Simultaneous Identification of Low and High Atomic Number Atoms in 2D Materials using 4D STEM

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Scanning transmission electron microscopy provides an easily interpreted elemental map under high angle annular dark field imaging mode as the image intensity depends on the atomic number of the materials, for example the Mo and 2S columns can be differentiated in MoS_2 crystal, while the light elements like C, N and O are not always detected simultaneously. To overcome this, we collected an array of convergent beam electron diffraction patterns at each probe position using an fast 2D pixelated direct electron detector (2D-PED) [1] and extracted the bright field and low angle annular dark field to reconstruct phase image by ptychography [2,3], and divergence of differential phase contrast, and various annular bright and dark field images via integration, which shows a sensitive detection of light elements at lateral (nanopores) (fig.1) and vertical interfaces (surface dopants) (fig.2) within 2D monolayer MoS_2, giving us insight into the actual pore sizes in nanopore membranes made from 2D materials and the binding of single surface ad-atoms.

References

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Figures

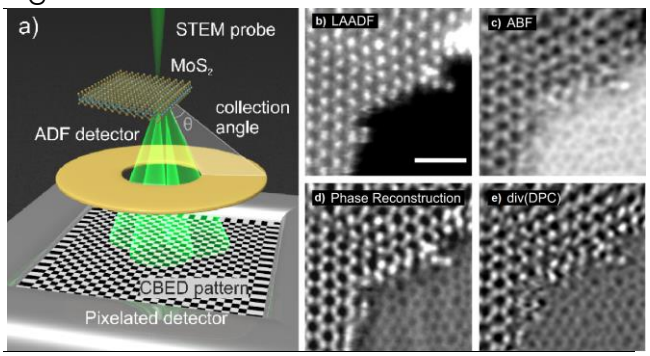

Figure 1: (a) Schematic of 4D-STEM data acquisition. (b-e) A nanopore in MoS2 filled with a carbon layer reconstructed from 4D STEM data. (b) LAADF reconstructed using a 40-60 mrad collection angle, (c) ABF using a 27-39 mrad collection angle. (d) Ptychographic reconstruction of the phase. (e) Div-DPC. Scale bar indicates 1 nm and applies to (b-e).

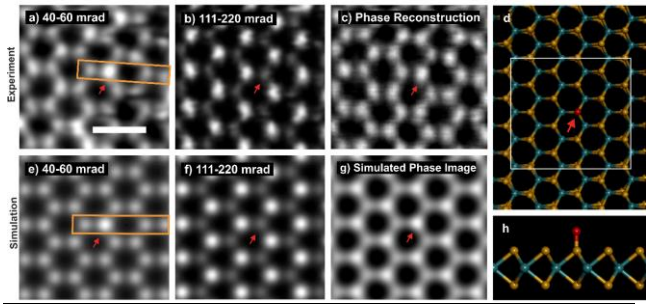

Figure 2: A surface adatom (indicated by red arrows) on 2S site in a MoS2 lattice. (a) LAADF reconstruction using a 40-60mrad collection angle. (b) HAADF reconstruction using a 111-220mrad collection angle. (c) Phase reconstruction. (d) Crystal model of a C adatom on 2S site where the red arrow indicates the adatom position. (e) Simulated LAADF and f) HAADF images and g) phase contrast image based on the boxed regions in the crystal model in (d). (h) Side view of the model shown in (d). Scale bars indicate 0.5 nm and apply to (a-d).