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New STEM/TEM Objective Lens for Atomic Resolution Lorentz Imaging

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During high resolution STEM/TEM imaging, a specimen has been always placed in strong perpendicular magnetic field using ordinary magnetic objective lens. If the specimen is magnetic material, such strong field can strongly affect its magnetic structures or even break the whole specimen. The simplest way to avoid such effect is turning off the objective lens and using the next nearest lens from the objective lens. This method can be used for almost all STEM/TEM, but the focal length of the lens should inevitably become much longer. The long focal length results in large chromatic aberrations, and being susceptible to noises. These drawbacks make it difficult to observe specimen at very high resolution with objective lens off mode, i.e. in Lorentz mode.

There have been several attempts to realize high resolution imaging in Lorentz mode. For example, it is reported that monochromator and Cs corrector can reduce the effect of the chromatic and spherical aberrations and realize about 0.6 nm of lattice resolution and information limit [1]. Another example is not to turn off the objective lens, but place the specimen out of the objective lens' magnetic field. This is realized by using dedicated pole piece which shields the sample from the magnetic field [2] or providing second stage [3]. The focal length becomes relatively short in these microscopes. By using the latter type in combination with Cs corrector, the available point resolution becomes 0.24 nm at 1.2 MV [3].

From these results and the experiments in high resolution imaging with Cs correctors, we realized that the short focal length for Lorentz objective lens is indispensable for reducing chromatic aberration, and thus realizing high resolution imaging under no magnetic field at a sample. Based on these considerations, we have been developing a new STEM/TEM objective lens shown in figure 1. This objective lens composed of two round lenses, which are called as Front Objective Lens (FOL) and Back Objective Lens (BOL). Specimen is placed in between the FOL and BOL. The magnetic pole and coil is symmetrical with respect to the specimen plane, but the polarities of their excitation currents are anti-symmetric. In this case, the z components of the magnetic fields at the specimen plane by FOL and BOL have the same magnitude but the opposite polarities. Generally, a radial component of the magnetic field of a round lens is small near an optical axis. Therefore, the magnetic field applied on the specimen becomes very small by the symmetry. This may make it possible to have an objective lens with short focal length, while the field on the specimen is maintained to be very small.

Figure 2 shows the experimental results showing the characteristics of BOL acquired at 180kV. The characteristics of FOL are almost the same because of the symmetry. Fig. 2(a) shows the image of MAGICAL and SA aperture. We calculated the BOL magnification from the difference of magnifications of sample and the aperture. The BOL focal length was estimated from the magnification and the object/image plane positions assuming the BOL as a thin lens. The resultant focal length is estimated to be 3.1mm. Fig. 2(b) shows the defocus variation of the image forming system with respect to the accelerating voltage shift. The Cc* was estimated to be 2.9mm from the gradient of the graph. Fig. 2(c) shows a diffractogram from an image of carbon thin film with gold particles. The point resolution by the BOL was measured to be 0.48nm from the diffractogram and the corresponding Cs is estimated to be 14mm.

We developed new STEM/TEM Lorentz lens which have small focal length and Cc*. It was stable enough to obtain 0.2 nm lattice resolution at 180kV using gold foil as shown in Fig. 2(d). It is expected that the combination of this lens with higher order aberration corrector [4] will realize high resolution Lorentz imaging better than 0.2nm [5].

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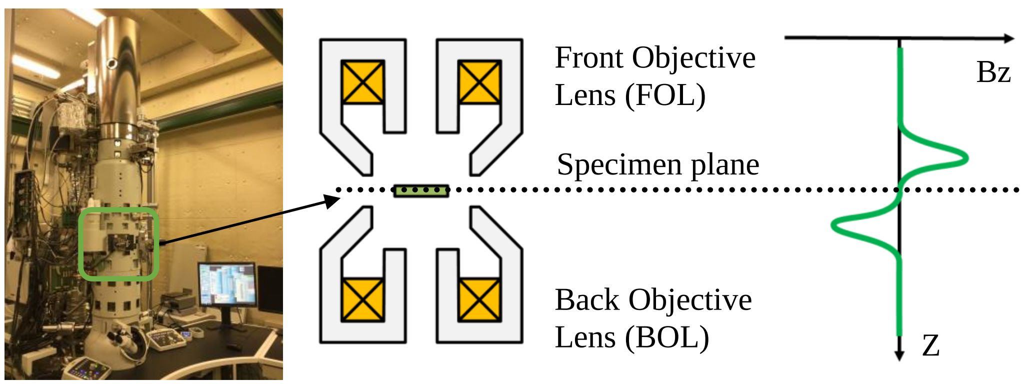

Figure 1. Appearance of the microscope, schematic and Z-field distributions of the new objective lens

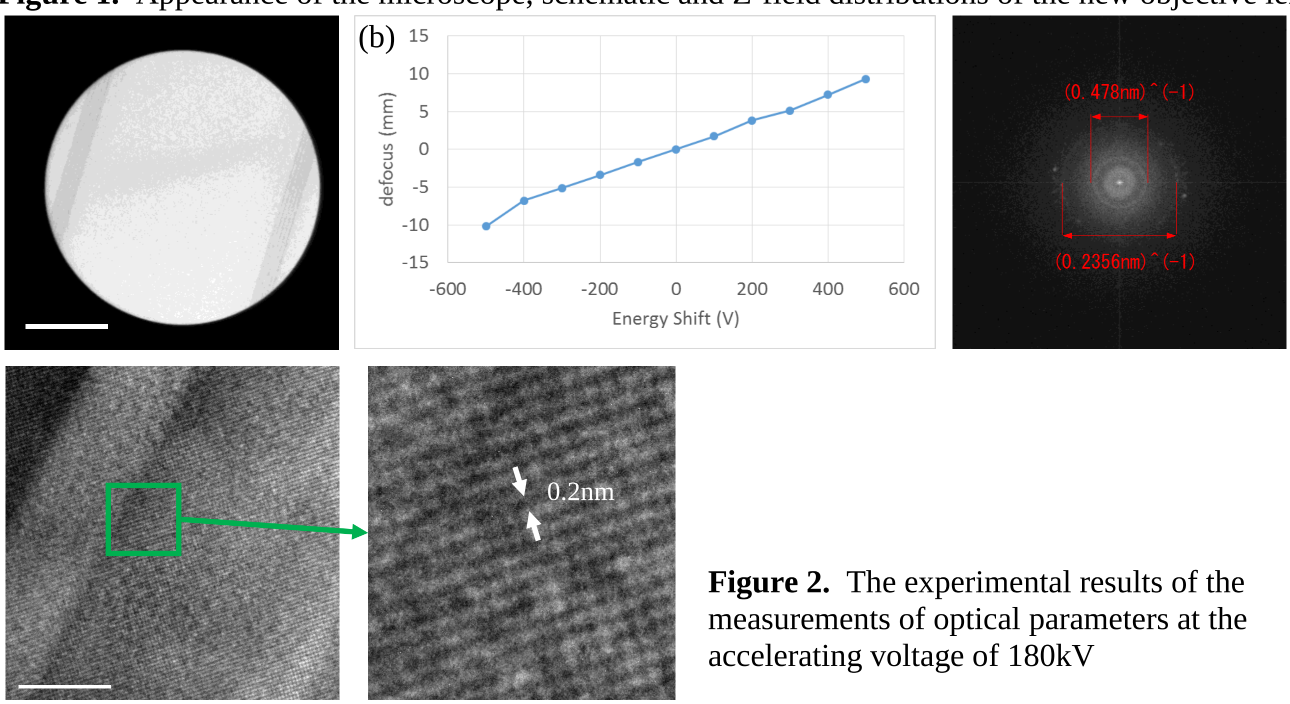

Figure 2. The experimental results of the measurements of optical parameters at the accelerating voltage of 180kV

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