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Direct Imaging of Light Elements in Aberration-Corrected Scanning Transmission Electron Microscopy

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It has been a long-standing goal in analytical electron microscopy to achieve imaging and quantification of individual atomic columns in crystal lattices, especially those formed by light atoms. The recent development of aberration-correction lenses in conventional transmission electron microscopy (CTEM) now allows direct imaging of individual atomic columns formed by light elements [1], and even direct image quantification for extremely thin specimens, < 4 nm [2].

Before aberration-correction, observing light elements in high-angle annular dark-field (HAADF) imaging in scanning TEM (STEM) was not possible due the intrinsic weak electron scattering amplitude of the light elements (HAADF image intensity depends approximately on the square of the atomic number, $\sim Z^2$) and the low signal-to-noise-ratio (SNR) obtained in the images due to small objective apertures. However, aberration correction now permits the use of larger objective apertures, leading to greater contrast and increased SNR allowing light elements to be directly observed in HAADF. Moreover, because of the larger apertures, scanning bright-field (BF) images, equivalent in SNR and spatial resolution to CTEM, can be acquired simultaneously with HAADF images. This has allowed using HAADF images to directly identify heavier atomic columns and use that information to recognize lighter elements in the BF image, i.e oxygen columns in Al_2O_3 [3].

Figures 1 and 2 show Z-contrast and BF images acquired simultaneously of a [0001] β-Si_3N_4 grain. The grain changes in thickness a few nanometers (the maximum thickness measured was ~20 nm, calculated by the absolute log ratio method [4]). However, individual silicon and nitrogen columns can be resolved directly in the both images. Resolving N columns in Si_3N_4 was only achieved before aberration-correction by focal series reconstruction [5].

In this study we will discuss the advantages and limitations of using aberration-correction in scanning TEM (STEM) with respect to CTEM to directly image and quantify individual atomic columns formed by light elements. The experiments in this study were performed in the aberration-corrected STEM, FEI Titan S 80-300 located at Oak Ridge National Laboratory [6].

References:

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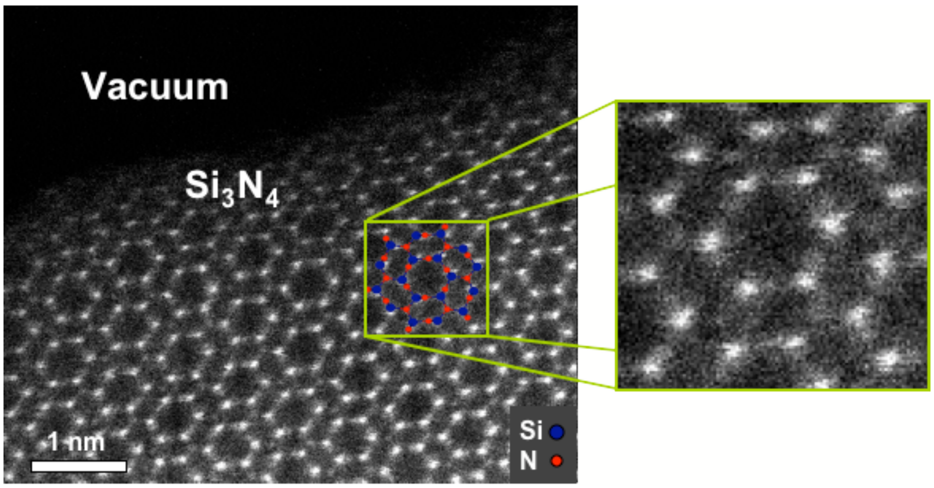

FIG. 1. Z-contrast image (raw data) of β-Si_3N_4 [0001] where Si and N columns can be clearly resolved.

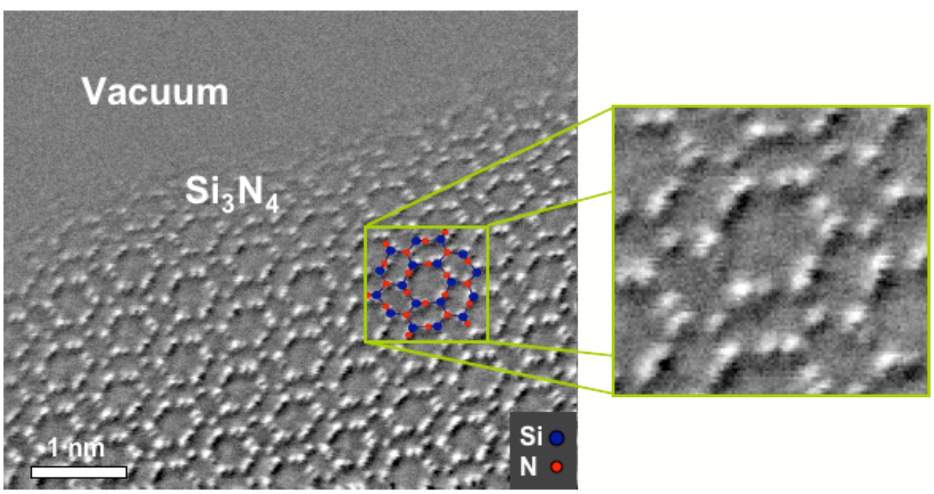

FIG. 2. Simultaneously acquired BF image (raw data, contrast has been inverted) of β-Si_3N_4 [0001] where Si and N columns can be resolved and have different intensities.