A Monochromatic, Aberration-Corrected, Dual-Beam LEEM

Marian Mankos and Khashayar Shadman

Electron Optica, 1000 Elwell Court, Palo Alto, CA 94303, USA

Email: marian@electronoptica.com

The monochromatic, aberration-corrected, dual-beam low energy electron microscope (MAD-LEEM, Fig.1) is a novel instrument aimed at imaging of nanostructures and surfaces at sub-nanometer resolution that utilizes electrons with landing energies in the range of 0 to a few 100 eV for imaging. The monochromator [1] reduces the energy spread of the illuminating electron beam, which significantly improves spectroscopic and spatial resolution. The aberration corrector [2] is needed to improve the spatial resolution in order to achieve sub-nm resolution. Dual flood illumination [3] eliminates charging generated when a conventional LEEM is used to image insulating specimens. The electron-optical properties of the objective lens combined with an electron mirror aberration corrector have been analyzed up to 5th order for electron energies ranging from 1 to 1000 eV. The spherical and chromatic aberration coefficients of the electron mirror are fine-tuned iteratively to cancel the aberrations of the objective for a range of electron energies, thus providing a path for sub-nm resolution.

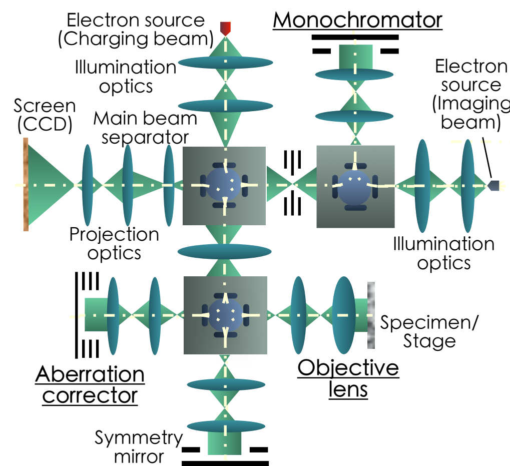

Figure 1. Electron-optical layout of MAD-LEEM.

MAD-LEEM is in particular aimed at imaging of biological and insulating specimens, which are difficult to image with conventional LEEM, Low-voltage SEM, and TEM instruments. The low energy of electrons is critical for avoiding beam damage, as high energy electrons with keV kinetic energies used in SEMs and TEMs cause irreversible damage to many specimens, in particular biological materials. A potential application for MAD-LEEM is in DNA sequencing which demands imaging techniques that enable DNA sequencing at high resolution and speed, and low cost [4]. The key advantages of the MAD-LEEM approach are long read length, the absence of heavy-atom DNA labeling, and use of low electron energies. Image contrast simulations of the detectability of individual nucleotides in a DNA strand have been developed in order to refine the optics blur and nucleotide contrast requirements.

The MAD-LEEM approach promises to significantly improve the performance of a LEEM for a wide range of applications in the biosciences, material sciences, and nanotechnology where nanometer scale resolution and analytical capabilities are required.

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References

[1] M. Mankos, U.S. Patent No. 8,870,172; (May 22, 2012).
[2] D. Preikszas and H. Rose, Journal of Electron Microscopy 1, 1 (1997).
[3] M. Mankos, Nucl. Instr. Meth. Phys. Res. A, 645, 35 (2011).
[4] M. Mankos et al., submitted to JVST B (2012).