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Development of micro-channel plates on a basis of aluminum oxide

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Abstract

Micro-channel plates (MCP) are widely used in different fields of science and technology. They have good operational parameters, such as short response time (<1 ns), good spatial resolution, sensitivity up to single electron mode, high-radiation hardness and immunity to magnetic fields. We propose a new kind of MCP based on an anodic aluminum oxide substrate formed by electrochemical oxidation of aluminum. This work presents preliminary results on Al_2O_3-based MCPs. A research program is proposed which includes studies of the electrophysical properties of these MCPs in function of various geometric parameters (thickness, channel diameter-to-length ratio, effective surface, etc.).

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1. Introduction

Electron Multipliers (EM) have a wide range of applications due to their good characteristics such as: high gain (10^3–10^6) and good operational stability. Nevertheless conventional EM with discrete dynodes also present some disadvantages such as: relatively poor time and spatial resolution, sensitivity to magnetic fields and relatively large size.

Micro-channel plates (MCP) consist of a matrix of parallel micro-channels. Each one is a continuous dynode structure presenting the required resistive and secondary emissive properties. Voltage is applied onto opposite surfaces of the plate. The incidence of primary electrons with channel walls causes an electron avalanche [1,2].

Modern MCPs are mostly produced from lead silicate glass (LSG). Their technology of fabrication is based on multiple processes of dragging and agglomeration of fibers having soluble metal or glass core resulting in the production of primary multiple fibers. The agglomeration of multiple fiber bundles into a MCP block is performed at high temperature. Afterwards the block is cut under a certain angle into separate plates, the surfaces of which are polished. MCP channels have hexagonal packaging; channel axis tilt is 5–15° with respect to the perpendicular MCP surface in order to diminish parasitic ion feedback. Conducting electrodes (chrome, nickel, etc.) are sputtered on the polished surfaces. Transparency coefficient (ratio of the total area of input channel holes to the total MCP area) is about 50–70%. Modern MCPs have a 0.4–4 mm thickness, and channels diameter 10–100 μm, channel-to-channel distance 6 μm, resistance is about $10^8\,\Omega$. The MCP channel length-to-diameter ratio (so called "operational aspect ratio," OAR) is in the range of 40–100. They have high gain (10^5–10^6); high sensitivity up to single electron mode; time resolution $<10^{-10}$ s, high spatial resolution; ability to work in strong magnetic fields.

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However, LSG MCP has serious disadvantages mostly linked to their fabrication process:

- Complex, labor consuming and expensive production technology.
- Large parameter deviation and low reproducibility of MCP characteristics due to glass irregularities.
- Image spottiness due to difference of thermal histories of MCP block elements.
- Presence of defects due to plate deformations caused by changes of glass composition and its temperature expansion coefficient.
- Operating in strong radiation environment causes about 10–15% decrease of gain.
- Channels with diameters of less than 10 μm are impossible to produce with conventional methods which limits the MCP spatial resolution.
- Large area MCP are difficult to produce.

The development of a MCP based on alternative technology, less expensive and more flexible could solve some of these problems. Many attempts to create new MCP technology were made during the last 20 years. Different micro-channel structures made of glass, ceramics and other materials, and methods of conductive and secondary emissive layers creation are proposed. But in spite of the abundance of publications, a new MCP technology, able to concurrence the existing one has not emerged.

2. Anodic aluminum oxide (AAO) as a material for MCP production

Recently, AAO was proposed as a possible option for MCP production. AAO is a dielectric material consisting of parallel, hexagonal packed cells, perpendicular to the surface of aluminum substrate. Each cell has an axial pore, closed by an oxide layer barrier on the side of the aluminum substrate. The cell diameter is mainly a function of the anodization voltage. The diameter of the pores depends on the nature of the electrolyte, and on several parameters of the anodization process. The adjustment of these parameters allows the adjustment of the dimensions of the cells and pores. Also a selective etching of cell walls can enlarge pore diameter [3,4].

The technology of AAO production, including a deposition of oxide films with suitable electrophysical properties on the walls of the MCP channels was developed [5–7]. A deposition of these films modifies the conduction and secondary electron emission properties of the AAO MCP.

In comparison with conventional technology, the proposed one has several advantages:

- The use of standard microelectronics technology at all stages of MCP production (from plates growth up to production of operational MCP) will lower every costly aspect of the production process.
- The formation of micro-channel structure by batch technology (instead of individual treatment of fibers), allow us to raise the MCP production yield and provide good reproducibility of parameters.
- The possibility to produce MCP with channel density up to $10^{10}\,cm^{-2}$, channels diameters from 10 nm up to several micrometers, and aspect ratio up to 600 allows us to choose the optimal combination of parameters and gain higher spatial resolution of AAO MCP compared to conventional LSG MCP.
- The possibility to produce a MCP with thickness from 40 to 200 μm and up to 500 μm with use of special technological methods.
- Ratio between the surface of channels and the surface of the plate can be up to 50% without a significant loss of mechanical hardness.
- Possibility to produce a large area MCP up to 50×50 mm and probably even up to 80×80 cm.
- Working temperature from -200 to $+500\,^{\circ}C$.
- Low sensitivity to magnetic fields.
- Extremely high radiation hardness.
- Possibility to implant by special technology a significant quantity of lead atoms into the MCP structure in order to increase its stopping power.

Listed parameters and characteristics of AAO MCP are impossible to obtain in a LSG MCP produced by conventional methods. These advantages noticeably extend the field of application of micro-channel multipliers. Industrial implementation of such technology will allow the decrease of labor and material consumption and costs in many times over.

One can expect that micro-channel EM on the base of AAO are able to replace conventional MCPs in all fields of their current application, as well as in other fields where the application of conventional MCPs is now limited by the shortcomings of the existing technology.

3. Simulation of the AAO MCP detection efficiency

Single AAO MCP have a very small detection efficiency for the gamma with energies higher than 100 keV. A calorimeter for registration of gamma radiation with energy up to 1 MeV should present a special design (see, for example, Refs. [8,9]). A series of GEANT4 simulations were carried out to estimate a detection efficiency of single MCP as well as sandwiches of three MCP and absorbers as shown in Fig. 1.

The results of the simulations are presented in Fig. 2a and b and in Fig. 3a and b.

As one can see: single MCP is efficient for electrons and X-rays registration, but inefficient for gamma with energy higher than 30 keV. So, use of a sandwich design gives an advantage. Amongst simulated materials, beryllium looks the best for the energy region from 0 to 70 keV and copper is preferable for the region after 50 keV.

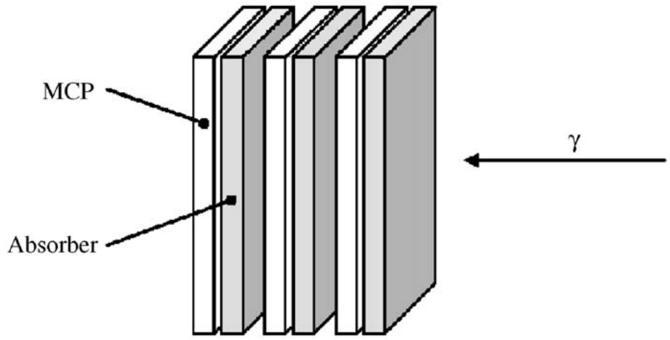

Fig. 1. Sandwich of AAO MCP (100 μm) and 500 μm absorber.

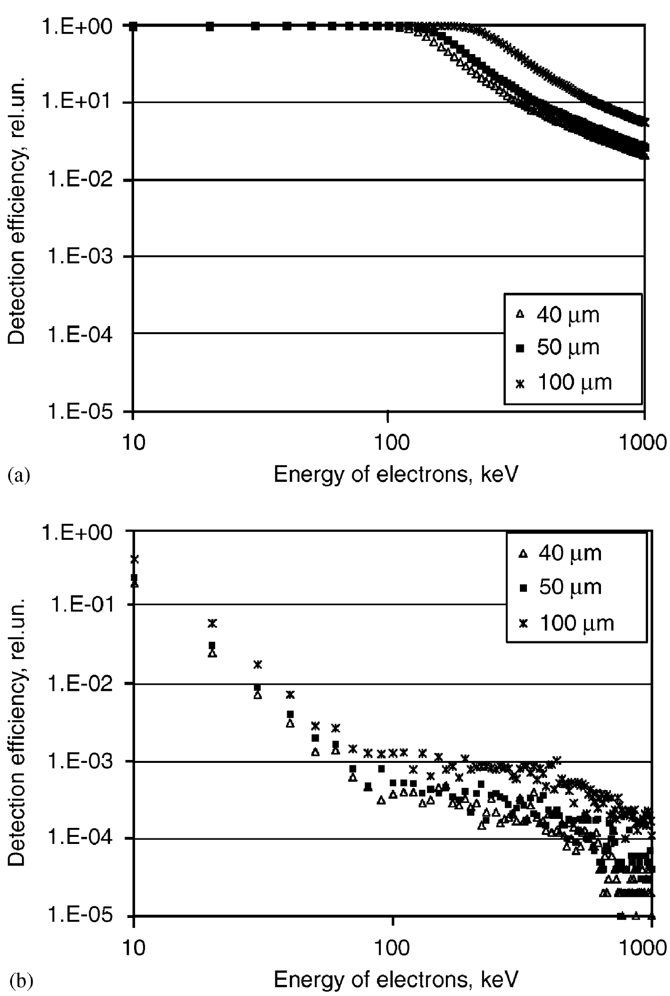

Fig. 2. Detection efficiency for electrons (a) and gamma (b) for single AAO MCP of different thickness.

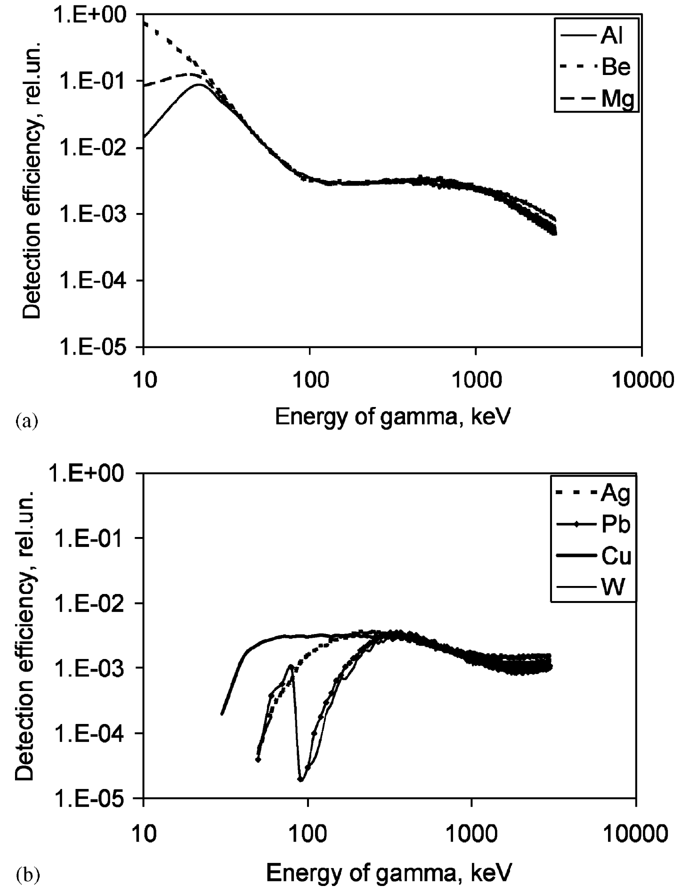

Fig. 3. Detection efficiency of the sandwich of three AAO MCP and three different metal absorbers.

4. Research program

The research program with the purpose of completing a development of a production technology of AAO MCP with optimal electrophysical properties and to develop a prototype of calorimeter for the registration of gamma radiation with energy up to 1 MeV is already started. The following tasks are planned:

- To develop a technology of deposition of regular homogeneous conductive and emissive coatings of with controllable electrophysical properties and good adhesion to the walls of deep narrow channels.
- To produce a series of MCPs prototypes with different thickness, aspect ratio and size, and supplementary secondary emissive coatings (if the necessity of them will be found).
- To make regular research of the MCP with various parameters in order to find their optimal combinations, this will provide the best electrophysical characteristics of the MCP for different particular applications. The MCP amplification coefficient versus voltage, timing response (jitter), and the MCP response to electrons excitation will be measured for single MCPs and sandwich on a basis of MCPs.
- To develop technology means to implant a significant quantity of lead atoms into the MCP structure in order to increase MCP stopping power.

5. First results of AAO MCP tests

For the time being several different types of MCP with natural porosity have been produced. They are of two

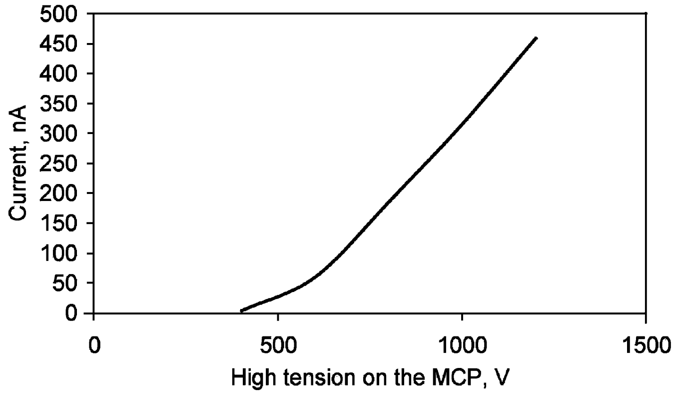

Fig. 4. Voltage–current characteristic of 40 μm MCP with 70 nm channels diameter.

thicknesses 40 and 190 μm and have channels of 70–100 nm diameter. Some MCPs of 190 nm thickness were treated in order to increase channel diameter to 8 μm. The resistance was measured for all MCPs. Depending on the MCP thickness it varies from tens to hundreds of MΩ.

Voltage–current characteristic of 40 μm MCP with 70 nm channels diameter is shown in Fig. 4

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