A LARGE-APERTURE ION-BEAM LENS
CORRECTED FOR BOTH CHROMATIC AND SPHERICAL ABERRATION

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Microbeam columns using round electrostatic lenses have a fundamental defect caused by their inherent chromatic aberration. If the lens aperture is increased in order to increase transmitted current and ultimately the throughput of the column, the size of the focal spot increases so that the beam is useless for nanofabrication. In addition, chromatic aberration causes the current into a spot of fixed size to fall as the cube of the energy, or by a factor of 1000 if the energy is reduced to 3 keV from the typically used 30 keV. Lower energies are desirable for thin film applications and because of smaller, less cumbersome factory equipment, and higher throughput may open new applications for ion beams.

Nanobeam has made tests on a column including a doublet of achromatic quadrupole lenses with a 16-pole compensating plate included in the separation unit between the lenses. This system is capable of simultaneous correction of both chromatic aberration and 3rd-order (spherical) aberration. The achromatic quadrupoles have interleaved electric and magnetic poles (insulated from the magnetic yoke by thin films), creating an interleaved 8-pole structure. Ions are provided by gallium LMIS and a round electrostatic lens focused to a crossover spot. The ion energy is 5 keV, the object distance is 30 cm, the separation of the lenses in the doublet is 11 cm, and the distance from the downstream lens to the stage is 14 cm.

Micrometer-adjustable slit jaws are inserted on the four sides of the separation unit in order to define the location (a,b) and extent (da, db) of a ray as it passes through the lens aperture. Aberrations are measured by the secondary electron signal collected when the focused beam is deflected across the edge of a fine filament. This apparatus can be used in focusing, and once the lens is in focus, it can be used to measure the third-order aberrations, which have the form

$$x = A a^3 + B a^2 b + C a b^2 + D b^3$$

$$y = B a^3 + C a^2 b + D a b^2 + E b^3$$

where the coefficients A, C, and E are affected by normally oriented parasitic octopoles (oriented with a maximum potential in the principal sections), and B, D by skew octopoles (oriented at 22.5 degrees from the principal sections). These expressions have a slope at the origin determined by the third term, for example $dx/da = C b^2$. at a=0..

Following Hawkes' dictum that "it is clear that if all the octopole effect could be obtained by exciting the electrostatic lenses .. this problem [of the large number of electrodes] would be greatly simplified", a voltage Uoc is applied to the insulated magnetic poles of the upstream lens. Since the 4 poles are separated by 4 electrodes, the voltage introduces a compensating normal octopole. This lens is the principal cause of C and E. If measurements of x(a,b) are made as a is changed with b kept constant, C can be set to zero and E greatly reduced, by setting Uoc so that the slope of the scan is zero at the center .

Because the doublet structure itself contains no skew components, addition of the 16-pole plate is necessary. Adjustment of its skew voltage Mos so that the slope of y(a,b) becomes zero at the center makes D=0. An independent skew octopole would be required to simultaneously set B=0, but in theory B is small and so far has not been found necessary. The 16-pole plate also provides an additional normal octopole which can be used to set A=0 by eliminating the cubic wings in x(a,b). In addition, because the poles of the downstream lens are not required to introduce a second normal octopole, they can instead be excited with a small quadrupole voltage R in order to align the two lenses rotationally.

Adjustments of the four parameters R, Uoc, Moc, and Mos are measured to set aberrations smaller than the beam diameter over a lens aperture of 0.25mm x 1.00mm. Beam diameter at present appears to be limited by inadequate alignment of the condensing electrostatic lens.

Lenses of this type can be expected to provide a useful increase in the throughput of low-energy single-beam systems. Operated at maximum aperture they will improve gross throughput. The technique of aberration measurement at the edge of the lens aperture should also be useful to reduce parasites to nanometer levels at the central thread of beam used in helium microscopes. A single objective lens with a minimum of electrodes and a large aperture offers the prospect of an inexpensive way to overcome complaints that mid-column correcting systems have low throughput.

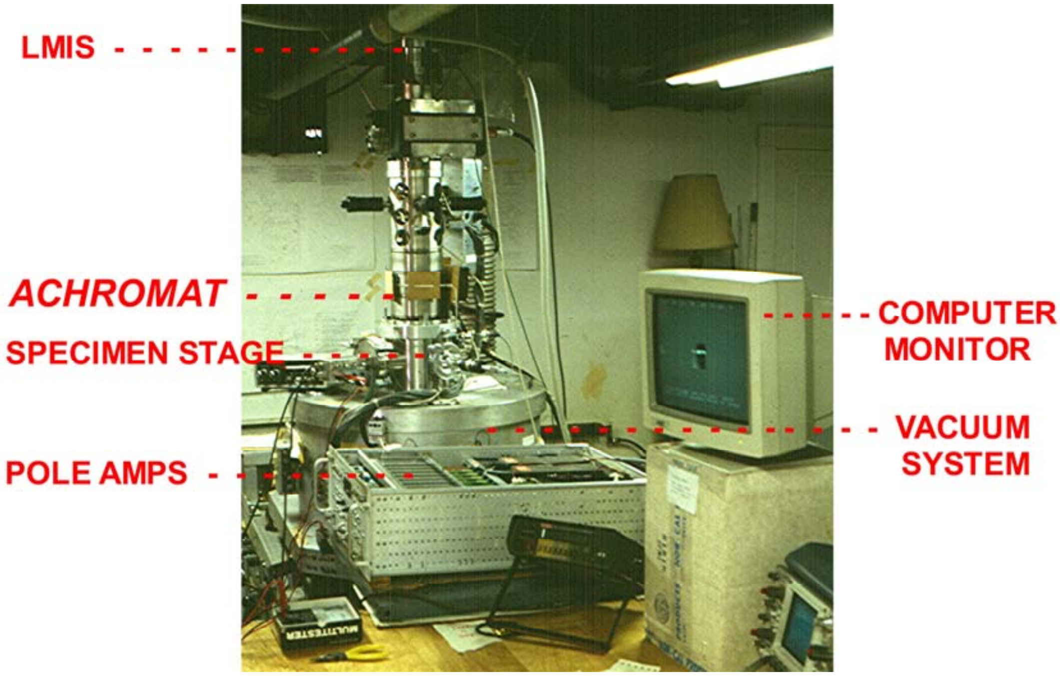

Fig. 1. Ion Beam Column

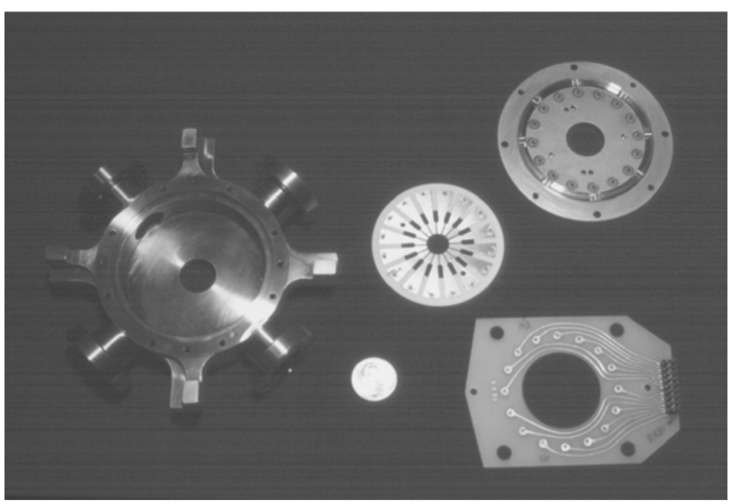

Fig.2. Separation unit, consisting of vacuum housing with four micrometer ports, 16-pole plate, housing cover, external PC board, and Lincoln cent (diameter 19 mm).