The effect of conductivity on ion guiding through tapered insulating capillaries

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Guiding of highly charged ions (HCI) through tilted insulating capillaries, both straight and tapered ones [1-5], has developed from an area of basic research to a tool to efficiently collimate and focus ion beams. Applications range from nanoscale modifications of surfaces to irradiation of single living cells. A key control parameter for guiding is the electrical conductivity of the insulating capillary material [6], whose dependence of temperature σ(T) is nearly exponential.

For our experiment we use a single tapered glass capillary (length: 55 mm, entrance diameter: 0.86 mm, exit diameter: 82 µm) made of Borosilicate. The current experimental set-up allows a controlled and uniform temperature variation of the glass capillary between room temperature and +90°C. Within such a moderate variation of the temperature the conductivity changes by three to four orders of magnitude [6]. A beam of Ar^{q+} (q=7,8) ions with a kinetic energy of 4.5 keV or 16 keV is collimated to a divergence angle of less than 0.7° and eventually hits a metallic entrance aperture directly in front of the capillary. Transmitted ions are registered by a position sensitive micro-channel-plate detector with wedge-and-strip anode and the transmission rates are recorded for each capillary tilt angle after steady-state conditions are reached.

At room temperature we observe “guiding” of the incident ions up to several degrees tilt angle of the capillary with respect to the incoming ion beam. At very small tilt angles a considerable drop of the transmission curve can be noticed. Such a “break-in” of the transmission has been reported previously by Nakayama et al. [7] and Kreller et al. [5] and explained by repulsive Coulomb forces of a uniformly charged ring-shaped region in the tapered part of the capillary which is blocking the transmission. By heating the tapered capillary to temperatures above 80°C we no longer observe a drop in the transmission curve but the transmission has its maximum in forward direction. However, this maximum transmission at high temperature is still smaller than the (reduced) transmitted intensity in forward direction at room temperature. This leads us to the conclusion that even at room temperature and in forward direction the focussing effect due to guiding is dominant and only partially weakened by blocking.

References:

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