Aberration Correction for Electron Beam Inspection, Metrology and Lithography

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Electron beams offer extremely high resolution for inspection, metrology and lithography of integrated circuits, because the electron beam wavelength (λ = 0.0053 nm at 50 keV) is 100,000 times shorter than visible light, so diffraction effects are much smaller. In practice, however, electron beam systems are usually limited by two main factors: (1) Lens aberrations and (2) Coulomb interactions. This paper describes various schemes for correction the aberrations, so that the numerical aperture ("NA") can be increased, thereby reducing the Coulomb interactions.

The two main methods of aberration correction in electron optics are ***multipole lenses*** and ***electron mirrors***. In the last 10 years, such correctors have been used successfully to improve the resolution of commercial electron microscopes (e.g. the JEOL JSM-7700F SEM)[1], which uses a CEOS *Cs*/*Cc* corrector, offering an unprecedented resolution of 0.6 nm at 5 kV. No analogous aberration-corrected e-beam systems have yet been reported for semiconductor manufacturing.

We have developed special software, using the differential algebraic ("DA") method, for simulating the high order aberrations of multipole lenses and electron mirrors.[2,3] After briefly describing the principles of this new DA software, we present simulations of some proposed aberration correctors for e-beam inspection, metrology and lithography applications.

All conventional electron lenses have positive spherical (*Cs*) and chromatic (*Cc*) aberration.[4] These aberrations can be corrected with a ***multipole corrector***[5] (Figure 1). *Cs* is corrected with 4 quadrupoles and 3 octopoles (Figure 1(a)), and *Cc* is corrected with 2 magnetic/electrostatic crossed-field quadrupoles (Figure 1(b)). Such a corrector can improve the resolution and NA of a CD SEM for e-beam metrology, as we have demonstrated for an example of a simple CD SEM column (Figure 1(c)), with 1kV landing energy, 1eV energy spread and 20nm source size. Before correction, the aberrations were *Cs* = 8.9mm and *Cc* = 2.9mm, giving 16nm spot size at 4mrad NA. After correction (with Cs = *Cc* = 0), the dominant high order aberrations were *Cs5* = 195mm and *Cc3* = 76mm, giving a smaller spot size (3 nm) at a much larger NA (25 mrad). Our results also show the effectiveness of such correctors for cell projection ("CP") lithography.

E-beam projection systems for high-throughput lithography are usually limited in NA and field size by field curvature (*Fc*) and astigmatism (*As*) in the projection lenses. H. Rose has invented a ***hexapole planator***[6], which correct both *Fc* and *As*. The hexapole planator (Figure 2), containing 6 hexapole lenses and 4 round lenses, is inserted between the 2 magnetic projection lenses (Lens 1 and Lens 2). We show that, by adjusting the strengths and orientations of the hexapole lens fields, *Fc* and *As* can indeed be cancelled, and by adjusting the size for the planator, *Cs* can also be eliminated. This allows both the NA and the field size to be increased.

Reflection electron beam lithography[7] offers an opportunity for using an ***electron mirror*** (Figure 3(a)) to correct the system aberrations. We demonstrate that a mirror placed in such a system (Figure 3(b)) can correct the *Cs* and *Cc* of the projection optics, and we investigate whether it can also be used to correct the field aberrations (e.g. *Fc* and *As*).

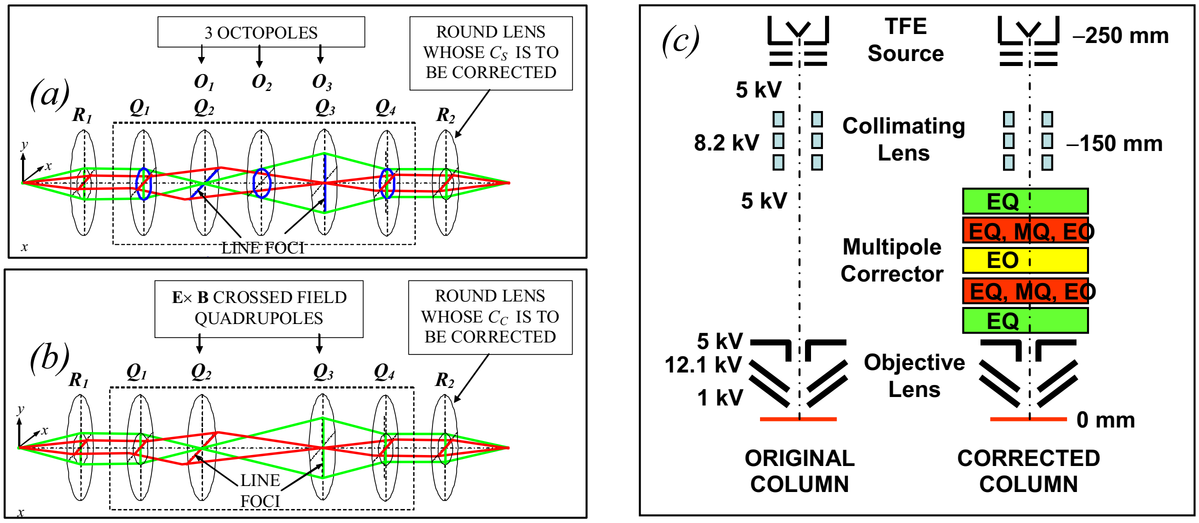

Figure 1. (a) Spherical ab. Cs correction, using 4 quadrupole lenses (Q1 – Q4) 3 octopoles (O1 – O3).
(b) Chromatic aberration Cc correction, using 2 E×B crossed-field quadrupoles.
(c) Low voltage CD SEM, with quadrupole/octopole corrector for eliminating Cs and Cc.

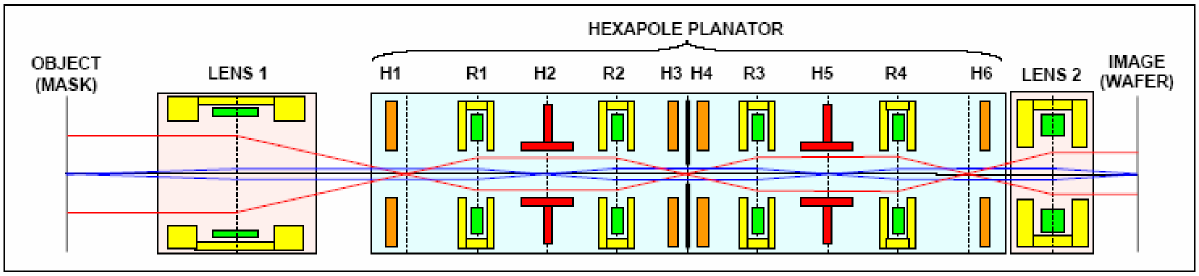

Figure 2. Hexapole planator for correcting field curvature (Fc) and astigmatism (As) in an e-beam projection lithography system. The planator contains 6 hexapoles (H1 – H6) and 4 round lenses (R1 – R4). It is inserted between the original projection lenses (LENS 1 and LENS 2).

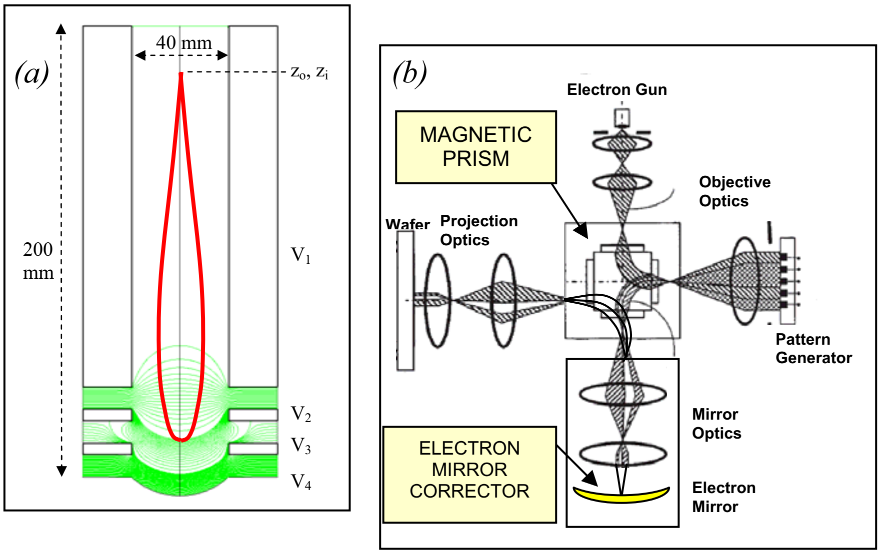

Figure 3. (a) Tetrode electron mirror, which produces a real image with negative Cs and Cc. (b) Reflection Electron Beam Lithography system (from KLA-Tencor Corp. US Patent No. 6,870,172) showing how an electron mirror could be added in one arm of the magnetic prism to correct the aberrations of the projection optics.

References:

[1] Information on JEOL Company website – www.jeol.com
[2] MULTIPOLE_WR5 Version 1, User Manual, Munro's Electron Beam Software Ltd (2007).
[3] L. Wang et al., "Aberration analysis of electron mirrors by a differential algebraic method", *Optik,* in the press, available online since 1 September 2006.
[4] O. Scherzer (1936*), Z. Physik* **101**, 593.
[5] O. Scherzer (1947), *Optik* **2**, 114.
[6] H. Rose (2005), "Electron optical corrector for eliminating 3rd order aberrations", US Patent No. 6,861,651 B2.
[7] M. Mankos et al. (2005), "Maskless reflection e-beam projection lithography", US Patent No. 6,870,172 B1.