Simulation investigation of Compact Cs/Cc Corrector with Annular and Circular Electrodes for SEM

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The spherical aberration (Cs) corrector for S/TEM has come into wide use all over the world in the past several years. Mainstream of the Cs corrector has been a system consisted of multi-pole magnetic lenses [1-2]. However, the cost of multi-pole magnetic lens is very high and also, high accuracy of assembling, power source stability and adjustment for the systems are required. Moreover, to correspond immediately for the change of optical condition is very difficult due to the hysteresis phenomenon of magnetic lens. These are part of the reason why the conventional Cs correctors have not been popular for high-resolution SEMs. Recently, Kawasaki and Ikuta have developed a simple and compact electrostatic Cs corrector using annular and circular electrodes (called “ACE corrector”) to overcome these issues. [3-4]. They also demonstrated effectiveness of the Cs/Cc correction by the ACE corrector in STEM [3]. In this report, we reveal optical behaviors and optimum conditions of the ACE corrector in the SEM optics, based on analyses of three-dimensional electric field and electron beam trajectories inside the corrector.

Figure 1(a) shows an example of equipotential lines around the model of electrodes simulated by the boundary element method using a LORENTZ-3EM software. In this case, applied voltages to the circular electrode (upper) and the annular electrode (lower) are -5V and GND, respectively. Then electron trajectories in various conditions (applied voltages, incident angles β, and accelerating voltages) were calculated by 4th Runge-Kutta method. From these simulated data, amounts of angle change Δβ caused by electrostatic fields in the ACE corrector were measured, as shown in Fig. 1(b). Finally, probe sizes δ on the SEM specimen plane with Cs correction were derived on the basis of geometrical optics. It should be noted here that the parameter δ corresponds to blurring due to only Cs with no effect of electron source sizes.

Figure 2(a) shows a graph of probe size δ vs voltages applied to the ACE corrector. The calculating condition is 5 kV for accelerating voltage, 12.3 mrad for angle of aperture and 6.7 mm for WD. This represents that δ changes linearly with applied voltage, as indicated by a blue broken approximation line. The intersection point of this line and δ = 0 (red line) means “optimum voltage” for Cs correction. We have evaluated the optimum voltages in various conditions. Figures 2(b), (c), and (d) are graphs of optimum voltages vs SEM accelerating voltages, the cube of convergence angles, and working distances, respectively. They clearly represent linear relationships. Although
three parameters here are usually varied even in general SEM operations, the ACE corrector can be then realigned easily and quickly according to these results. These simulation investigations demonstrate that the ACE corrector has great possibilities for Cs correction of SEM whose optical conditions are changed frequently.

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References

Figure 1. Schematic illustrations of (a) an example of equipotential lines around the ACE corrector and (b) enlarged figure of the annular slit.

Figure 2. (a) Graph of $\delta$ vs applied voltages of ACE corrector. Graphs of optimum voltages vs (b) SEM accelerating voltages, (c) the cube of convergence angles, and (d) working distances, respectively. The blue broken lines in each graph indicate the linear relationship.