

*From low dose in-line electron holography to atomic resolution tomography*Fu-Rong Chen<sup>1</sup>, Dirk Van Dyck<sup>2</sup>, Christian Kisielowski<sup>3</sup>

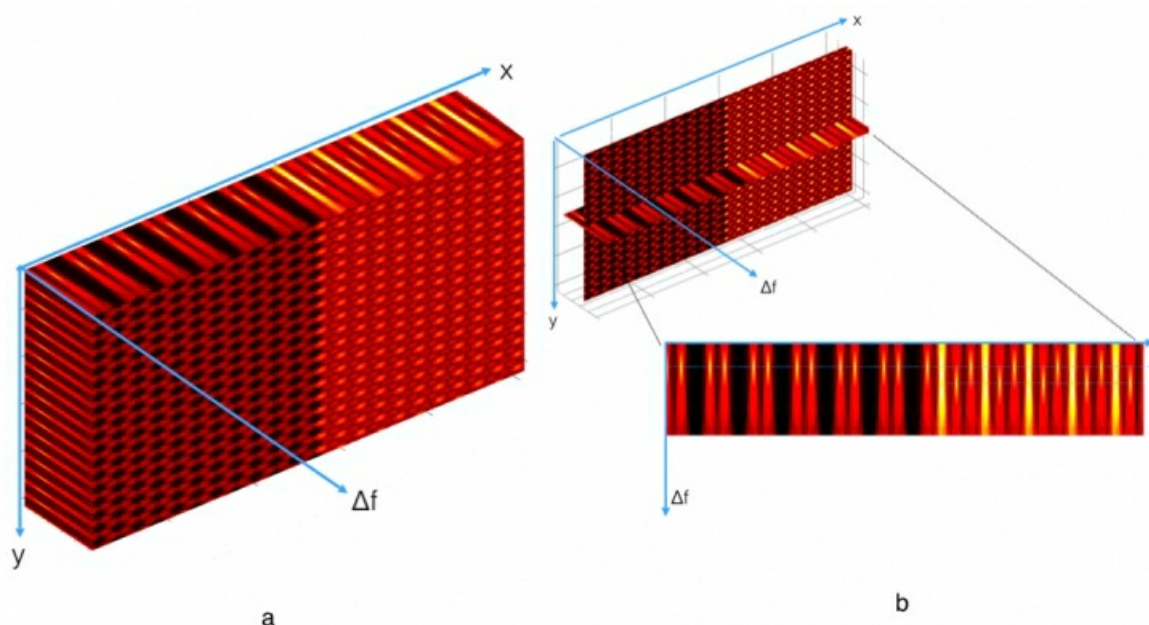
<sup>1</sup>Dept. Of Engineering And System Science, National Tsing Hua University, Hsin Chu, Taiwan, <sup>2</sup>EMAT, Department of Physics, University of Antwerp, 2020 Antwerpen, Belgium, Antwerpen, Belgium, <sup>3</sup>Lawrence Berkeley National Laboratory, The Molecular Foundry and Joint Center for Artificial Photosynthesis, One Cyclotron Road, Berkeley California 94720 USA, Berkeley, United States  
E-mail: fchen1@me.com

To address Feynman's dream, it is important to extract 3D atomic coordinates in a nano-object [1]. So far, there are two approaches, namely, STEM-tilt series [2] and in-line holography [3] have been demonstrated to achieve the atomic resolution tomography for fulfilling Feynman's dream to understand physical and chemical properties of nano-object. Most noticeable bottleneck is the large accumulated electron dose required to produce tilt series of atomic resolution images, because electron dose are commonly chosen large ( $10^4$ - $10^5 e\text{\AA}^2 s^{-1}$ ) to achieve a needed resolution around  $1\text{\AA}$  and single atom sensitivity. Any such single image can exhibit uncontrolled electron beam-induced surfaces alterations or even bulk modifications, in particular if particles are small or for the organic materials such as protein or molecules. For biological sample, protein, the 3D structure are usually reconstructed from images recorded at the cryo-mode to slow down the electron radiation damage. But drawbacks of cryo-microscopy is that at the low temperature the shape of the protein will be deformed. And the proteins are required exists high symmetry for cryo-microscopy with single particle reconstruction. In my talk, we present a self-consistent approach to recover the 3D atomic structure of nanocrystalline particles from single projections by exploiting the dynamic nature of electron scattering and pursuing a quantitative interpretation of the electron exit wave reconstructed from focal series of high-resolution images recorded at low dose mode. Beyond investigations of radiation hard periodic matter, the approach offers intrinsic advantages to study beam-sensitive materials such as catalysts and molecules because dose-rate dependences can be exploited to help reducing beam-sample interactions so that atomic resolution and single atom sensitivity may be achieved without altering the pristine structure of radiation sensitive matter. In my talk, we demonstrate the the 3D information of the atomic position in encoded in the exit wave function reconstructed from simulated focus series images. Fig. 1a. shows propagation intensity of a simulated wave function of a double/single layer graphene at  $g_{\max}=4\text{\AA}^{-1}$ . Fig. 1b is a cross-sectional propagation intensity across a row of atomic column. The intensity maximum reveals double/ single layer structure. The noise will affect the precision of the focus and mass determination which has been demonstrated in our earlier publication [3] with experimental exit wave functions.

[1] Feynman, R. P. (1960) There is plenty of room at the bottom. Eng. Sci. 23, 22-36.

[2] Scott, M. C. et al. (2012) Electron tomography at 2.4-ångstrom resolution. Nature 483, 444-447

[3] Chen, F.-R., Van Dyck, D. & Kisielowski, C. (2016) In-line three-dimensional holography of nanocrystalline objects at atomic resolution. Nat. Commun. 7, 10603.



**Keywords:** [In-line holography](#), [exit wave function](#), [atomic resolution tomography](#)