A quantitative comparison of atomic resolution phase contrast microscopy : off-axis electron holography vs. high resolution electron microscopy

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Phase is the fundamental information derived from the atomic resolution phase contrast microscopy. Phase contrast technique enables a detailed examination of the object based on the atomic arrangement and electron density. Two different experimental atomic resolution phase contrast techniques; high-resolution transmission electron microscopy (HRTEM) and atomic resolution off-axis electron holography, are commonly used to extract phase information from the material of interest. The recorded image contains information about the object as well as the microscope. Even though HRTEM is the most used technique to visualize atoms, it fails to obtain the direct phase information of the electron waves scattered from the object. Since the detectors can only record the intensity, and due to the presence of aberration, phase modulation of the electron beam is modified further and lost in the recorded TEM image. Therefore, the phase information is extracted through focal series reconstruction (FSR). Series of images are acquired at various focus values under negative Cs imaging condition. The exit wave function reconstructed contains all the information about the electron-object interaction and is free from geometrical instrumental artifacts.

On the other hand, a reference wave is used to record phase information directly on the camera through intensity modulation of the object wave function. Off-axis electron holography offers the phase information without the problem of twin image which appears in in-line holography technique. There has been a report that the phase information obtained via inline holography does not match with the off-axis holography [J. Phys. D: Appl. Phys. 49 (2016) 194002]. Therefore, in the present report we have extended the work comparing quantitative phase information via three different routes, from HRTEM negative Cs microscopy [Bangalore TITAN], from the central band of off-axis electron holographic data and from the side band of off-axis electron holographic data [from special Berlin TITAN aberration corrected atomic resolution off-axis electron holography microscope]. The sample investigated is ZnO epitaxial thin film grown on lattice-matched ZnO 'c' plane substrate, and the background carrier concentration is ~ 10^{19} cm^{-3}. Phase shift caused by a single atom, a column of atoms, and the defective column is studied and compared. Calculation of phase of a single atom is estimated based on the screened Coulomb potential, which serves as the guide to calculate the number of atoms present in the column. Atomic resolution hologram and the reconstructed phase images by different methods are shown in Figure1. Holographic reconstruction is carried out using a code developed by TU-Dresden and TU-Berlin group. HRTEM FSR reconstructions are performed using MacTempas. Briefly, the phase shift value is systematic with increasing number of atoms (or thickness) between central and side band reconstruction of atomic resolution hologram, unlike earlier report. However, very low phase value compared to holographic data and no systematic trend is observed in case of HRTEM reconstructed phase information.

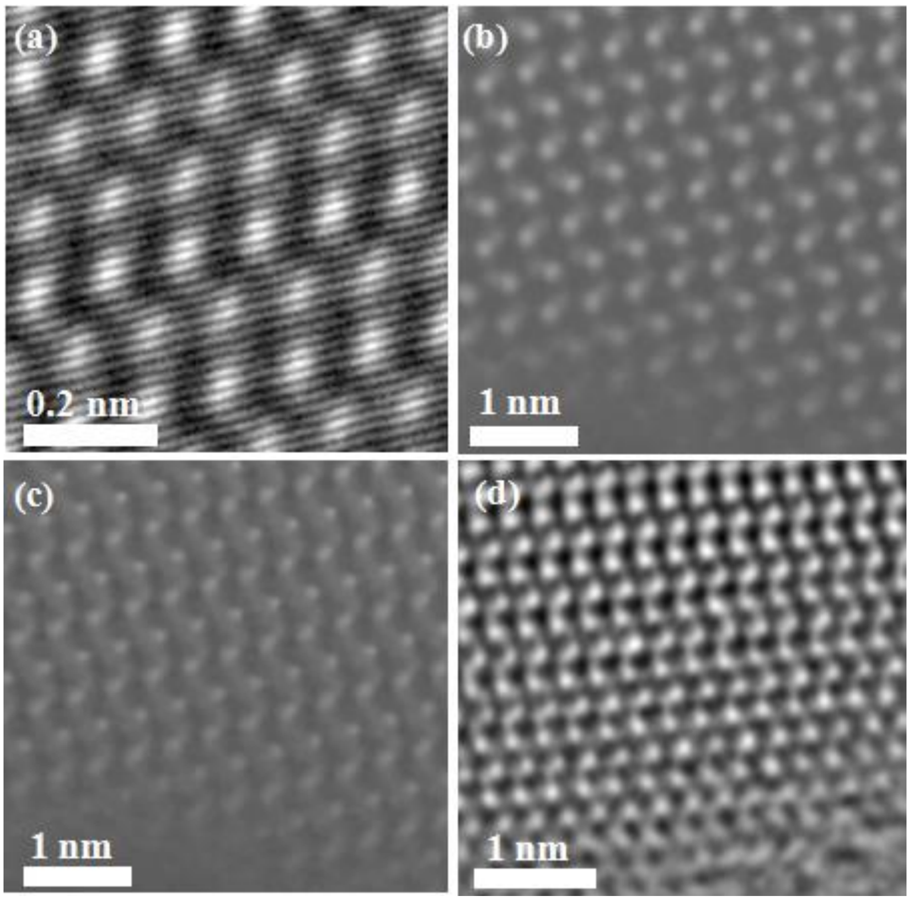

Fig. 1 (a) Example for an atomic resolution hologram, reconstructed phase image from, (b) the side band, (c) central band and (d) FSR methods, for ZnO thin film.