LOCALIZATION OF IONIZING RADIATION USING NANOPOROUS ALUMINA MATRICES

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Introduction

The topic of positive ions passing through a dielectric channel began to be intensively studied in the 1990s since the discovery of guiding effect. One of the main expected applications of micro beams was the irradiation of living cells, this stimulated an increase in the number of works to implement the external beam. PET capillaries and porous membranes are most often considered as a focusing device. Porous membranes are also used as the basis for doping patterns when creating emitting matrices by ion implantation methods. Both types of focusing devices (capillaries, porous membranes) are interesting from the standpoint of their transmissive properties, a crucial objective being the dependence of the ion transmission coefficient on the incidence angle of the beam.

Materials and methods

The focusing coefficient is defined as the ratio of the densities of the input and output currents. It depends on the type and energy of the ions and the shape of the capillary. This coefficient varies in a wide range from 10 for Ar^{8+} with an energy of 8 keV to 1000 for He^{+} with an energy of 2 MeV. The low divergence of the beam at the exit from the membrane makes nanoporous alumina a promising material for use as masks for nanolithograpy.

Matrices of dielectric channels based on porous anodic alumina (PAA) were formed by electrochemical anodizing. Aluminum foil was used as a substrate. The geometric dimensions of voids are determined by the technological conditions of production in a wide range. Pore diameters can vary from units of nanometers to units of micrometers. The dependence of the anodizing process speed on the concentration of glycerol in the electrolyte based on H_2SO_4 and anodizing temperature was revealed on the basis of a large amount of experimental data in the form of an equation:

$$V(T,C) = 0.41\times \exp\left(\frac{T}{13.42}\right) + 0.96\times \exp\left(-\frac{C}{11.99}\right) - 0.69$$

The structure of the obtained membranes was examined using a scanning electron microscope (SEM). Examples of the surface structure of membranes obtained in various electrolytes are shown in Fig. 1.

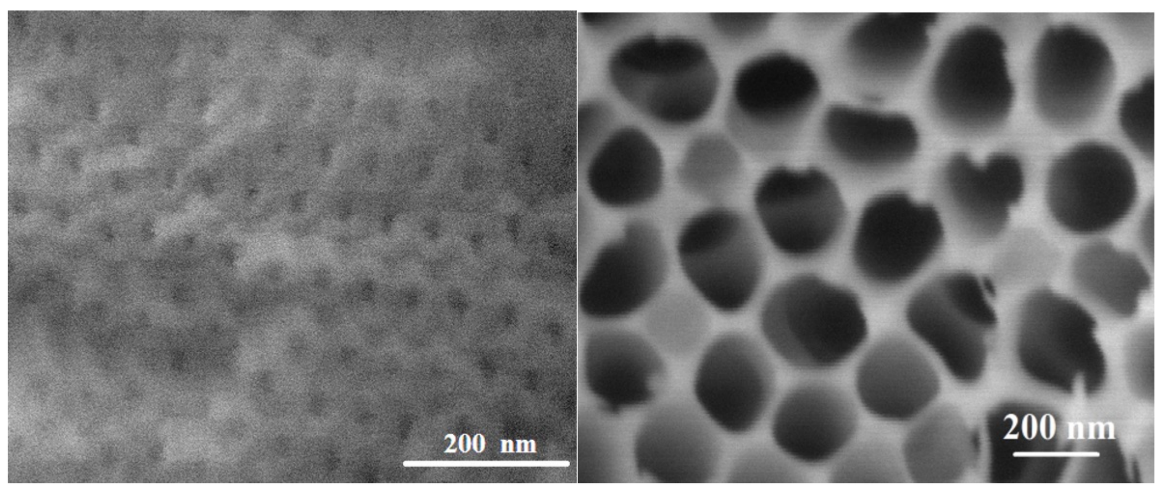

Fig. 1. SEM images of the surface of membranes PAA obtained in electrolytes based on H_2SO_4 (left) and H_3PO_4 (right).

Results

To study the transmission of accelerated He+ ions through dielectric matrices, two series of membranes with pores of significantly different diameter sizes were obtained. When using the electrolyte based on H_2SO_4, membranes with a thickness of about 10 μm are formed, with an average pore diameter of 20 nm, a barrier layer thickness of ≈ 200 nm, and their pore concentration is 350 pieces/μm². In turn, the geometrical parameters of the membranes obtained in an electrolyte based on H_3PO_4 are as follows: an average pore diameter of 80 nm, a porous layer thickness of 10 μm, a barrier layer thickness of ≈ 200 nm, a pore concentration of 50 pieces/μm². In all the resulting membranes there is a barrier layer - the bottom of the pore - a layer of dense alumina separating the porous layer from the substrate (Fig. 2).

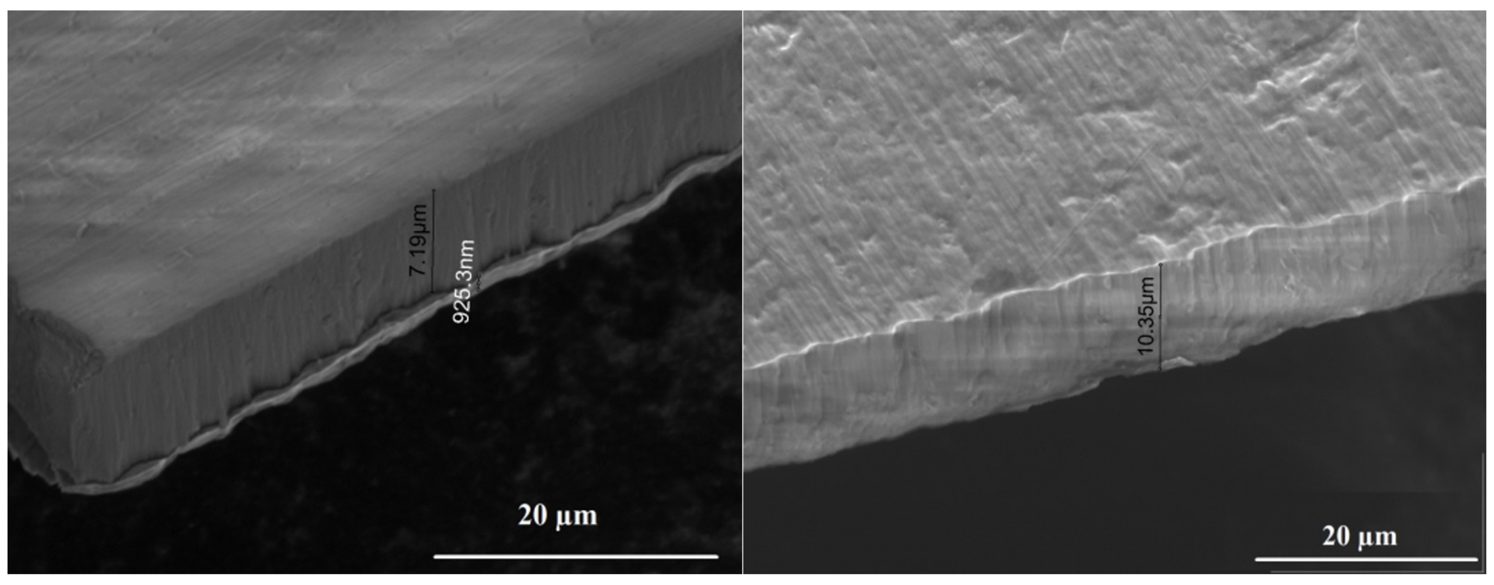

Fig. 2. Cross section of PAA membranes before (left) and after (right) removal of the barrier layer

The presence of a barrier layer greatly affects the transmittance in experiments on the interaction of membranes with ion beams. In this case, the transmittance is the ratio of the intensity of the transmitted beam of helium ions to the incident beam. The difference in transmittance with and without a barrier layer can differ tenfold. Taking this important point into account, the removal of the barrier layer was carried out by chemical etching of the back side of the membrane in concentrated hydrochloric acid (HCl) for 10 minutes.

The accelerator based on Van de Graaff system is capable of accelerating particles (protons and He^{+} ions) to an energy of 2.5 MeV was used in this study. A collimated beam of 1.2 MeV He^{+} ions enters the membrane: one part of the beam passes through the capillaries and the current is recorded using a Faraday cup, while the other part is scattered and recorded using a semiconductor detector. In all experiments, the detected scattering angle was 1200. The diameter of the beam on the membrane was about 1 mm. The results of the ion beam transmission through membranes obtained in an electrolyte based on H_3PO_4 are demonstrated at Fig. 3 left. A small part of the ion beam passes through a porous matrix. Transmittance of 0.15 was registered by means of current measurement device, a significant current drop was observed when the membrane deviates from the normal by 1.5 degrees.

At the same time, the results of accelerated beams transition through membranes prepared in an electrolyte based on H2SO4 (Fig. 3 right) showed that the intensity of transmitted beam practically does not change within 2.5 degrees. The reducing of the signal in two times corresponds to the rotation of the target by 3 degrees. Measured transmittance was in range 0.50-0.625, depending on the sample thickness.

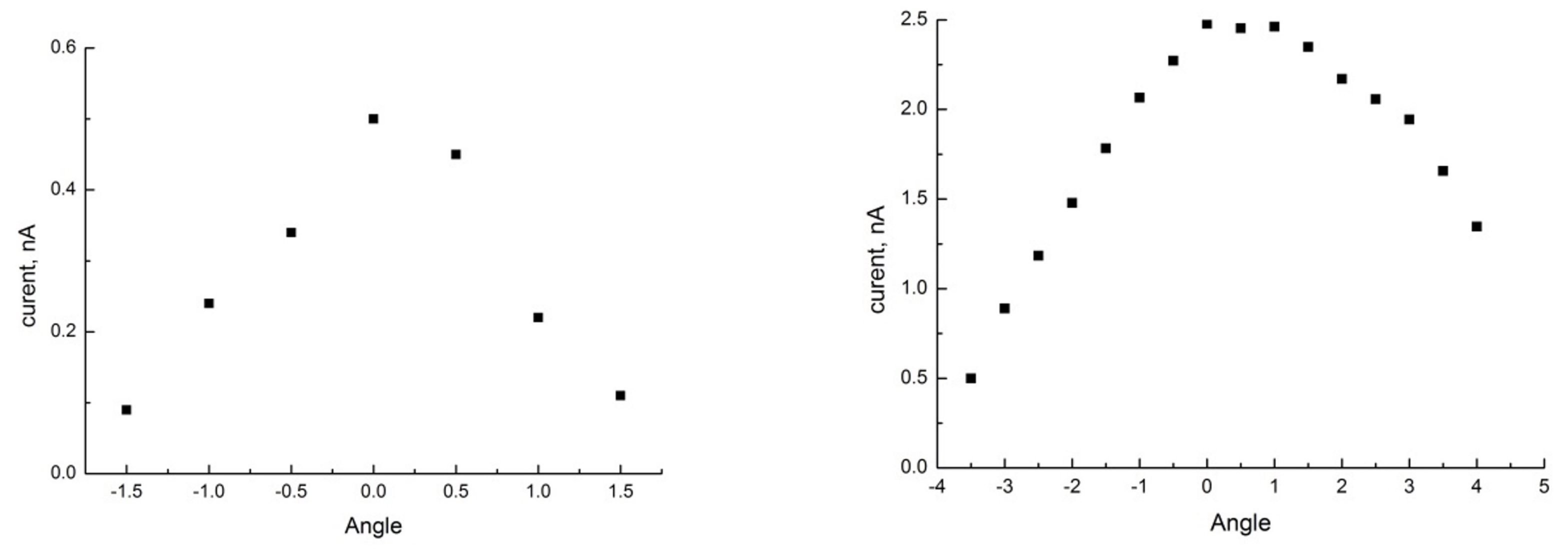

Fig. 3. Dependence of the He^{+} ions number passing through membranes on the angle of inclination. Membranes obtained in electrolytes based on H_3PO_4 (left) and H_2SO_4 (right)

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Conclusion

We have studied porous anodic aluminium oxide membranes with a system of ordered nanoscale (pore diameter of 20 nm and more) capillaries with an aspect ratio of up to 500. It was shown that the transmittance of high-energy ion beams for membranes made on the basis of H_2SO_4 is significantly greater than based on H_3PO_4. Nanoporous alumina-based membranes were used successfully to provide the transporting of a flux of high-energy helium ions.