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About a contactless transmission of 10 keV electrons through tapering microchannels

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ABSTRACT: The possibility of increasing the current density of a beam of fast electrons passes through glass cone-shaped channels was demonstrated in [1]. But the fraction of the electrons that passed through the conical channels without loss of the initial energy was not cleared up. Measurements of X-ray spectra generated by transmitted electrons in copper target mounted in vicinity of capillary output were performed for a detailed study of the contactless passage of 10 keV electrons through conical capillaries. All the measurements were made at different tilting angles with respect to the incident beam axis. It is shown that a significant part of electrons retains its initial energy even at the angles exceeding geometric opening of the capillary.

KEYWORDS: Beam Optics; Inspection with x-rays

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Contents

1 Introduction

The problem of guiding of charged particles by dielectric capillaries got high attention after the obtaining of contactless transmission of Ne^{7+} ions through nanochannels [1]. The majority of ions that passed through nanocapillaries created in PET foil retained their initial energy and charge state. After this work, a series of studies on the passage of both positively and negatively charged particles through dielectric channels with different characteristics were made. A detailed review of these studies is given in [2]. The considered effect manifestation is explained by a formation of a surface self-sustained charge distribution on the channel walls due to charging-up of a dielectric material and its low conductivity. A consequence of the formation of a surface charge distribution is the possibility to increase an ion and electron beam current density after its transmission through a dielectric tapered macro-channel [3–6]. In some works with conical channels a significant increase (up to several orders) in the beam current density was obtained [3, 5]. However, some measurements of the energy state of charged particles at the output of the channels demonstrate a significant loss of the initial energy of electrons [4]. Possible reasons for these results could be geometric parameters of used capillaries, values of particles energy and current of a used beam, etc.

The detailed studying of characteristics of 10 keV electron beam transmitted through the tapering microchannel for various tilt angles relative to the incident beam axis is performed in present paper.

2 Experiment setup

The goals of the research are in studying the energy spectrum of an electron beam passed through a capillary and in comparison of the measured spectrum with the one for the primary beam. We used an experimental layout, described in details in [5–7] for studying the grazing interaction of the electron beam with dielectric surfaces. Plane and curved electrostatic deflectors were used to study the energy spectrum of a beam interacting with a dielectric. The method of energy measuring can be inconvenient in case of large divergence of an output beam because only small part of the electron beam passes the diaphragms used in spectrometry system. Therefore the study of electron energy spectrum by X-ray generated in a metal target mounted next to the capillary exit was performed.

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Similar method was used earlier in [8].The layout of experiment is shown in figure 1. The capillary can be rotated relative to the incident beam axis around the axis "z" passing through its entrance. We call this angle as the tilting angle.

The angle $\vartheta = 14°$ between the metal target and the detector axis was chosen experimentally based on the optimal conditions for observing the effect studied: minimal backgrounds, optimal level of X-rays measured by the detector, sufficient viewing angle.

The semiconductor silicon X-ray detector Amptek XR100SDD fast with 12.5 μm thick beryllium window and effective area 21 mm^2, mounted in the distance 330 mm from the center of metal target, was applied for measurements of X-ray spectra. The energy resolution is 150 eV at photon energy of 5.9 keV. The electron gun generates an electron beam with energy of 10 keV at a current of 10–1500 nA. The diameter of the beam was 1 mm (FWHM), the divergence was less than 0.25°.

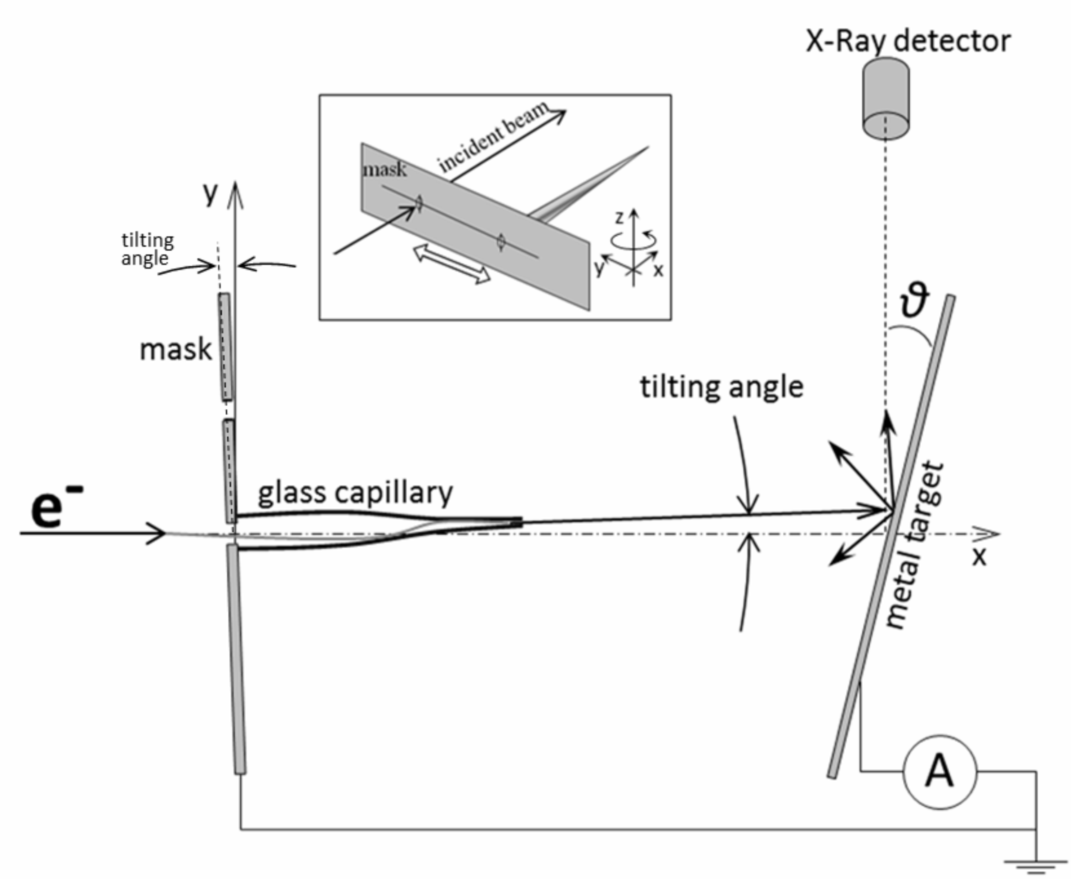

Figure 1. The layout of experiment. Insert — aluminum mask with two apertures: for studying of an incident beam (left, empty aperture) and the beam transmitted through a capillary (right, with mounted tapered channel).

The X-rays from a copper target are used to determine the fraction of scattered beam which does not have energy loses during the beam interaction with the capillary. The detector measures the X-rays spectrum generated under the primary and passed through the capillary beam interaction with the copper target. The spectrum consists of bremsstrahlung, which has a smooth shape, and quasimonochromatic characteristic X-ray lines located at energies 8.04 keV (K_α-lines) and 8.9 keV

(K_β-line). It is important that both copper K-lines can be generated by electrons with energy lager than 8.99 keV. This feature allows to determine the fraction of electrons which do not have energy loses more than 1.01 keV in comparison with primary electron beam energy of 10 keV.

We denote a number of registered by the detector events (counts) corresponding to the electron energies larger than 8.99 keV as Y while the total number of events in the X-ray spectrum as Y_0. The information about the fraction of transmitted electrons with energy larger than 8.99 keV can be estimated comparing the ratio Y/Y_0 for transmitted and primary beam even for large beam divergence. The grounded mask of aluminum with apertures of 0.9 mm (the insert in figure 1) is used to prevent charging of the edge of the capillary entrance. Aperture without capillary is used in order to get the X-ray spectrum excited by the primary beam. The current and spectrum were measured from the copper target. The second aperture with dielectric capillary is shifted by the liner translation after the measurement under the beam and the same measurements are made.

3 Results and discussion

The spectrum excited by primary electron beam cut off by the empty aperture is shown in figure 2. The measured beam current value is 17 ± 1 nA.

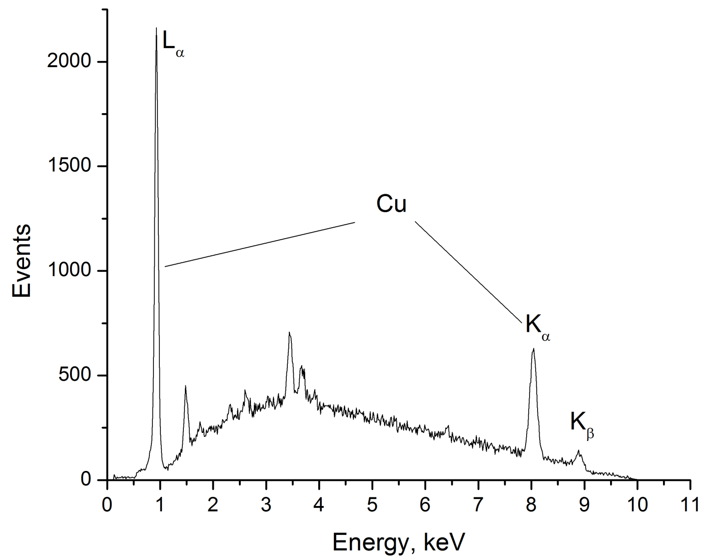

Figure 2. X-ray spectrum of copper target, produced by 10 keV electron beam.

The spectral peaks corresponding to K_α and L_α characteristic lines are clearly seen in the spectrum.

The experiment is made with the glass (Soda Lime Glass type: SiO_2 — 71%, Al_2O_3 — 0–2%, Na_2O — 15%, CaO+MgO — 13–16%) capillary with length of 43 mm and input/output diameters 1.15/0.193 mm. The measurements of output current (the fraction of electron beam transmitted through the capillary) and spectra are made for various tilting angles. The results are shown in figures 3 and 4 respectively. The data in figure 4 are obtained by using method described in the previous section. The spectrum acquisition time for each tilting angle is 10 min.

The geometry opening of the capillary is less than 1.5° and it is seen that the beam is guided by the capillary on the larger angles. Besides the fraction of electrons with energy higher than 8.99 keV is considerable even for angles where the transmission is small.

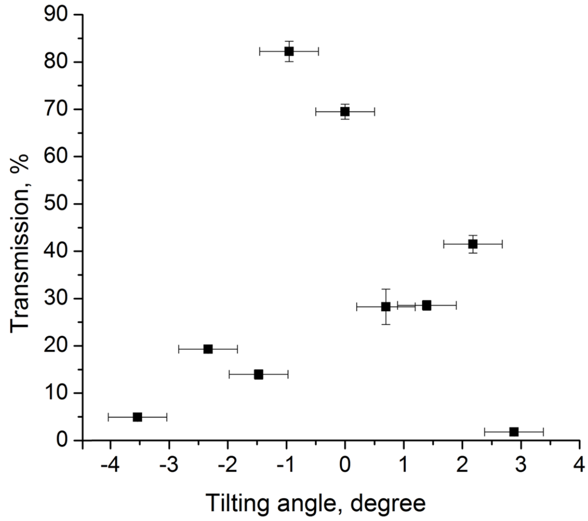

Figure 3. The fraction of electron beam (transmission) guided by the Soda-Lime glass conical capillary as a function of the tilting angle.

The transmission is about 70% for the position of capillary parallel to incident beam axis (tilting angle is 0°). As the mean input current is 17 nA through the aperture of 0.9 mm and the output diameter of the capillary is 0.193 mm it can be concluded that the output beam current density is roughly fifteen times larger than primary beam current density This result indicates the existence of focusing effect made by used capillary.

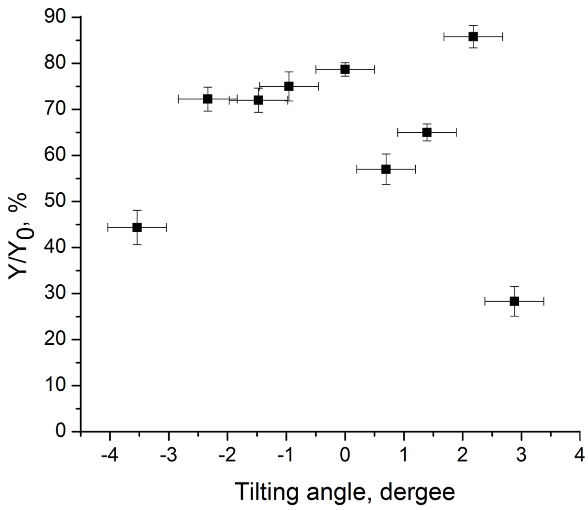

Figure 4. Estimated fraction of electrons of the transmitted beam with an energy exceeding 8.99 keV as a function of the tilting angle.

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The results can be explained by formation of a surface charge distribution on the inner walls of the capillary. This charge distribution forms a field that prevents direct contact of some part of beam electrons with the walls of the channel. Thereby that mechanism provides focusing of the beam incident to the capillary and passing a significant fraction of electron beam through the capillary without large energy losses. Several processes contribute to the formation of the charge distribution: capture of electrons by the surface, secondary electrons emission, and the charge leakage. All the processes are in dynamic equilibrium with each other and therefore the transmission of the beam is not stable in time. That leads to a difference in current transmission and statistical errors even for neighbor points (figures 3 and 4). The every measurement for each tilting angle is made after 10 minutes pause during which the beam is switch off. That pause is necessary to stabilize any excitations on the glass surface of the capillary arose after irradiation by the electron beam. But we suppose that some amount of defects can be accumulated by the surface what can be a reason of asymmetry of the data relative to zero tilting angle. Another possible reason of the asymmetry is irregular geometric shape of the tapering part of the capillary and an imperfection of the output part of the capillary.

4 Conclusions

We study the guiding of 10 keV electron beam by the glass microcapillary measuring the X-ray spectra produced by electrons passed through capillary at different tilting angles relative to the incident beam axis. The guiding allows to deflect the beam for $\pm 3^\circ$ relative to incident beam axis whereas the total opening of the capillary is less than 1.5°. Fifteenfold increase of beam current density is obtained at the output of the capillary due to focusing of the electron beam in the capillary. Both results can be explained by the formation of surface charge distribution inside the capillary that provides contactless motion of electrons along the channel.

Unfortunately, the repeatability of the results obtained is not absolutely stable. The complexity of studying this effect is determined by the presence of a large number of parameters, such as dielectric material type and capillaries shape. Therefore, it is necessary to reduce the number of parameters.

In order to control the geometrical parameters of the channels we will investigate the passage of electrons through tapered flat channels made of plates, the distance between which can be easily regulated. The results obtained in the works [9, 10] are demonstrating that ZrO_2 and $LiNbO_3$ can be used as a prospective materials for such channels. Further work will be dedicated for investigation of flat tapered channels.

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References

[1] N. Stolterfoht, J.-H. Bremer, V. Hoffmann, R. Hellhammer, D. Fink, A. Petrov et al., *Transmission of 3 keV Ne7+ ions through nanocapillaries etched in polymer foils: Evidence for capillary guiding*, *Phys. Rev. Lett.* **88** (2002) 133201.

[2] N. Stolterfoht and Y. Yamazaki, *Guiding of charged particles through capillaries in insulating materials*, *Phys. Rep.* **629** (2016) 1.

[3] T. Nebiki, T. Yamamoto, T. Narusawa, M.B.H. Breese, E.J. Teo and F. Watt, *Focusing of MeV ion beams by means of tapered glass capillary optics*, *J. Vac. Sci. Tech.* **A 21** (sep, 2003) 1671.

[4] W. Wang, J. Chen, D.Y. Yu, B. Yang, Y.H. Wu, M.W. Zhang et al., *Transmission of electrons through a tapered glass capillary*, *Phys. Scripta* **T144** (2011) 014023.

[5] K.A. Vokhmyanina, G.P. Pokhil, P.N. Zhukova, E. Irribarra, A.S. Kubankin, V.S. Levina et al., *Guiding of a beam of 10 keV electrons by micro size tapered glass capillary*, *Nucl. Instrum. Meth.* **B 355** (2015) 307.

[6] K.A. Vokhmyanina, V.S. Sotnikova, I.A. Kishchin, A.S. Kubankin, R.M. Nazhmudinov, A.N. Oleinik et al., *Propagation of 10-keV electrons through tapered glass macrocapillaries*, *J. Surf. Invest. X-ray* **10** (2016) 429.

[7] K.A. Vokhmyanina, A.A. Kaplii, V.S. Sotnikova, I.A. Kishchin, A.S. Kubankin, R.M. Nazhmudinov, A.N. Oleinik, A.V. Sotnikov, *Propagation of 10-keV Electrons through Glass Macrocapillaries*, *J. Surf. Invest. X-Ray* **11** (2017) 844.

[8] V.P. Petukhov, *Low-energy electron transmission through dielectric capillaries*, *J. Surf. Invest. X-ray* **4** (2010) 189.

[9] K.A. Vokhmyanina, V.S. Sotnikova, A.A. Kaplii, A.S. Kubankin, O.O. Ivashchuk, I.A. Kishchin et al., *Possibility of using dielectric channels as deflecting systems for controlling accelerated electron beams*, *Glass Ceram.* **74** (2018) 355.

[10] A.N. Oleinik, A.S. Kubankin, R.M. Nazhmudinov, K.A. Vokhmyanina, A.V. Shchagin and P.V. Karataev, *Pyroelectric deflector of charged particle beam*, 2016 *JINST* **11** P08007.