Segmented annular all field detector for atomic-resolution scanning transmission electron microscopy

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In scanning transmission electron microscopy (STEM), a finely focused electron probe is scanned across the specimen and the transmitted and/or scattered electrons from a localized material volume are detected by the post specimen detector(s) as a function of raster position. It has been well recognized that STEM image contrast characteristics can be controlled and different materials information can be obtained by controlling the detector geometry. Several imaging modes such as bright-field (BF), low-angle annular dark-field (LAADF), high-angle annular dark-field (HAADF) and the recent annular bright-field (ABF) have been devised, and are now utilized in many fields. Other detector geometries using segmented type detectors have been considered by many researchers at intermediate resolutions [1-7]. However, other detector geometries for STEM have not been considered nor demonstrated at atomic resolution.

Recently, we have developed a new area detector called SAAF ("segmented annular all field"), which is capable of atomic-resolution STEM imaging [8]. This new area detector can obtain 16 simultaneous atomic-resolution STEM images which are sensitive to the spatial distribution of the scattered electrons in the detector plane. Fig. 1 shows a schematic illustration of the detector and 16 $SrTiO_3$ [001] STEM images demonstrating that we can simultaneously obtain atomic-resolution STEM images from the different detector segments. Note that the combined STEM images are consistent with the expectations for annular detectors spanning the same annular range. Especially, the (5+6+7+8) image corresponds to the ABF imaging condition, and we can clearly visualize the oxygen atomic columns in addition to the Sr and Ti-O columns. It should be noted that the present system allows precise alignment between the crystallographic orientation of the sample and the detector orientation. This capability can be used for exploring novel imaging techniques such as atomic-resolution differential phase contrast imaging. Details of the detector system and some application results will be presented.

References

[1] H. Rose, *Ultramicroscopy* **2**: 251-267(1977).
[2] I. Daberkow, K.H. Herrmann and F. Lenz, *Ultramicroscopy* **50**: 75-82(1993).
[3] M. Haider, A. Epstein, P. Jarron and C. Boulin, *Ultramicroscopy* **54**: 41-59(1994).
[4] M. Hammel and H. Rose, *Ultramicroscopy* **58**: 403-415(1995).
[5] M. Taya et al., *Rev. Sci. Inst.* **78**: 083705(2007).
[6] T.A. Caswell et al., *Ultramicroscopy* **109**: 304-311(2009).
[7] J.N. Chapman and M.R. Scheinfein, *J. Magn. Magn. Mater.* **200**: 729-740 (1999).
[8] N. Shibata *et al., J. Electron Microscopy* **59**, 473 (2010).

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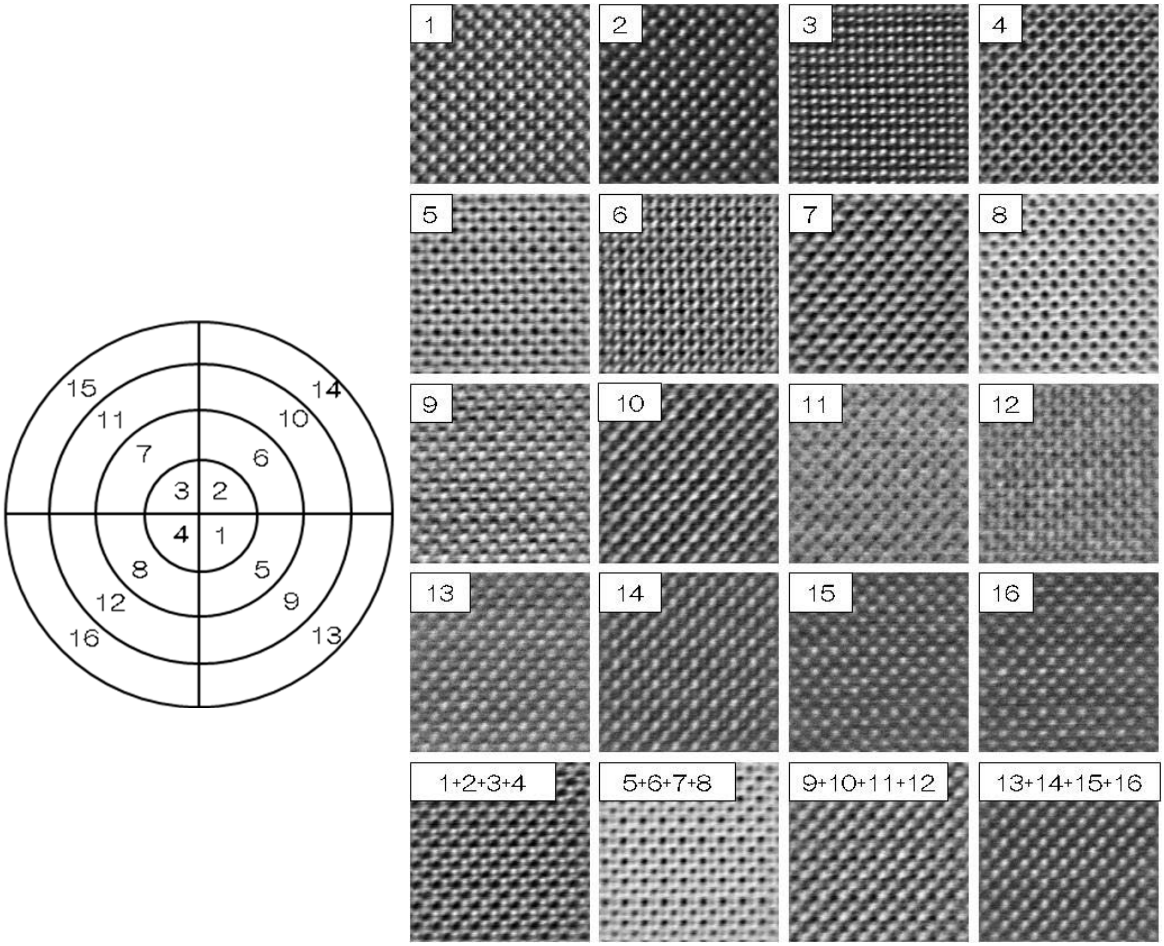

FIG. 1. Left: Schematic illustration of the SAAF detector. Right: Sixteen atomic-resolution STEM images simultaneously obtained by the SAAF detector. The sample is a $SrTiO_3$ [001] single crystal. The angle range covered by the whole detector area is 0 - 46 mrad. All the images were filtered using the Radial Difference Filter released by HREM Research Inc.