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INVESTIGATION OF 12 – 15 KEV ELECTRON TRANSMISSION THROUGH TAPERED GLASS CAPILLARIES

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The results of experimental studies of the transmission of 12 and 15 keV electron beams through tapered glass macro-capillaries are presented. Measurements showed that there is no explicit dependence of the output current on the electron energy. The time dependence of the beam current at the output from the capillaries was measured.

Keywords: electron beam, dielectric channel, guiding, energy dependence.

INTRODUCTION

The first experimental investigations on the grazing interaction of charged particle beams with dielectric surfaces were reported in [1], where an effect whereby a polymer film with nanocapillaries was used to control (guide) an ion beam was described. The first experimental results on the control of electrons with energy < 1 keV by means of nanocapillaries were presented in 2007 [2, 3]. In the course of the investigations it was concluded that as the energy of the electrons increases, the guidance effect worsens and completely disappears. A similar conclusion was also drawn in [4 – 6] after investigations of the transmission of charged electrons with energy ≤ 1 keV through conical glass capillaries. The control of 10 keV charged electrons by means of tapered glass capillaries has been under investigation since 2016 [7]. Electron beam control has been observed at channel slope angles from –0.57° to +2°.

EXPERIMENT

This article reports on investigations of the time variation of the transmission of 12 – 15 keV electrons through tapered glass capillaries.

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A schematic representation of the experimental setup is displayed in Fig. 1. An electron gun *1* generates an electron beam which passes through a system of electromagnetic lenses *2* and a 1-mm in diameter collimator *3*. The formed beam *4* arrives at the ingress into the test sample, which is secured in a movable holder with a goniometer *5*. The goniometer allows linear movement along the vertical and horizontal axes as well as tilting of the holder with capillaries to within 0.1°. A grounded metal mask with a millimeter hole covers the front end of the channel. The mask shields the end of the channel, preventing irradiation by beam electrons and 'blockage' of the channel. An additional through hole (1 mm in diameter) is provided in the mask to measure the current of the primary beam incident into the channel. A copper

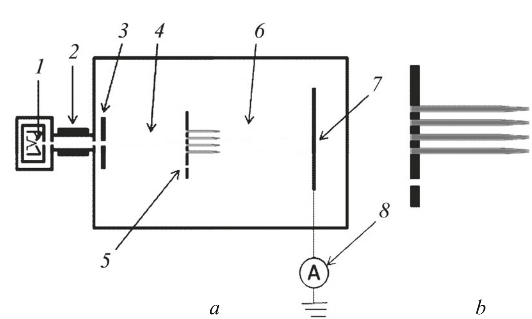

Fig. 1. Diagram of experiment (*a*) and holder with glass capillaries (*b*): *1*) electron gun; *2*) system of electromagnetic lenses; *3*) collimator; *4*) electron beam; *5*) movable holder with goniometer; *6*) electron beam transmitted through the capillary; *7*) copper screen coated with scintillator powder; *8*) Keithley 6482 picoammeter.

TABLE 1. Averaged Measurements for Four Capillaries for 12 and 15 keV Electrons

Sample No.	Diameter of capillary opening		Capillary length, mm	Incident current, ±3 nA	Average current at output, nA
	input, ±0.1 mm	output, μm			
Energy of beam electrons 12 keV					
1	0.90	70	46	30	3.53 ± 0.66
2	0.76	30	48	30	2.68 ± 0.64
3	0.76	230	40	30	3.95 ± 0.50
4	0.76	10	46	30	3.37 ± 0.69
Energy of beam electrons 15 keV					
1	0.90	70	46	30	5.52 ± 3.28
2	0.76	30	48	30	1.68 ± 1.04
3	0.76	230	40	30	0.78 ± 0.29
4	0.76	10	46	30	4.71 ± 2.99

plate *7* and a Keithley 6482 picoammeter *8* are used to record the transmitted electron current *6*. The experiment was performed with four capillaries made of Soda Lime glass. The capillaries have a tapered shape and differ in length and diameter of the egress (Table 1).

The experiment followed a general scheme for all capillaries. First, the current of the primary electron beam passing through the through hole was measured. Then the holder with the samples was linearly shifted so that the electron beam hit the input end of the first channel. For several hours the values of the electron beam current passing through the capillary were recorded until the channel was 'blocked.' Then the holder was shifted to the second channel and the measurements were repeated. Thus, measurements were made for all four macro-capillaries, after which the energy of the primary beam was changed and the experiment repeated.

RESULTS AND DISCUSSION

The typical time variation of the electron current passing through the channel is shown in Fig. 2. Note that the diameters of the output opening of the channels for which the results are shown in the figures differ by three-fold but the lengths and diameters of the input opening are similar.

The results have a fairly similar time variation of the electron transmission. The transmission gradually increases to a certain maximum. Then the transmitted electron current decreases in time until the channel is completely 'blocked.' Attendant oscillations are present throughout the entire electron transmission process. Hypothetically, the oscillations are due to a rearrangement of the charge on the inner surface of the channel.

The averaged measurements for four capillaries and electron beam energies 12 and 15 keV are given in Table 1. The transmitted electron current was averaged over the zone with stable channel transmission. Markedly, there is no explicit dependence of the current of electrons transmitted through the channel on the energy of the electron beam. It is clear that the current density at the output of the channels increases; channels have a so-called focusing power. The measurements show that the focusing power of a tapered channel in-

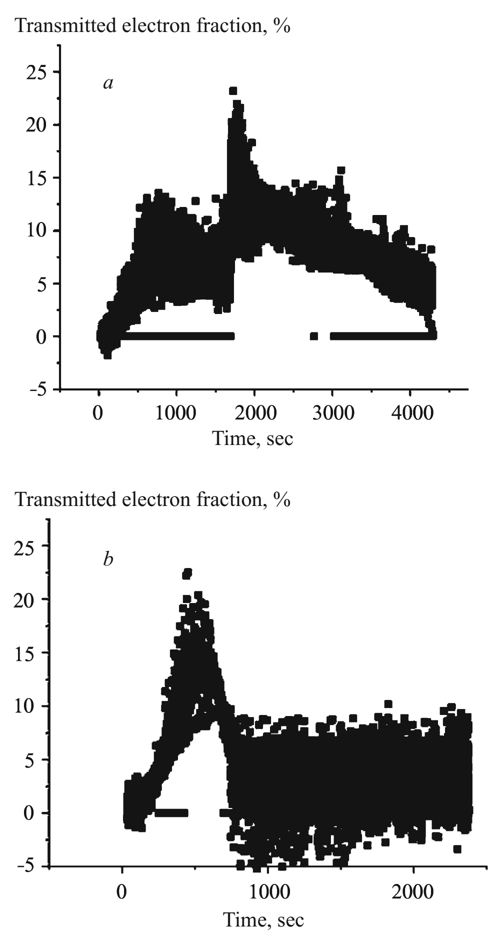

Fig. 2. Time dependence of the 12 keV electron current passing through capillaries Nos. 1 (*a*) and 3 (*b*), whose parameters are given in Table 1.

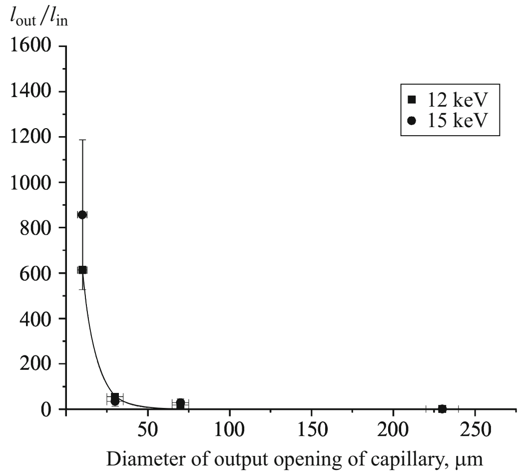

Fig. 3. Focusing power of capillaries versus the diameter of the output opening for different electron energies (the solid line depicts an exponential fit to the obtained data).

creases with decreasing diameter of the channel output, regardless of the electron energy of the incident beam (Fig. 3).

CONCLUSIONS

The transmission of 12 and 15 keV electrons through tapered glass capillaries with different output-hole diameters was investigated. The channels under study were made of Soda Lime glass. All channels were installed in one holder with a mask. The input holes in each channel provided the same input current of the incident beam. The time variation of the electron transmission through the channels was constructed. It was shown that the intensity and focusing power of the transmitted electron beam were independent of the electron energy but they do depend on the diameter of the capillary output. These results show that successful transmission of electrons through dielectric capillaries is possible at 12 and 15 keV.

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