

Microchannel Plate (MCP)

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Abstract – Microchannel plate (MCP) is the main component in image intensifier tubes (IIT), which role is to amplify the input signal without distortion. MCP shows high efficiency in amplifying electrons, has good resolution, response time, S/N ratio, and with such characteristics are widely used in imaging and non-imaging applications. In this paper operating principle and manufacturing of MCP is depicted and explained.

Keywords – MCP, Image intensifier tube, generations of IIT

I. INTRODUCTION

Microchannel plate is a wafer (thin plate) with a thickness of 0.3-0.4mm, round or rectangular in shape. MCP consists of millions of very thin, conductive glass capillaries (4 to 25 micrometers in diameter) fused together and sliced into a thin plate. Each capillary or channel works as an independent secondary-electron multiplier which together forms a two-dimensional secondary-electron multiplier. MCP shows high efficiency in amplifying electrons, more than any other type of electron multiplier. It is compact, lightweight, has good transit time due to the low channel length, high amplitude, excellent amplitude distribution. With these characteristics is used as a key component in the image intensifier tube (IIT) for night vision devices, SEM (Secondary Electron Microscope), MCP-detector, Photomultiplier tube...

Night vision devices require a very good electronic image at the output of the device. The quality of MCP is crucial for image quality and it needs to meet stringent production criteria. The main parameters for a good electronic image are gain, resistance, signal-to-noise ratio, resolution and absence of defects.

MCP application can be distinguished as imaging and non-imaging applications. The split is based on the requirements for the quality of the electronic image, i.e. more specifically for use in image intensifier tube used in night vision devices.

Image intensifier tube is an electro-optical vacuum tube that enhances the intensity of the available light, allowing use in low-light conditions, such as the night. The night scene has a very low level of light whose spectrum falls into the infrared portion of the spectrum. Therefore, photocathodes, as an input window in the image intensifier tube should be sensitive to this part of the spectrum. Usually, the so-called multialkali photocathode is used for the second generation, or GaAs

photocathodes for the 3rd generation image intensifier tube.

A. Generation of the image intensifier tube

As technology progressed, so were generations of night vision devices alternated in order to meet new requirements. The following are the typical characteristics of each generation of image intensifier tube, as well as generations that come in between major generations that appeared on the market.

Generation 0- Typically use the S-1 photocathode (bialcal) with a pick sensitivity in the blue-green area of the spectrum, a typical sensitivity of 60 μ A/lm, using focusing by electrostatic field, as well as the acceleration of the electrons to achieve gain.

Generation 1- S-10 or S-20 photocathode (multi-alkaline) are mostly used, typical sensitivity of the photocathode is 1200-200 μ A/lm. Also uses focusing by electrostatic field, and acceleration of the electrons to achieve gain. Gen 0 is the first true passive image intensifier tube with amplification, resolution 25-30lp/mm, MTTF 1000hrs. It's characterized by flash-resistance, so-called blinding and image distortion between the center and the periphery. Due to insufficient amplification, 3 modules are connected to one another in order to obtain the required amplification.

Generation 2- Standard type of photocathode is multialkali S-25 (extended red), alkali Na, K, Sb, Cs. Typical sensitivity of photocathodes 240-350 μ A/lm with a microchannel plate as an electron multiplier. Good features at low levels of light and very slight distortion of the image. Resolution at center is 28-36lp/mm, typical SNR- 11, MTTF 2.000h.

Generation 2⁺ - Based on the Gen 2 characteristics but with a higher sensitivity of the photocathode 300-450 μ A/lm, resolution at the center 32-40lp/mm, typical SNR-13, MTTF 2,000hrs.

Super Gen- Based on Gen 2 technology but with further increase in cathode sensitivity 500-600 μ A/lm, resolution at center 45-54lp/mm, typical SNR- 18-21, MTTF 10.000hrs.

Generation 3- Photocathode GaAs wafer and microchannel plate with ion barrier. Excellent sensitivity to minimum levels of light due to high cathode sensitivity, 1600-2000 μ A/lm. Resolution at center 55-72lp/mm, typical SNR- 20-28, MTTF 15.000hrs.

Figure 1 shows the design of image intensifier tube generations.

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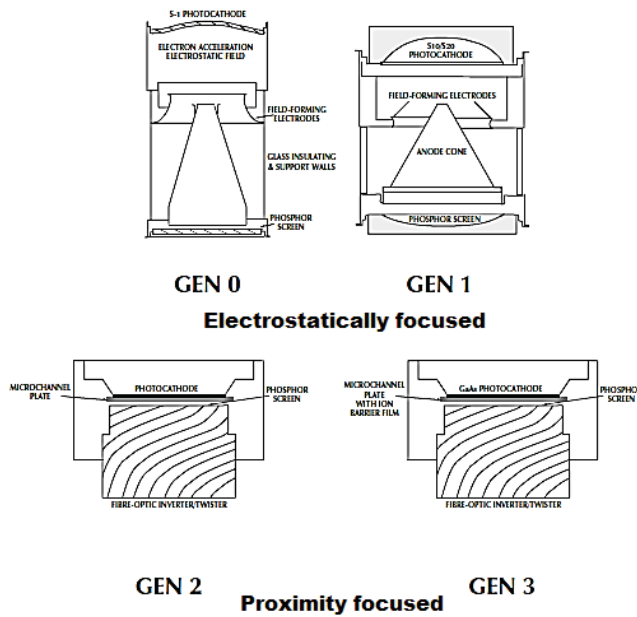


Fig. 1. Overview of image intensifier tube generations.[1]

B. Application of microchannel plates

Image intensifier tubes are widely used in the defense industry, starting with monocular, night vision gun rifle scope, binoculars, pilot goggles, and various combat armored vehicles. Civilian applications have a lot of possibilities, in traffic, border and airport surveillance, firefighting, medicine, science. Microchannel plate as an electron multiplier is used in an electronic microscope. As far as non-imaging applications are concerned, a microchannel plate is used as a detector of various charged particles, gamma, x-ray radiation.

As far as imaging is concerned, it is very important that the image from the input to the output is enhanced without distortion, i.e. the introduction of additional defects. The ideal picture at the output of the image amplifier would be the same as the input image only amplified. The real picture is somewhat different, the structure itself and the production technology cause some defects, the most common are black spots, image nonuniformity, dark or light hexagonal structure that can cause the problem in the picture quality itself.

II. STRUCTURE AND OPERATION OF MICROCHANNEL PLATE

The main component of the image intensifier tube is MCP, composed of several million channels that can be 5, 6, 8, 10 or 12 μm in diameter. The MCP consists of an active area where the channels are located with a semiconductor property and the ability to multiply electrons. The peripheral part is called RIM and gives the tiles mechanical strength during manipulation and MCP built into the device. In the image intensifier tube, that is, the vacuum tube from the beginning to the end, we have a strong electric field, potential difference up to 6-7kV depending on the type, so we have a straight line motion of the electron from the photocathode to the microchannel plate. A several million channels form an active area of the microchannel plate, independently acts as a mini multiplier of the electrons. Operating principle of the MCP is based on the secondary electron emission (Fig. 2a). The channels are positioned under a slight angle in relation to the

direction of the electrons in order to secure a necessary collision of electrons with the walls of the channel. For the 25-10 MCP channel angle is 12° and for 18-6 it is $4-5^\circ$. In each collision, the electron from the channel wall excites the new 3-8 electrons, which further move accelerated by the influence of a strong electric field, striking the channel wall and exciting new electrons. This is a cascade process which continues through the channels, eventually causing the avalanche of so-called secondary electrons at the end (output) of a channel. This phenomenon of multiplication of an electron under the action of an electric field is called the secondary electron emission. The input signal is increased about 10^3-10^4 times, depending on the operating mode of the MCP and applied voltage.

At the end, such amplified signal hits the phosphor screen and creates a monochromatic image at the output through the ocular.

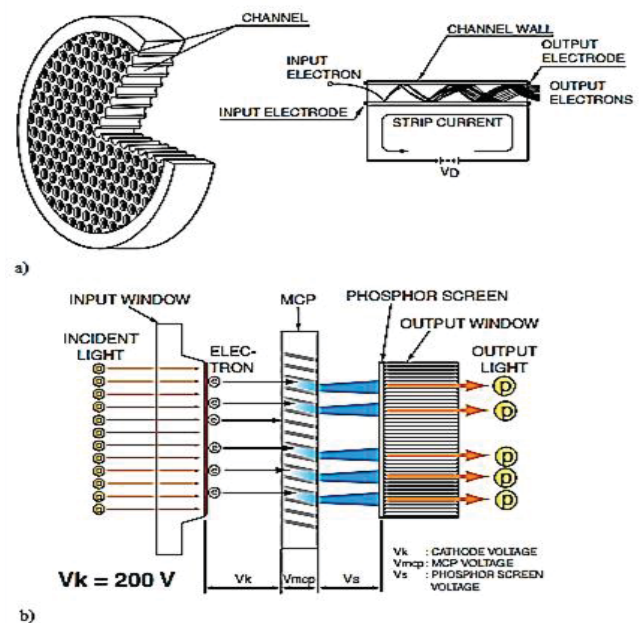


Fig. 2. The principle of operation of the microchannel plate (a) and structure of the image intensifier tube (b). [2]

In Figure 2(b), we can see the working principle of the image intensifier tube: incident light strikes photocathode, that converts photons into electrons. Once released by the photocathode, these photoelectrons are accelerated and focused by a high electric field towards the MCP. For each electron that enters MCP, approximately one thousand electrons are generated and accelerated from the output of MCP to the phosphor screen, which converts the electrons back into photons. All of these components are integrated into the final device- image intensifier tube. The very principle of image intensifier tubes is based on technological processes through which the components are individually processed, starting from the technological processes for the production of photocathodes, MCP as an amplifier and the phosphor screen used to display this image.

A. MCP Operating Background

It is well known that when silica glass with a high amount of lead oxide is treated in hydrogen at elevated temperatures, a semiconductor surface layer is formed. The surface layer of

the glass appears black due to the formed dispersion of metallic lead particles during the hydrogen reduction of PbO.[3] On the surface of a cross-section of the channel wall there is a secondary emission layer mostly composed of silicon dioxide and rich in alkali metals, that easily releases electrons. The thickness of the emission layer formed in the process of hydrogen reduction is 10-20 nm. A tiny emission layer formed at the channels wall surface determines the MCP gain, i.e., how many electrons will be emitted from that layer, and a lifetime of MCP.

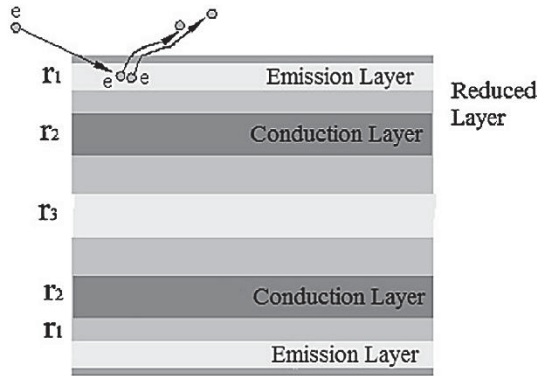


Fig. 3. Channel wall structure. [4]

The next layer is a conductive (resistant) layer of 50-100nm thickness. This layer is placed deeper in the channel and it is rich in lead.[3] The conductive layer determines another electrical characteristic of MCP and that one is its electrical resistance. The composition of the glass and the conditions of the reduction process (time and temperature) affect the resistance of MCP. This resistant layer contains clusters (small groups and aggregates) of lead that transfers electrons. In the first phase of the hydrogen reduction process, small lead grains are formed and after that, they group up. At temperatures of 450-500°C, grains begin to the grouping into clusters, and the principle of conducting the current is the principle of skipping the electron from the clusters to next clusters of lead. The function of the conductive layer is to donate the electrons to the emission layer for the secondary emission by the support of the strip current. When the electron leaves the lattice of potassium silicate, a hollow left in the lattice is occupied with an electron from a conductive, lead layer and that makes the MCP current ("strip current"). Usually, the saturation of MCP starts when the output current is up to 10% of the strip current.

$$R = U_{mcp} / I_{strip} \quad (1)$$

III. MANUFACTURING OF MCP

The production of microchannel plates (MCPs) belongs to a group of multidisciplinary technologies. Production is organized in the high special area, in the so-called clean rooms of the ISO6 class of cleanliness according to ISO 14644-1 or Class 1000 according to the FED US 209E standard and very strict operating standards of the operator. The necessary prerequisites are the control of the microclimate (temperature and humidity), which significantly affect the quality of the process. However, technology depends mostly on raw material, special semiconductor

glasses: lead glass- cladding (rich in alkalis) and boron silicate-core.

Here is briefly presented technological process in the manufacturing of MCP. Microchannel plate begins as a glass tube (cladding) fitted with a solid rod (core) - together they are called single fiber preform and drawn via fiber optic techniques to form a single fiber. This kind of technology is used for producing optic fibers (for communications), etc. A number of these fibers are then stacked in a hexagonal array, so-called bundle- multi-fiber preform; the entire assembly is then drowned again to form multi-fibers. In the same time, the hex rode (RIM) is drawn in the same way as single fibers, they serve as a support for MCP. The multi-fibers and hex-rim fibers are then stacked together (multi-fibers are in the center of MCP forming active area surrounded with rim hex-fibers) and fused at high temperature to form boul. As it's shown in the picture below.

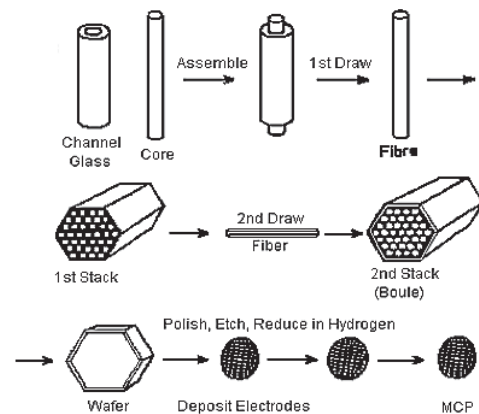


Fig. 4. Fabrication of MCP. [5]

The boul is sliced to wafer with required bias angle, edged to size and then ground and polished. And this is the first part of technology. After that, the second part of technology includes next steps. The individual wafers are chemically processed to remove the solid core material, leaving the structure of millions of tiny holes. Then, through reduction at elevated temperatures, conductive and secondary emission properties are given to the glass wafers. Finally, a thin metal electrode (usually chromium, Inconel or Nichrome) is vacuum deposited on both input and output surfaces of the wafer to electrically connect all the channels in parallel. Finished products are then tested under certain criteria in the tester.

IV. CONCLUSION

In terms of further improvement and new trends, the following directions are possible in order to improve the characteristics of MCP:

1. Upgrading the traditional MCP manufacturing technique by:

- 1.1 Miniaturization of the existing model in terms of reducing the diameter of the channel (e.g. 3μm), in order to get a better resolution.
- 1.2 Introduction of additional physical and chemical treatment of plates in order to reduce the impact of ion feedback (applying ion barrier film- IBF).
- 1.3 Optimizing the chemical composition of the glass to achieve the above-mentioned results.

2. A new approach of MCP manufacturing based on Atomic Layer Deposition (ALD), which combines glass capillary array substrates with thin film deposition techniques that provide the necessary resistive and secondary emissive properties of an MCP. [6,7,8]

In the table below we can see the advantages and disadvantages of these two technologies.

TABEL I
ADVANTAGES AND DISADVANTAGES OF CONVENTIONAL MCP TECHNOLOGY OVER ALD TECHNOLOGY.

Technology	Advantages	Disadvantages
Conventional	<ul style="list-style-type: none"> -Well-known technology -Row material- known. -Lifetime. -The equipment is inexpensive, relatively. 	<ul style="list-style-type: none"> -Structure defects. -Defects in the electronic image. -Limit by IBF.
ALD	<ul style="list-style-type: none"> -Simpler procedure. -Possibility of independent choosing glass, resistive and emissive properties-layer control. -Mechanically robust glass and may be selected to have a low content of radioactive material for reduction of background activity. -Better image quality. 	<ul style="list-style-type: none"> -Expensive equipment. -Not proven technology.

REFERENCES

- [1] Ientilucci, Emmett. (2019). Synthetic Simulation and Modeling of Image Intensified CCDs (IICCD).
- [2] https://www.hamamatsu.com/resources/pdf/etd/II_TH0007E.pdf
- [3] A.M. Then, C.G. Pantano, "Formation and behavior of surface layers on electron emission glasses", Journal of Non-Crystalline Solids, vol. 120, no. 1-3, pp. 178-187, Apr. 1990.
- [4] J. Pan, J. Lv, R. Zhang, Q. Yu, H. Zhao, S. Sun, X. Hanb, "Formation mechanism of 'memory' Phenomenon of micro-channel plate image Intensifier", Optik International Journal for Light and Electron Optics, vol. 124, no. 20, pp. 4509-4513, Oct. 2013.
- [5] F. Sauli (2010). Photon detectors [PDF Presetation]. Retrieved from:https://indico.cern.ch/event/80223/sessions/112102/attachments/1061990/1514408/4_PHOTON_DETECTORS_CHIPP10.pdf
- [6] A. Mane, Q. Peng, M. J. Wetstein, R. G. Wagner, H. J. Frisch, O. H.W. Siegmund, M. Minot, B. W. Adams, M. Chollet, J. W. Elam, „An Atomic Layer Deposition Method to Fabricate Economical and Robust Large Area Microchannel Plates for Photodetectors", Physics Procedia, vol. 37, pp. 722-732, 2011.
- [7] M. A. Popecki, B. Adams, C. A. Craven, T. Cremer, M. R. Foley, A. Lyashenko, A. O'Mahony, M. J. Minot, M. Aviles, J. L. Bond, M. E. Stochaj, W. Worstell, J. W. Elam, A. U. Mane, O. H. W. Siegmund, C. Ertley, L. M. Kistler, M. S. Granoff, "Microchannel plate fabrication using glass capillary arrays with Atomic Layer Deposition films for resistance and gain", JGR Space Physics vol. 121, no.8, pp. 7449-7460, Avg. 2016.
- [8] C. Ertley, O. Siegmund, T. Cremer, C. Craven, M. Minot, J. Elam, and A. Mane, "Performance studies of atomic layer deposited microchannel plate electron multipliers", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 912, pp. 75-77, Dec. 2017.