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TV-rate Atomic-resolution STEM Imaging

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Since the development of aberration correction technology, atomic-resolution imaging is routinely available in STEM and the spatial resolution is now reached into deep sub-ångström down to 40.5 pm [1]. In addition to the electron optics, detectors such as complementary metal-oxide-semiconductor (CMOS) camera and silicon drift detector (SSD) have also significantly improved. Although *static* materials' analyses are remarkably progressed with the aid of these technologies, it is still lacking in the capability of *dynamic* observations in atomic-resolution STEM imaging. This is because the present scanning probe system takes a finite time to form an atomic-resolution image, and the temporal resolution is normally in a second per frame [2]. Therefore, in-situ observations are mostly performed in TEM mode owing to their high reading-out time of recent CMOS cameras. Towards high temporal resolution STEM imaging, several approaches have been proposed such as sparse or spiral scanning of the electron probe [3,4], which can reduce the number of sampling pixels or avoid fly-back time. However, the demonstrated temporal resolutions are still in the same order or even worse, compared with the current STEM imaging. In this study, we have developed a new scanning probe system, which has electromagnetic scan coils with a considerably small inductance combined with a short lifetime scintillator for annular dark-field (ADF) STEM. Using this probe scanning system, we have achieved 25 frames per second (fps) with the image size of 512×512 pixels in atomic-resolution ADF STEM imaging, where the acquisition time is 83 ns/pix and the fly-back time for respective line scans is 35 µs. The present scanning system leads to the temporal resolution of 40 msec.

Figure 1 shows the frame rate as functions of acquisition time and fly-back time for different image sizes. To achieve TV-rate observations with the image size of 512×512 pixels, the acquisition time and the fly-back time should be smaller than 100 ns/pix and 50 µs, respectively. In such a short acquisition time, it may require a very high beam current and we here consider the electron dose effects on the visibility of the atomic column in ADF-STEM. We have simulated the electron dose effect on the visibility of atomic columns by adding Poisson noises in the simulated images [5]. Figure 2 shows the Poisson noise added simulated ADF-STEM images of $SrTiO_3$ viewed along the [001] direction, where we used two parameters of pixel size (pm/pix) and electron dose per pixel (or pixel dose). Although we can obtain a large field-of-view with the larger pixel size such as 30 pm/pixel, the image is strongly suffered by Poisson noise. It is therefore the pixel size should be smaller than 10 or 20 pm/pix. As indicated by arrowheads, Ti-O atomic column becomes visible with the higher pixel dose of 60 e^-/pix, corresponding to the conditions (beam current and acquisition time): (i) 192 pA with 50 ns/pix or 96 pA with 100 ns/pix. We will discuss the details of the developed scanning coil system and performance of the microscope: TV-rate acquisition of atomic-resolution ADF-STEM imaging [6].

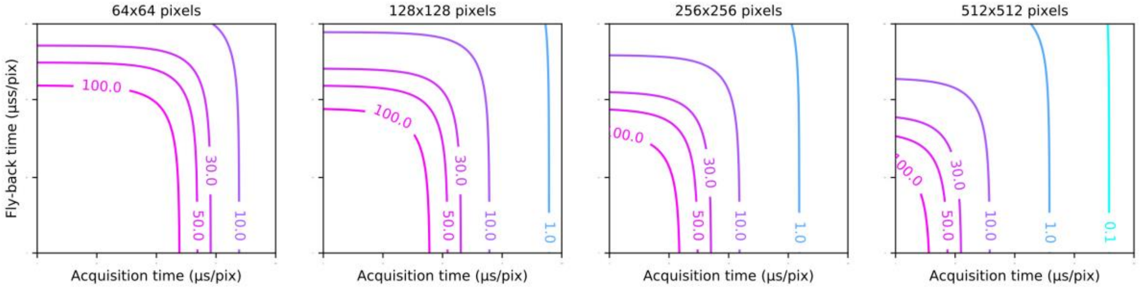

Figure 1. Frame rate (fps) as functions of acquisition time (µs/pix) and fly-back time (µs/pix), where the image sizes are given on the top.

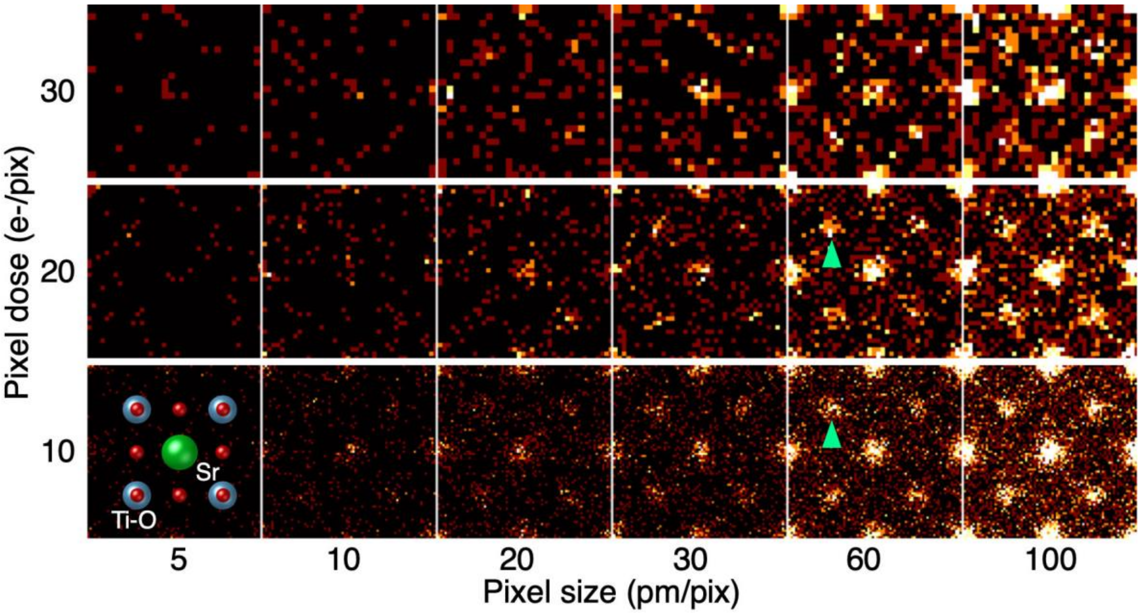

Figure 2. Poisson noise added simulated ADF-STEM images of SrTiO3 viewed along the [001] orientation.

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