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An Aberration-corrected Low Energy Electron Microscope for DNA Sequencing and Surface Analysis

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Monochromatic, aberration-corrected, dual-beam low energy electron microscopy (MAD-LEEM) is a novel technique aimed at high resolution imaging of organic materials, nanoparticles and surfaces that utilizes electrons with landing energies in the range of 0 to a few hundred eV for imaging. MAD-LEEM combines a monochromator, a mirror aberration corrector and dual electron beam illumination in a single instrument. The monochromator reduces the energy spread of the illuminating electron beam, which significantly improves spectroscopic and spatial resolution. The aberration corrector is needed to improve the spatial resolution in order to achieve sub-nm resolution at landing energies of a few hundred eV. The dual flood illumination approach eliminates charging effects generated when a conventional low voltage electron microscope is used to image insulating specimens. The low landing energy of electrons is critical for avoiding electron beam damage, as high energy electrons with keV kinetic energies cause irreversible damage to many specimens, in particular biological materials. 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 spherical and chromatic aberration of the objective lens for a range of electron energies, thus providing a path for sub-nanometer spatial resolution. A potential application for MAD-LEEM is in DNA sequencing. Image contrast simulations of the detectability of individual nucleotides in a DNA strand have been developed in order to refine the LEEM optics blur and nucleotide contrast requirements. Experimental images of DNA structures immobilized on a gold substrate obtained in a LEEM demonstrate that high contrast is achievable at low electron energies in the range of 1-10eV. Electron reflectivity measurements derived from these LEEM images over a range of landing energies show that small changes in landing energy have a strong impact on the DNA contrast and thus hold promise for distinguishing individual nucleotides without heavy atom labels. 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.