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Phase detection limits in electron holography with automatic stabilisation and direct electron detection

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Electron holography can measure local electric, magnetic and elastic strain fields. Furthermore, the incident wave can be structured with the aid of a biprism in the illumination system for specialised interference configurations [1]. In all cases, the measurement precision is directly related to the precision with which the phase of the holographic fringes can be determined. Random errors from shot noise are related to the fringe visibility and the electron dose but also depend on the transfer characteristics of the detector and the mask used in the Fourier reconstruction:

$$\sigma(\phi) = \sqrt{2/N} \times 1/V \times (MTF(q)) / \sqrt{DQE(q)} \times \sqrt{a} \quad (1)$$

where N is the number of incident electrons per pixel, V the observed visibility of the fringes, $MTF(q)$ and $DQE(q)$ the modulation transfer function and the quantum efficiency, respectively, of the detector at the spatial frequency corresponding to the hologram fringes and “ a ” a factor depending on the Fourier mask size [2]. We will test the limits of the theory and present two ways of maximising sensitivity: acquiring holograms over very long exposure times through automation [3] and with direct electron detection.

Methods

Automatically stabilised holograms were acquired on the I2TEM (Hitachi HF3300-C) microscope, operating at 300 kV and equipped with a cold-field emission gun (C-FEG), double stage, image aberration corrector (B-COR, CEOS), condenser biprism and three post specimen biprisms. In particular, two series were acquired: one on a conventional scintillator-coupled CMOS camera (OneView, Gatan Inc.) and the other on a direct detection device (K3, Gatan Inc.). Holograms covered the field of view of the detector and were adjusted to have identical fringe spacing (5.5 pixels) using two post-specimen biprisms. Hologram phases were monitored in real-time using HoloLive! v1.1 (HREM Research Inc.) and dynamic automation was implemented through customised scripts [3].

Holograms were acquired continuously over 15 minutes (900 s) at comparable dose rates ($< 9 \text{ e}^-/\text{pixel}/\text{s}$), the cumulated intensity output every 4 s (Fig. 1a) so that the progression could be monitored. Automatic stabilisation also allows the choice of the exact position of the hologram fringes. Systematic errors were investigated by recording holograms with different initial phase values [4].

Results

The phase error, measured by the standard deviation in a region of vacuum, diminishes over time as expected by the theory (Fig. 1b). Indeed, direct

detection provides a spectacular improvement in the precision of the phase. However, in both cases, the phase error reaches a plateau, with little improvement beyond a certain dose. We will show the cause of the systematic errors and how they can be corrected.

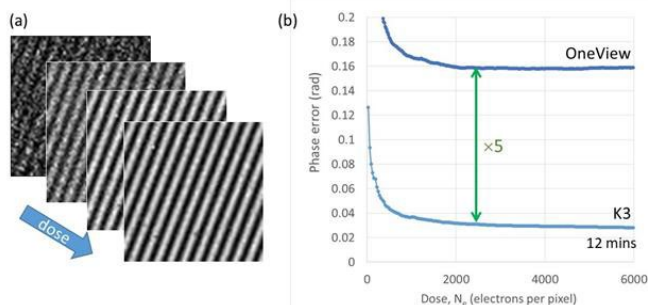
Conclusions

The theoretical limit for the phase precision can be obtained using dynamic automation and direct electron detection. We will show how systematic errors can be removed by controlling the incident illumination for an ultimate precision of 1 mrad at nanometre spatial resolution.

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Graphic:



Keywords:

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