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# Multiple differential-aperture microscopy

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**Abstract**

Differential-aperture X-ray microscopy (DAXM) is a powerful approach to 3D tomography with particular relevance to X-ray microdiffraction. With DAXM, scattering from submicron volumes can be resolved. However, the method is intrinsically a scanning technique where every resolved volume element (voxel) requires *at least* one area-detector readout. Previous applications of DAXM have used a single wire for knife-edge step profiling. Here, we demonstrate a way to accelerate DAXM measurements using multiple wires. A proof-of-principle experiment with a three-wire prototype showed that the speed of measurements can be tripled, but careful calibrations of wires will be required to maintain the spatial accuracy. In addition, related possibilities for accelerating measurements are briefly discussed.
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## 1. Introduction

Differential-aperture microscopy [1,2], illustrated in Fig. 1, is a knife-edge scanning technique that determines the origin of X-ray scattering along the incident beam path. At the detector, the scattering from volume elements along the direct beam path overlap and the signal in each pixel can be from any volume element. The scattering origin is determined by translating an absorbing wire near the sample surface. The signal in each pixel is changed when the edge of the wire passes through a beam scattered in the direction of that pixel. If the wire is close to the sample, then the derivative of the pixel intensity as a function of wire position can yield submicron spatial sensitivity [1,2]. By reverse ray tracing from the pixel past the wire surface and onto the incident beam path, the positions of diffracting voxels along the incident beam are determined.

With a single wire, differential-aperture X-ray microscopy (DAXM) is a direct reconstruction technique and is relatively robust. However, the scanning approach is slow [3] and as indicated in Fig. 1; for any wire position, only a small fraction of the detector pixels can be affected by incremental wire motions. Here, we demonstrate a method for accelerating this technique with little or no loss of generality using multiple wires and explore the acceleration that is achievable with various geometries.

## 2. Theory

Although conceptually simple, DAXM is challenged by conflicting restrictions on resolution and measurement speed. For example, larger diameter wires improve the edge-limited resolution, but increase the sample-to-wire spacing, which slightly degrades the pixel-limited resolution, and requires a greater number of steps. In practice, wire diameters of $\sim 50\,\mu m$ and sample-surface-to-wire distances of $\sim 200\,\mu m$ are good compromises. To obtain $< 1\,\mu m$ spatial resolution, more than 400 wire steps are typically required, which becomes a bottleneck for speed. Multiple wires can reduce the number of required steps significantly. Our goal is to determine conditions that minimize the required number of steps without loss of resolution. But with multiple wires, each pixel can be

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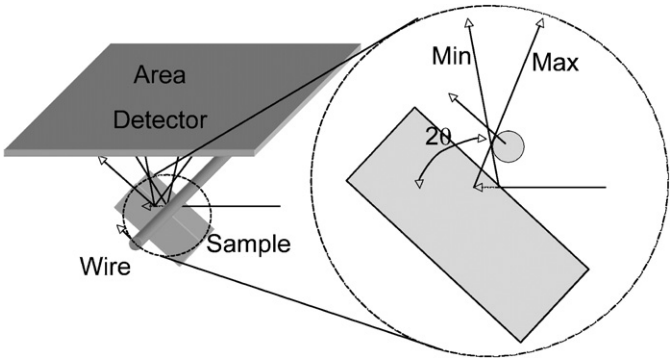


Fig. 1. Geometry for differential-aperture microscopy. For a given beam penetration, there are the minimum and the maximum angles that touch the leading edge of the wire.

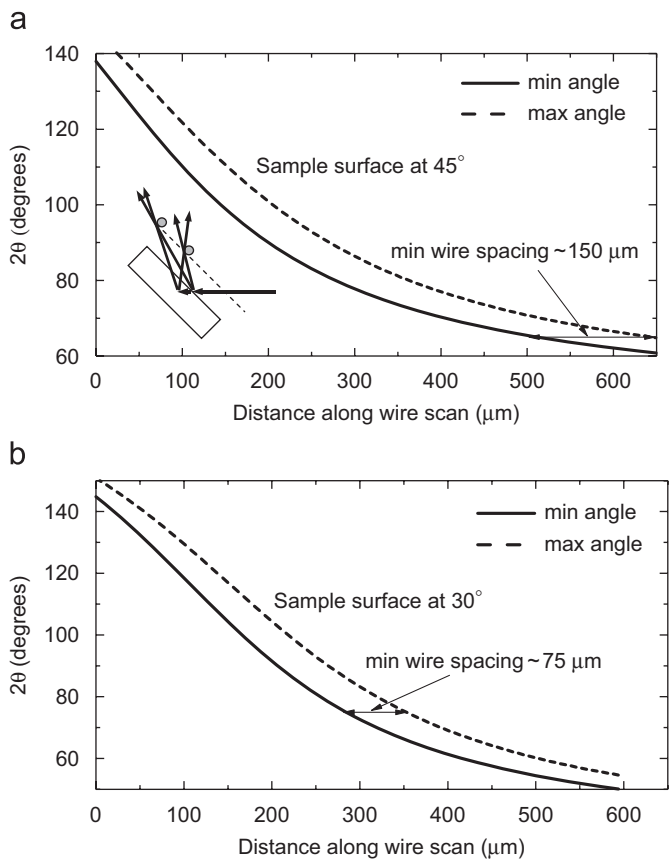


Fig. 2. The minimum and maximum angles intercepted by the leading edge of a wire are plotted as a function of wire path along the sample surface. The calculations assume a penetration depth of 50 μm, a wire height above the sample surface of 200 μm, and a wire diameter of 50 μm. The minimum spacing between wires to avoid confusion is 150 μm with the 45° inclination and only 75 μm with the 30°.

influenced by more than one wire if the wires are spaced too closely together.

To determine the limits to the spacing between multiple wires, we plot in Fig. 2 the minimum and the maximum angle intercepted by the leading edge as a function of wire position, assuming 200 μm to the sample surface, a 45° inclination of the sample surface to the beam (Fig. 2a). This is compared to the same conditions, but with 30° inclination (Fig. 2b). There is no confusion about which wire intercepts any particular beam when the minimum and the maximum angles from adjacent wires do not overlap. This condition is indicated in Fig. 2 by the horizontal distance between the curves. With a sample surface inclined 45° to the incident beam, the minimum wire spacing is ~150 μm when three wires are scanned over the full detector acceptance of $\pm 30^\circ$ from $2\theta = 90^\circ$. With 30° inclination, the minimum spacing is ~75 μm.

Since typically the penetration depths for 10–20 keV X-rays in Fe, Ni, Cu and similar materials are 20–40 μm, 50 μm penetration was assumed here. However, in lower absorbing materials such as Al, the penetration may be $>1000$ μm, which would complicate the use of multiple wires.

## 3. Experiment

To test the feasibility of multiple-wire differential-aperture microscopy, a three-wire prototype was fabricated. Three 50 μm diameter Pt wires were stretched over a polished Si single-crystal frame and glued under tension. The substrate confined the wires to a common plane. A photograph of the three-wire assembly is shown in Fig. 3. The performance of the prototype was tested at APS 34ID XOR-UNI beamline with $\sim 0.5 \times 0.5\,\mu m^2$ beam focused by a pair of elliptic K–B mirrors.

A depth-resolved scan was first performed using the standard single-wire DAXM approach. This measurement yielded the lattice orientations and location of the boundary between two grains in a large-grained Ni test sample. After the spatial origins and the directions of reflections from the different grains were determined, the single wire was replaced with the multiple-wire prototype. Three-wire calibration parameters were determined by minimizing errors in origins of diffracted beams from those measured with a single wire. With the calibrated wire

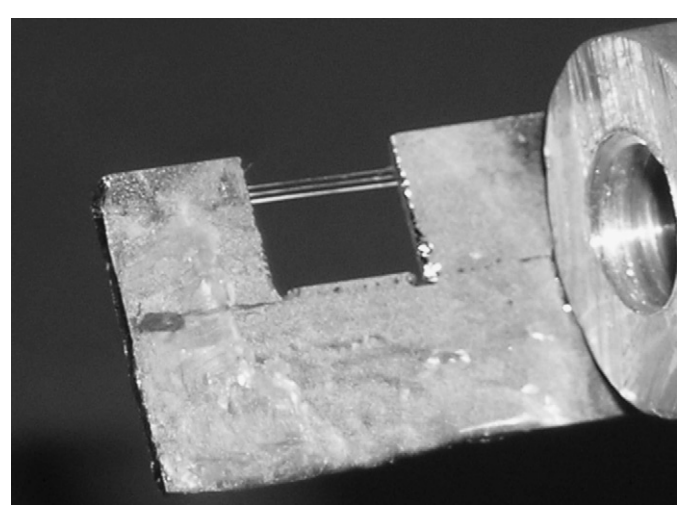

Fig. 3. Prototype three-wire assembly for multiple differential-aperture microscopy.

coordinates, the direction of the each diffraction peak and the depth of the intercepted volume were reconstructed and compared with results from the single-wire scans. The reconstructed data successfully reproduced the spatial positions and the lattice orientations of the two Ni grains. The multiple-wire scan covered the same depth range with a factor of three fewer steps and thus a significant savings in time.

## 4. Discussion and conclusions

A multiple-wire approach for accelerating the DAXM technique has been presented. The first trial of three-wire prototype has shown that it can triple the speed of differential-aperture microscopy without losing spatial or angular resolution, when wires are carefully calibrated. But there are still many other possibilities for improving differential-aperture microscopy. The sample surface is nominally inclined at 45° to the incident beam, to maximize the penetration depth of a beam scattered at 90°. However, this geometry may not be ideal since the penetration depth for $2\theta < 90^\circ$ is greatly increased with a surface inclination of 30°. The same angle range can be covered with $\sim\frac{1}{2}$ of the scan distance with the 30° inclination. Even, in the case that wires are spaced close enough that their signals can overlap, it will be possible to unambiguously know which wires are contributing if the separation between wires is unique for each wire pairs. Thus, more wires can be used for faster measurements. Demonstration of the next step after this, however, goes beyond the scope of our first prototype and begins to enter the realm of coded-aperture imaging.

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