Holography in LEEM: Electron Phase Measurement

Kazuo Ishizuka

HREM Research Inc
14-48 Matsukazedai, Higashimatsuyama, 355-0055 JAPAN

Holography was proposed by Denis Gabor to correct spherical aberration of an objective lens of a transmission electron microscope in the rather early stage of its development. Since then holography find its application in visible light, but the main stream in electron microscopy is to reduce spherical aberration by improving hardware. Electron holography revived by the development of a cold field emission gun. In Low-Energy Electron Microscopy (LEEM) an elastically backscattered electron is the main source of signal, and thus electron holography will be theoretically applicable. However, the design of LEEM may hinder off-axis electron holography, since it requires an electron bi-prism placed behind an objective.

Here, we will present another holography, a method to determine whole (amplitude and phase) information, for a backscattered electron wave in LEEM using image processing based on the Transport of Intensity Equation (TIE) [1]:

$$\frac{2\pi}{\lambda}\frac{\partial}{\partial z} I(xyz) = -\nabla_{xy} \cdot \left(I(xyz) \nabla_{xy} \phi(xyz) \right)$$

This is an equation for wave propagation in terms of a phase and intensity under the small angle (paraxial) approximation, and showed that the phase may be determined by measuring only the propagating intensity. An accurate estimate of the intensity differential to be used in this equation may be given by a difference of intensities measured at sufficiently close image planes. However, this is not possible in practice due to non-negligible noise on the images. It has been pointed out that the difference may be a good approximation for the differential, when the following condition for a propagation distance ε (a defocus step) is satisfied [2]:

$$\frac{\varepsilon^2}{3!}\left(\frac{\pi\lambda g^2}{2}\right)^2 << 1$$

Using this condition for a 300-kV transmission electron microscope phase distributions were successfully obtained at medium resolutions as well as at atomic resolution [2]. A defocus step for a 10-nm resolution will be 11.6 micron assuming 20 keV electrons. Thus, the defocus steps should be appropriate for typical LEEM instruments, and this technique to measure phase information will open up a new field of application of LEEM. We may note that spherical aberration will be corrected using a reconstructed complex wave function [2].

[1] M.R. Teague, J. Opt. Soc. Am. 73 (1983) 1434.
[2] K. Ishizuka, B. Allman, J. Electron Micros. 53 (2005) 191-