

Full-field illumination ptychography with a structured electron beam

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Background incl. aims

Coherent diffractive imaging (CDI) is a technique for reconstructing the complex wavefield from far-field diffraction pattern. CDI has advanced rapidly with the improvement of recent detectors and computing performances, and among them, ptychography has been attracting great interest. One of the key challenges in ptychography is accurate phase reconstruction for large structures. The diffraction intensity carrying the information of large structures is generally concentrated in the low scattering angle region and is often saturated beyond the dynamic range of the detectors. To overcome this obstacle, near-field ptychography [1][2], which utilizes the Fresnel diffraction pattern for the reconstruction, has been proposed in recent years. In this study, we propose a novel configuration for near-field ptychography with full-field illumination using a structured electron beam, aiming at the accurate and efficient observation of large structures.

Methods

The proposed method is configured on the conventional TEM setups. A series of in-line holograms observed in the Fresnel region below the specimen are obtained at different beam positions by scanning the illumination beam. Then, both the wavefield of the illumination beam and the complex transmission function of the specimen are reconstructed from the obtained holograms through a ptychographic procedure. This method does not require a spatial restriction on the specimen plane as a constraint, and instead introduces an irregular structure into the illumination beam that works as an alternative constraint. The structured beam is generated by using a film with random openings, placed in the condenser lens system above the specimen. The diameter of the incident beam is adjusted so that the entire field of view is always illuminated during the scanning. Full-field illumination prevents error accumulation when reconstructing a large field of view compared with conventional ptychographic reconstruction, which “concatenates” small patches of local structures. Full-field illumination provides uniform redundancy over the field of view since the entire field of view of each hologram is fully overlapped. These contribute to accurate and robust reconstruction of large structures. The use of random openings for beam structuring also suppresses coherence degradation of the illumination beam due to inelastic scattering, thereby improving the accuracy of phase determination.

The performance of the proposed method was first evaluated using simulated holograms. Then, its experimental feasibility was evaluated using MgO particles.

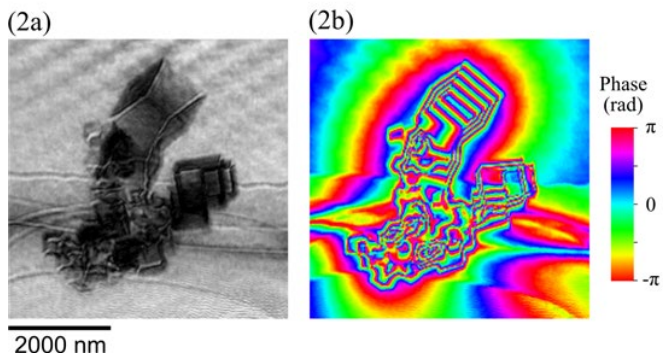
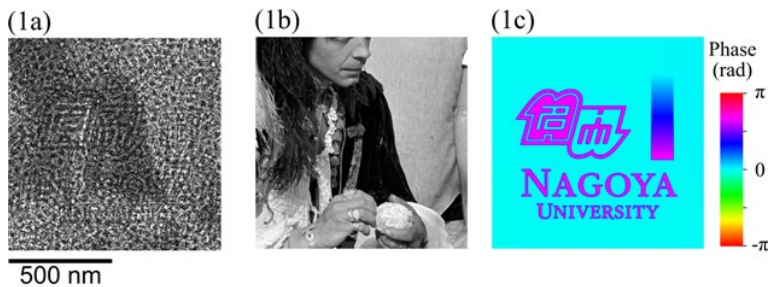
Results

Graphic 1a shows one of the in-line holograms obtained below the specimen. The wavefield of the illumination beam and transmission function of the specimen were reconstructed from the obtained holograms. The reconstructed amplitude (Graphic 1b) and phase (Graphic 1c) of the specimen transmission function show good agreement with the given structure. The phase reconstruction error was $1/12,097$ and $1/3,485$ of the wavelength for the fine (20 nm) and large (400 nm) structures, respectively. Both are comparable to other accurate phase measurement methods [3]. Graphics 2a and 2b respectively show the amplitude and phase components of the transmission function reconstructed from the experimental holograms of MgO particles. The reconstructed phase component shows a periodic phase contour at the edge of the particle, and also shows a uniform phase in the constant thickness region of the particles with faces oriented toward the beam direction. These results are consistent with the particle shape, indicating the validity of the method.

Conclusion

In this study, we proposed a new configuration for near-field ptychography using full-field illumination with a structured electron beam. A simulation study demonstrated phase reconstruction with an accuracy of $1/3,485$ of the wavelength, a performance comparable to other phase measurement methods. An experimental study using a MgO crystal also showed reasonable reconstruction consistent with the specimen structure. These results suggest that this method can be adopted for accurate and efficient observation of large structures.

Graphic:



Keywords:

Wavefield reconstruction, Structured illumination, Ptychography

Reference:

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