Sub-resolution Nanostructuring of 2D Materials by Anisotropic Etching

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Nanostructuring of two-dimensional (2D) materials has shown to be challenging due to the requirement of well-defined structuring without edge disorder and contamination.
We explore various routes for nanostructuring by employing anisotropic etch mechanisms in different 2D materials. The fairly consistent etch angle (ca. 65°) obtained by fluorine-based reactive ion etching (RIE) of multilayer hBN is not only an advantage for making edge contacts to an encapsulated 2D material, but can also be utilised for downsizing features below the resolution of high-end electron beam lithography systems, see figure 1. However, the finite etch angle does make the fabrication of high-density structures difficult, unless very thin hBN is used, as we previously did to achieve lithographic bandgap engineering in hBN-encapsulated graphene [1]. We also demonstrate that etching with a fluorine-based RIE may lead to strong in-plane anisotropic etching for some TMDs [2], in contrast to etching of hBN where the etching rate does not show any strong dependence on crystallographic orientation [1]. The anisotropic etching leads to a self-sharpening of the initially rounded electron beam lithography (EBL) defined structures into hexagons, as seen for WSe_2 in figure 1. The significant two-way etch selectivity of fluorine-based etches for hBN/TMDs and oxygen-based etches for graphene, allows use of hBN and TMDs as ultra-sharp etch masks for patterning of graphene/graphite. The ability to create well-defined, sub-lithographical structures in 2D materials using EBL is a unique opportunity for fabrication of electronic devices with nm-scale feature sizes.

References

[1] B. S. Jessen, L. Gammelgaard, *et al.*, Nat. Nano. 14 (2019) 340-346
[2] D. R. Danielsen, L. Gammelgaard, *et al.*, unpublished

Figures

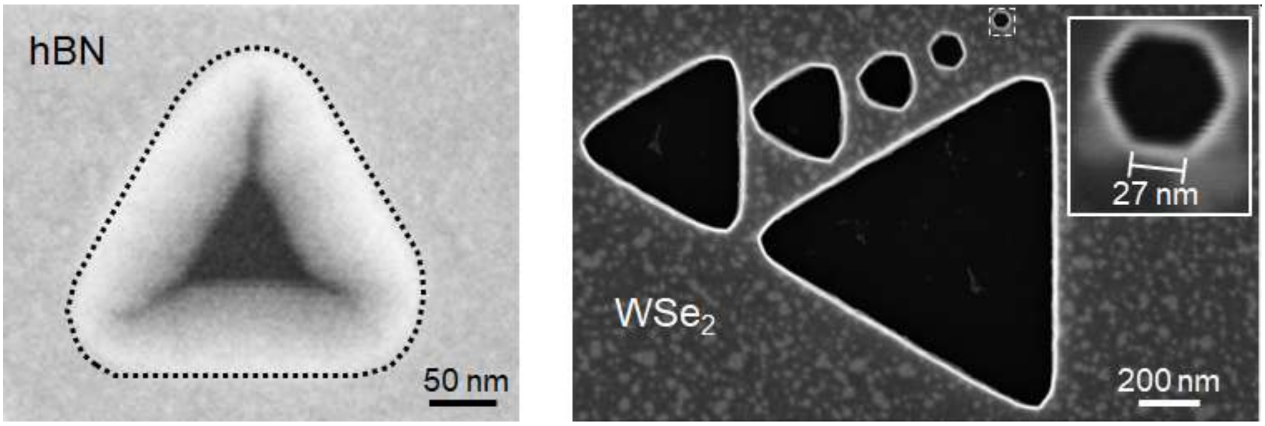

Figure 1: Scanning electron micrographs of EBL defined triangular structures etched into hBN and WSe_2. Left: The corners of the triangle are round at the top surface of the hBN flake (indicated by the black dotted line), and sharp for the downsized triangle at the bottom, because of the etching angle. Right: The triangular structures etched into WSe_2 develop into well-defined hexagons do to the anisotropic etching. Inset shows a zoom-in of the small hexagons indicated by dashed white lines.