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IT-2-P-3171 Quantitative study of defocus-dependent annular bright field images

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Previously, we found that the lithium column intensity of an annular bright field (ABF) image varied by a step of a single lithium atom in correlation with the thickness change of the LiV₂O₄ crystal [1]. But, ABF imaging mechanism has not been investigated quantitatively. In this study, we observed ABF and high angle annular dark field (HAADF) images of very thin specimen simultaneously and investigated defocus dependency of visibility of atomic columns [2].

By using a spherical aberration corrected electron microscope (R005), both ABF and HAADF images were taken simultaneously for very thin lithium manganese oxide, LiMn₂O₄ specimen from the [001] view direction. The incident convergent semi-angle was 30 mrad, and the detector semi-angles were 15-30 mrad for ABF and 102-272 mrad for HAADF. Fig.1 shows the through focus series of ABF and HAADF images obtained from 10 nm over-focus to -10 nm under-focus condition. In the ABF images, the atomic column had dark contrast at over-focus, but the contrast reversed into bright one when the defocus condition was changed to under-defocus. While, the HAADF image showed the bright column contrast which did not reverse regardless the focus change. It indicates that ABF image is a kind of phase contrast image, and could be explained by weak-phase-object approximation (WPOA).

We measured visibility in the ABF and HAADF images in order to estimate the defocus for obtaining the maximum contrast and the depth of focal (DOF). The optimum defocus was different between both images: the maximum contrast of the atomic columns was obtained at a few nm over-focus in the ABF image, while it, at a few nm under-focus in the HAADF image. And, DOF was determined to be 4 and 8 nm in the ABF and HAADF image, respectively. DOF of ABF image is obviously narrower than one of HAADF image. ABF imaging which has a narrow DOF could be used for visualizing light elements three-dimensionally.

[1] S. Lee, et al., J. Appl. Phys. 109 (2011) 113530.

[2] S. Lee, et al., Ultramicroscopy 125 (0), 43-48 (2013).

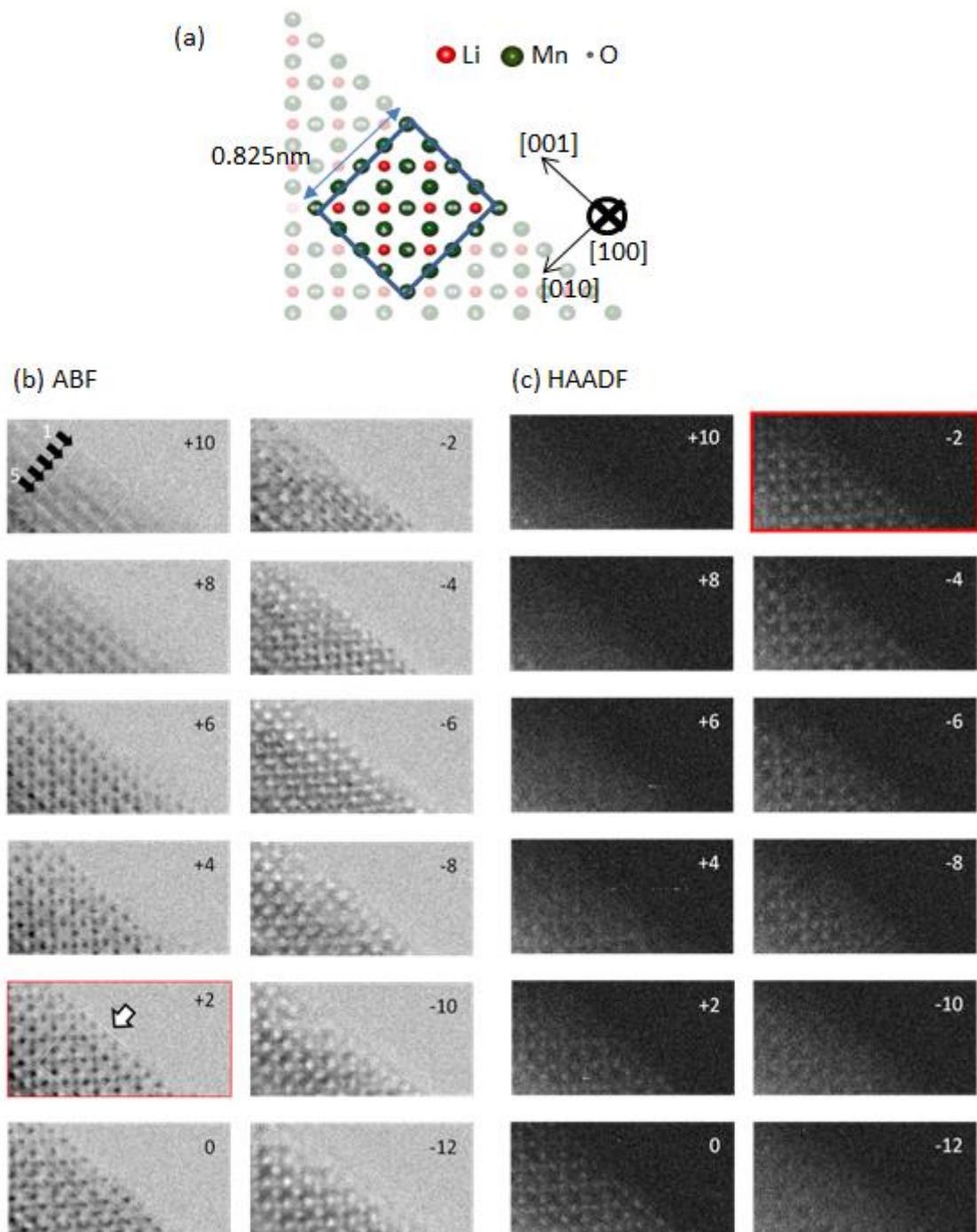


Fig. 1: (a) A structure model of very thin lithium manganese oxide (LiMn_2O_4) specimen. Through focus (b) ABF and (c) HAADF images are shown from 10 nm (over-focus) to -10 nm (under-focus). The maximum contrast is obtained at the defocus indicated by red rectangle.