Algorithmic reconstruction methods in diffraction microscopy using *a priori* information

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There exists a clear need for an inspection microscope that features sub-optical resolution and high penetration but requires no ambient vacuum for the sample. The most prominent application of such a microscope is the non-destructive examination of fabricated integrated circuits. Current semiconductor fabrication processes would require resolution of approximately 10 nm to a penetration depth of 100 um. These requirements are expected to increase over time due to process shrinks. The coherent X-ray diffraction microscope is a recent development where highly coherent X-ray sources are used without focusing optics. Instead the diffraction pattern of the beam is recorded and reconstruction of the sample image is achieved by recovering the phase information using computational algorithms.

Phase retrieval is a central problem in coherent X-ray diffraction microscopy. Various methods have been proposed to solve the problem with the most successful being iterative methods such as Fienup's Hybrid Input Output algorithm and the generalized Difference Map algorithm [1, 2]. These algorithms are constraint satisfaction problems where a solution satisfying two sets of constraints is sought. In the context of diffraction microscopy these are diffraction measurements in the Fourier domain and typically some form of finite support in the spatial domain.

In the proposed approach the design specification and other constraints such as positivity, known indices of refraction and smoothness are imposed and are compared to conventional algorithms as shown in Figure 1. These constraints enable reconstruction of an extended object with improved resolution and faster convergence. This is the first time that a successful reconstruction of such an object from a single exposure has been demonstrated. Results are presented using both scaled optical experiments and a hard X-ray experiment. This was performed at the SPring-8 synchrotron in Japan where an object positioned on 70 um of silicon substrate was imaged and was reconstructed as shown in Figure 2.

[1] Veit Elser. Phase retrieval by iterated projections. Journal of the Optical Society of America, 20(1):40–55, 2003.
[2] J. R. Fienup. Phase retrieval algorithms: a comparison. Applied Optics, 21:2758– 2769, 1982.
[3] Jianwei Miao, Tetsuya Ishikawa, Bart Johnson, Erik H. Anderson, Barry Lai, and Keith O. Hodgson. High resolution 3d x-ray diffraction microscopy. Phys.Rev. Lett., 89(8):088303, Aug 2002.

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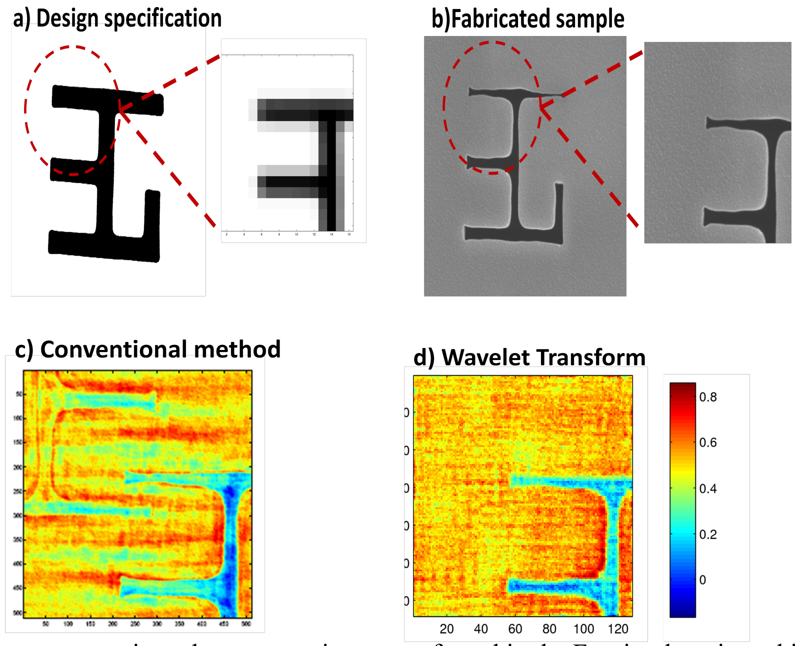

FIG. 1: Iterative phase reconstruction where constraints are enforced in the Fourier domain and in the wavelet domain. (a) shows the original sample from which diffraction measurements are obtained and the low resolution approximation used for the wavelet constraint (b) shows the fabricated sample (c) shows a reconstruction using a basic finite support constraint (the support is not modified as the algorithm progresses—as such the phase ambiguity is not resolved) while (d) shows the reconstruction using constraints in wavelet Space.

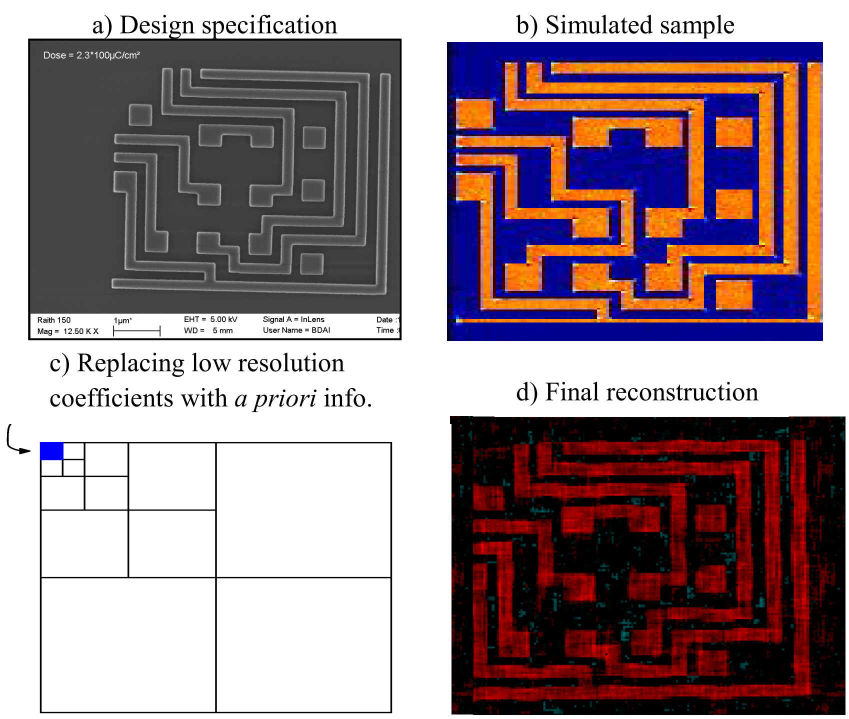

FIG. 2: Iterative phase reconstruction where constraints are enforced in the Fourier domain and in the wavelet domain. (a) shows the original sample from which diffraction measurements are obtained and the low resolution approximation used for the wavelet constraint (b) shows the simulated sample (c) shows a use of a priori information from simulation for low resolution coefficients while (d) shows the reconstruction using constraints in wavelet Space.