A Novel Electron Monochromator for High Resolution Imaging and Spectroscopy

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Electron beam instrumentation has been widely used to study materials and pattern structures with spatial resolution in the nanometer range. Many recent applications demand low electron probing energies (below 5 keV) in order to obtain high sensitivity and to minimize radiation damage. For these landing energies, the chromatic aberrations associated with the energy spread of the electron source limit the spatial resolution for imaging and patterning. Consequently, Low Voltage SEMs are practically limited to a resolution of a few nanometers. A reduction of the energy spread to a value of 50 meV would improve the spatial resolution into the sub-nanometer regime. The energy spread of the electron source also limits the energy resolution for electron spectroscopy techniques. In particular, the spectra show a broad zero-loss peak that buries many features of interest, such as band-gaps, dielectric function maps, and phonon excitations. To reveal these features, the energy spread of the electron source must be reduced to values of order 10 meV.

In this paper, we focus on the design of a novel monochromator that reduces the energy spread of commonly used electron sources from the characteristic range of 0.2-0.5 eV into the 10-50 meV range. The monochromator (Fig. 1) combines a beam separator with an electrostatic electron mirror, which enables the use of a knife-edge aperture. The beam separator, a magnetic prism array, deflects the electrons with nominal beam energy E_0 (green) by 90^o, while electrons with a lower (red) or higher energy (purple) are deflected more or less, respectively, as a result of the energy dispersion of the separator. As the electrons proceed towards the mirror, the knife edge aperture stops the lower energy tail of the energy distribution. After reflection in the mirror, the higher energy tail is stopped on the same knife edge. The knife-edge is easier to manufacture than conventional slit apertures, it is less prone to contamination, and it provides a seamless switch for trading energy resolution for sample current. The performance of the monochromator is illustrated in Fig. 2, which shows a through-focus series of spot diagrams at the knife-edge for electron beams that differ from E_0 by 10 and 50 meV. Simulations of the optical properties of the separator, the electron mirror, the transfer lenses, and of the Coulomb interactions show that the monochromator can deliver currents exceeding 1 nA with a 50 meV energy spread. The monochromator can make further improvements to the energy resolution, to values of a few meV, for high-end, low current spectroscopic applications.

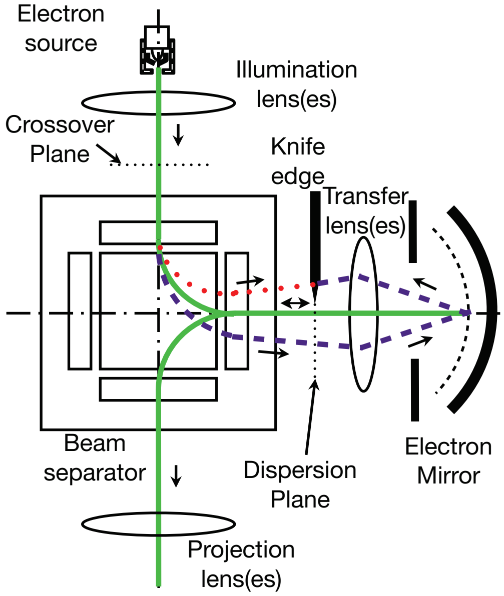

Figure 1. Key mirror monochromator components.

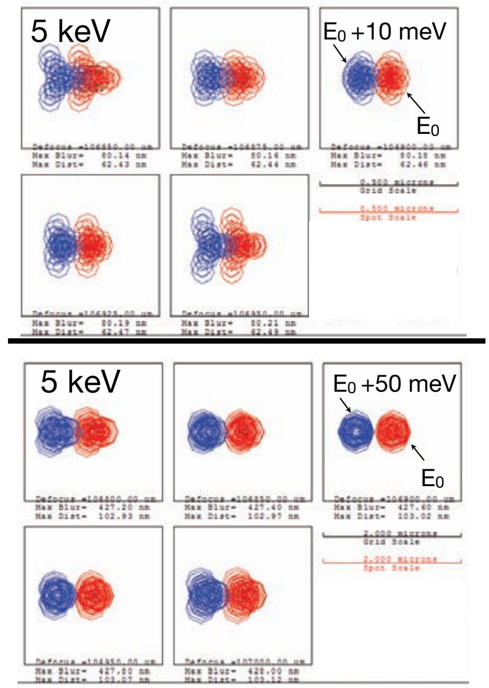

Figure 2. Through-focus series of beam blur in the dispersion plane for two electron beams with a nominal beam energy of 5 keV and an energy difference of 10 meV (top) and 50 meV (bottom). A clear separation of the two beam envelopes for each case indicates that a knife-edge that is placed in the dispersion plane can effectively remove the electrons in the tail of the distribution that are outside the 10 meV or 50 meV energy windows.

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