. First, the absence of stacking fault energy, a unique property of bilayer graphene, leads to a characteristic dislocation pattern (Figure 1c, center), which corresponds to an alternating AB ↔ BA change of the stacking order (Figure 1c, right). Most importantly, our experiments in combination with atomistic simulations reveal a pronounced buckling of the bilayer graphene membrane (Figure 2a-d), which directly results from accommodation of strain (Figure 2e). In fact, the buckling completely changes the strain state of the bilayer graphene and is of key importance for the electronic properties. Our findings will significantly contribute to the future understanding of the structural, mechanical and electronic properties of bilayer and few-layer graphene.


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Fig. 1: a) Graphene membranes on SiC. b) One membrane at higher magnification: number of layers indicated. c) Series of bright-field (BF) and dark-field (DF) TEM images of same area. (11-20) images show pronounced contrast due to the presence of partial dislocations (dark lines), while (2-200) images depict respective changes of stacking sequence AB ↔ BA.

Fig. 2: a) Membrane topography and b) side-/top-view of pair of partial dislocations (change of stacking sequence enlarged shown). c) Burgers vector analysis using (11-20) DF images. d) Validation of Burgers vector analysis and atomistic model by DF-image simulation. e) Atomistic-strain distributions and derived disregistry/Burgers vector distributions.