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Micro- and Nanocapillary Structures Based on Dielectric Materials to Focus the Ion Beams

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The 255 keV and 150 keV proton beams transmission through tapered glass capillaries with 10 μm and 5 μm outlet diameters, respectively, were studied. The dependence of the output current on input current and the dependence of coefficient of proton beam transmission through capillary on the tilt angle of the capillary with respect to the beam axis were investigated. The focusing and guiding effects for transmitted proton beams were observed.

Keywords: Tapered glass capillary, Proton beam, Guiding effect, Ion beam focusing.

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1. INTRODUCTION

Electrostatic and magnetic focusing lenses are one of the most extending methods of producing beams of micron and submicron sizes. However, these devices have several disadvantages: the operational inconvenience, complexity and high cost. Therewith they require a good beam emittance, i.e. low energy spread of the initial ion beam. Therefore, tapered glass capillaries with micro or submicro sizes outlet diameters attract much attention as ion beam focusing lens. Previous studies have demonstrated the focusing effect with respect to many kinds of ions and energies [1, 2].

The purpose of the present investigations is to study the dependence of proton transmission through capillaries on the tilt angle between the capillary and beam axis and the dependence of output proton current on input current. An ion energy region was chosen to satisfy the experimental conditions of local implantation, local elemental and structure analysis, micro- and nanolithography, X-ray radiography, and applications in biology and medicine.

2. EXPERIMENTAL TECHIQUE

Experiments were carried out using the Van de Graaff ion accelerator in the Institute of Applied Physics Problems of the Belarusian State University.

The experimental device for studying the transmission of accelerated ions through capillaries is shown in Fig. 1.

The 255 keV proton beam transmission through tapered glass capillary with the length of 50 mm and inlet and outlet diameters of 800 μm and 10 μm, respectively, was studied. The results of studies were compared with the results of proton beam transmission through tapered glass capillary with the length of 150 mm and outlet diameter of 100 μm [3]. The dependence of 150 keV proton beam transmission through tapered glass capillary with the length of 50 mm and inlet and outlet diameters of 800 μm and 5 μm, respectively, on the tilt angle between the capillary and beam axis was studied, also.

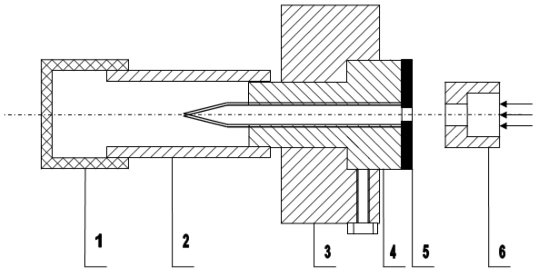

Fig. 1 – Schematic diagram of the device for measuring of total current of transmitted through capillary ion beams

1 – Faraday cup, 2 – isolating tube, 3 – goniometer holder, 4 – capillary holder, 5 - current-collecting collimator, 6 – beam monitor (Faraday cup)

3. EXPERIMENTAL RESULTS AND DISCUSSION

The dependence of coefficient of 255 keV proton beam transmission on the tilt angle between the capillary and beam axis is shown in Fig. 2.

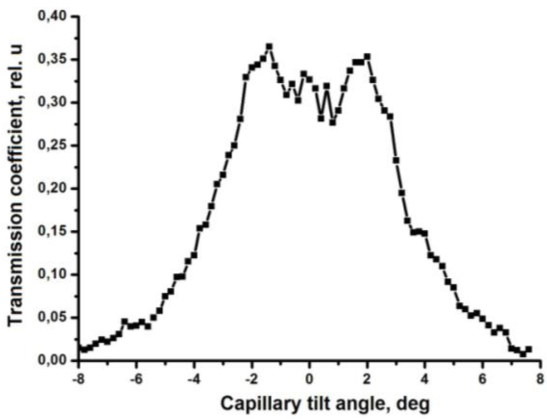

Fig. 2 – The dependence of coefficient of proton beam transmission on the tilt angle between the capillary with an outlet diameter of 10 μm and beam axis (E = 255 keV, I_{av} = 1,5 nA)

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The full width at half maximum (FWHM) of the curve in Fig. 2 is about 6 deg. This indicates that the transmitted beam current through the capillary is high enough in a broad range of angles of capillary with respect to the beam axis. Such FWHM of this curve can't be explained by direct pass of ions through the capillary as viewing angle of the outlet relative to the beam axis is about 0.5 deg. Therefore, we can assert that the proton beam transmission through the capillary at such high tilt angles is due to guiding effect. Two symmetrical peaks and central dip are observed in this figure.

The dependence of proton output current on input current is shown in Fig. 3. As follows from this Figure the experimental points are well approximated by the linear dependence in a presented range of input currents.

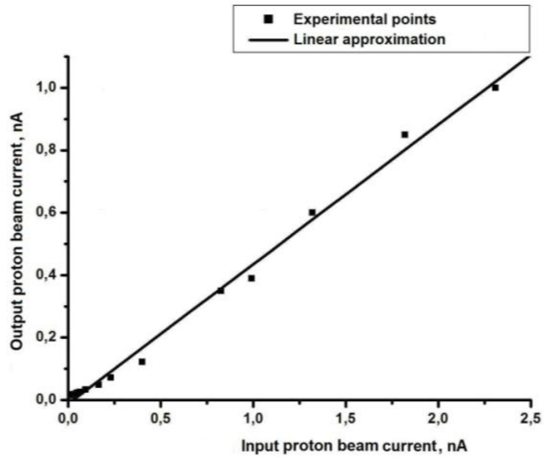

Fig. 3 – The dependence of output proton beam current on input proton beam current (E = 255 keV) for a capillary with the output diameter of 10 µm

The graph shows that approximated line doesn't pass through the origin. It means that the proton beam transmission through the glass capillary reveals threshold nature. The linearity of approximated line features large input proton currents.

Similar results were also obtained for tapered glass capillary with an outlet diameter of 100 µm (Fig. 4).

The results presented in Fig. 4 demonstrate a strong nonlinear behavior of the current at the output of the capillary on intensity of the input beam up to an input current of $5\cdot10^{-13}$ A. The behavior of the presented curve is explained by guiding effect. It is well accepted that such protons are guided electrostatically due to the charging up of the inner wall of capillaries made of insulating material [4].

For tapered capillary with an outlet diameter of 5 µm the dependence of coefficient of 150 keV proton beam transmission on the tilt angle between the capillary and beam axis is presented in Fig. 5.

As shown in Fig. 5, the both curves is enough similar. They have some asymmetry that are due to alignment error of the proton beam relative to capillary input. The accuracy of alignment error is 0.05 mm. The full width at half maximum (FWHM) of the curve is about 3 deg.

For the capillaries with the output diameters of 100, 10 and 5 µm transmission ratio between the transmitted ion current and the incident ion current was measured.

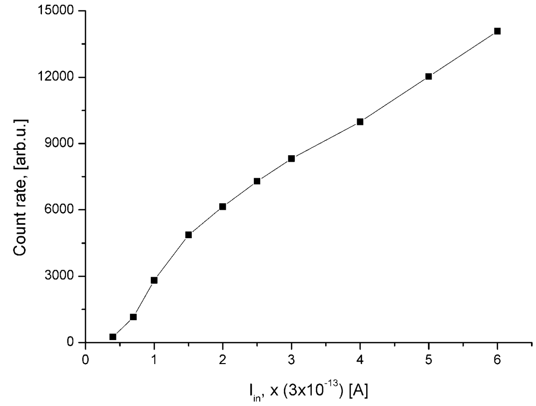

Fig. 4. – Count rate of particles transmitted through the capillary versus proton current at the input of the capillary

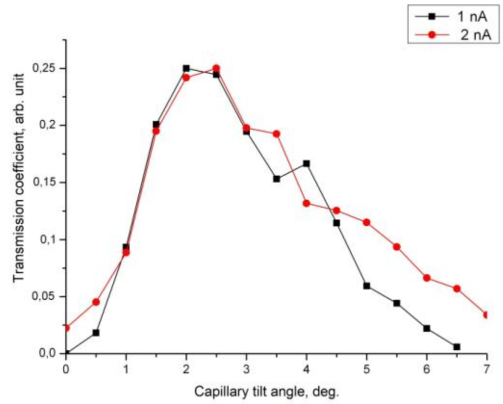

Fig. 5 – The dependence of coefficient of proton beam transmission on the tilt angle between the capillary and beam axis (E = 150 keV)

For 100 µm capillary the ion current density was increased by a factor of about 20 by compressing the ion beam due to the guiding effect. The fraction of the ion current lost in the capillary is needed to compensate the discharging of the capillary wall by the surface and the bulk conductivity. This ion current lost amounts to 20 %.

For 10 µm capillary the areal ion current density was increased by a factor of about 1000 by compressing the ion beam. The transmission coefficient achieves 35 % for 255 keV proton beam.

For 5 µm capillary the focusing factor increases up to about 2500. The transmission coefficient achieves 25 % for 150 keV proton beam.

4. CONCLUSIONS

We have confirmed that a few hundred keV proton beams are successfully focused by the tapered capillary optics. The areal density of the transmitted beam is increased with decreasing capillary outlet diameter. The strong guiding effect is observed. Such focused ion beams are very efficient in RBS and PIXE measurements with high spatial resolution.

REFERENCES

1. M. Kreller, G. Zschornack, U. Kentsch, *Nucl. Inst. Meth.* **B269**, 1032 (2011).
2. R. Nakayama, M. Tona, N. Nakamura, H. Watanabe, N. Yoshiyasu, C. Yamada, A. Yamazaki, S. Ohtani, M. Sakurai, *Nucl. Inst. Meth.* **B267**, 2381 (2009).
3. A.S. Kamyshan, F.F. Komarov, P.A. Grishin, *The materials of IV Int. sc. And tech conference "Instrument engineering - 2011"*, 339 (2011).
4. F.F. Komarov, A.S. Kamyshan, P.A. Grishin, *Il Nuovo Cimento,* **C34**, No4, 365 (2011).