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10-keV Electrons Transmission through a Set of Dielectric Macrochannels

L. V. Myshelovka[a,*], **K. A. Vokhmyanina**[a], **V. S. Sotnikova**[a,b], **A. A. Kubankina**[a], **A. D. Pyatigor**[a], **I. A. Kishchin**[a,d], **and Y. V. Grigoriev**[c]

[a] *Belgorod State National Research University, Belgorod, 308015 Russia*
[b] *Shukhov Belgorod State Technological University, Belgorod, 308012 Russia*
[c] *Federal Research Center Crystallography and Photonics, Shubnikov Institute of Crystallography, Russian Academy of Sciences, Moscow, 119333 Russia*
[d] *Department of High Energy Physics, Lebedev Physical Institute, Russian Academy of Sciences, Moscow, 119991 Russia*
**e-mail: lareczn@gmail.com*

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Abstract—The results of the study of the 10-keV electron beam transmission through cylindrical dielectric macrochannels with various lengths. All channels made of polyethylene terephthalate had an identical inner diameter of 1.55 mm and lengths of 20, 30, 35, 40, 45, and 50 mm. The dependence of the current passed through beam channels on their tilt angle relative to the incident electron beam is measured. The electron beam fraction suffered energy losses no more than 1 keV after passing through the dielectric channel is estimated. The dependence of the maximum electron transport through channels on their length is also studied. The data obtained show that the passed current intensity weakly depends on channel lengths in the length range of 20–50 mm under study. These results can be explained by the fact that such a dynamic charge distribution is formed on channel walls, which provides the best conditions of electron transport through the dielectric channel.

Keywords: electron beam, X-ray radiation, dielectric macrochannels

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1. INTRODUCTION

The possibility of controlling charged particle beams using dielectric channels (guiding) is a relevant problem in view of the potential feasibility of inexpensive off-line control and focusing devices. Charged ion beams find wide application in various fields of science: basic researches (the development of tailored materials, studies of material properties, and others), engineering (ion implantation, electron beam welding, and others), medicine (treatment of oncological diseases, cellular surgery, and others).

Experiments in this direction show a high potential of dielectric system applications to control ion beams, whereas this feasibility for electron beams is still studied.

For the first time, the control by beams of non-relativistic electrons was studied in 2007 with 500- and 1000-eV electrons. Electrons were transmitted through nanochannels formed in a polyethylene terephthalate foil. The current of electrons transmitted through channels was measured at various tilt angles of the membrane. In this case, the transmission was observed at the membrane tilt angles in the range of ±10° [1].

Similar studies were performed in [2–7], but with macrochannels. For example, the dependence of the 1100–1500-eV electron beam transmission through a glass bent tube on the energy and current of the incident beam was studied in [2]. The length of the used glass tube is 50 mm, the inner diameter is 2.3 mm, the tube was bent by heating and turning the output tube end by 15° relative to the input end. The results of [2] showed that the transmitted electron beam intensity is proportional to the incident beam intensity, and the transmitted electron beam angular divergence decreases with the primary electron energy.

In [3], 10-keV electrons were transmitted through the cylindrical plastic channel 5 cm long with an inner diameter of 1.63 mm.

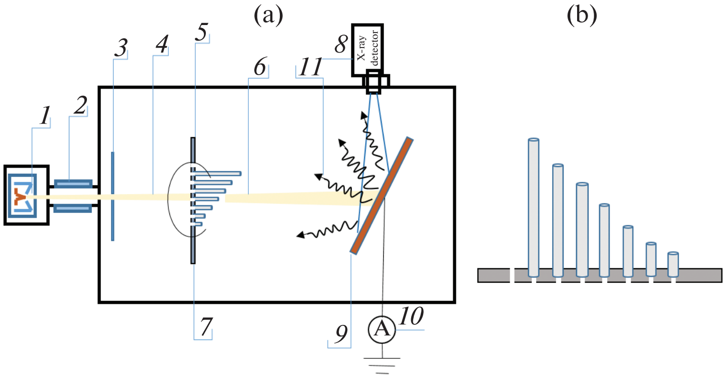

Fig. 1. (a) Experimental scheme: (*1*) electron gun, (*2*) system of electromagnetic lenses, (*3*) collimator Ø1 mm, (*4*) accelerated electron beam, (*5*) samples with grounded mask, (*6*) electron beam transmitted through the sample, (*7*) sample axis tilt relative to the incident beam, (*8*) X-ray detector, (*9*) copper plate, (*10*) ammeter, (*11*) radiation generated by electron incidence on the copper plate; (b) schematic representation of samples mounted in the common holder.

The channel was inclined at a certain angle with respect to the beam axis, motion of the transmitted beam trace was tracked on the screen coated with scintillator. The results of [3] showed the possibility of controlling by the electron beam in the range from –4° to +4°.

In the present work, the 10-keV electron beam transmission through plastic macrochannels with various lengths was studied. The approximate fraction of transmitted electrons whose energy loss in channels was no more than 10% was determined.

2. MATERIALS AND METHODS

In this paper, we present the experimental data on the study of 10-keV electron transmission through cylindrical polyethylene terephthalate channels 20, 30, 35, 40, 45, and 50 mm long, with the inner diameter of 1.55 mm, and a wall thickness of 0.5 mm.

The schematic of the experimental setup and the set of samples under study in a common holder are shown in Fig. 1. A more detailed description of the experimental setup is given in [8].

The electron beam is generated by an electron gun (*1*), is transmitted through a system of electromagnetic lenses (*2*), and 1-mm-diameter collimator (*3*). The formed beam (*4*) arrives at the input of the currently studied channel fixed in a single set of seven channels (Fig. 1b). The channel set (*5*) is installed in the goniometer holder allowing linear displacement of channels for their sequential irradiation and irradiated channel tilt relative to the incident beam axis about the axis (*7*). Channel inputs are closed by a single grounded mask with millimeter holes in front of each sample, which allows shielding ends of plastic channels from beam electron irradiation, hence, prevents channel blocking. Samples were put into a single holder to provide identical experimental conditions for each individual sample. To measure the primary beam current incident on channels, an additional through hole 1 mm in diameter was made in the mask. Electrons (*6*) transmitted through the irradiated channel are incident on the copper plate (*9*). The spectrum of radiation generated in the plate is measured by an XR-100SDD solid-state semiconductor detector (*8*). Simultaneously, the current of transmitted or direct beam was measured using a Keithley 6482 picoamperemeter (*10*). To suppress the secondary electron yield from the copper plate, a brass gauze is placed immediately in front of it (is not shown in the figure), to which a voltage of 400 V is applied. The experiment was performed in vacuum at ~10^{-6} Torr.

Measurements were performed as follows. First, for the direct beam transmitted through the through hole, the current and spectrum of radiation generated in the copper plate were measured. Then, the set of channels was linearly displaced so that the electron beam would arrive at the first channel, charging its inner surface. The current of electrons transmitted through the channel and the spectrum generated during the interaction of these electrons with the copper plate were measured for 2 minutes. Then, the holder with samples was displaced to irradiate the following channel, and measurements were repeated. Thus, measurements for the complete set were performed. Then, the holder with samples was inclined relative to the incident beam axis at a certain angle, and the same sequence of measurements was reproduced again. It should be noted that the current of transmitted electrons was stabilized for about one minute. However, the time dependence of transmission is omitted in this paper, since it requires independent study.

Table 1. Angles of geometrical transmission of channels

Channel length (mm)	Angles of geometrical transmission of samples (±, degrees)
20	3.6
30	2.4
35	2
40	1.8
45	1.6
50	1.4

Geometrical transmission angles for each sample are listed in Table 1.

3. RESULTS AND DISCUSSION

Figure 2 shows the measured dependence of the electron beam fraction transmitted through the dielectric channel on the tilt angle for each channel. The fraction of incident beam electrons transmitted through the channel and lost no more than 10% of their initial energy is also shown for each channel. This value was estimated by the method described in more detail in [9]. The method essence consists in the comparison of the spectra of electromagnetic radiation generated during the interaction with the copper plate of the electron beam transmitted through the through hole and through channels. Therewith, the spectral region associated with the characteristic K_α copper line (the photon energy is 8.048 keV) whose formation requires an electron energy no lower than 8.993 keV (K_{edge} for copper). Since it is assumed that the number of spectral events linearly depends on the number of electrons incident on the copper plate, this method is estimating.

Figure 2 shows that the electron transport occurs near the region of corresponding geometrical transmission angles for all used channel lengths. Therewith, for each channel, the final beam contains a significant fraction of electrons transmitted through the channel with energy losses less than 10% even at angles

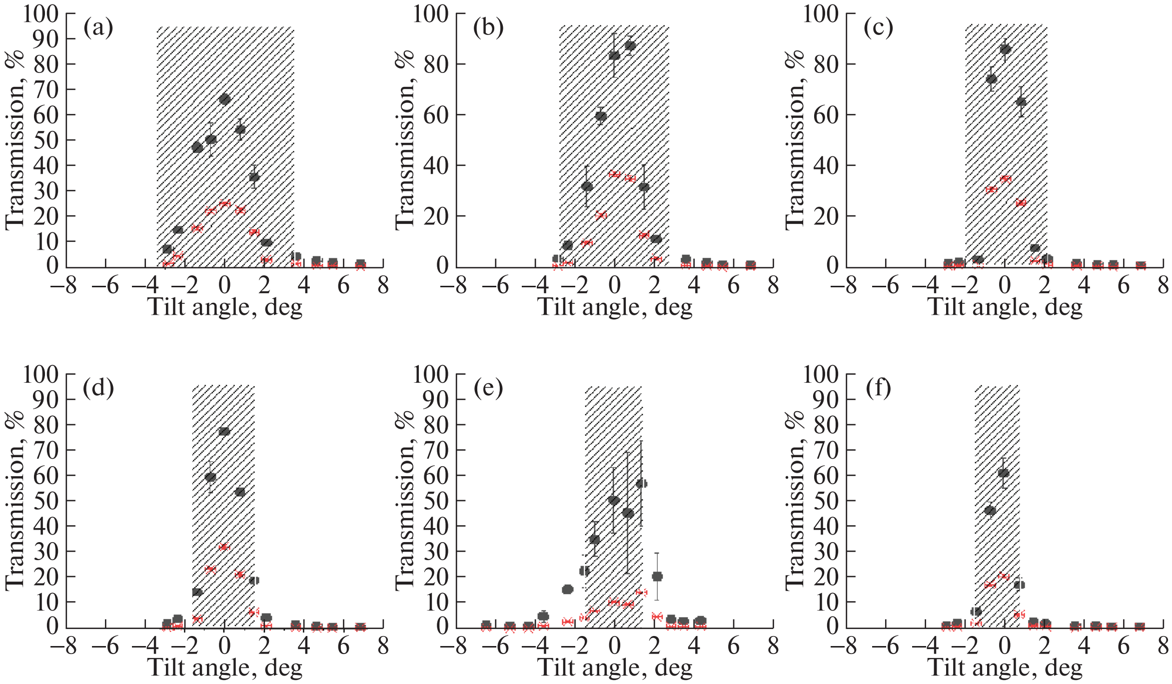

Fig. 2. Dependences of the electron beam fraction transmitted through the channel and the electron fraction whose loss does not exceed 1 keV (crosses) on the channel tilt angle relative to the incident beam axis. Channel lengths are (a) 20, (b) 30, (c) 35, (d) 40, (e) 45, and (f) 50 mm.

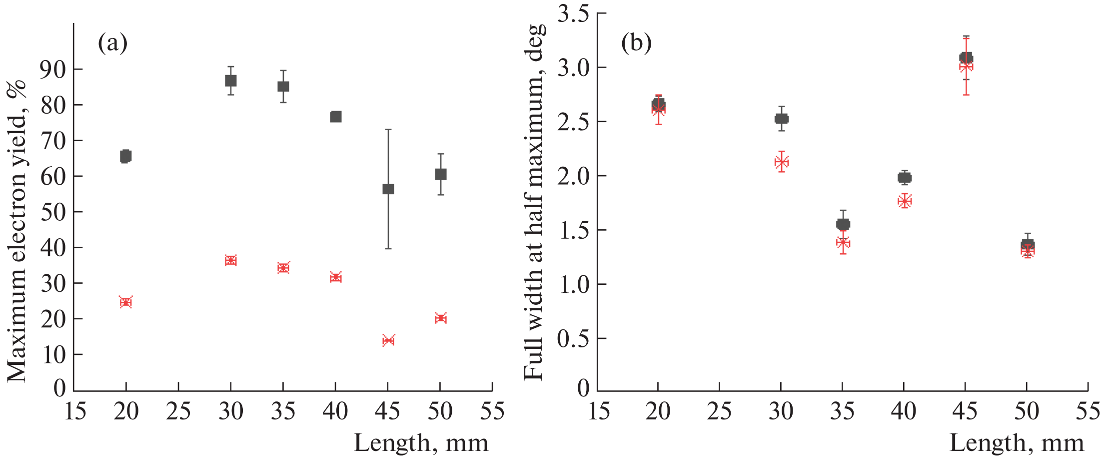

Fig. 3. (a) Dependence of the maximum electron yield under the condition that the channel is parallel to the beam on the channel length and (b) dependence of the FWHM on the channel length.

near geometrical transmission boundaries. The data of Fig. 2 for each length are well approximated by the Gaussian. Such processing results in the dependence of the maximum current intensity of the electron beam transmitted through the channel (Fig. 3a) and the corresponding full width at half-maximum (Fig. 3b) on the channel length. From the obtained curves, we can see a very weak dependence of the electron transport through samples on their length.

It is also important to note that the fraction of electrons transmitted through channels without significant energy losses also remains almost unchanged within 15–35% for all channels. It is noteworthy that the full width at half-maximum of the corresponding dependences for the total number of transmitted electrons and for electrons lost no more than 10% are almost identical; in other words, the fraction of electrons noncontactly transmitted through the channel slightly varies with the channel tilt angle axis with respect to the incident beam axis. Despite the fact that the data obtained show a weak dependence of the passed current intensity and the energy state on the length, it should be noted that this dependence (Fig. 3a) contains an intensity maximum at a certain channel length (in this case, 30–35 mm). This observation probably indicates the existence of an optimum aspect ratio at which such a dynamic charge distribution exists on channel walls, which provides the best conditions for electron transmission through the dielectric channel. In this case, it can be assumed that the electron transport will increasing the fraction of electrons required for charging the increased channel surface area with lengthening the dielectric channel. However, this assumption requires further investigation.

4. CONCLUSIONS

We studied 10-keV electron transmission through a set of plastic channels with various lengths. All channels are made of the same material, their inner diameter of 1.55 mm and wall thickness of 0.5 mm are identical. All channels were installed in a single holder with a mask, holes in which at the input of each channel provided an identical input current of the incident beam. Thus, it became possible to measure the current and energy state of electrons transmitted through channels as functions of lengths of these channels and their tilt angles relative to the incident beam axis.

It was shown that the beam current intensity of electrons transmitted through the dielectric cylindrical channel with axis parallel to the incident beam axis weakly depends on the channel length in the range of 20–50 mm. Therewith the fraction of electrons transmitted through channels without energy loss slightly varies with increasing tilt angle of channels relative to the incident beam axis, which indicates the existence of the control effect [1]. It should be noted that the obtained experimental results represent the only first step in the study of the control by charged using polyethylene terephthalate macrochannels. This work requires further investigation.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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