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 landing energies (< 5 keV) in order to obtain sensitivity and to minimize radiation damage. For these landing energies, the spatial resolution is limited by the chromatic aberrations associated with the energy spread of the electron source. Consequently, LV SEMs are practically limited to a resolution of a few nanometers. At even lower probing energies (100 eV to 1 keV), the resolution degrades rapidly into the 10 nm range. A reduction of the energy spread would significantly improve the spatial resolution at low landing energies. 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 introduced by the energy spread that buries many features of interest, such as band-gaps, dielectric function maps, and phonon excitations.

In this paper, we focus on the design and testing of a novel monochromator that can reduce the energy spread of electron sources from the characteristic range of 0.5 - 1 eV into the sub-100 meV range. The monochromator (Fig. 1) combines a magnetic beam separator with an electrostatic electron mirror, which enables the use of a knife-edge aperture. The knife edge is easier to manufacture than conventional slits, it is less prone to contamination, and it provides a seamless switch for trading energy resolution for beam current. The improvement in the spatial resolution with a reduced energy spread is illustrated in Fig. 2, which shows the angular dependence of the simulated probe size for energy spreads ranging from 60 meV to 0.65 eV, for a high performance LV SEM with a beam energy of 5 keV and landing energy of 300 eV. A prototype monochromator has been built (Fig. 3). Experimental data obtained from this prototype with a Schottky emitter demonstrates the improvement achieved to date (Fig. 4): the energy spread (FWHM) has been reduced from the initial value of ~ 0.75 eV to 0.18 eV with a final probe current exceeding 1 nA. The optical properties of the monochromator show that the current scales inversely as the cube of the energy resolution. Consequently, 60 meV should be achievable at 1 nA, and further improvements to values of a few meV are possible for low current spectroscopic applications. Work is in progress to refine the test setup in order to improve its resolution and stability and thereby improve the achievable energy spread.

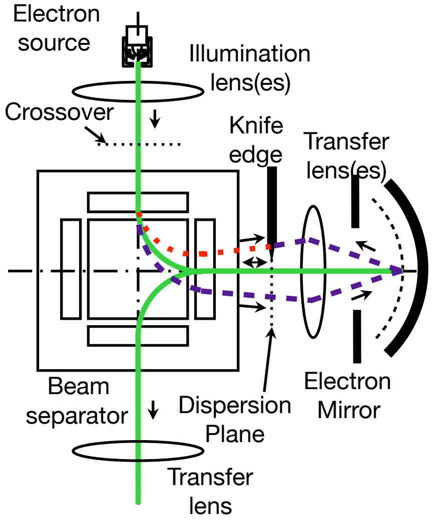

Figure 1. Key mirror monochromator components.

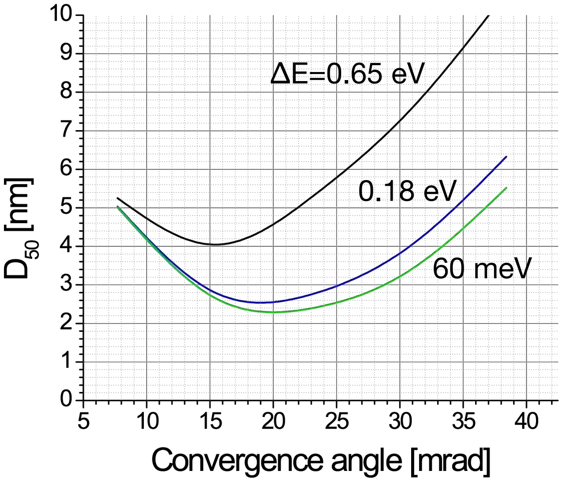

Figure 2. Simulated probe diameter vs. convergence angle for energy spreads ranging from 60 meV to 0.65 eV and landing energy of 300 eV.

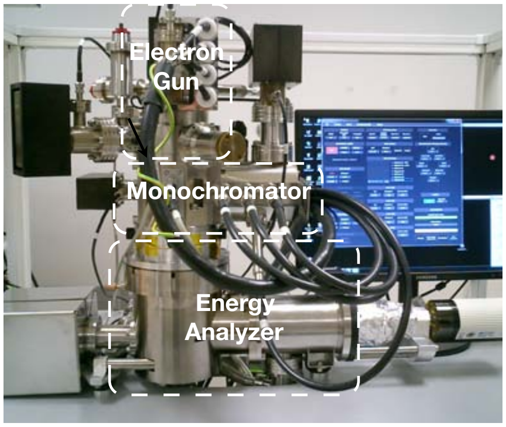

Figure 3. Monochromator prototype mounted on an energy analyzer for initial testing.

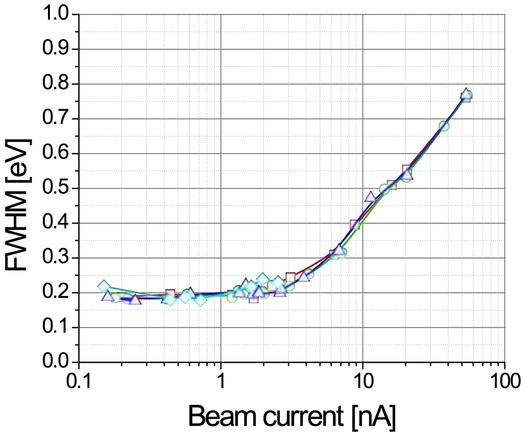

Figure 4. Measured energy spread vs. probe current after monochromatization.

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