Type of presentation: Oral

IT-2-O-1921 Assessment of lower-voltage TEM performance using 3D Fourier transform of through-focus images

Kimoto K.[1], Ishizuka K.[2]

[1]National Institute for Materials Science, Tsukuba, Japan, [2]HREM Research Inc., Higashimatsuyama, Japan

Email of the presenting author: kimoto.koji@nims.go.jp

The performance of an aberration-corrected TEM is determined by the information limit that is often demonstrated using Young's fringe method. However Young's fringe method could show unexpected high frequency information due to the non-linear terms as pointed out by several researchers [1,2]. The three-dimensional (3D) Fourier transform (FT) of through-focus TEM images allows us to discriminate between the linear and the non-linear imaging terms [3,4]. The linear imaging terms are observed on twin Ewald spheres in the 3D FT using an amorphous specimen. Here, we use the 3D FT of through-focus TEM images for the assessment of two low-voltage TEM systems.

Two spherical-aberration-corrected microscopes were assessed and compared. One was a Titan^3 (FEI) equipped with a monochromator and a spherical aberration corrector for image forming (CEOS, CETCOR) operated at an acceleration voltage of 80 kV. The energy spread of the electron source was 0.1 eV under monochromated condition. The other microscope, the TripleC microscope, was equipped with a cold field-emission gun (CFEG) and the spherical aberration corrector developed for the TripleC project. This microscope was operated at 60 and 30 kV [5], and the energy spread was 0.3-0.4eV.

Figure 1 schematically shows various 3D data processed in this study [6]. Acquired through-focus TEM images are stacked as a function of the defocus z (Fig. 1a). The 3D Fourier transform I_{uvw} (Fig. 1c) of through-focus images shows two paraboloids called Ewald spheres, attached at the origin. The information limit can be estimated as an observable range of the Ewald spheres.

The signal of Ewald spheres depends on various factors, such as atomic scattering factors, a specimen structure, thickness, and the modulation transfer function of an imaging device; therefore, the quantitative evaluation of diverse TEM systems is not straightforward. Here we apply the tilted incidence in the 3D Fourier transform method (Fig. 2) to normalize those factors. We evaluate the spatial frequency at which information transfer decreases to $1/e^2$ (Fig. 3). It was found that the energy spread of the electron source is the major limiting factor even in a monochromated TEM [7].

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Acknowledgement: We thank Drs. Nagai, Freitag, Sawada, Sasaki, Ohwada, Sato and Suenaga for invaluable discussions. This work is supported by Nanotechnology Platform of MEXT and Research Acceleration Program of JSPS.

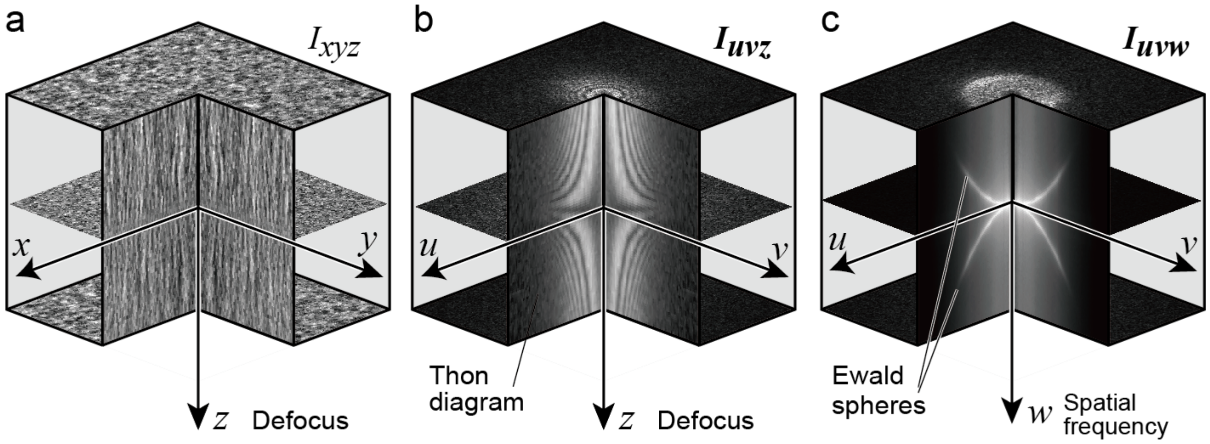


Fig. 1: Schematics of (a) through-focus TEM images I_{xyz}, (b) stack of 2D FTs I_{uvz}, and (c) 3D FT of the through-focus images I_{uvw}. Since I_{uvz} and I_{uvw} are complex, their moduli are shown in gray scale. The cross section I_{vz} is similar to the Thon diagram. Two Ewald spheres attached at the origin are observed in the 3D Fourier space I_{uvw}.

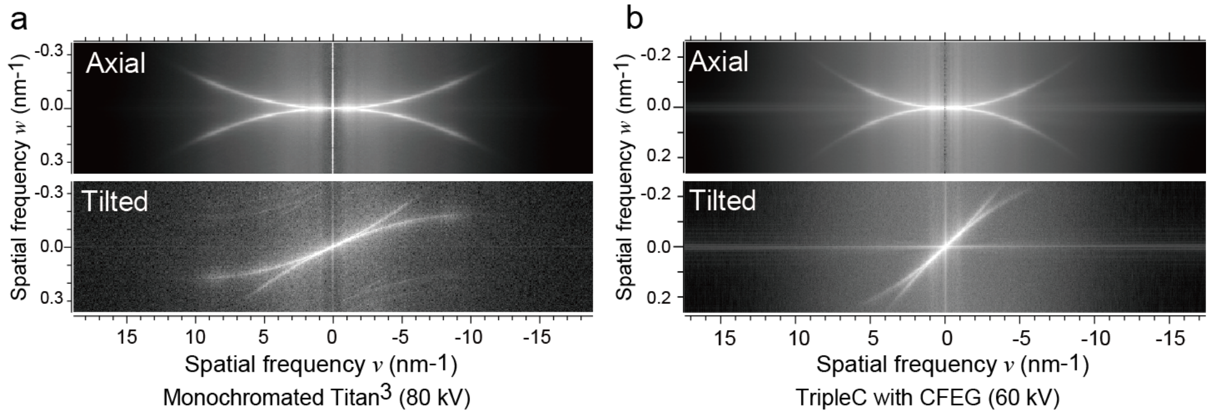
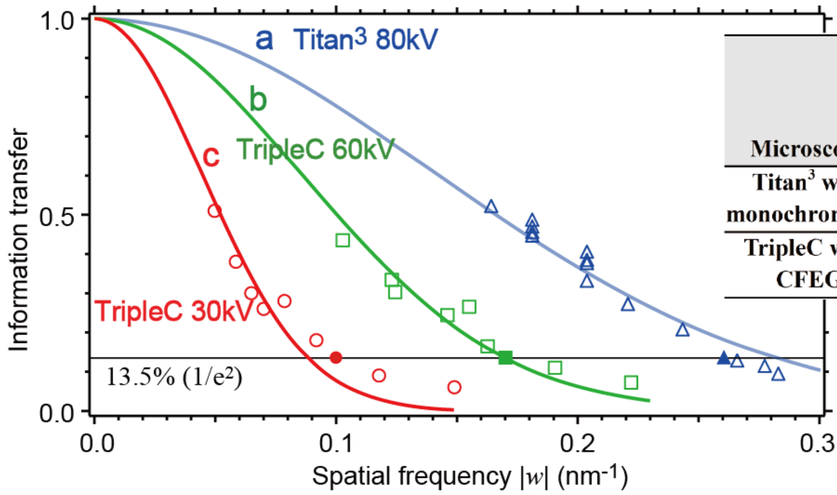


Fig. 2: Cross sections of 3D FTs under on-axial and tilted incidence conditions. (a) Titan^3 (80kV) and (b) TripleC (60kV).



Microscope	Acceleration voltage (kV)	$1/e^2$ information limit, $(\lambda/2w_{info})^{1/2}$ (pm)
Titan^3 with monochromator	80	90
TripleC with CFEG	60	120
	30	187

Fig. 3: Information limit of (a) monochromated Titan^3 (80kV), TripleC at 60kV (b) and 30kV (c).