Aluminium Oxide Microchannel Plates

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Microchannel electron multipliers of a new type are proposed - anodic alumina microchannel plates (MCP). They implement the conventional concept of lead glass microchannel plate with a new material - anodic aluminium oxide. Anodic alumina is a very suitable material for microchannel plates due to the presence of natural microchannels. Diameters of these channels lie in the range of 0.02 - 0.5 μm, channels of greater diameter can be easily produced by means of additional processing based on the presence of intrinsic microchannel structure. We have produced MCPs with channel diameters 0.2 - 8 μm and thickness 40 - 150 μm. We have also developed two methods of deposition of conductive and emissive films inside MCP channels: plasma sputtering and liquid-phase deposition from metal-organic precursors. MCP samples with NiO-MgO and Cu-CuO-BeO-MgO coatings have demonstrated promising results. Alumina MCP potentially have serious advantages over traditional lead glass MCP: they are much cheaper, large area plates (hundreds of cm²) can be easily produced, spatial resolution can be much better (due to smaller channel diameter).

1. INTRODUCTION

At present microchannel electron multipliers (or microchannel plates - MCP) are widely used in different fields of science and technology. MCP have good operational parameters: gain up to 10⁶, response time 1 ns or less, spatial resolution of the order of the channel diameter, sensitivity up to single electron mode, high radiation hardness, ability to work in strong magnetic fields. MCP are used in brightness amplifiers, navigation equipment, electron-optic converters, scientific measuring devices, medical diagnostic equipment, night vision devices, detectors of charged particles and gamma-quanta etc.

2. EXISTING MCPs AND THE TECHNOLOGY OF THEIR PRODUCTION

MCP is a matrix of parallel microchannels. Each microchannel can be considered as a continuous dynode structure having necessary resistive and secondary-emissive properties. The concept of a continuous dynode of channel type was formulated by Farnsworth (1930) [1], the first operating prototype of MCP was created by I. Pesyatsky (1943) [2]. In the 1960s technology of MCP was actively developed [3-6]. The basic elements of modern MCP technology were created at that time. Modern MCPs are plates with a thickness of 0.4 - 4 mm, having channels with diameters of 10 - 100 μm with package density up to 10⁶ cm⁻². Due to the small dimensions of the channels MCPs have a good time resolution (hundreds of picoseconds) and spatial resolution (comparable with the channel diameter); the gain is up to 10⁶. MCP channels are usually slightly tilted (5° - 15°) in relation to the perpendicular to the plate surface, which is diminishing parasitic ion feedback. Currently the main material for MCP production is lead-silicate glass. Modern technology of lead glass MCP production is based on methods of optic fibers production and consists of multiple processes of dragging and agglomeration of fibers having a soluble metal or glass core, resulting in the production of primary multivein fibers. Then the block is cut under a
certain angle into separate plates, and their surfaces are polished. Thermohydrogen reduction provides the necessary electrophysical parameters of MCPs and consists of the reduction of lead oxide in the surface area of the channels by heating the MCP in a hydrogen flow. It is necessary to maintain precise time-temperature profile of hydrogen reduction, which complicates the lead glass MCP technology.

3. SHORTCOMINGS OF EXISTING MCP TECHNOLOGY

Lead glass MCPs have good parameters, but there are also serious disadvantages:

- very complex, labour consuming and expensive technology;
- large parameter deviation and low repeatability of MCPs due to possible glass irregularities;
- large deviation of channel diameters within a MCP;
- spottiness of the image due to the difference of thermal histories of elements of the MCP block;
- during MCP production the glass undergoes different influences: thermochemical, mechanical, chemical, which cause defects due to plate deformations caused by changes of glass composition and of its temperature expansion coefficient;
- the limit of spatial resolution is already reached - channels with diameters less than 10 μm are impossible to produce with conventional methods;
- it is difficult to produce large area MCPs.

4. ATTEMPTS TO CREATE AN ALTERNATIVE TECHNOLOGY

So, the development of the alternative MCP technology, less expensive and able to produce MCPs with larger area and smaller channel diameters, is quite urgent. There were many attempts to create a new MCP technology during the last 20 years. In [7] a multilayer structure made of etched glass plates is proposed. In [8] and [9] microsphere plates made of agglomerated glass balls are described. In patents [10–18] different versions of microchannel structures made of glass, ceramics and other materials, and methods of creation of conductive and secondary emissive layers, are proposed. But despite the abundance of publications, a new MCP technology, able to replace the conventional one, is still not created.

5. ANODIC ALUMINIUM OXIDE

We propose a new material for MCP production: anodic aluminium oxide. It is formed by electrochemical oxidation of aluminum in electrolytes, weakly dissolving alumina, and consists of regular hexagonally packed cells, which are parallel to each other and perpendicular to the surface of the aluminium substrate (Fig. 1 and

Figure 1. Natural pores of anodic aluminium oxide. View from above.
2). Each cell has an axial pore, closed by a barrier oxide layer on the side of aluminium anode (Fig. 3). The cell diameter is mainly defined by the anodization voltage. Cell diameter rating is about 2.5 - 3.0 nm per volt of anodizing voltage.

Figure 2. Anodic aluminium oxide. Side view.

The diameter of the pores depends on the electrolyte nature, its temperature and concentration, the current density and other parameters of the anodization process. It is possible to vary the diameters of the cell and the pore size by the variation of the electrolyte composition and anodization conditions. The pore diameter can also be enlarged by selective etching of the cell walls. Anodic alumina is a very suitable material for microchannel plates due to presence of natural microchannels [19]. Diameters of these channels lie in the range of 0.02 - 0.5 \( \mu m \), channels of greater diameter can be easily produced by means of additional processing based on the presence of an intrinsic microchannel structure. It is possible to produce MCPs with channel diameters 0.2 - 8 \( \mu m \) and thickness 40 - 150 \( \mu m \).

Figure 3. Barrier layer of anodic aluminium oxide

6. POTENTIAL ADVANTAGES OF ALUMINIUM OXIDE TECHNOLOGY

The main advantage of aluminium oxide MCP technology is the formation of a microchannel structure by means of group methods (instead of individual dragging of fibers with subsequent agglomeration). It provides considerable reduction of the cost of MCP production. The possibility to use standard microelectronics technological processes at all stages of MCP production also helps to further reduce prices. Group methods of microchannel structure formation allow also the production of MCPs of significantly larger area than it is possible with a conventional technology. Channel diameters can be made considerably smaller (down to the submicron region), which increases the resolution and the ability to work in strong magnetic fields.
7. BRIEF DESCRIPTION OF THE METHOD OF ALUMINA MCP PRODUCTION

We have developed a procedure of anodic alumina MCP production [20-22] which consists of the following steps:

- growing of anodic alumina of the required thickness;
- separation of the alumina plate from aluminium substrate;
- deposition of a photolithographic mask;
- protection of a nonoperational surface;
- etching of the alumina through a protective mask in multicomponent acidic and alkaline etchants;
- liberation of the MCP matrix;
- annealing of the MCP matrix.

A MCP produced with this procedure is shown in Fig. 4. Fig. 5 presents a magnified picture of one of the channels of this MCP.

8. COATING PROBLEM

Anodic aluminium oxide is a typical dielectric, so it is necessary to create a conductive and emissive coating on the walls of the MCP channels to use it as an electron multiplier. This can be done by deposition of oxide films with suitable properties on the walls of MCP channels. Deposition of regular homogeneous coatings with controllable electrophysical properties and good adhesion to the walls of deep narrow channels is a difficult problem. We have tested a large variety of methods of deposition of such coatings, including

- MCP impregnation in acetate, nitrate and oxalate salt solutions with consequent dry-
ing and thermal decomposition resulting in
the creation of oxide films on channel walls;

- deposition of oxide films on channel walls by means of decomposition of hydro-
  xipolimers of metals produced by the sol-gel method;

- deposition of glass-enamel coatings by means of co-precipitation of components
  from solutions based on tetraetoxisilane (creation of coatings having composition
  close to that of standard lead-glass MCPs)

- deposition of oxide coatings by MCP im-
  pregination in alcohol solutions of oxides of
  acid-forming metals;

- deposition of metals on the channel walls by means of thermal "explosion" sputtering
  with consequent oxidation.

Unfortunately, all these oxide coatings had unsta-
ble electrochemical parameters due to nonhomo-
geneous structure and bad adhesion to alumina.
So we have developed new methods of oxide film
deposition directed specifically to the deposition
of thin homogeneous coatings on the walls of deep
narrow channels.

9. DEPOSITION OF THIN OXIDE
FILMS FROM LIQUID PHASE AND
BY MEANS OF PLASMA SPUTTER-
ING, AND DESCRIPTION OF MCPs
MADE BY THESE METHODS

We have developed two methods of coating for-
mation: deposition from liquid metallo-organic
precursors with consequent annealing, and depo-
sition of a discontinuous metal film by plasma
sputtering with consequent partial oxidation. We
also tested a hybrid coating deposition procedure
consisting of the formation of partially oxidized
metal films by means of plasma sputtering with
subsequent deposition of oxides of different met-
als from the liquid phase. For the liquid phase
deposition we used solutions of metal acetylacet-
onates. During annealing of acetylacetonate films
the organic ligands are evaporated leaving dense
homogeneous oxide films with good adhesion to
the surface. The best results were achieved with
a complex nickel-magnesium coating. The nickel
oxide film was deposited first, and served to pro-
vide conductivity. Then on top of it a magnesium
oxide film was deposited, which served to pro-
vide secondary electron emission. The method of
plasma sputtering was used to deposit a discon-
tinuous film of berillium bronze which was then
partially oxidized by means of heating in air atmos-
phere. The conductivity of such a film was
more stable than that of the nickel oxide film de-
posited from the liquid phase, but its secondary
emissive properties were worse than those of the
nickel-magnesium coating. So a hybrid proce-
dure was used where the magnesium oxide film
was deposited from the liquid phase on top of the
berillium bronze oxide film deposited by plasma
sputtering. Such a coating was combining a sta-
bile conductivity with a high secondary emission
efficiency. MCPs modified with all these three
methods had a resistivity of about 1 GOhm (the
MCP area was 1 cm² and the thickness 100 μm).
Conventional lead glass MCP have a similar re-
sistivity. The coefficient of secondary electron
emission of the coatings containing magnesium
oxide was rather high, probably higher than that
of conventional lead glass MCPs. We have put
MCPs of all the three types described above in
vacuum and applied an input electron beam. In
all three cases there was a prevalence of output
current over input current, which proves elec-
tron multiplication. The gain calculated as the
ratio of output to input currents, happens to
be more than 1000 for plates modified with the
nickel-magnesium coating deposited from the liq-
uid phase, about 20 for plates with the hybrid
berillium-bronce-magnesium coating, and about
1.5 for plates with the berillium-bronce coating.
During the investigation of electron multiplica-
tion in the microchannel structures produced, we
discovered the effect of parasitic spontaneous elec-
tron emission. Some output current, which is
not a conductivity current, exists even in the ab-
sence of an exciting input electron beam. That is,
the plate is multiplying its own electrons sponta-
nously emitted by the channel walls. This effect
exists in all three types of MCP coatings, and
is most intensive in the case of NiO-MgO coat-
ing, probably due to the largest coefficient of secondary electron emission of this coating. The effect of spontaneous electron emission is probably caused by the non-flat surface of the channel walls leading to significant fluctuations of the electric field. The mechanism of spontaneous electron emission is probably similar to the Malter effect, which was studied in detail exactly for anodic aluminium oxide, out of which our MCPs are made. Nonflatness of the surface of the channel walls is due to the currently used procedure of microchannel structure formation - directional etching of anodic alumina already having natural pores. Such a procedure allows to form microchannel structures with optimal, for research purposes, ratio of channel length to its width - from 10 to 20. However the channel walls produced by this procedure have a very complex relief created by the sharp partially etched remnants of the pores. Currently we are looking for a solution of this problem.

10. CONCLUSIONS

Our research proves that the anodic aluminium oxide technology is a promising alternative to convenient lead glass MCPs. It has the potential to make MCPs much cheaper, easier to produce, to increase the spatial resolution of detectors based on MCPs, to improve their ability to work in strong magnetic fields.

REFERENCES

10. US patent 3,967,001. Process of preparing a secondary electron emissive coating on the interior walls of a microchannel plate