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Ion Guiding in Alumina Nanocapillaries

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The 150 keV proton beams transmission through nanocapillary structures of Al_2O_3 was studied. The dependence of count rate of transmitted particles on tilt angle and the angular distribution of transmitted beams were measured.

Keywords: Capillary structures, Guiding effect, Nanoporous aluminum oxide.

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1. INTRODUCTION

In the past few years, dielectric nanocapillaries in thin film have received particular attention due to their great perspectives for use in nanoelectronics. As it was shown in Refs. [1-3], that ions in a wide energy range (a few keV – a few MeV) are efficiently transmitted through capillaries of thin insulating foils in their initial state. Transmitted ion beams are directed along the capillaries with a narrow angular distribution. In the papers reported, the significant ion transmission through insulating capillary are observed at large tilt angles, i.e. when there is no geometrical transparency for straight line trajectories. Due to these properties, insulating nanocapillary structures might find numerous applications. Such structures can be used for irradiating single biological cells, formation of matrixes for ion-beam and electron-beam lithography and writing on charge sensitive surfaces.

In the present work proton transmission through Al_2O_3 nanocapillaries is studied. The dependence of count rate on tilt angle of the sample relative to beam axis and the angular distribution of transmitted ions are measured.

2. EXPERIMENTAL SETUP

The measurements were taken by the equipment for the study of the accelerated ions transmission through capillaries and capillary systems [4]. The scheme of experimental setup is shown in Figure 1. The capillary array was mounted on a goniometer, which permitted to turn the samples in both vertical and horizontal planes. The transmitted protons are detected using mobile silicon surface barrier detector positioned at a distance of 90 cm from a capillary holder. The research chamber was operated at a base pressure of $2 \cdot 10^{-6}$ mbar. For studies of Al_2O_3 capillaries, the beam of 150 keV protons was collimated to diameters of 1 mm.

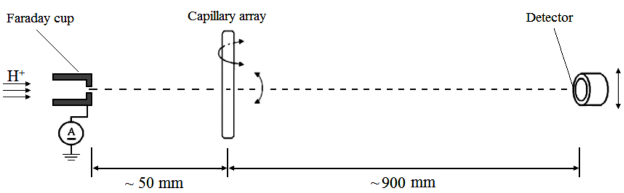

Fig. 1 – The schematic view of experimental setup

In this study, we used amorphous nanoporous Al_2O_3 substrates with a thickness of 40 μm. The mean diameter of pores is about of 50 nm and the density of pores amounts to $5 \cdot 10^9$ cm^{-2}.

3. RESULTS AND DISCUSSION

Figure 2 shows the angular distribution of 150 keV protons transmitted through untilted capillaries ($\varphi = 0°$).

The FWHM of this curve is about of $7 \cdot 10^{-2}$ deg which corresponds to the angular width of initial beam. Thus, the angular divergence of the ion beam behind the Al_2O_3 membrane is practically equal to the angular divergence of the initial ion beam. This property makes nanoporous aluminum oxide templates promising for use as photomask in nanolithography. The ion beam transmission through the Al_2O_3 membrane, defined by integrating the angular distributions, amounts to about 10^{-3}.

The presented in Figure 2 proton beam intensities were measured behind the sample with a thickness of 40 μm that considerably (more than one order of magnitude) exceeds ranges of protons in this material. This is an evidence of an anomalous motion of ions like the hyperchanneling of charged particles along the low-index directions of crystal lattices.

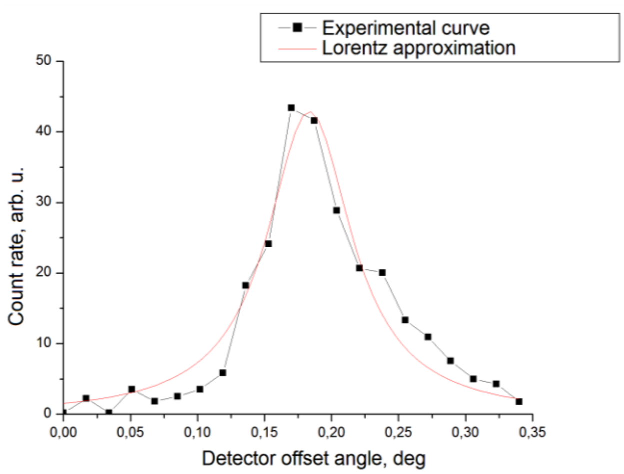

Fig. 2 – Angular distribution of 150 keV protons transmitted through an amorphous nanoporous Al_2O_3 sample with a thickness of 40 μm

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The dependence of count rate of particles registered by the instrumentality of semiconductor detector on tilt angle of the sample with respect to proton beam axis is shown in Figure 3.

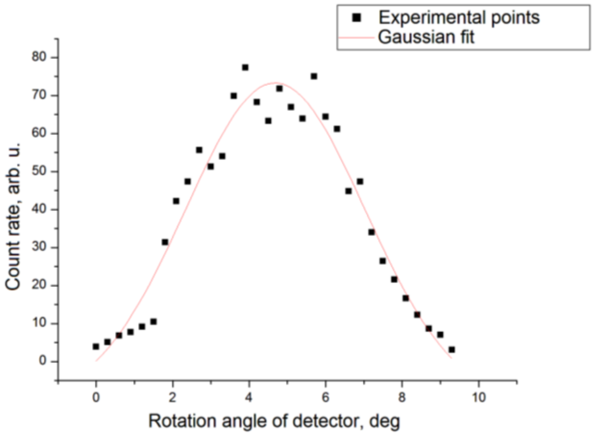

Fig. 3 – The dependence of count rate of 150 keV protons on tilt angle of the nanoporous mambrane with respect to proton beam axis

This graph shows that the proton beam transmits through the sample in a wide range of tilt angles. The FWHM is about of 6 deg. It can not be explained by direct flight of proton through capillaries since angle of geometrical transparency for straight line trajectories does not exceed 0,1 deg. This effect is due to the interaction between proton beam and charged inner capillary wall, i.e. strong guiding-effect within the channels of the sample.

4. CONCLUSIONS

We have studied 150 keV proton transmission through insulating nanocapillaries in amorphous aluminum oxide. The angular distribution of transmitted proton beams is measured. Angular width of the ion beam behind the Al_2O_3 membrane is practically equal to the angular width of the initial beam. It means that nanochannel alumina is a promising template for pattern transfer by ion lithography. The dependence of count rate of transmitted particles on tilt angle of sample relative to proton beam axis is measured. The strong guiding-effect is observed.

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