Fabrication and analysis of 2D and mixed-dimensional heterostructures from combinations of aligned stacking, e-beam patterning, ion doping and molecular sandwiching

Jannik Meyer, Jonas Haas, Kevin Strobel, Ivan Musil, Christoph Hofer, Nils Rieger, Lennart Rieger
University of Tuebingen, Institute of Applied Physics, Auf der Morgenstelle 10, 72076 Tuebingen, and NMI Natural and Medical Sciences Institute, Markwiesenstr. 55, 72770 Reutlingen, Germany
jannik.meyer@uni-tuebingen.de
Xiao Wang
School of Physics and Electronics, Hunan University, Changsha, Hunan 410082, China
Kai Braun
University of Tuebingen, Institute of Physical and Theoretical Chemistry, 72076 Tuebingen, Germany

Aberration-corrected electron microscopy is a versatile tool not only for analyzing, but also for manipulating materials down to the level of single atoms. I will present a recent development where we combine spatially controlled modifications of 2D materials, using focused electron irradiation or electron beam induced etching, with the layer-by-layer assembly of van der Waals heterostructures [1] (Fig. 1). A new transfer and assembly process makes it possible to stack the layers under observation in an electron microscope, such that pre-patterned features can be aligned to each other. The aligned stacking of individually patterned 2D materials layers can be considered as a form of 3D printing, where each layer is only one or a few atoms thick, and features within each layer can be defined with a nm-scale resolution. Beyond the results of Ref. [1], I will also present from encapsulation of molecules between graphene layers for electron microscopy studies, new ways of doping graphene with nitrogen, and applications of such doped nanocarbons for gas adsorption.

References

[1] J. Haas et al., ACS Nano 16 (2022), 1836-46.

Figures

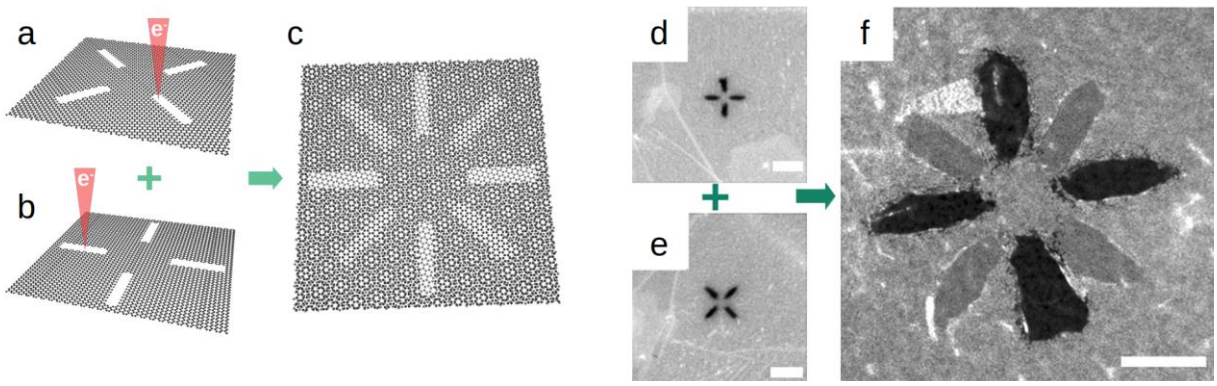

Figure 1: (a-c) Schematic of cutting a pattern into individual graphene layers (a,b) followed by aligned stacking (c). (d-f) Experimental realization, (d,e) SEM images of crosshair structures cut into graphene, (f) Dark-field TEM image showing the assembled structure, set for highlighting one of the two layers. Scale bars are (d,e) 500 nm and (f) 200 nm. Adapted from Ref. 1.