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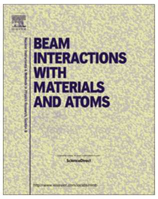
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Conceptual design and sample preparation of electrode covered single glass macro-capillaries for studying the effect of an external electric field on particle guiding

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ABSTRACT

We present the design and construction of a macroscopic glass capillary covered by electrodes on the outside. With these new capillary targets it will be possible to study the influence of an external electric field on the process of guiding of charged particles through a capillary. The new degrees of freedoms will contribute to both a better fundamental understanding of the guiding phenomenon but might also be of use in practical applications.

1. Introduction

Charged particles are able to pass through insulator capillaries keeping their initial energy and charge state even if the capillary axis is tilted with respect to the incident beam axis larger than the geometrical limitation. The phenomenon is called "guiding effect" and it has been intensively studied since its discovery [1–21]. For a recent comprehensive review the reader is referred to Lemell et al. [20]. Following the pioneering work of Stolterfoht et al. [1] several groups studied the ion guiding through insulating foils like polyethylene-terephthalate (PET) [2], silicon dioxide (SiO_2) [4] and aluminum oxide (Al_2O_3) [5,6] nanocapillaries with aspect ratios around 100. Ikeda et al. investigated ion guiding through a single tapered glass capillary [7]. The guiding effect was observed for a micrometer-sized tapered glass capillary. Systematic measurements in collisions between slow HCIs and a macroscopic glass capillary with large aspect ratio and with cylindrical shape were also performed [9,21]. The results strongly support that the guiding effect known from nanocapillaries is also valid up to macroscopic dimensions of the order of mm. The angular distributions of the transmitted ions have a similar width as the incident beam. Considerable transmission of guided ions could be observed for tilt angles up to roughly 5° [9,11,21]. The charging-up of the insulating wall material could be observed in time-dependent transmission measurements (see e.g. [20]).

For nanocapillaries in foils, depending on the wall material and the corresponding production technique, there have been found large differences in the behavior. While the angular distribution of the HCIs passing through PET capillaries was very broad, and a significant fraction of the projectiles was transmitted through the capillaries even for tilt angles up to 25° with respect to the incident beam direction, the angular distribution of the guided beam for the case of SiO_2 nanocapillaries was very narrow, with full widths at half maximum (FWHM) of $\sim 1°$ [8].

Theoretical investigation for charged-particle transport through nano-capillaries show that guiding can be interpreted in terms of a self-organized charge-up of the capillary wall [3,12,20]. Microscopic simulations revealed that after a distributed transient charge-up of the capillary wall, a single or a few charge patches near the entrance dominate the guiding in dynamical equilibrium. The charging of the capillary wall acts as a Coulomb mirror which leads to elastic reflections from the wall ("trampoline") at distances sufficiently large as to preclude charge transfer or electronic inelastic processes. One consequence of this scenario is that capillary transmission of keV HCI's proceeds not only in their initial charge state but also without any significant energy loss.

To add new degrees of freedom we are currently preparing to investigate the influence of external electric fields onto the self-organized formation process of charge patches inside a macroscopic capillary. When investigating guiding through a straight,

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macroscopic glass capillary we have demonstrated that the guiding effect still works up to these dimensions [9,21] for tilt angles of up to several degrees. These large glass capillaries are well suited for testing the influence of an external electric field onto the transmission behavior, since the geometric dimensions are compatible to manufacturable electrode parts. At the same time, the geometry is simpler than in the case of tapered capillaries. By varying the voltages on a suitable (lens-like) electrode configuration, we expect to observe an enhancement of transmission, an improved emittance at the exit of the capillary and/or an increased acceptance at the entrance of the capillary. To our knowledge, no such experiments have been conducted so far.

In this work we therefore describe the design and construction of a special macroscopic glass capillary covered by electrodes on the outside. With these new capillary targets we intend to investigate the influence of an external electric field on the self-organized formation of charged patches inside a macroscopic-size glass capillary.

2. Design of the samples

As a first step we have designed two different electrode configurations. These two configurations referred as 1 and 2 can be seen in Fig. 1.

The affixed electrodes are supposed to act as a lens by applying different voltages to succeeding electrodes. The first electrode configuration can be described as a short-long-short-type, referring to the width of every single electrode in the sequence, while the second electrode configuration can be described as a short-short-long-type (Fig. 1). By varying the voltages on configuration 1 we hope to be able to achieve an enhancement of transmission in general, while configuration 2 should lead to an increased acceptance at the entrance of the capillary or an improved emittance at the exit of the capillary if turned around.

As important as the electrode configurations themselves was to find the optimum dimensions, in particular the width of every single electrode and the gap in between them. Considering the limitations of the capillaries length (typ. 10–20 mm), the aim was to minimize the uncovered, electrode-free areas in order to create stronger electric fields inside the capillary. To check how strong the electric fields between the electrodes can get and to see the effect of inhomogeneities, a computer software called 'Poisson Superfish' [22] was used.

This software is a collection of programs for calculating static electric and magnetic fields amongst others. Typical results of our calculations are illustrated in Fig. 2.

One of the factors to be considered was the breakdown voltage of the surroundings of the electrodes. The breakdown voltage for glass in ultrahigh vacuum is about 13–14 kV/mm and for the instant adhesive used to glue the electrode covered capillary into the aluminum cylinder (see section below) it is typically 44 kV/mm. During the construction of the sample holder it is possible that the gap between two electrodes will be filled with adhesive. For practical reasons and as a result of our simulations we fixed the width of these electrode gaps to 1 mm.

3. Preparing the samples

Several different methods (sputter deposition, liquid graphite spraying, adhesive Cu tape) were tried to cover a single glass macro-capillary by electrodes [23]. The most successful turned out to be the Cu-tape method. In this method a 100 μm thin self adhesive copper foil is wrapped around the glass capillary (Fig. 3).

The advantages of the copper foil are its high conductivity and the easiness of the electrode wiring. The applied electrical connectors were 100 μm diameter molybdenum wires, which were wrapped around the copper tape. The target holder installed in the UHV chamber required that the electrode covered capillary should be inserted into an aluminum tube of an outer diameter of 3 mm. Drilling of three holes into the Al-tube was required to feed through the wires connecting the electrodes of the capillary to a voltage supply source and to bring in the constant adhesive used to glue the capillary into the interior of the aluminum tube. The three holes each had a diameter of 2 mm and those were centered at a distance of 3.5, 10.5 and 17.5 mm. The length of the aluminum tube was 20 mm. This hole arrangement was suitable for both electrode configurations shown in Fig. 1.

The difficulties in the process of embedding the capillary into the Al-tube needed to be examined in great detail. The biggest challenge was to align the capillary and the Al-tube, to assure that they are both entirely parallel and concentric. A special device was built helping to realize this task.

The idea was to run a mounting wire through the interior of the capillary and clamp it tight, while the Al-tube was aligned through being fixed immoveable in a milled edge. The completed construction device, consisting of two clamping parts and one middle component containing the precisely milled edge, can be seen in Fig. 4. The main components are made of Polytetrafluoroethylene (Teflon). The surface tension and the coefficient of friction of Teflon are so low, that even the instant adhesive does not stick with it. To make the process of wiring as simple as possible, the two outside electrodes are directly connected to the conductive Al-tube and thus grounded. The wire affixed to the middle-electrode needs to be connected directly to a high voltage source, therefore it is essential that its insulation starts from where it emerges from the drilled hole in the aluminum.

4. HV break-through testing

To test whether a sufficiently high voltage can be actually applied, the mounted capillary was put into our UHV chamber and the middle electrode was connected to a suitable power

Fig. 1. Schematic plot of the two different electrode configurations. The black stripes show the single electrodes along the outer surface of the glass capillary.

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