Development of Observation Method for Spatial Electromagnetic Fields by Using Conventional Scanning Electron/Ion Microscope

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Scanning electron/ion microscopes (SEMs/SIMs) show sometimes distorted background images even under infocus observation conditions for specimens. These phenomena can be considered as electron beams are deflected by spatial electromagnetic fields around the specimens, resulting in distorting background images under defocused condition [1 - 3]. By utilizing these effects, we have developed a method of visualizing spatial electromagnetic fields around specimens by using SEMs and SIMs with cross-grating combined with the electron holography reconstruction technique [4].

Figure 1 shows schematics of electron beam deflection by uniform electric field E and magnetic field B. The interaction between electrons and electromagnetic field is given by Lorentz force (Eq. 1) in Fig. 1. Electric field distribution $|E(x, y)|$ is given by Eq. 2 and magnetic flux density distribution $|B(x, y)|$ is given by Eq. 3, where $\eta(x, y)$ is the phase distribution based on periodic structure of cross-grating.

Figure 2(a) shows an experimental setup of the specimen stage and cross-grating. The specimen was an epoxy resin attached to the Cu wire tip, and Cu grating with 12.7 μm period was positioned under the specimen of 5 mm. Figure 2(b) shows an SEM image of infocued resin and defocused grating, showing a distorted grating image. Figure 2(c) shows a fast Fourier transformed (FFT) pattern of (b). Two orthogonal Fourier spots, circled X and Y in Fig. 2(c), were used for reconstructing and visualizing the electric fields around the epoxy resin by holography's reconstruction technique.

Figure 3(a) shows a reconstructed distortion image corresponding to the last term of Eq. (2). Figure 3(b) shows $\cos|\eta(x, y)|$ image as an equi-electric field contour map from Fig. 3(a). Figures 3(c) and (d) are similar images of Figs. 3(a) and (b), obtained from SIM image (not shown here). Although the quantity of charge accumulation depends on the acceleration voltage of the beam, and elements and polarity of the charged particles, the reconstructed distribution profiles in Figs. 3(b) and (d) shows similar and consistent characteristics.

We were able to visualize the magnetic flux density distributions similarly in the same manner. The reconstructed contour maps of magnetic fields, however, showed equi-magnetic flux densities, not magnetic-lines of force as in electron holography.

This method depends on the Lorentz force for charged particle beams. Also, it can be realized in any SEMs/SIMs without holography electron microscopes. We note that this method requires small grids and regular array gratings for high resolution and high magnification observations. This method can also be used in transmission electron microscopes in the conventional mode. We intend to extend this method to wide-area observations of electromagnetic fields where electron holography is not applicable [6].
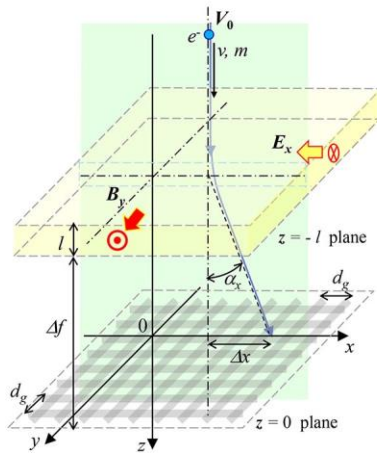
Equations

$$F(r) = -e\big(E(r) + v \times B(r)\big), \qquad (1)$$

$$|E(x,y)| = \sqrt{E(x)^2 + E(y)^2} = \frac{2V_0}{l}\sqrt{\alpha_x^2 + \alpha_y^2} = \frac{2V_0}{2\pi}\frac{d_g}{l\Delta f}|\eta(x,y)|, \qquad (2)$$

$$|B(x,y)| = \sqrt{B_y(x,y)^2 + B_{-x}(x,y)^2} = \frac{h}{e}\frac{|\alpha|}{l\lambda} = \frac{\Phi_0}{2\pi\lambda}\frac{d_g}{l\Delta f}|\eta(x,y)|, \qquad (3)$$
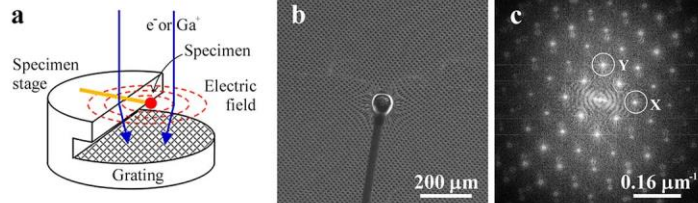

Figure 1. Schematics of particle beam deflection in the uniform and constant field model.

Figure 2. (a) Experimental setup; (b) 15-kV SEM image for electric field observation; (c) fast Fourier transformed pattern of (b).
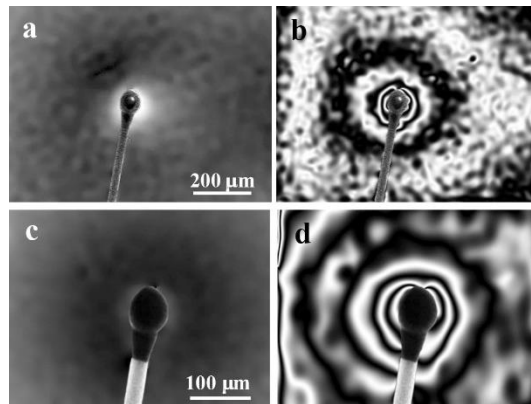

Figure 3. (a) reconstructed distortion image of epoxy resin from 2-kV electron beams; (b) contour map of projected electric field from (a); (c) reconstructed distortion image of epoxy resin from 10-kV Ga+ ion beams; (d) contour map of projected electric field from (c).

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