# Experiment Brief

## Stela Hybrid-Pixel Camera and STEMx System

### Title

High throughput differential phase contrast (DPC) imaging of Si-$MoS_2$ core-shell structure

### Gatan Instrument Used

The Stela™ hybrid-pixel camera, utilizing DECTRIS technology, enables a high signal-to-noise ratio (via electron counting) high dynamic range diffraction imaging at fast frame rates (>16000 fps). STEMx® system hardware synchronizes the scanning probe to the detector frame rate, enabling high throughput 4D scanning transmission electron microscopy (STEM) data acquisition and processing within the DigitalMicrograph® software.

### Background

Transition metal dichalcogenide (TMD) core-shells are very recently emerged structures with potential applications in optoelectronics, biomedicine, energy, and sensing[1, 2]. In such materials, a multilayer TMD shell encapsulates a nano-sized core, presenting the opportunity to engineer and design the shell defects/properties/functionality via manipulating the underlying core structure. The core-shell structure also provides a natural platform to leverage built-in strain to tune electronic and chemical properties. DPC is applied to elucidate the in-built electric field distribution across the core-shell structure.

### Materials and Methods

Si-$MoS_2$ core-shell specimen was prepared following the procedure detailed in Ref 3. 4D STEM data collection was done at 80 kV, on a JEOL Grand ARM microscope, using the Stela camera operating at 4,500 fps in HS mode. Region of interest was identified and scanned in 320 x 320 pixels covering a region of 800 x 800 nm. Data acquisition was done using the STEM SI technique in DigitalMicrograph and was completed in 46 s. 4D STEM data was then processed using the DPC technique panel, with no need to transfer to a different PC or data format conversion. The Center of Mass (CoM) method was applied to calculate the two orthogonal beam displacement components and then the beam displacement vector map below.

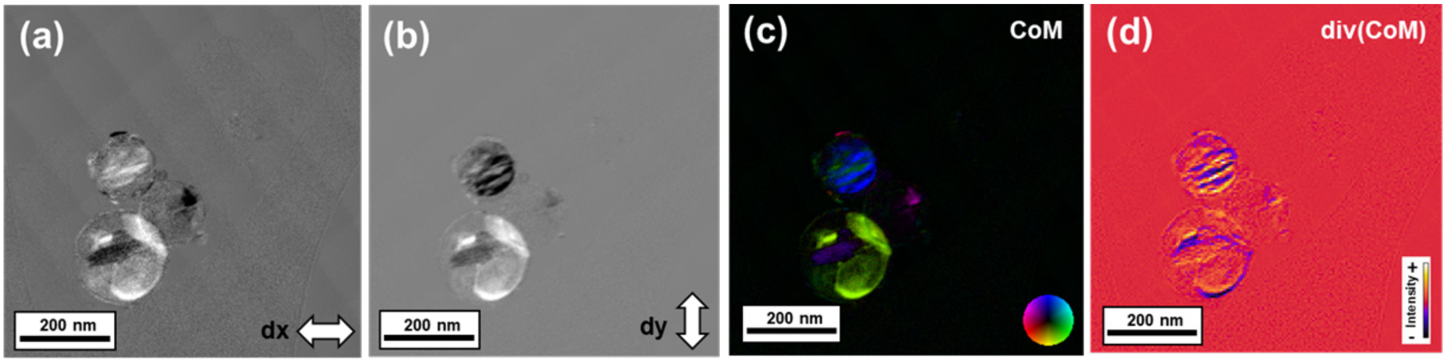


**Figure 1.** DPC analysis of Si-$MoS_2$ core-shell nanoparticles. Beam displacement in (a) x- and (b) y-direction. (c) Map calculated using the center of mass method (Differential Phase Contrast technique panel in DigitalMicrograph software). (d) Divergence map calculated from (c).

### Summary

By seamlessly combining the STEMx system and Stela camera, the 4D STEM workflow is fully integrated with hybrid-pixel electron detection in the DigitalMicrograph software interface. This integration allows optimized data acquisition and processing and streamlines the 4D STEM workflow to shorten the time to results. The STEMx system combined with the high-speed of the Stela camera enabled the rapid scanning of hundreds of Si-$MoS_2$ core-shells, allowing for high-throughput analysis and the collection of a hardware synchronized 4D STEM data cube, which was then processed to calculate the DPC map within a few minutes. We can tailor the core-shell nanoparticle to achieve the desired optical properties by identifying regions with higher net-E-field accumulation using DPC.

### Credit(s)

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[1] J.G. DiStefano, et al., Au-$MoS_2$-$WS_2$ Core–Shell Architectures: Combining Vapor Phase and Solution-Based Approaches, J. Phy. Chem. C, 124, 2627-2633 (2020).

[2] J.G. DiStefano, et al., Structural defects in transition metal dichalcogenide core-shell architectures, Appl. Phys. Lett. 118, 223103 (2021).

[3] Y.S. Lee, et al., Resonance Couplings in Si-MoS2 Core-Shell Architectures, under review (2022)