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Performance and Ongoing Development of the Velociprobe, a Fast Hard X-ray Nanoprobe for High-Resolution Ptychographic Imaging

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The Velociprobe is a next generation X-ray microscope built to make efficient use of the dramatic increase in coherent flux from the Advanced Photon Source Upgrade (APS-U) [1,2]. Fast ptychographic imaging with high spatial resolution is achieved using novel hardware/stage designs, new positioner control designs, and new data acquisition strategies, including the use of high bandwidth interferometric measurements. The capabilities and performance of the current instrument are demonstrated with ptychographic measurements of micron-scale complex oxide particles. A planned upgrade to extend the fast-scanning range and improve the 3D imaging capability of the Velociprobe is discussed.

The Velociprobe instrument at APS beamline 2-ID-D was designed and built to optimize stability during high-speed optics scanning for ptychography and scanning probe measurements with an emphasis on 2D imaging. The use of novel granite, air-bearing-supported stages provides high stability during imaging. Fast, on-the-fly scanning is implemented by scanning the low-mass zone plate across a small area at high speed. Unlike current commonly used fly-scan schemes in which only one axis is fly-scanned, both axes on the Velociprobe are continuously moved throughout the scan. This is achieved by an optimized control algorithm providing large tracking bandwidth and good positioning resolution using National Instruments FPGA-based control hardware [3]. With the current instrument, a ptychographic fly-scan of a 4 μm × 4 μm area with diffraction patterns captured every 50 nm in both X and Y axes (~6400 exposures in total) can be completed in as little as 2 seconds at a speed of 0.16 mm/s. The speed is limited by the frame rate of the detector (3 kHz) rather than the optics scanning mechanics (5.7 mm/s). The spatial resolution at 3 kHz is flux limited, with ~30 nm or ~17 nm achieved with a double-crystal (~5×10^8 ph/s) or double-multilayer monochromator (~8×10^9 ph/s), respectively.

Figure 1(a) shows the schematic of a typical ptychography scan on the Velociprobe. To benchmark the performance of the Velociprobe, 2D ptychography measurements of micron-scale perovskite particles were performed and analysed. In the ptychography experiment, 10 keV X-rays from an APS undulator A were spectrally filtered using a double-crystal Si (111) monochromator. A Fresnel zone plate with an outermost zone width of 50 nm was used to focus the coherent X-ray beam down to a spot size of approximately 60 nm. $LaFe_{0.3}Co_{0.7}O_3$ perovskite particles were placed on a Si_3N_4 window which was put 100 μm downstream of the focus. The zone plate was continuously moved in a snake-pattern trajectory (see Fig. 1(a)) at a speed of ~2.5 μm/s. Far field diffraction patterns were collected with an area detector (Dectris Eiger X 500K) with 75 μm pixel size. The detector was positioned 2 m downstream of the sample and triggered by the FPGA every 20 ms (time-based triggering). The threeaxis interferometer positions of the zone plate were simultaneously recorded as the detector was triggered. For the reconstruction an area of 512 × 512 pixels of the diffraction pattern was used, resulting in a pixel size of about 6.5 nm. Figure 1(b) shows the ptychographic reconstruction of this scan that covered a 4 µm × 6 µm field of view. The spatial resolution determined by a line profile across the sharp edge is about ~11 nm.

High-speed, on-the-fly scanning along both zone plate axes is possible over a ~9 µm × 9 µm area. To image larger areas, the sample stages can be stepped for tile scans, as shown in Figure 1(a). However, the stepwise translation between tiles adds an overhead cost which effectively limits the scanfield to ~1 mm^2. Efficient imaging of larger specimens should incorporate on-the-fly scanning of one or more sample stages. This places stringent requirements for motion trajectory errors and laser interferometry which the current hardware and stages do not satisfy. Accordingly, an upgraded sample stack for the Velociprobe has been designed to accommodate large scanfields (up to 1 cm^2) without compromising the stability or performance of the original instrument.

The upgraded Velociprobe will combine a 3-axis, 400 µm range piezo scanner (Piezosystem Jena, Tritor 400 SG) with two high-performance, linear motor, air bearing-guided linear stages (Physik Instrumente PIglide models A-131 and A-141) for smooth sample scanning. In addition, the existing rotation stage will be replaced with a high precision air bearing stage to minimize runout and wobble (Professional Instruments Company 10R-606 with <0.1 µrad wobble) and thereby improve 3D tomographic reconstructions [4].

References:

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[4] This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

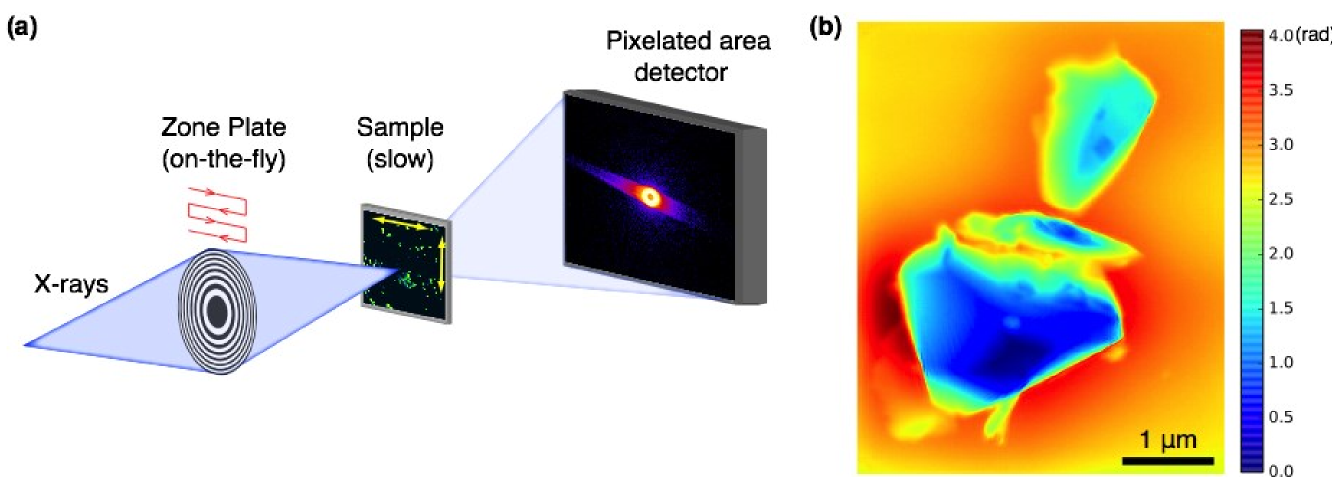

Figure 1: (a) Schematic of ptychography scan on the Velociprobe. The zone plate is fly-scanned in a snake-pattern trajectory or other high-efficient trajectories using FPGA-based control scheme. The sample can be moved for tile scanning. (b) Ptychographic image of $LaFe_{0.3}Co_{0.7}O_3$ perovskite oxides.

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