Experiment Brief

K3 IS Camera and STEMx System

Title

Electric field mapping in 2D heterostructures using differential phase contrast

Gatan Instrument Used

The K3® IS camera delivers simultaneous low-dose imaging via real-time electron counting, fast continuous data capture, and a large field of view. In a 4D STEM experiment, the STEMx® system precisely synchronizes the speed of the scanning probe to the camera frame rate to enable high-speed data acquisition and eliminates the potential for data loss.

Background

Two-dimensional (2D) material heterostructures have produced a wide variety of features for the next generation of optoelectronic architectures and quantum information science. These heterostructures are composed of diverse 2D materials such as graphene, boron nitride (h-BN), and transition metal dichalcogenides. And their performance and functionalities largely result from the charge transport dynamics present at various 2D or contact interfaces.

Beyond information about a structure, 4D STEM can capture short- and long-range electrostatic fields and charge distributions by measuring the intensity fluctuations of the CBED patterns. The resultant differential phase contrast images depict the momentum transfer from the electron beam interactions with the sample's electrostatic fields by measuring the deflection of an electron beam due to the field at each probe point. With a high-speed camera, these same methods can be applied in a dynamic framework where the sample is subjected to external biases to measure how the electrostatic profile evolves.

Materials and Methods

The K3 IS camera and a STEMx system were used to capture 4D STEM diffraction datasets at approximately 300 frames per second in electron counting mode on a JEOL JEM-ARM 300F (S)TEM operated at 300 kV and with probe convergence angle of 30 mrad. Using gold interdigitated electrodes, a sample comprised of a monolayer of MoS_2 on hBN substrate was probed (Fig 1a). Charge carriers are able to quantum mechanically tunnel through the insulating hBN layer and are injected into the semiconducting MoS_2 layer. CoM along the scanning direction (CoMx) at 0 and 5 V, and their respective electrostatic field maps were generated using Gatan Microscopy Suite® plug-in. A clear variation in the E-field distribution in the semiconductor region of the tunnel junction is observed when the external bias is applied (Fig 1c and 1d).

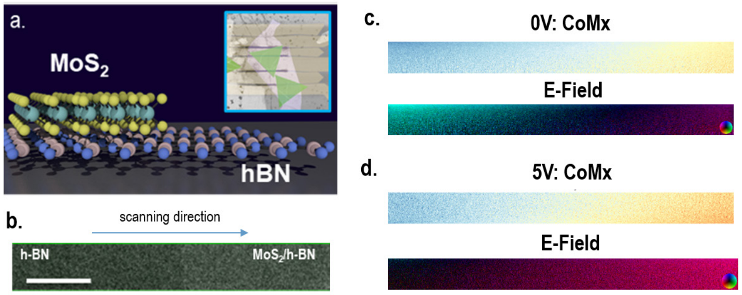

Figure 1. a) Schematic of MoS_2/hBN sample analyzed. Inset shows an optical image of the final architecture with MoS_2 (green) on top of hBN (light purple). b) Scanning area – full dataset was 680 x 60 x 1048 x 1048 pixels, took 136 s to acquire. c) CoMx and electrostatic field maps of the sample without external biasing. d) CoMx and electrostatic field maps of the sample under external biasing of 5V. Color wheel scale bars show the normalized magnitude and direction of the E-field extracted from CoM.

Summary

The K3 IS with STEMx enables hardware synchronized 4D STEM diffraction experiments at a very high speed (>3500 fps at 256 x 256-pixel resolution) with the highest possible signal-to-noise ratio (using electron counting). This enables such multi-dimensional experiments, as shown here: by combining electrical biasing and 4D STEM DPC, we could explore how the electrostatic profile in a heterostructure of MoS_2/hBN evolves when subjected to an external electric field.

Credit(s)

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