Transport of the Beams of Charged Particles by Using Dielectric Capillaries

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Abstract – The angular distributions of protons of 240 keV energy were measured. Protons passed through the glasses (boron-silicon) capillaries with a diameter of 0.1, 0.5 and a length of 30, 65, 178 mm at the axial entry angles of particles ± 0.2° and in the range of proton beam currents from $8.5 \cdot 10^{-13}$ to $5 \cdot 10^{-11}$ A.

1. Introduction

Aberrations of electron and ion optical systems are the fundamental restriction for designing of any optical systems [1]. Applying additional charges, non-uniform static and alternating fields or different kind of field symmetry approach the compensation of aberrations to a great extent can be reached. However, such compensations are technically complicated and essentially increase cost of the setups as whole. We suppose that the more efficient way is to apply inside of the setups such elements and systems which could ensure the necessary minimum aberrations itself. This work is aimed to give an analysis of the operation of such systems.

Recently the guiding of highly charged ions through insulating cylindrical capillary has been studied in several laboratories [2]. A phenomenon of slipping of charged particles beams along the charged dielectric surface can be applied for some practical applications [3]. In general, this is based upon interaction of slipped ion beams with a smooth internal surface of a glass capillary wall. The new systems of transformation, controlling and transporting of charged particle beams could be developed based on this principle. Also, micro- and nanometer size ion beams can be reached that especially have importance for applications in the local elemental and structures analysis, nanolithography, biology, radio-ecology and medicine. Comparing with already existing micrometer size ion techniques the offered method is simpler and chipper. This can simply ensure the method of less than one micrometer size RBS spectroscopy and X-ray analysis [4].

2. Experimental setup

To study the efficiency of propagation of ions through the capillaries and capillary systems the special experimental setup with the parameters described in [5] has been developed and manufactured. Fig. 1 is a scheme of the experimental setup used in the present study. Monoenergetic proton beam, generated by the Van de Graaf accelerator (ESA-2), is collimated by 1 mm circular diaphragms S_1 and S_2. Twinned diaphragm S_3 is used for ion beam monitoring.

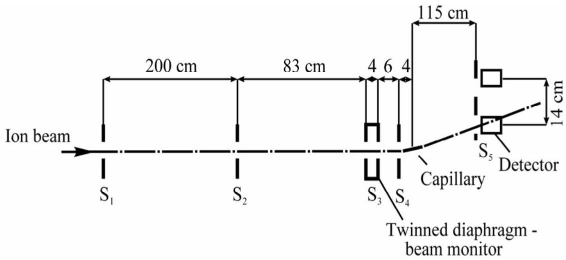

Fig. 1. Schematic of the experimental setup

The exit part of S_3 has a diameter of 0.5 mm. One more 0.5 mm collimator S_4 is placed in front of the sample to avoid the influence of the particles scattered at the edge of S_3. The sample is placed on two-axis goniometer having an accuracy not worse than 10^{-2} degree. Silicon surface-barrier detector with an aperture 0.3 mm is placed at a distance of 115 cm from the sample. The detector can move perpendicularly the ion beam axis direction in the range from 0 to 6.9 degrees with the velocity of $2.42 \cdot 10^{-3}$ degree per second. Measured angle divergence of the ion beam was not worse than $\pm 2.0 \cdot 10^{-2}$ degree. The energy of the proton beam was set by calibrated magnetic analyzer with the accuracy of ± 0.1%. The overall measured energy resolution of the system including the energy spread of the ion beam did not exceed 19 keV. The pressure in the vacuum chamber during measurements was $3 \cdot 10^{-5}$ Pa.

3. Angular distribution of protons with energy 240 кeV transmitted by dielectric capillaries

It was shown that the angular distribution profile of protons passed along the glass capillaries with a length of 65 mm is strongly determined by single scattering of the charge particles by capillary inner surface. Increasing of the capillary length of up to 178 mm changes the angular distribution profile since under these sizes it begins to tell the influence of charging an internal surface of the capillary (Fig. 2).

Figure 3 shows the angular distribution of quantity H+ ions transmitted through the capillary with a diameter of 0.1 and a length of 30 mm. Angle between beam and capillaries 0.15° and a current 0.8 pA at the input. The distribution has the form of a series of equally spaced peaks of almost identical width and amplitude gradually decreasing to the distribution edges.

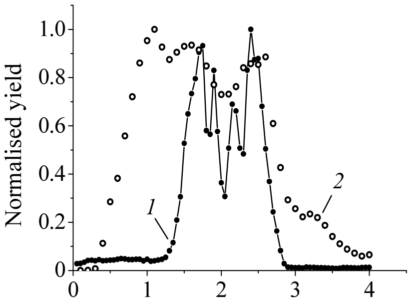

Fig. 2. Angular distribution of H^+ ions (E = 240 keV) transmitted through capillaries with a diameter of 0.5 and length of (*1*) 178 and (*2*) 65 mm. The angle between the beam and the capillaries is 0.0°

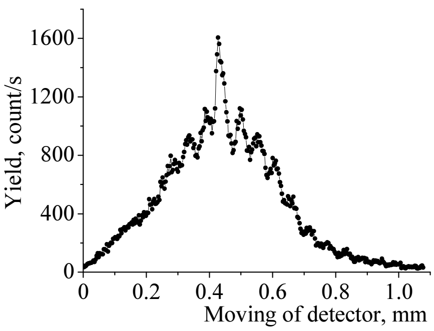

Fig. 3. Angular distribution of quantity of H^+ ions transmitted through a capillary with a diameter of 0.1 mm and a length of 30 mm

The comparison of the output angular distribution of protons with angular distribution the input beams allows revealing some particularities:

– the proton beam becomes much wider than the initial one after transmission through the capillary, which is most likely due to the large entrance angle;

– the continuous angular distribution of the initial beam is transformed into a line one, with a spacing of 0.06° between lines.

One might suggest that, under the above experimental conditions, the initial beam is split in the field of the charged capillary into a series of lines with transverse energies differing by $\Delta E^{\perp} = E(\Delta\varphi)^2 \approx 0.24$ eV.

4. Charge-exchange properties of dielectric capillary

The time distributions (Fig. 4) of protons of 240 keV energy were measured. Protons passed through the capillary with a diameter of 0.1 and a length of 30 mm at the axial entry angle of particles ± 0.0° and in the range of proton beam currents from 10–12 to 10–11A.

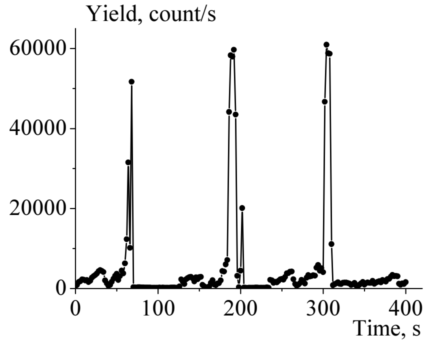

Fig. 4. Time distribution of protons

5. Conclusion

The shape of the angular distributions of protons transmitted through a glass capillary with a diameter of 0.5 mm and a length of 65 mm is determined to a large extent by single scattering of charged particles from the inner surface of the capillary. With an increase in the capillary length by a factor of 3, the angular distribution shape begins to be affected by charging of the inner surface of the capillary. A decrease in the diameter of the capillary to 0.1 mm revealed that transmission of protons through it is determined mainly by the degree of charging of its inner surface. Competition of the processes of charging of the inner surface and charge leakage in narrow capillaries results in an oscillating time dependence of the transmitted ion current.

References

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