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Investigation of Contactless Electron Transmission through Dielectric Channels

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Abstract—The effect of the contactless transmission (guiding) of 10 keV electrons through cylindrical dielectric channels and planar channels formed by glass plates is studied. The capture and propagation of an electron beam along the channel axis, usual in these cases, are observed in the experiments with two plates. The deviation of the reflection angle from the specular angle and its dependence on the plate length and beam-current value under beam reflection from a single plate are investigated.

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INTRODUCTION

The possibility of focusing and controlling positive ion beams using dielectric channels was discovered in 2002 and is currently being actively studied [1–9]. It has also been revealed in experiments with electrons that, under certain conditions, they, like ions, can traverse through dielectric channels without energy loss [8–11]. However, when one alters the path of an electron beam to a certain angle using dielectric channels or surfaces, features, different from those for the ions, arise. Our data testify to somewhat different mechanisms of particle transport and variation in the surface conductivity of insulators with respect to ions and electrons [12, 13].

In this work the experimental data on guiding an electron beam using cylindrical and planar dielectric channels and a flat dielectric surface are presented. A possible mechanism for the observed phenomena is discussed as well.

EXPERIMENTAL

The overall scheme of the experiments is shown in Fig. 1. The samples were mounted onto the solid platform of a goniometer allowing one to vary the oblique angle of the electron beam. In order to be able to work with a sheet-like beam with a rectangular cross section, a metal (copper or aluminum) mask with a hole of 0.5×4.0 mm was used. A glass screen, covered by a scintillator with a grid layout of 1.5×1.5 cm, was placed at a distance of 32.5 cm from the axis of rotation. The displacement of the beam trace on the screen was recorded with a webcam mounted outside the vacuum chamber. The sample was sequentially tilted and a snapshot was taken at each angle.

Cylindrical Channel

Electrons with an energy of $E = 10$ keV (the current at the mask was 150 nA; the beam cross section was about 2 mm in diameter; the divergence was < 0.2 degree) were transmitted through a cylindrical channel 1.63 mm in diameter and 5 cm long (a plastic tube with an aspect ratio of about 30) mounted in the goniometer. We tilted the tube relative to the beam axis at a certain angle and watched the displacement of the beam trace on the scintillator-covered screen.

As one can see in Fig. 2a, the beam transmitted through the channel diverges slightly as compared to a direct beam (far left image). The shape of the spot is evidently determined by the cut quality of the output end of the tube. One can see from the plot in Fig. 2b that the tube guides the beam in the range of angles from −4° to +4°, turning the beam by angles somewhat different from the tilt angle of the tube. Moreover, in this case the tilt angle is limited by the angle range of the goniometer, not by the disappearance of

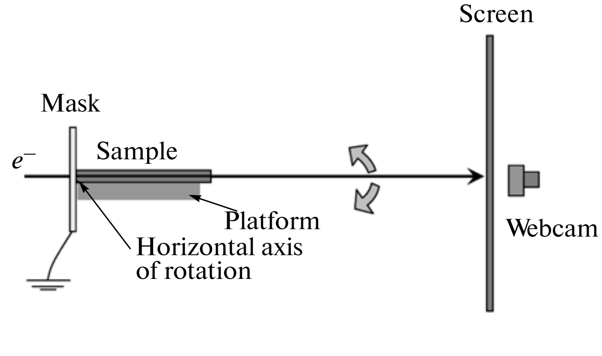

Fig. 1. Overall scheme of the experiments.

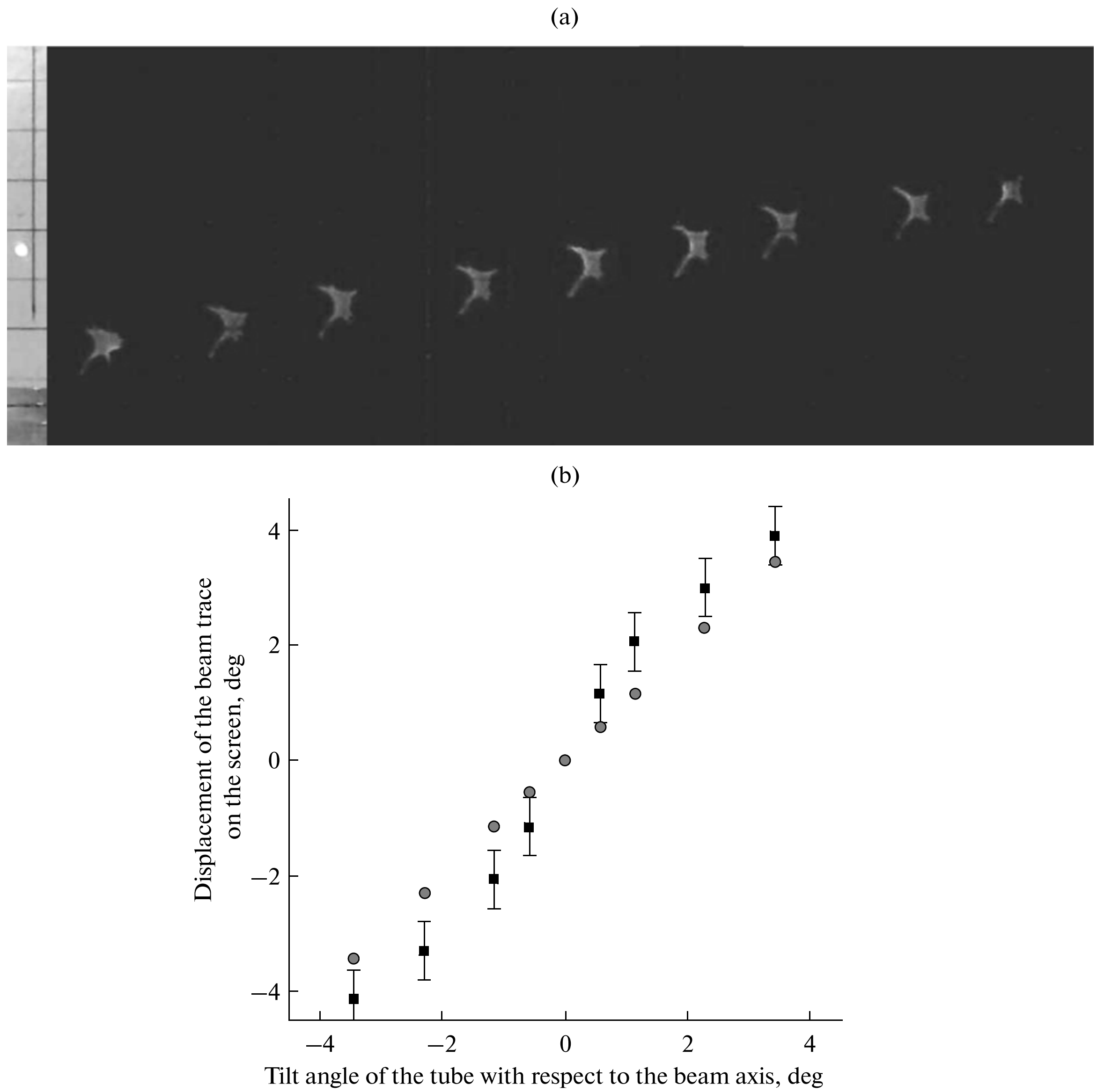

Fig. 2. (a) Displacement of the beam trace on the screen under tilting of the plastic tube from −4° to +4° relative to the beam axis. (b) Displacement of the beam trace on the screen as a function of the tilt angle of the plastic tube in the range from −4° to +4° relative to the beam axis.

the trace of the beam on the screen (i. e., it is limited by technical reasons only). For comparison, the direct relationship between the tilt angle of the tube and the displacement of the beam trace on the screen is shown in Fig. 2b by gray circles.

Planar Channel

A similar experiment was carried out for a planar channel formed by two glass plates 5 cm long with an interplate distance of 0.7 mm. The input end of the channel was grounded. The channel was tilted at angles from approximately −2° to +2° with respect to the beam axis. The experimental data are presented in Fig. 3. The plot is slightly asymmetrical with respect to the horizontal axis, which can be explained by a small discrepancy in the plate lengths; the upper plate is longer than the bottom one by up to 1 mm.

Dielectric Surface

To reveal the mechanism of the contactless transmission of electrons through different dielectric channels, an experimental study of beam reflection from a single plate has been carried out.

Plates of different lengths, with and without (the round beam) a mask, and at different currents, were used.

A short plate, 35 mm long, was mounted onto the insulating platform without grounding the bottom sur-

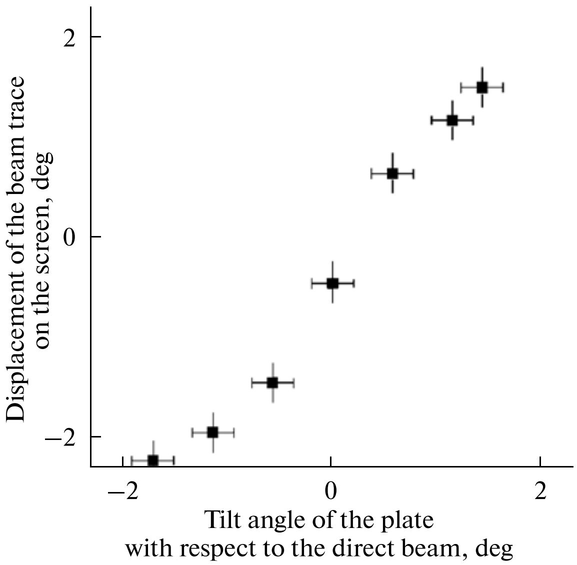

Fig. 3. Displacement of the beam trace on the screen as a function of the tilt angle of the planar channel with respect to the direct-beam trace.

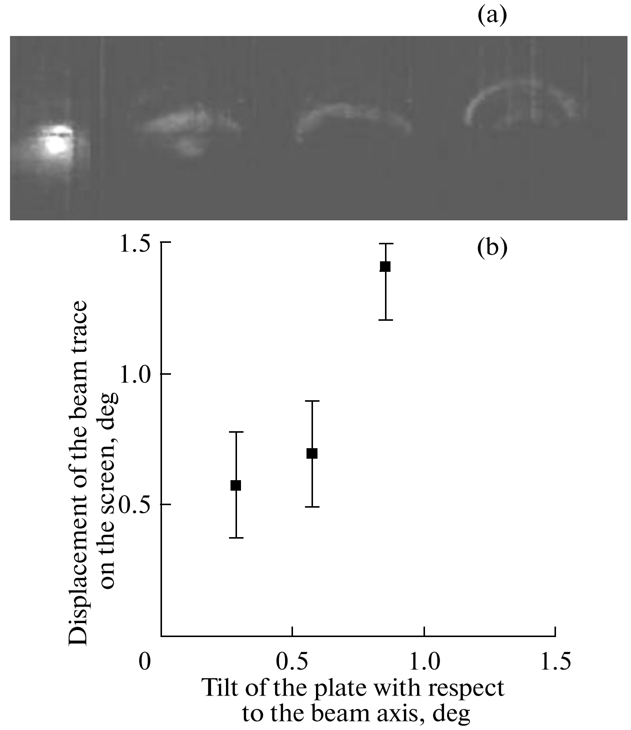

Fig. 4. (a) Displacement of the beam trace on the screen under tilting of the plate 35 mm long. (b) Displacement of the beam trace on the screen as a function of the angle of tilting of the plate 35 mm long in the goniometer.

face (only the front part was grounded). The plate was tilted at angles up to one degree (Figs. 4a and 4b). At larger tilt angles the trace on the screen disappeared, probably, due to the pronounced scattering of electrons. The beam current at the screen was about 150 nA.

Similarly a plate, 76 mm long, was mounted and tilted at angles up to one and half degrees (Figs. 5a and 5b). At larger tilt angles the trace on the screen disappeared also.

This experiment was carried out using a round beam, without a mask. It is seen in Figs. 4a and 5a that the beam trace splits. This creates a bright spot, the position of which varies slightly in the case of the long plate, and a halo, which follows the tilt of the plate about the horizontal axis (the graphs shown in Figs. 5b and 4b are plotted from the displacement of the outer arc of the halo). Perhaps this is due to the fact that the electrons moving either at different distances from the plate surface or at different angles to it are scattered by the surface charge in different ways.

To test the effect of the current value on variation in the beam-trace position on the screen, that is on the nature of the interaction of electrons with the surface of the plate, the following experiment was conducted. An electron beam was passed over the plate surface almost parallel to it. While leaving the position of the plate fixed, the current value was varied from 10 nA to 170 nA at the mask and the position of the beam trace on the screen was recorded. The experimental data are presented in Fig. 6. Displacement of the beam trace on the screen with increasing current is observed when the surface of the 76-mm long plate is almost parallel to the beam axis. The values of the current indicated in the photograph are set at the source; the actual current

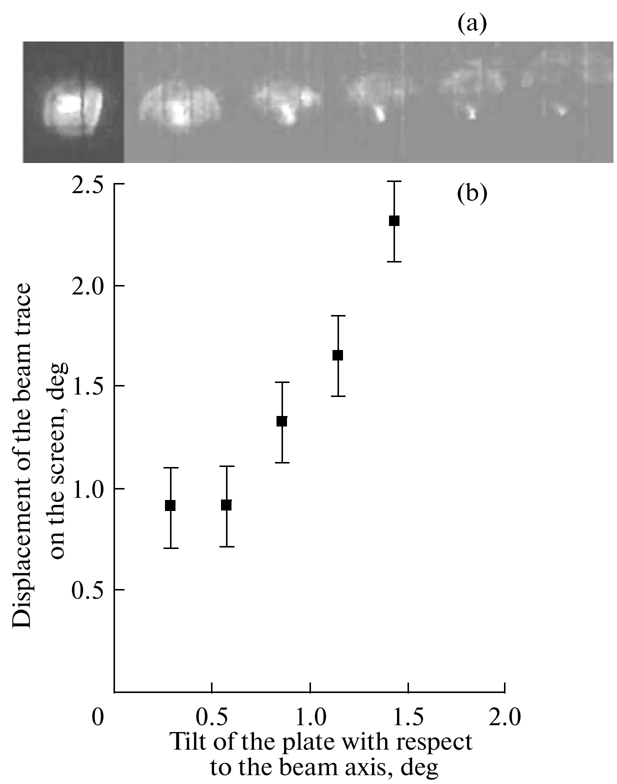

Fig. 5. (a) Displacement of the beam trace on the screen under tilting of the plate 76 mm long. (b) Displacement of the beam trace on the screen as a function of the angle of tilting of the plate 76 mm long in the goniometer.

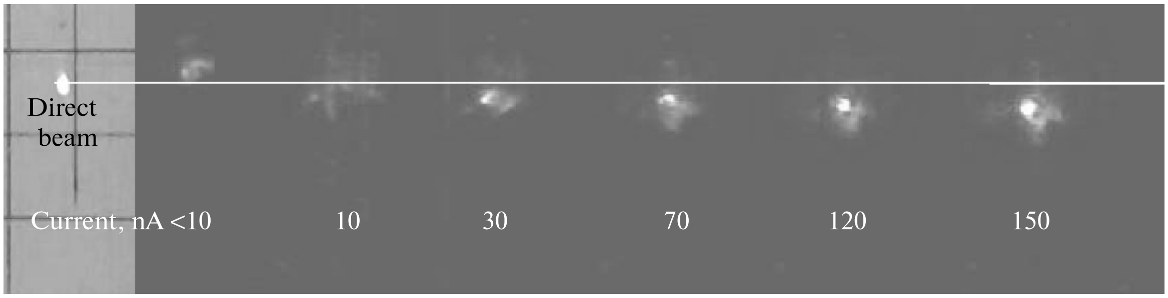

Fig. 6. Displacement of the beam trace on the screen when electrons pass almost parallel to the surface of the glass plate at different beam currents.

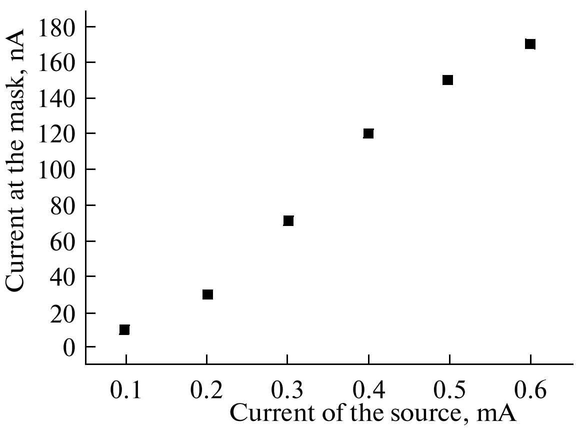

Fig. 7. Graph of the relationship between the source current and the current at the sample mask.

at the mask is less (the relationship between the current at the source and the resulting current at the mask is shown in Fig. 7); the dependence is nonlinear. In this case, when increasing the current from about 10 nA to 150 nA, the spot on the screen shifted downward by 0.5° below the direct-beam trace (the far left image).

DISCUSSION

The results of the above mentioned experiments have shown that, as in the case of ion transmission through dielectric capillaries, a self-consistent charge distribution appears at the inner walls of the channel causing the electrons to follow the channels of different geometry upon their rotation through small angles relative to the beam axis.

In the experiments with the plates and without a mask, a ring structure of the scattered beam arises (Fig. 5a), which can be explained by two-dimensionality of the carged trace potential, i. e. scattering occurs virtually at a charged wire.

The nature of the dependence of the spot position on the screen on the current value at angles close to zero with respect to the beam axis is not entirely clear. At relatively low currents the spot position on the screen is slightly above zero, which may be due to electron scattering by the surface charge of the plate. The spot on the screen drops noticeably with current increase, and the effect is most pronounced when the plate is almost parallel to the beam axis. To deviate electrons below the direct beam after passing over the surface of the plate, the existence of an attractive force is necessary, the mechanism of which is still unclear and requires further study.

CONCLUSIONS

In this work the possibility of controlling an electron beam using dielectric channels of different geometry (flat and cylindrical) was experimentally confirmed. The experiments using plates have revealed a number of features of the process, such as the deviation of the reflection angle from the specular angle and the dependence of the reflection character on the plate length, the presence of a round halo of the beam trace on the screen, and the dependence of the beam-trace position on the current value.

The experimental results can be partly explained by the interaction of an electron with the channel wall, charged by randomly deposited electrons from the original beam. However, the shape of the charge distribution on the surface, the rate and mechanism of charge leakage require further investigation.

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