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Aberration Corrected Off-Axis Electron Holography of Layered Transition Metal Dichalcogenides

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Two-dimensional transition metal dichalcogenides (TMDs) have attracted great attention for device applications in the last decade, in part due to their direct band gaps [1, 2]. Off-axis electron holography can provide unique information about the properties of TMDs that is complementary to the information provided by more conventional transmission electron microscopy (TEM) techniques.

TEM samples of TMDs were prepared by cleaving, followed by transfer onto an elastomer gel film. Subsequently, the flakes were transferred onto gold-coated holey SiN membranes without the use of wet chemicals. Before TEM measurements, each specimen was annealed at 85 °C overnight in a vacuum furnace ($< 1 \times 10^{-5}$ mbar).

Medium and high resolution off-axis electron holograms of a wide range of TMDs with nominal composition MX_2 (M: Mo, W, Re; X: S, Se) were acquired at accelerating voltages of 50, 60 and 80 kV using spherical and chromatic aberration corrected TEMs.

Figure 1 shows representative results acquired at 80 kV using off-axis electron holography from an MoS_2 flake. The holographic interference fringe spacing was 30 pm and a mask corresponding to a spatial resolution of 90 pm was applied to the sideband (Fig. 1c) before reconstructing the phase image. Figure 1d shows part of a phase image reconstructed from the hologram, showing a two and three monolayer region of the flake and the presence of some contamination at the specimen edge.

Phase images such as that shown in Fig. 1d were used to determine the mean inner potential, the number of monolayers and the number of atoms in each atomic column across the field of view.

Challenges in such measurements were found to arise from the stability of the specimen and the instrument, the presence of residual aberrations, contamination on the specimen surfaces and electron-beam-induced charging and damage of the specimen. Charging effects are visible in the line profile shown in Fig. 1e, in the form of a slight slope in the phase in a region of uniform thickness inside the specimen when compared with the slope of the phase in vacuum. Approaches for overcoming such problems will be discussed.

References:

[1] Radisavljevic, B. *et al,* Nature Nanotech. **6** (2011), p. 147.
[2] Wang, Q. *et al,* Nature Nanotech. **7** (2012), p. 699.

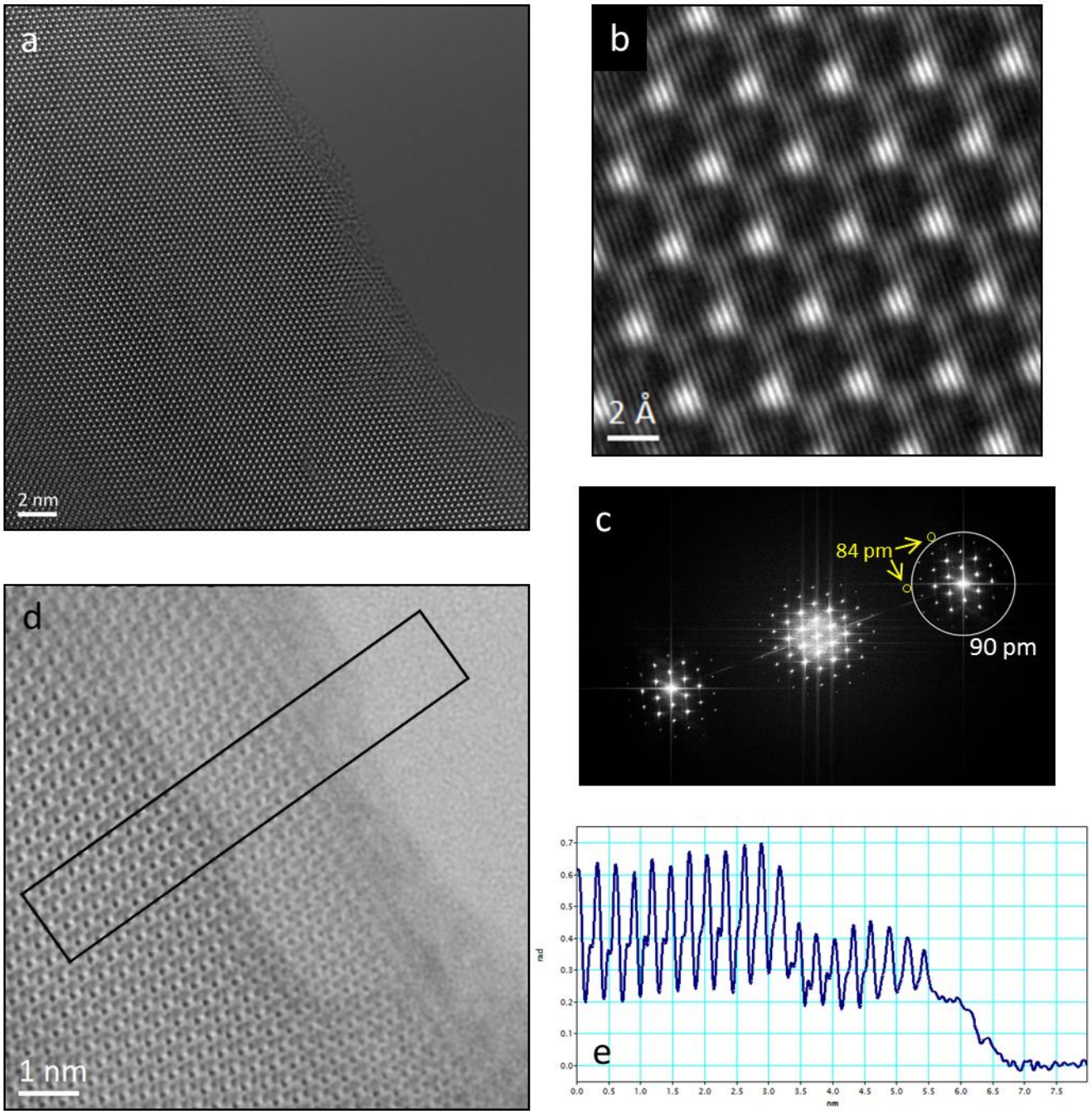

Figure 1. a) Off-axis electron hologram of an MoS_2 flake recorded at 80 kV. b) Magnified region of electron hologram showing fine shifts of interference fringes in a three-layer flake. c) Fast Fourier transform of the hologram, showing information at 84 pm. d) Part of a reconstructed phase image of two and three layer MoS_2, showing the presence of contamination at the specimen edge. e) Phase shift profile extracted from the black rectangle marked in the phase image.