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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Anodic aluminum oxide microchannel plates

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Abstract

A new material for microchannel plates (MCP) is proposed – anodic aluminum oxide. Microchannel plates made of this material may be much cheaper than with conventional lead glass MCP. Also a significantly smaller channel diameter (up to 70 nm) is easily achievable, which means better spatial resolution and the possibility to operate in strong magnetic fields. Methods and means are developed for overcoming two main obstacles on the way to anodic aluminum oxide MCP – low conductivity of aluminum oxide and too large a ratio of channel length versus diameter. Treating aluminum oxide with lead allowed to increase the conductivity by several orders of magnitude. Directional etching allows to produce etched channels with a diameter of 2.5 μm and a length of 65 μm. Microchannel structures are produced with such channels, and electronic microscope photographs are taken of them. On those photographs one can see the spatial structure of the channels. The electrical properties of these MCP, treated with lead, were investigated using the DC method. Excess of secondary current with respect to the input beam current was observed, which can be explained as a result of avalanche electron multiplication in the channels.

Keywords: Microchannel plates; Channel electron multiplier

Microchannel plates (MCP) are widely used in scientific research, space equipment, navigation equipment and so on. Currently used technology of MCP production is very labour consuming and expensive, and it has already reached its limits in spatial resolution. Thus MCP of a new type are needed – cheaper to produce and with a smaller channel diameter.

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Porous anodic aluminum oxide is a promising material for MCP production since it is theoretically possible to place up to 10^{10} channels per cm^2 in the plates with a ratio of channel length versus diameter in the range of 20–300. Conventional MCP technology does not allow to produce MCPs with such parameters. It is also possible to obtain channel diameters in the range from 1 to 10 μm by means of directional etching at a plate thickness up to 100 μm. Anodic aluminum oxide is diamagnetically weak, making it suitable for strong magnetic

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fields, which is very important for applications in high-energy physics. Tests of radiation hardness of aluminum oxide showed that it could be used even inside the nuclear reactor. There are no fundamental factors limiting the size of aluminum oxide MCP and it is quite possible to produce MCP with a size up to $50 \times 50\,\mathrm{cm}^2$.

The processes of electrochemical oxidation and directional etching are much simpler than lead glass MCP production thus it is possible to reduce the cost of MCP by two orders of magnitude.

The idea to make MCPs of anodic aluminum oxide is not new. It was formulated some 30 years ago and even patented in the USA [1]. But there are certain difficulties in the way of the practical implementation of this idea. We have tried to overcome these difficulties.

We have performed simulations [2] which proved that there are no fundamental obstacles preventing an MCP made of anodic aluminum oxide to operate properly.

The main characteristics of anodic aluminum oxide (cell size, channel diameter and so on) depend on oxidation conditions: current density, formation voltage, temperature and the nature of the solution. We have developed the method of growing of anodic aluminum oxide with a channel diameter of 0.1–0.3 μm and a length to diameter ratio of 100–500. The electronic microscope photograph of such a structure is shown in Fig. 1. In principle, this structure can be used as an electron multiplier, but it is easier (at least for now) to work with bigger channel sizes, so for our current investigations we were also using directional etching, which allows to enlarge channel diameters up to 10 μm.

The directional etching consists of the formation of the mask with holes on the surface of the aluminum oxide (by means of photolithography) and consequent etching through these holes. Due to the presence of natural channels in the oxide the etching is proceeding much faster along those channels than in the perpendicular direction. Thus it is possible to produce microchannel structures with a length to diameter ratio up to 30 and more. Figs. 2 and 3 present examples of such etched structures. The photographs were taken with an electronic microscope Hitachi S806.

To operate as an electron multiplier the MCP must have high resistance – to enable the application of high voltage to its opposite sides, but there also must be some finite conductivity so electrons taken from the channel walls can be restored. Aluminum oxide has good dielectric properties, so some method to increase conductivity must be found. We have tried to modify the aluminum oxide with different metals. It is known that the conductivity of a standard MCP is being provided by lead, which is one of the components of MCP glass. As a first step we have tried to modify our aluminum oxide MCP with lead. As it is very difficult, even almost impossible to insert metal in the bulk of a dielectric, we decided to apply some salt of this metal to the surface of the channels and then reduce it to a metallic state. We chose lead nitrate and lead

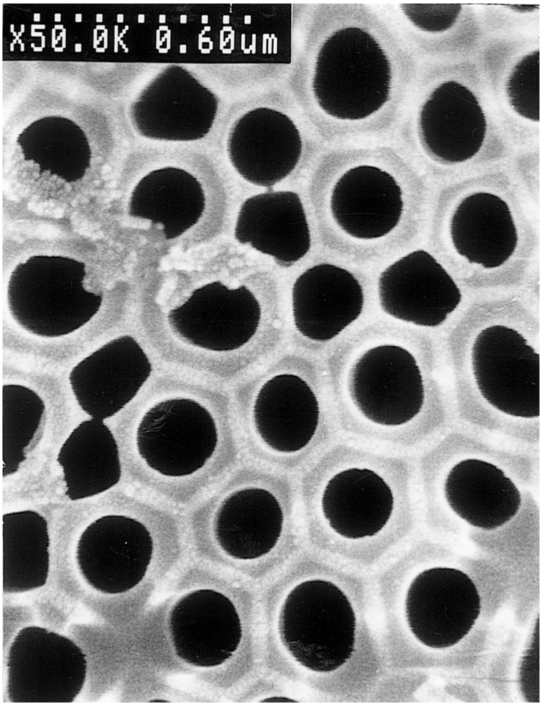


Fig. 1. The photograph of the surface of anodic aluminum oxide MCP. Pores are enlarged up to 0.2 μm by means of chemical etching. MCP surface as seen from above.

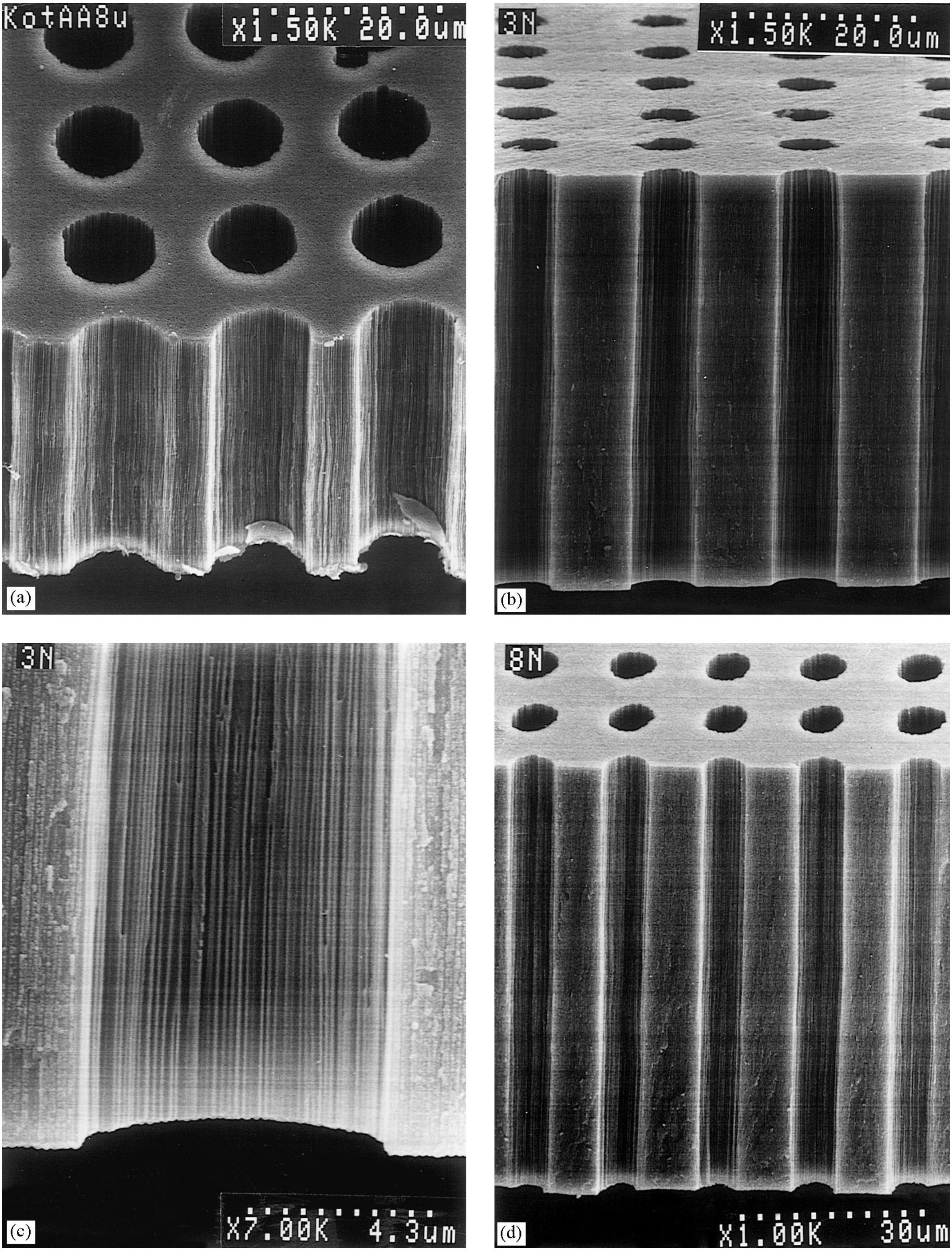


Fig. 2. Photographs of MCP, produced with micromachine processing of anodic aluminum oxide: (a) channel diameter is $9 \pm 0.7\,\mu m$, channel length is $42\,\mu m$; (b) and (c) channel diameter is $6.7\,\mu m$, channel length is $52\,\mu m$; (d) and (e) channel diameter is $6.3\,\mu m$, channel length is $85\,\mu m$.

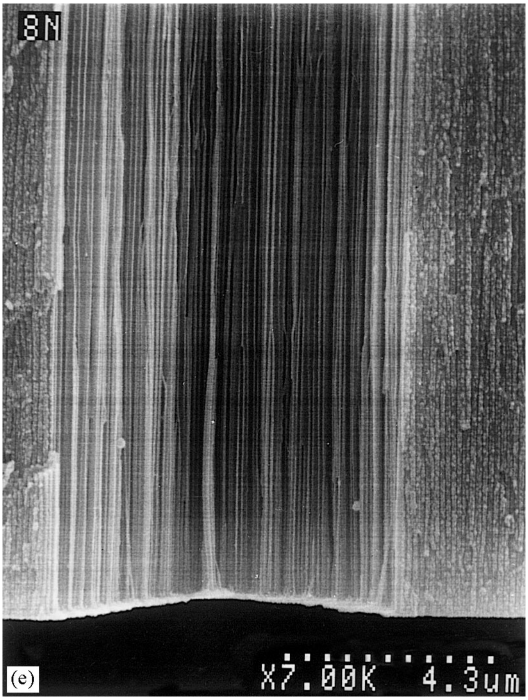


Fig. 2 (Continued)

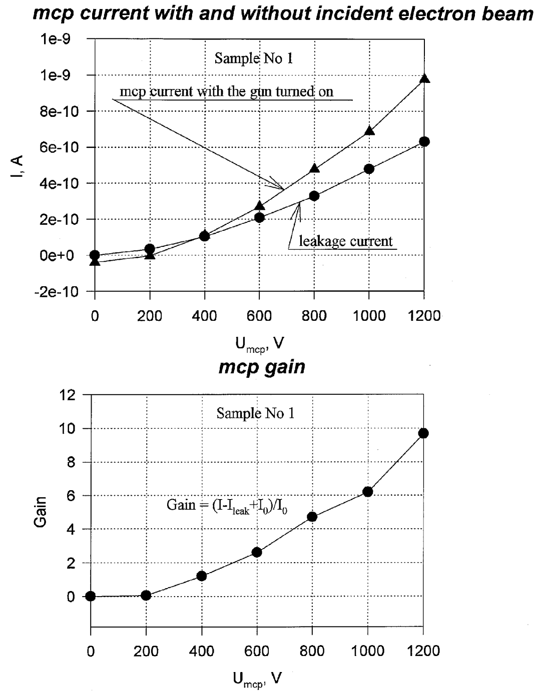


Fig. 4. DC mode performance of MCP, modified with Pb.

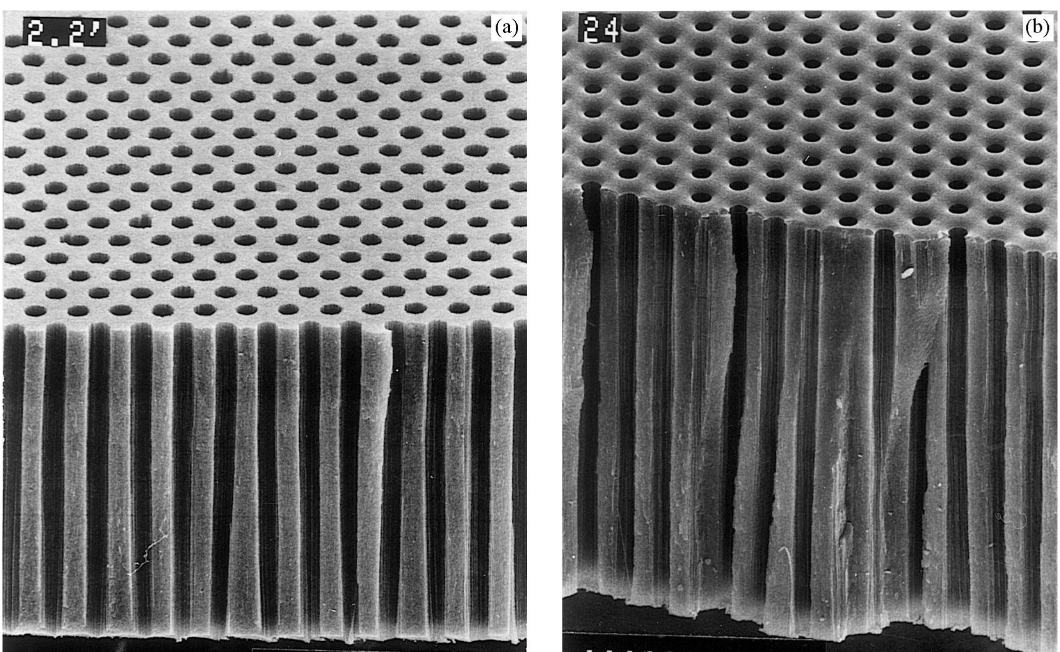


Fig. 3. Photograph of the broken edge of the anodic aluminum oxide MCP with channels, produced by means of directional etching: (a) channel diameter is $3 \pm 0.2\,\mu m$, channel length is $52\,\mu m$; (b) channel diameter is $2.8 \pm 0.2\,\mu m$, channel length is $67\,\mu m$.

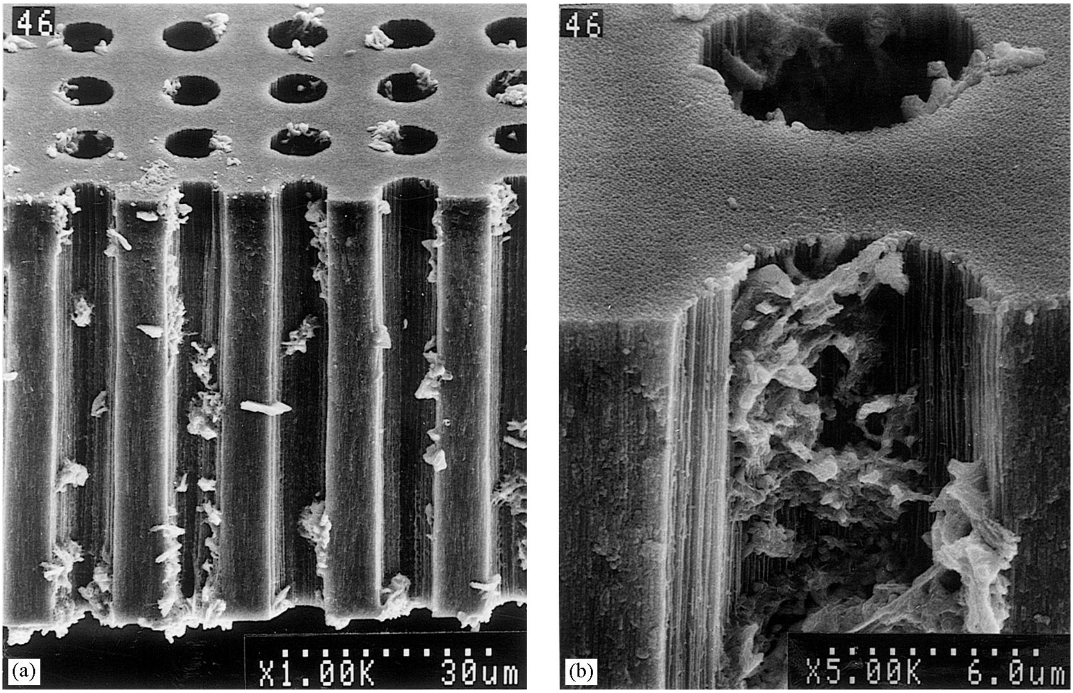


Fig. 5. Photographs of modified MCP; content of Pb is 33%, no thermoprocessing: (a) general sight; (b) enlarged fragment of the PbO crystal in the channel.

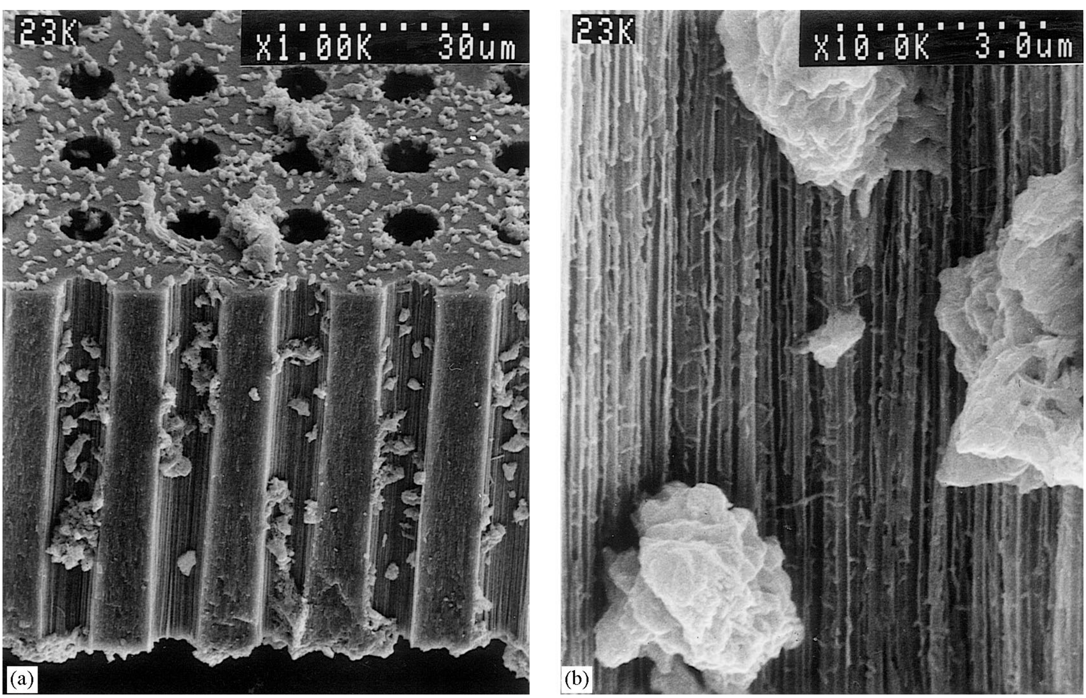


Fig. 6. Photographs of modified MCP after annealing in vacuum; content of Pb is 33%: (a) general sight; (b) enlarged fragment of the Pb crystal in the channel.

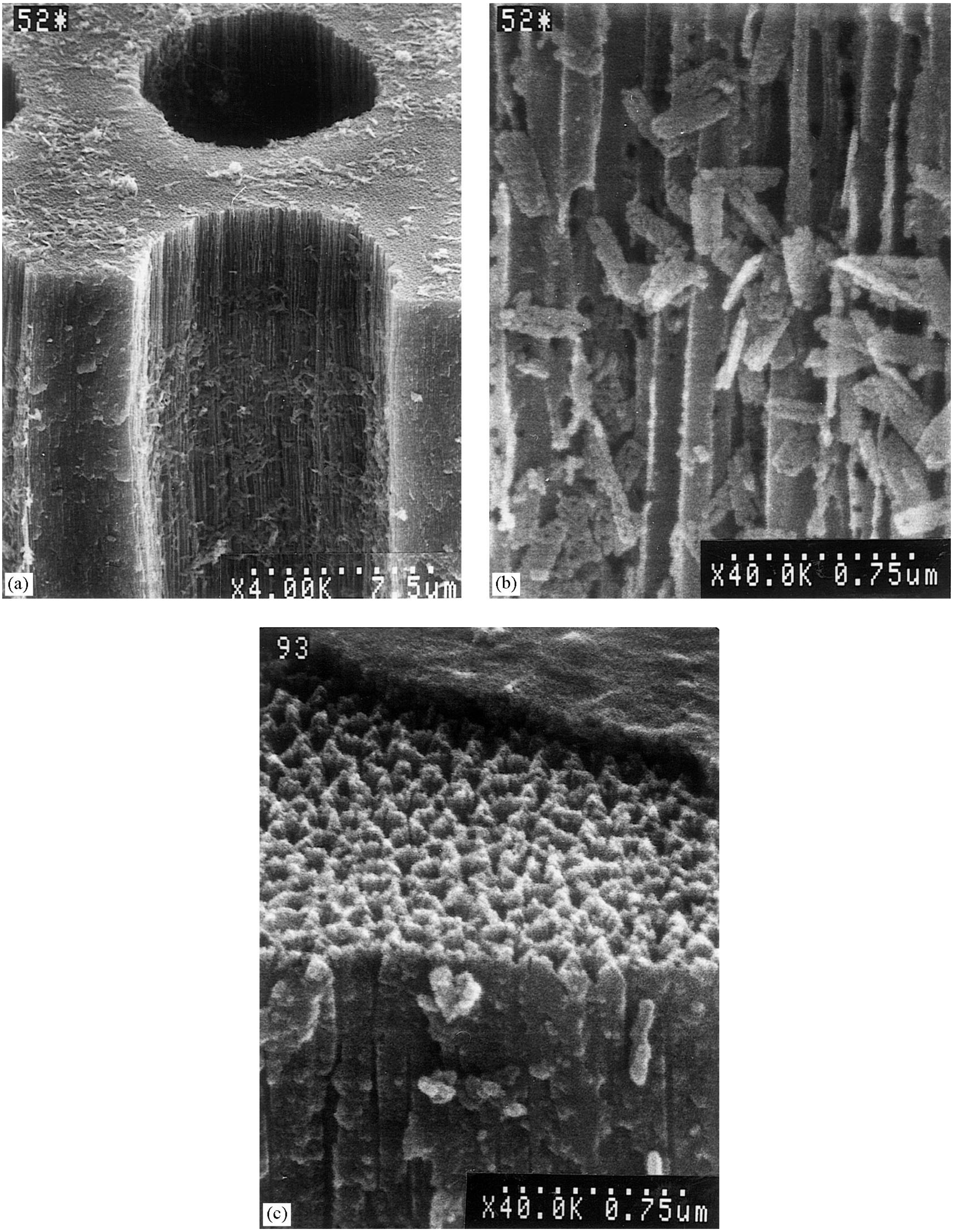
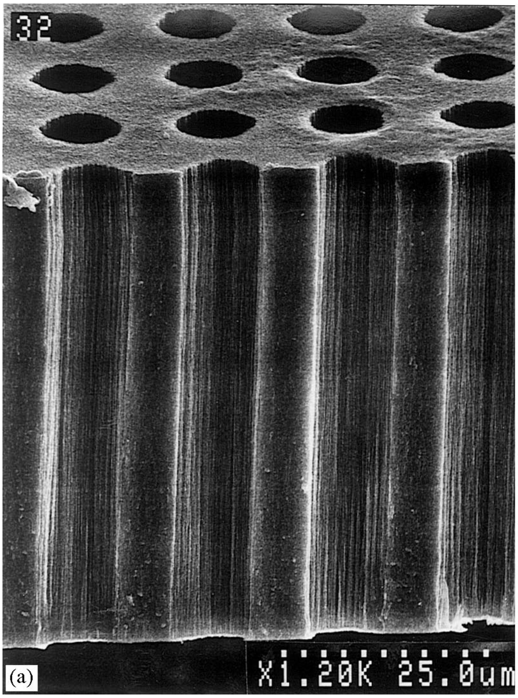


Fig. 7. Photographs of MCP, modified with indium oxide: (a) general sight of the etched channel of MCP with content of InO about 8%; (b) enlarged fragment of the channel wall; (c) general sight of the MCP without etched channels (only natural pores); content of InO is 13%; here one can see the surface and the broken edge of the porous oxide.



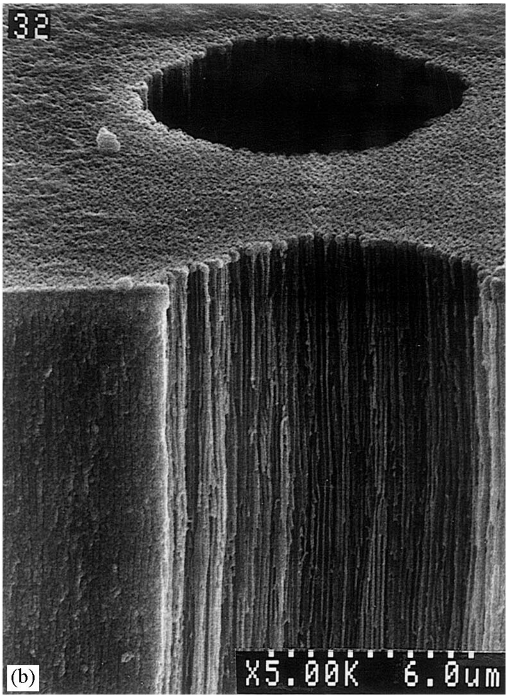


Fig. 8. Photographs of MCP containing 3.1% of the indium oxide – tin oxide mixture; In:Sn ratio is 10:1: (a) general sight of the MCP broken edge; (b) enlarged fragment of the channel wall and MCP surface.

acetate, because those salts are easily soluble and can be transformed into lead oxide by heating to 400°C in air atmosphere and then be reduced to a metallic state by annealing in a hydrogen environment. A similar method was further applied for modification with indium and tin oxides.

The electric resistance of MCP made of pure aluminum oxide with a dimension of $1\,cm^2$ and a thickness of $100\,\mu m$ is about $10^{14}\,\Omega$ and more. After modifying with lead resistance became about $10^{12}\,\Omega$. This is still too large, but it allows to observe the multiplication effect. Thus we have created an experimental installation consisting of a vacuum chamber (10^{-6} Torr), an electron gun and an measurement equipment.

To observe the electron multiplication we first measured the dependence of MCP leakage current versus applied voltage with the electron gun turned off. Then we turned on the gun and measured that dependence again. If there is some current excess with the gun turned on, it can be attributed to electron multiplication. The gain can be calculated with the formula

$$G = (I - I_{\mathrm{leak}} + I_0)/I_0,$$

where I is the MCP current with the gun turned on, I_{leak} is the MCP current at the same voltage with the gun turned off, and I_0 is the MCP current when the voltage is zero and the gun is on (i.e. the beam current). These dependencies for the best specimen of anodic aluminum oxide MCP, treated with lead, are presented in Fig. 4. Those dependencies can be interpreted as a result of electron multiplication in channels.

To investigate the distribution of the modifying substance inside the aluminum oxide MCP we have performed the microprobe analysis with an electronic microscope Cambridge Instruments Stereoscan 360 and an X-ray spectrometer AN-10000, produced by Link Analytical. Figs. 5 and 6 present

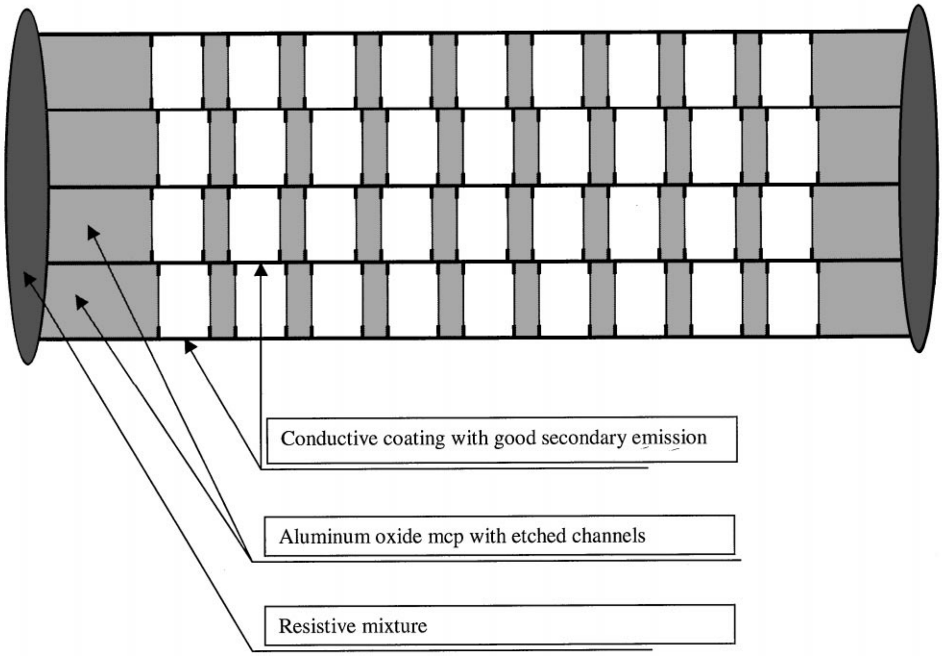


Fig. 9. Layered electron multiplier with discrete dynodes.

electronic microscope photographs of an aluminum oxide MCP treated with lead. One can see that there is no homogeneous solid coating, but rather separate crystals of lead on the walls of channels.

We have concluded that lead is not the best metal for the surface modification and decided to try to modify our MCP with indium and tin. Indium oxide can provide good conductivity and thin films of tin oxide can have good secondary emission properties [3].

Resistance of the MCP modified with indium oxide, which was additionally slightly doped with copper, was about $10^6\,\Omega$, but it was very unstable and unrepeatable. The photographs of these MCP are presented in Fig. 7. It can be seen that the coating is smoother and more regular than in the case of lead, but it is still not a homogeneous continuous film. Attempts to observe electron multiplication were also unsuccessful.

Finally we have tried to modify our MCP with indium oxide and tin oxide simultaneously. Such a mixture with an In:Sn ratio of about 10:1 (ITO) is known to have good conductivity. In this case coating is much better, it is smooth and continuous and there are no separate crystals (Fig. 8). The resistance was about $10^9\,\Omega$, which is very close to the resistance of the standard MCP of the same dimensions. The resistance was quite stable, but attempts to observe electron multiplication were unsuccessful. So we have concluded that the secondary emission of ITO is not good enough. We shall introduce the third component with good secondary emission into the In:Sn mixture; it may be MgO for example.

In conclusion, we want to describe the structure, which we are going to implement in the nearest future. It is shown in Fig. 9. It consists of several anodic aluminum oxide MCP, assembled in the layered structure. There is no conductive coating on the walls of the channels. Each MCP has a ratio of channel length to diameter of about 10 or slightly less. The outer surfaces are covered with an alloy with good secondary emission (maybe berillium bronze or something similar). This coating does partly penetrate into the etched channels (at least in the depth equal to the channel diameter). The edges of that layered structure are covered with a substance with limited conductivity. So we receive a structure with discrete dynodes, which can be considered as an array of tiny multipliers.

References

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