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Bloch Wave Based Analysis of Imaging Properties of High-resolution Scanning Confocal Electron Microscopy

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Recently, a novel technique of scanning confocal electron microscopy (SCEM) (see Fig. 1) has been proposed and preliminary experimental setups have been constructed [1]. By applying aberration correctors to both condenser and collector objectives of SCEM, high resolution 3D imaging should be possible [2,3,4]. Unfortunately, the atomic-resolution SCEM images of single crystals, where excitation of Bloch waves should be considered, have neither been recorded nor properly calculated yet. This paper attempts to partially fill this gap by simulating the imaging properties of the high-resolution SCEM.

An efficient Bloch wave based technique has been developed for atomic-resolution STEM by Nellist and Pennycook [4]. This technique not only provides a fast calculation method, but also gives a good physical insight into the imaging, which was mostly left hidden behind the equations. In the present work, the Bloch wave based image simulation method is applied to the SCEM technique based on Nellist's calculation technique, and the imaging properties of high-resolution SCEM are investigated.

In Figure 2, we analyze one of the most interesting properties of SCEM, namely the depth sectioning. For this task, the lens defocuses can not be held stationary and must be swept across the sample, and the results of the previous subsections imply that the best condition occur when the upper and lower defocuses coincide. As a test system, we analyzed a 50 nm thick Al sample containing a 10 nm layer of hypothetical gold metal buried at different depths. Figure 2(a) illustrates the system simulated. Five different Au layer depth were considered, and the positions of the layers are measured from the bottom surface. For each layer depth, the average image intensity and the atom column contrast were calculated changing the focus position from top to bottom keeping the confocal condition. The defocus is zeroed at the bottom surface. Note that real Al and gold metals have the same structure (*fcc*) but slightly different lattice constants (0.405 and 0.408 nm respectively). The latter difference was neglected in these model simulations. Figure 2(b) shows the average image intensity for three representative thicknesses. It reveals that via the average image intensity the position of the gold layer can be easily and accurately identified. The image contrast is plotted in Fig. 2(c). The atomic contrast in Fig. 2(c) shows complicated oscillatory behavior and the contrast reversals occur. However, the atomic sites always appear dark provided the average image intensity is at the maximum, i.e. the lower and upper lenses are focused at the gold layer.

To summarize, we would note that the depth of the impurity layer can be tentatively deduced from the experimental variation of the image intensity with the defocus setting. However calculations are required to ascertain the analysis. Indeed, several intensity maxima could be observed for a single impurity layer, and the maxima could originate not from the impurity, but from the matrix itself.
References

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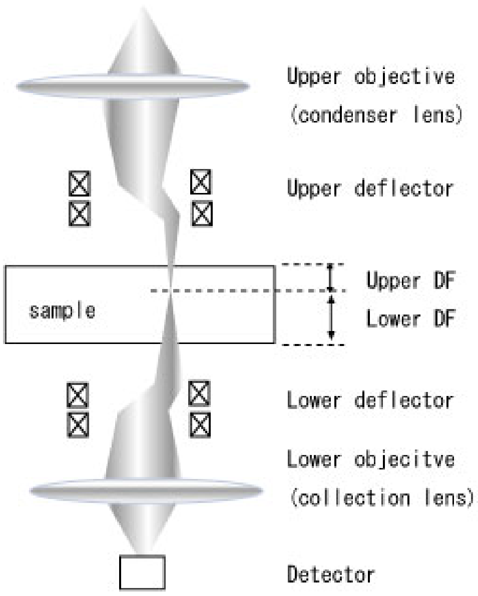

FIG. 1. Schematic drawing of SCEM setup. The electron probe is scanned by the upper deflector and de-scanned by the lower deflector. The zero defocus for the upper (lower) lens is defined at the upper (lower) crystal surface.

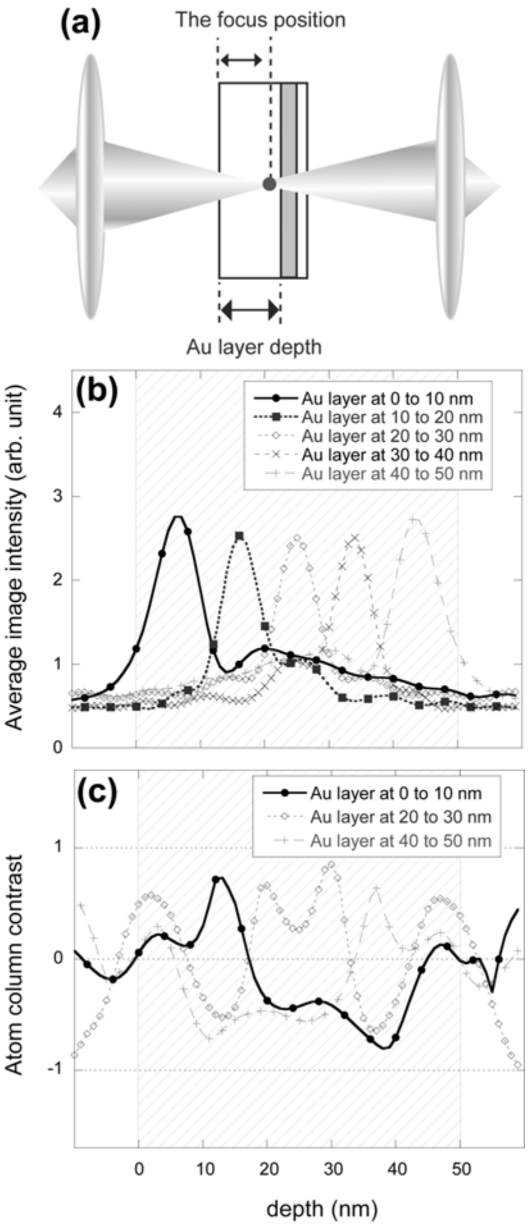

FIG.2. Effect of an impurity layer on the average image intensity (b) and atomic contrast (c). Panel (a) outlines the experimental geometry. The studied samples are 50 nm thick Al foils containing a 10 nm thick gold layer located at various depths. The focuses of the upper and lower lenses coincide and are changed simultaneously along the normalized sample thickness. Note that the average intensity, but not the atomic contrast, exhibits a maximum at the defocus value corresponding to the Au layer position revealing depth sectioning capabilities of SCEM.