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T. Ruiz
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High-Resolution LEEM/PEEM by Employing Mirror-Type Aberration Correctors - in Memory of Gertrude F. Rempfer

Harald Rose

Ulm University, Center for Electron Microscopy, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Low-Energy Electron Microscopes operating in the deflection mode (LEEM) or in the photo-emission mode (PEEM) are increasingly employed in surface science and biology [1, 2]. The high surface sensitivity, the reduction of radiation damage, the possibility for in-situ and real-time investigations under ultrahigh vacuum conditions and the combination of pure microscopy with diffraction and spectroscopy are the main advantages of these instruments. Unfortunately, a fundamental barrier limits the resolution of electron lenses. Unlike in light optics, where aberrations of a lens system can be compensated by a simple combination of convex and concave lenses, this method is not possible in electron optics, as shown by Scherzer in 1936 [3]. Owing to this obstacle, the best resolution of conventional LEEMs or PEEMs is in the range of 6 to 8 nm. To appreciably improve this resolution, one must compensate for the unavoidable aberrations of the rotationally symmetric electron lenses either by employing multipole correctors or electron mirrors which do not satisfy the conditions on which the Scherzer theorem is based. Although it was known for a long time that electron mirrors can compensate for the chromatic and spherical aberrations of electron lenses, a mayor drawback preventing their use was the difficulty to separate the incident and outgoing beams without introducing deleterious aberrations. Because the problem of appropriately separating the beams was a major obstacle, electron mirrors were not considered as feasible correctors.

Revived interest in electron mirrors originated in the mid-1980s when Rempfer found a reasonable solution for the separation problem. Her finding served as the basis for the compact beam separator of the SMART electron microscope [4]. In order to correct the spherical and chromatic aberrations of a PEEM, Rempfer and Mauck proposed a hyperbolic two-electrode mirror [5, 6]. However, for adjusting the chromatic and spherical aberrations of the mirror independently at a fixed focal length, we must increase the number of electrodes from two to four as realized by the tetrode mirror of the SMART electron microscope. Unlike a light-optical mirror, where the reflection occurs at the physical surface, the electron mirror represents a “soft” mirror, which allows the electrons to penetrate into the inhomogeneous refracting medium determined by the electrostatic mirror potential. The arrangement of the constituent elements of the SMART microscope is shown in Fig.1. This aberration-corrected microscope is located at BESSY 2 in Berlin and can operate either in the PEEM mode or in the LEEM mode with adjustable energy E_0 of the electrons at the object. The best resolution obtained so far for the LEEM mode is about 2nm [7], as shown in Fig. 2.

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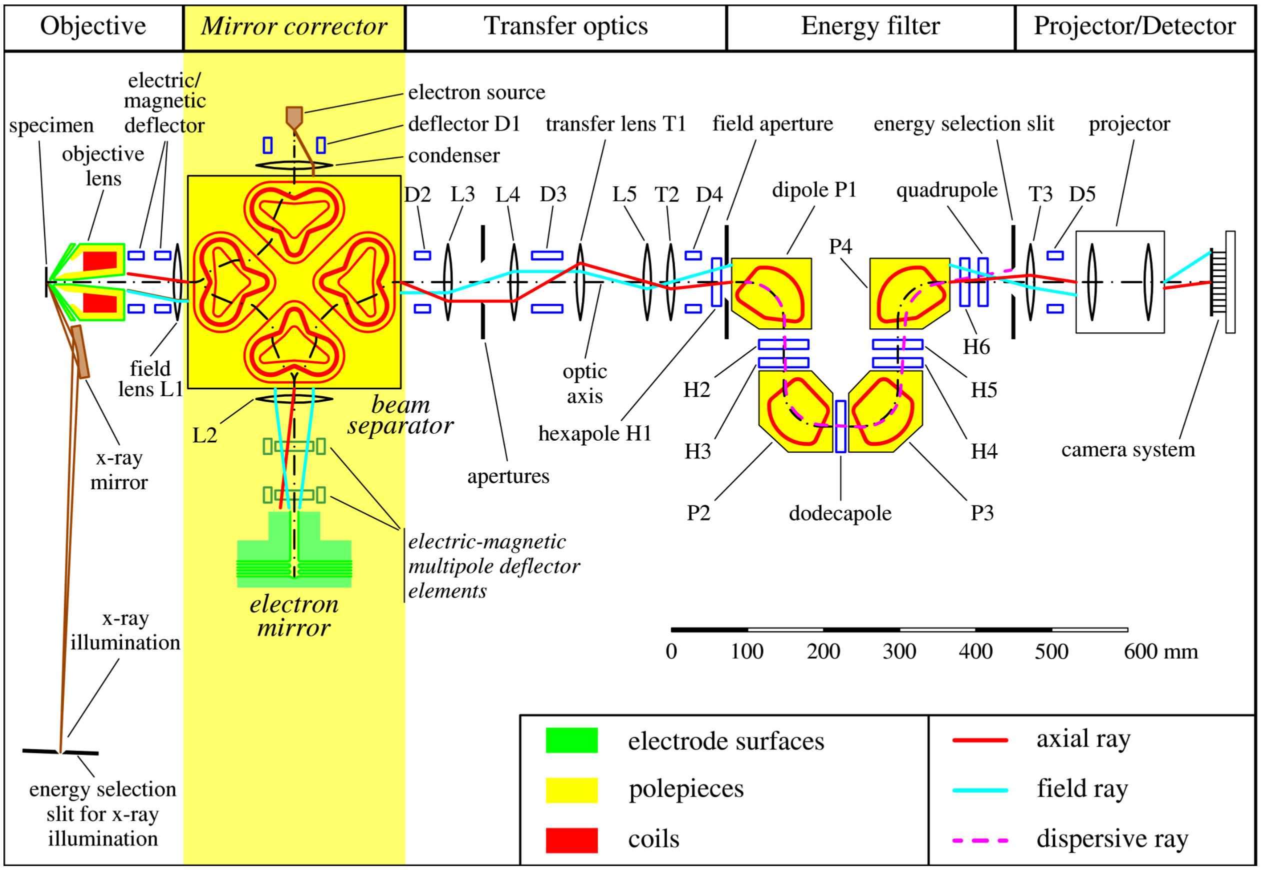

Figure 1. Construction scheme of the SMART electron microscope [4] consisting of an electron gun, alignment deflectors, an electric and magnetic immersion objective lens, a compact beam separator, transfer lenses, an aberration-corrected imaging energy filter, projector lenses , and a recording system.

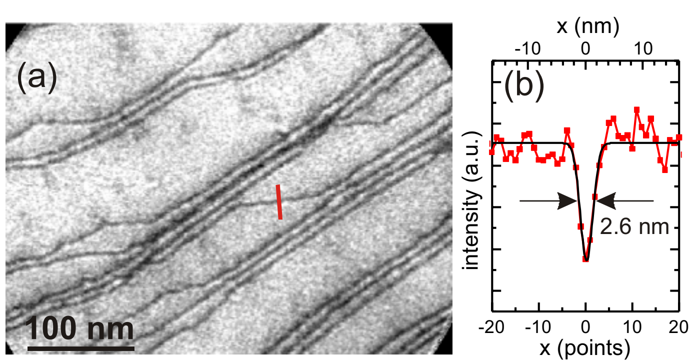

Figure 2. Lateral resolution of the SMART operating in the LEEM mode at E_0 = 15eV [7]: (a) atomic steps on a Au (111) surface, (b) a lateral resolution of 2.6 nm is obtained from the cross section through a step indicated by the line in (a).

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