Low dose electron holography using direct-electron detection camera

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The advent of commercially-available direct detection cameras (DDCs) for transmission electron microscopy (TEM) offers the opportunity to reduce noise in images and diffraction patterns as well as providing fast frame rates for image recording. For sufficiently low dose rates, their design can enable significant improvements in detective quantum efficiency (DQE) and modulation transfer function (MTF) when compared to conventional charge-coupled device (CCD) cameras. Existing literature on DDCs is focused predominantly on structural biological applications, where they provide clear advantages under low dose conditions, e.g., typically < 10 $e^{-}Å^{-2}$. Whereas the characteristics of DDCs at dose rates and spatial resolutions that are applicable to biological materials are already well established, in many other areas of TEM the dose rate can exceed 1000 $e^{-}Å^{-2}$, while the spatial resolution can vary from nanometers to better than 1 Å. In these contexts, the benefit of DDCs is less clear.

Here, we examine this question in the context of high-resolution phase contrast imaging and off-axis electron holography and demonstrate that the improved MTF and DQE of a DDC result in clear benefits over conventional CCD cameras. For electron holography, we find a significant improvement in the holographic interference fringe visibility and a reduction in statistical error in the phase of the reconstructed electron wavefunction. In addition, we show that at least three-fold improvement in optimum phase resolution using the counting mode provided by DDC with four time less dose rate compared that of a conventional CCD camera (with a fringe spacing of 83pm in this case). Further improvement in SNR could be obtained by correlation and averaging over a series of holograms. As a result of the low camera noise, the correlation of individual hologram is robust even at low dose rates, and the averaging leads to an improvement in SNR that is close to the ideal root-N behavior (N being the number of images).

Using $BiFeO_3$ on $DyScO_3$ substrate as an example, we demonstrate that both specimen and birpism fringe drift can be successfully correlated over 100 frames of hologram (total exposure of 20 sec at a dose rate of 10 e^{-} per pixel per sec), as shown in Fig. 2. Our results show that DDCs are highly beneficial for electron holography (and similarly to high-resolution TEM) at low dose rates, thereby minimising potential specimen damage while maintaining an adequate SNR for analysis.

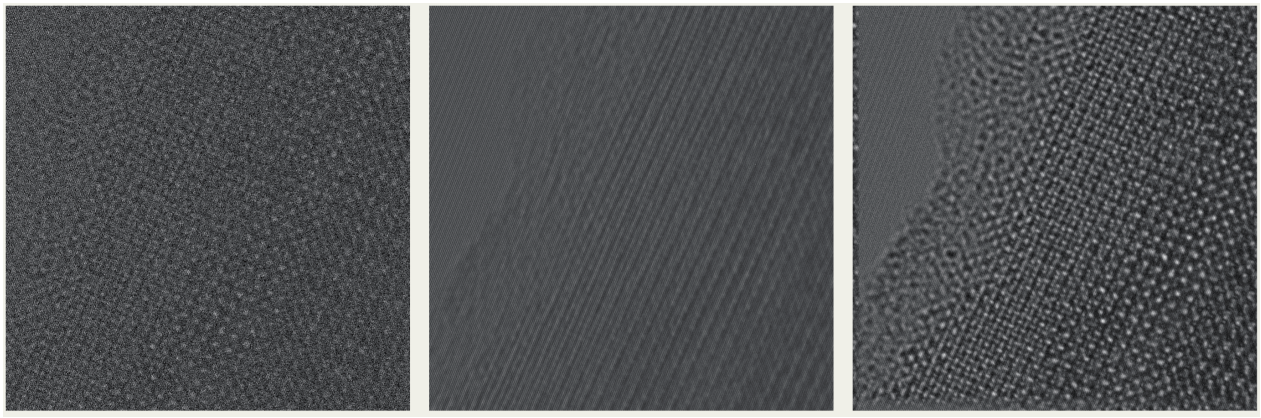

Fig1. (left) Single frame (0.2 sec) of electron hologram (middle) averaged hologram (100 frame, 20 sec) without correlation (c) averaged hologram (100 frame, 20 sec) with correlation correction.