Super-resolution nanolithography of 2D materials by anisotropic etching

Peter Bøggild
[1,2]Dorte R. Danielsen, [1,3]Anton Lyksborg-Andersen, [1,2]Kirstine E. S. Nielsen, [1,2]Bjarke S. Jessen, [1,2]Timothy J. Booth, [1,2]Peter Bøggild, [1,2]Lene Gammelgaard

[1]*Center for Nanostructured Graphene,*
[2]*DTU Physics, Technical University of Denmark, B309 Fysikvej, Kgs. Lyngby, Denmark*
[3]*DTU Nanolab, Technical University of Denmark, B307 Fysikvej, Kgs. Lyngby, Denmark*

Contact: pbog@dtu.dk

Nanostructuring allows altering of the electronic and photonic properties of two-dimensional (2D) materials. The efficiency, flexibility, and convenience of top-down lithography processes are however compromised by nm-scale edge roughness and resolution variability issues, which especially affects the performance of 2D materials. Here we study how dry anisotropic etching of multilayer 2D materials with sulfur hexafluoride (SF_6) may overcome some of these issues, showing results for hBN, WS_2, WSe_2, MoS_2 and $MoTe_2$. SEM and TEM reveal that etching leads to anisotropic hexagonal features in the studied TMDs, with the relative degree of anisotropy ranked as: WS_2 > WSe_2 > $MoTe_2$ ~ MoS_2. Etched holes are terminated by zigzag edges while etched dots (protrusions) are terminated by armchair edges. Patterns in WS_2 are transferred to an underlying graphite layer, demonstrating robust creation of sub-10 nm features. In contrast, multilayer hBN exhibits no lateral anisotropy, but shows consistent vertical etch angles, independent of crystal orientation. This is used to create super-resolution lithographic patterns with ultra-sharp corners at the base of the hBN crystal, which are transferred into an underlying graphite crystal. We find that the anisotropic SF_6 reactive ion etching process makes it possible to downsize nanostructures *through hBN encapsulation* to obtain smooth edges, sharp corners, and feature sizes significantly below the resolution limit of electron beam lithography. See Figure 1.

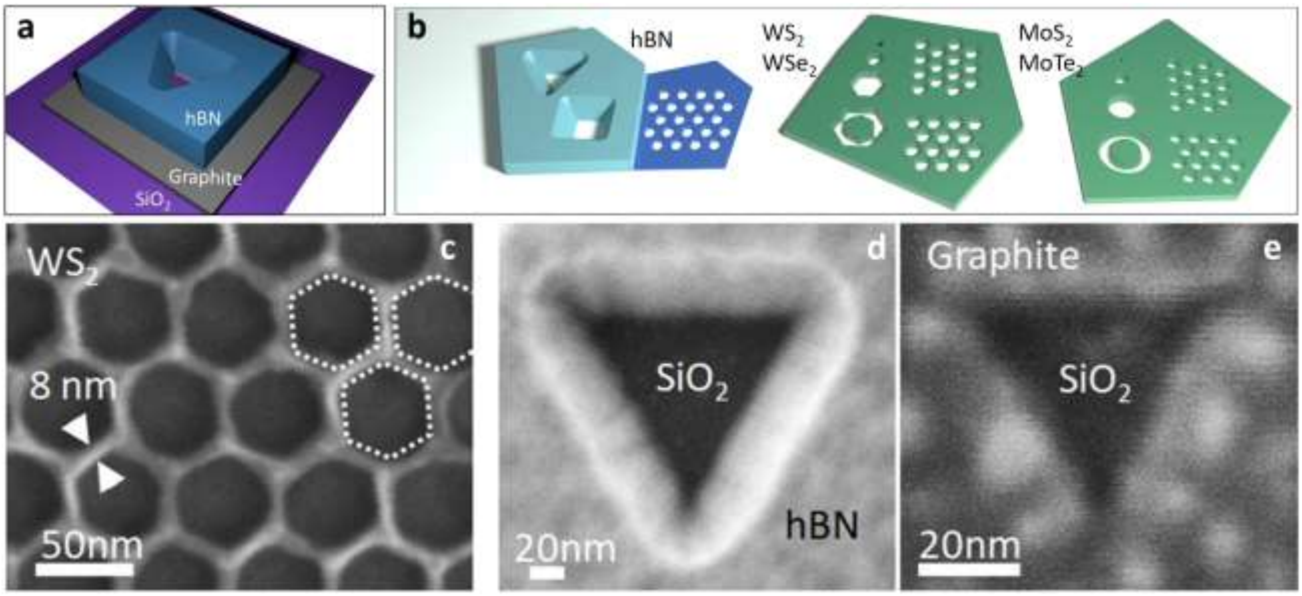

Figure 1: (a) Illustration of down-sizing of pattern defined in hBN crystal to underlying graphene layer. (b) Different anisotropic characteristics leading to different 3D pattern morphologies. (c) Connected network of 8 nm nanowires etching into WS2. (d) Down-sized triangular hole in hBN. (e) Graphite triangle with sharpness of corners below the lithography resolution limit.