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Optimizing Phase Resolution for Off-Axis-Type Holograms at 2π/1000 Levels

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In off-axis-type holography [1,2], phase- and amplitude images are conventionally reconstructed using the Fourier based method described initially by Leith et al. for light optics [2], and later by Lichte [3] for electron holography. Once the light- or electron hologram is recorded digitally, its key parameters as fringe contrast and pixel values, as well as its noise content is fixed, whereas the noise in the reconstructed images still depends on the reconstruction algorithm used [4].

As long as the noise level before the digital camera and in the reconstructed images can be described as pure stochastic noise, and as long as the fringe contrast before the acquisition of the hologram can be measured with e.g., a GIF (using its large magnification factor) and as long as the electron density via the (calibrated) flu screen (and corresponding geometrical considerations) a consistent model from the actual wave front before being recorded to the noise levels in the reconstructed images can be established.

Under these circumstances it becomes relatively easy to determine the key parameters that affect the noise level in the reconstructed images the most and these parameters are discussed in [5]. Although it is no surprise that improving the fringe contrast (i.e., the actual fringe contrast of the intensity distribution before digitization) has a strong effect, the resulting potential improvements are comparable with results that might be obtained by simply improving existing digitization devices (CCD cameras).

The biggest improvements however are obtained via stochastic means, i.e., by increasing the number of relevant electrons (or photons – thus covering both Fermions and Bosons). The main obstacle in increasing those numbers is, at least in electron microscopy, the tolerance of the sample for a higher particle dose. Excluding dose issues, the wave front stability becomes the key parameter because specimen- and fringe drift, even if they pursue different directions can be compensated via – albeit extensive – automated data processing [6].

The latest Titan microscopes especially with their high brightness field emitter (XFEG) are an excellent example for what can be achieved with an improved wave front stability [7] and coherence [8] compared to some of the initial attempts [9] on improving phase resolution.

Today, we can report phase resolution values in the order of 2π/1000 for the strong object case with three holographic fringes per detail. Fig. 1 shows reconstructed amplitude and phase images obtained from processing 50 holograms and 50 reference holograms. Given today's CCD cameras with their inherent readout time and a 2GHz dual core processor, the processing time is just about the same time it takes to acquired all images (in this case we used 4s exposure time per image). Of course, the images are acquired and stored into a 3D data cube and data processing is designed to work on both standard images and data cubes. Details for routine operation at this level of phase resolution will be provided.

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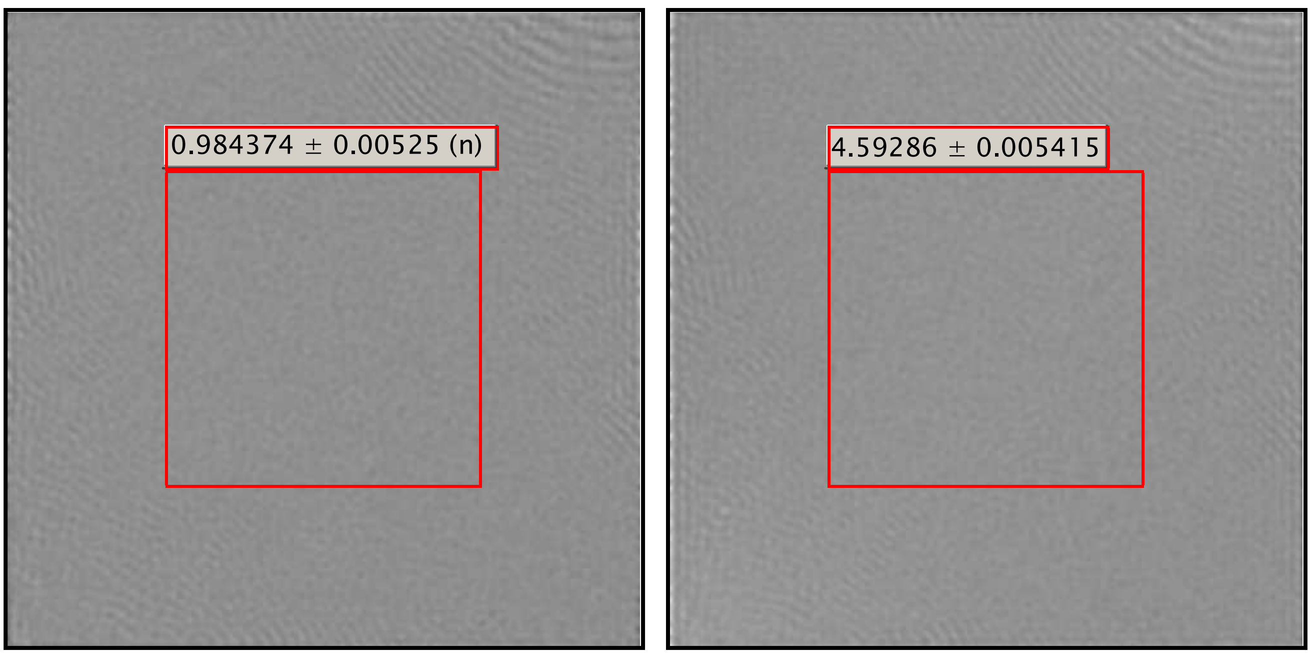

FIG. 1. Amplitude image (see left) and phase image (see right) after averaging over 50 hologram and 50 reference hologram data sets. The reconstruction aperture was set corresponding to 3 fringes per highest spatial frequency and the average fringe contrast in the holograms was 20%. The exposure time per hologram was 4s. Left: the mean and (normalized) standard deviation is indicated with the image. The dynamic range corresponds to 0.67 to 1.23. Right: the standard deviation measured in the indicated area show is less than $2\pi/1000$. The dynamic range for the phase image was selected as 4.25rad to 4.85rad. The upper right corner in both images represents a small local charge on the biprism that is invisible in both, the single holograms and single reconstructed images.

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