AMTC Letters
Vol. 1 (2008)

A novel reconstruction technique for electron exit wave fields by a combination of diffractive imaging and selected area nano diffraction

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Diffractive imaging is one of novel methods for obtaining structural information in the real space from diffraction patterns. Because of a remarkable ability to obtain images of localized structures without lenses, the method has been studied extensively by X-ray researchers, and some successful results have been reported[1][2][3]. On the other hand, the notable merit when applying this method to electron diffraction is that image contrast and spatial resolution in the reconstructed images are not limited by lens aberrations in TEM. To reconstruct images by the diffractive imaging, boundary conditions in the real and the Fourier spaces are combined consistently by iterative optimisations through Fourier transforms. The boundary conditions for electron wave fields are that the amplitude in the Fourier space must be the square root of the diffraction intensity and, in the real space, must be a constant value in areas where no material exists. The latter condition means that the diffractive imaging can be applied only to samples in isolated shapes like carbon nanotubes. The restriction is one of the reasons that there is only one report in which an atomic-resolution image is reconstructed from an electron diffraction pattern[4].
To avoid the restriction, we propose a new method applicable to samples in arbitrary shapes by using the selected area diffraction (SAD). In the new method, a region where electron beams are intercepted by the selected area aperture is used for the boundary condition in the real space. It is known that a spherical aberration of an objective lens generally causes area-selection-errors in the SAD. To remove the errors, we use a Cs-corrector for imaging system in the present study, which is referred as the selected area nano diffraction (SAND)[5]. By using the SAND, we can select a well-defined area a few nanometers in diameter in a sample. This is important for reconstruction of atomic-resolution images, due to a limit of the minimum sampling intervals for diffraction intensity by present standard detectors such as imaging plates (IP). Figures 1(a) shows a TEM image of the selected area aperture effectively about 3 nm in diameter. Figure 1(b) shows the corresponding electron diffraction pattern, which is almost the Airy pattern, i.e., Fraunhofer diffraction from a circular aperture. Figure 1(c) shows a intensity profile along the line in 1(b). As the result of detail analysis of the profile, we have found that enough high degree of illumination coherency is achieved inside the aperture[6], which is known as an essential element for the diffractive imaging[7].
Figure 2(a) shows a SAND pattern from a silicon crystal from a [011] direction. Figure 2(b) shows the amplitude map of the exit wave field reconstructed from the pattern after removal of background and noise. The dumbbell structure with a separation of 0.136 nm is resolved clearly in the image[6]. It is concluded that the combination of the SAND and the diffractive imaging is effective in obtaining images with atomic resolution. It is expected that this new technique will be applied to structure analyses of various kinds of nano-materials.

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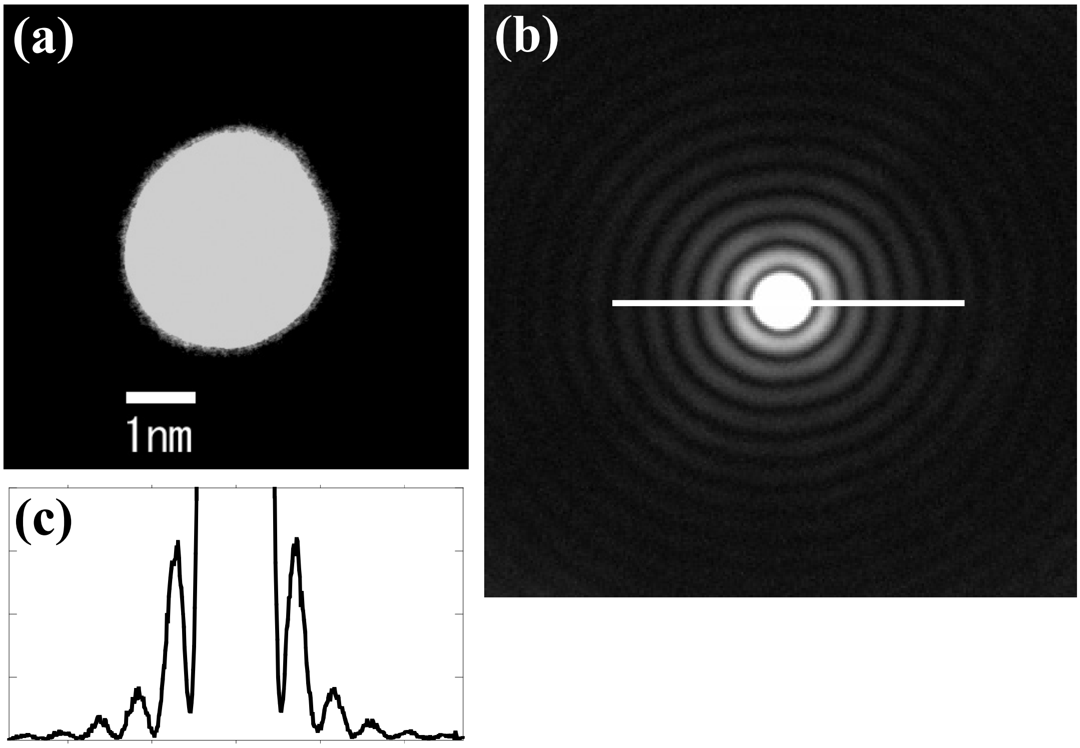

Fig. 1 : (a)The TEM image of the selected area aperture effectively about 3 nm in diameter.
(b)Diffraction pattern from the aperture in (a).
(c)Intensity profile along the white line in (b).

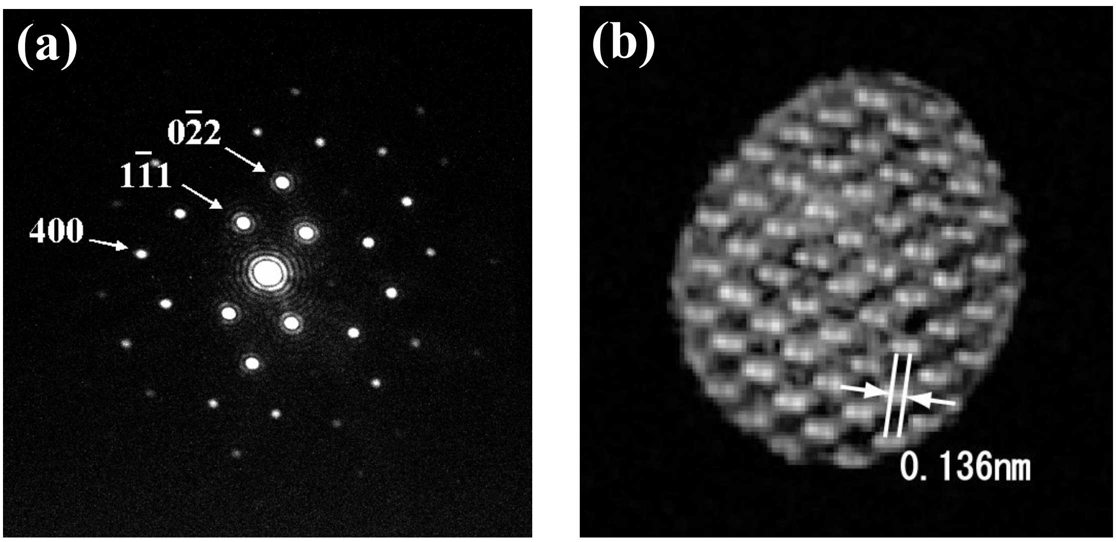

Fig. 2 : (a)Selected area nano diffraction pattern from a silicon crystal from [011].
(b) Amplitude map of the exit wave function reconstructed from (a).