Quality of microchannel plate working surfaces

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ABSTRACT

The basic physical-and-chemical aspects of influence of microchannel plate working surface quality on a complex of parameters determining a technological level, quality and reliability of plates are considered in this paper. A radically new approach to technology consisting in directional change of composition and properties of channel wall material directly in the course of MCP manufacturing process is presented.

Technical level, quality and reliability of MCP are eventually evaluated by quality and purity of working surface including resistive-emissive layer of MCP channels and input-output faces. Working surface characteristics are in many respects responsible for MCP performances such as picture quality of electron image, gain and gain stability in longtime operation, noise characteristics (field-emission effects, ion feedback), outgassing as well as thermal stability of performance in vacuum baking degassing. Thus, working surface condition is one of the key MCP characteristics which quality enhancement can not be attained without understanding physical and chemical processes and in absence of system approach to this problem.

Over a period of years regular studies of MCP working surfaces and their characteristics have been carried out in the following directions: surface relief on micro and nano-level; chemical and structural surface defects and their classification; in situ and integral diagnostics on the basic of currently available methods of surface diagnostics and studies of MCP characteristics; influence of technological factors and various methods of physical and chemical treatments on surface condition; MCP channel walls outgassing; MCP surface behavior in storage under exposure to air.

The thickness of the wall between channels does not exceed 1.0 – 1.6-µm, therefore, in terms of physics the channel wall is a thin-film element or a physical surface.

The analysis made with the aid of atomic force microscopy and other currently available physical and analytical methods [1] showed that channel wall surface of domestic and foreign MCP have bad roughness on nano-level with relief height of order 2-10 nanometer (see Fig. 1).

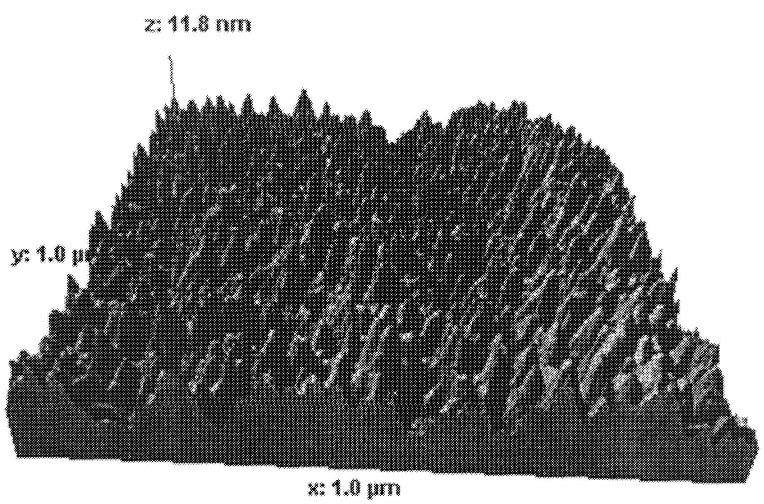

Fig. 1. MCP channel surface profile seen in AFM

Surface with such a bad roughness has high adsorption capacity and removal of surface contaminants with regard to micro-relief is of great difficulty. It should be noted that in order to attain rather low level of outgassing the first thing required is atomic smoothness of channel walls. Secondly, films (spots) of any side contaminations within the limits of 0.01 monolayer should not be available. Thirdly, channel walls (with total area of order 500 cm^2) should be degassed throughout their thickness and removed in such a way that the level of the remaining outgassing would not exceed 10^{-17} l·torr/s·cm^2 at room

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temperature. Besides, surface roughness brings about additional electron dissipation, resulting in noise factor increase and gain decrease.

The resistive-emissive layer in itself in the first approximation consists of 2 layers, that is, of SiO_2-based (up to 10-20 nm) thin emission layer and of a thicker (100-200 nm) resistive substrate having high conductivity where reduced lead is concentrated. It is found [1, 4] that on the surface of channels having resistive-emissive layer there may occur film-spot contaminations based substantially on alkaline metals (carbonates, silicates, hydrates, chlorides). In the course of the manufacturing process they are formed during MCP hydrogen reduction due to the best conditions provided for initiated diffusion of alkaline cations-modifiers onto the surface through the wall thickness. Modifiers exposure at the surface is accompanied with subsequent formation of various compounds when in contact with water vapor, hydrogen and silicate on the channels walls. These films easily decompose under electron bombardment. Their presence is the main factor of outgassing, ion feedback and other adverse effects under MCP operating in IIT.

It is availability of alkaline films on the inner surface of channels that governs the mechanism of conductivity enhancement at the output of the channel and as a result MCP gain degradation in longtime operation. Desorbed neutral and charged atomic and molecular particles define MCP outgassing in its operation and in particular intensity of ion feedback and MCP channel outgassing flow towards photocathode. Certain portion of positive ions (hydrogen, alkaline metals) formed on the surface is drawn by the electric transversal field into deep resistive-emissive layer, promoting material additional reduction and channel conductivity enhancement at the output. Channel electric field changes, conditions of secondary electron multiplication at the channel output are impaired, MCP channel gain reduces.

Avoidance of such layers formation and removal of alkaline component from channel walls solves the problem of pure channel surface and finally the problem of unfilmed MCP. Our researches showed that this problem can be successfully solved in the context of key MCP manufacturing process based on the introduction of "hybrid technique" for MCP hydrogen reduction.

Some other important points should be noted. In an effort to deepen degassing and enhance chemical stability as well as to stabilize channel walls structure, nitrogen high- temperature treatment at 460°-500°C [6] is performed after hydrogen reduction. In this case due to decomposing alkaline hydrates formed during hydrogen reduction practically complete removal of water from channel walls can be attained. Investigations show that such a process dramatically reduces MCP outgassing during thermal vacuum degassing. Notice, that:

a) after heating at 200°-300°C required for removal of physically adsorbed gases outgassing rate abruptly decreases and remains low up to 480°C, that is, the temperature exceeding that of the plate thermal treatment in nitrogen medium during hydrogen reduction;
b) as a part of gases released at temperature higher than 450°C, CO constitutes more than 90-95%. CO source is a thermolysis of alkaline (alkali-earth) carbonates and carbides on the surface. It is found that to solve the problem of unfilmed MCP outgassing, the temperature for nitrogen treatment of plates during hydrogen reduction should be 500°-520°C, whereas MCP thermal vacuum degassing (including at IIT technological process) can be performed at no more than 440°C, confining to the task of removal of physically adsorbed gases on the surface. It is also well known that nitrogen thermal treatment results in enhancement of chemical surface stability of optical glass products.

From the above it follows that quality problem of MCP working surfaces is mainly reduced to the problem of adverse effect of the alkaline component of the glasses used. In some cases peculiarities of MCP relief and surface structure promote such an adverse effect, in other cases (film formation on the surface) alkaline constituent is an independent surface forming factor.

The simplest, but far short of optimum method is an application of alkaline-free high-temperature working glasses used by Litton in the early 90s [7] and thereafter by Chinese and other MCP manufactures. However, Litton announced about introduction of effective high-temperature working glasses into MCP manufacturing process as far back as 1992 [7] and about problem resolution only 8 years later [8]. It is safe to assume that those years went into the process upgrading with the use of new high-temperature glasses, since mechanical replacement of glasses , being the basic technological element, could not but cause changes in the entire process.

The second variant of minimizing adverse effect of alkaline constituent consists in working surfaces purification. In work [9] channels were purified of alkaline contaminations with ion-plasma treatment. But after several weeks-of-storage alkaline cations were exposed at the surface from the channel walls thickness with all negative consequences (increase in outgassing and noise level). Therefore, we believe that alkaline cations should be completely removed from channel walls by various means.

According to a new technology version of small pore low-noise unfilmed MCP being developed at VTC Baspik we are putting into effect the principle of purposeful transformation of original characteristics. It should be noted here, that chemical composition and structure of channel walls material differ in significant ways from the original working lead-silicate glass [5, 10]. This most critical technological peculiarity of MCP manufacturing process formed the basis for a principally new approach.

Previously accepted but with some corrections of composition and characteristics, C87-2 / C78-5 working glasses are in our use. Based on Galileo experts reports, the given glasses have considerable advantages for multifiber drawing [11] [just due to the presence in alkaline oxides of 7% Na2O (C87-2) and 8% K2O (C78-5)]. Since channel surface is an exposed and modified in the course of subsequent processing border of core glass-array glass seal, smoothness and purity of MCP surface depend considerably on the quality of core-clad glasses seal. The seal is formed during single fibers and multifibers drawing and boules baking; the seal quality depends in its turn on compatibility of working glasses [3] and technological factors of the operations indicated.

It should be pointed out that application of high-temperature working glasses with alkaline modifiers excluded (Litton technology) complicates the problem of providing good quality core glass-array glass seal during fiber and multifiber drawing without boundary micro and nano-nonhomogenities (crystallization and opalescence). When using domestic glasses, containing Sodium and Potassium, during drawing and baking operations future channel walls because of interdiffusion in core glass-array glass system lose to a large degree alkaline component which passes into core glass and is removed then during etching. The alkaline component of the etched plate channel walls decreases approximately up to 3%, and alkaline cations remained accumulate on the surface where they may be removed from in different ways. Then quality of channel surface will be greatly dependent on core etching factors, in particular, on additional chemical treatment of channels after core removal, which may secure soft polishing effect.

Thus, the key idea of a new version of technology is in efficient and directional change of compositions and properties of channel walls material in the course of MCP manufacturing. In this sense, this technology is a result of studies being conducted [12,13] and the technological task of implementing this principle consists in defining optimum (from the point of view of maximum removal of alkaline components onto the surface from the glass) conditions for the progress of natural physical-and-chemical processes .

In an effort to upgrade quality of working surfaces the following important problems should be solved:
- Soft chemical polishing of channel surfaces to enhance their smoothness;
- Introduction of effective contact electrodes coating at input and output as discussed earlier;
- MCP deep degassing at no less than 500^0C;
- Adopting thermal-and-chemical, ion-plasma and light-beam processes for channel walls final purification.

These problems are currently being solved in the framework of a new variation of MCP manufacturing process to fit small pore MCP of channel diameter 4.5-6-μm.

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