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Characterizing microchannel plates for x-ray detection and imaging

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ABSTRACT The goal here is to characterize crucial parameters involved in design and operation of such devices as detectors and also position sensitive detectors for X-ray detection and imaging. For example, MCP gain, dark noise, quantum efficiency, and image readouts for MCP X-ray detectors are discussed. In the case of MCP, we consider parameters affecting the linear and saturated operation of the device. Gain fatigue and gain desperation at high count rates are described and optimum conditions are explained for the case of MCP soft X-ray detectors. The geometrical probability functions that provide optimum quantum detection efficiency are described in this study. A limitation of a channel multiplier is the surface area of the entrances to the channel, which is usually less than the surface area of the entrance plate. For this reason, MCPs with the circular, square, and hexagonal channels are examined in this work. The geometrical efficiency for detecting hard X-rays as a function of the wall thickness for different thickness values is presented in this study. The geometrical efficiency as a function of the open width, d, for different L values is also investigated. The obtained results show that for each thickness value there exists an optimum opening diameter value for a given channel thickness and photon energy. Microchannel plates based on the position sensing technique are also described in this study.

(X-ray, Image, Microchannel plate, Position sensitive)

INTRODUCTION

Microchannel plates (MCPs) are widely used to sense ions [1], electrons, and photons as detectors and also producing amplified electron signals and images in many applications. Image readout for the MCP X-ray detector can use digital or analog encoders. Anodes for MCP position sensing devices are two types in material type and in geometrical configurations. Resistive anodes are usually used for the case of X- and γ-ray detections. In position sensing; discrete counter patterns intended to locate each event digitally, and anodes, which yield a continuous variation in output with respect to event position, giving an analog position signal. In this combination a simple anode instead of the phosphor screen is placed behind the MCP and can be in different forms. Here anode registers the position of a pulse of electrons emerging from a MCP so that data (PMT) provides a sensitive electronic device for producing an electrical signal. Position sensitive detectors can combine the advantage of the integration of the photographic plate, as well as the electronic readout of the PMT. In linear array a large number of light sensitive elements (256, 512, 1024) are closely arranged in a row. Each one is connected to one channel of MCA, in which a certain number of counts are stored, proportional to the intensity of the impinging light. If the array of detector is arranged in the focal plane of a spectrograph the spectrum is immediately obtained on the optical Multichannel can be stored or manipulated. These position sensitive anodes may include an array of separate detectors, wire anode grids, anodes providing binary output, capacitor strings, resistive plate, a quadrant or a wedge-strip anode geometries.

The simplest visual detector for the photon is the photographic plate and photomultiplier tube analyzer analyzer (OMCA). A linear diode array can consists of about 512 optical diodes, each 50 μm wide and 2.5 mm high, which forms an electronic photographic plate of the size 25×2.5 mm^2. The simplest visual detector for the photon is the photographic plate and photomultiplier tube analyzer (OMCA). A linear diode array can consists of about 512 optical diodes, each 50 μm wide and 2.5 mm high, which forms an electronic photographic plate of the size 25×2.5 mm^2. In order to obtain higher sensitivity in the generated electrons or images the array can be placed behind an MCP image intensifier tube. In this way we can take advantage of a very high gain of the microchannel plate (MCP). A typical MCP consists of many channels that provide a gain factor of about 10^4 in amplifying process. At the early stages, a great deal of attention was paid to the development of the MCP devices as compact electron multipliers of high gain which have found many applications as detectors of UV radiations, X-ray, and γ-rays.

In some applications, however, there is a need for an electrical rather than a visual output (the simplest such sensor is a MCP photomultiplier), it resembles a MCP intensifier in which a simple metal anode replaces the fluorescent screen. An electrical output pulse is obtained from the anode each time electrons cascade through MCP. A conventional photomultiplier has only one connection for its electrical output, and so is not suited to the sensing of images. A microchannel photomultiplier, on the other hand, can be designed so that the position of an output pulse on the anode can be decoded electronically. Position sensitive detectors based on MCP are used to generate electrical images. Such sensor is acting like an MCP photomultiplier; it resembles a MCP intensifier in which a metal anode replaces the fluorescent screen.

The introduction of MCP has revolutionized the measurement of weak event in the field of charge particle and photon detections. MCP detectors have high temporal (<1ns) and positional (20 microns) resolutions, and high internal gain (10^4). These types of detectors have also magnetic field immunity and as amplification elements for image devices have found wide applications in different fields. In addition such detectors are light that allow applications in small and portable devices.

Imaging detectors include CCD and MCP devices. MCPs can be used to obtain images from X- and γ-ray radiations and UV/VIS photon detections. The output of a MCP can be registered on a fluorescent screen to produce an intensified image such as in an image tube. In image tube based on MCP intensifier, usually the MCP is sandwiched between a photocathode, and a fluorescent screen. The MCP image intensifier tube is a glass wafer, perforated by millions of electron-multiplying tubes. This device as image intensifier can transform a dim pattern of electromagnetic radiation into a brightened image.

MCP AS AMPLIFIER OR INTENSIFIER

A schematic of the MCP optical detector/intensifier including the position sensitive readout is shown in Fig.1. It includes a Photocathode, microchannel plates, focusing ring for generated electrons and the readout anode. The same geometry with a fluorescent screen instead of the anode can serve as an image tube [2].

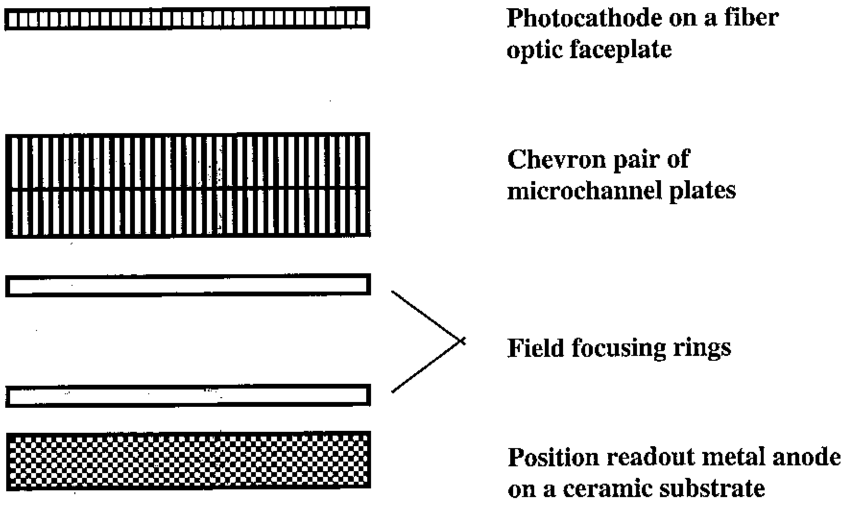

Figure 1. Schematic of an MCP optical detector including the position sensitive readout. In image tube a fluorescent plate is used instead of the metal anode. Same device without photocathode is used for direct X-ray detection.

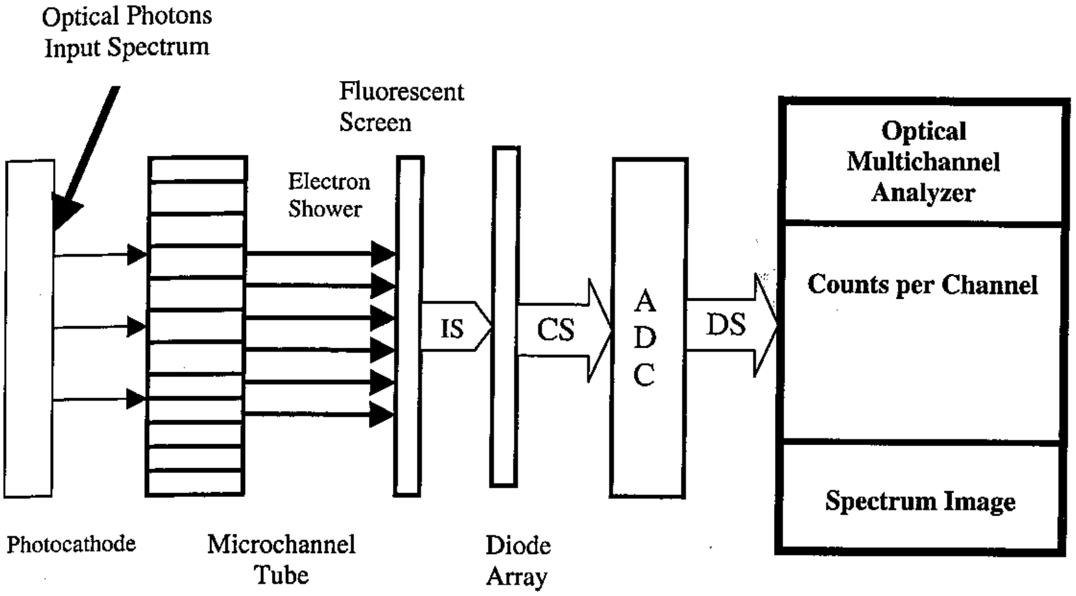

Figure 2. Block diagram shows the arrangement for a typical conventional application of MCP in UV/VIS optical photon detection and imaging. AS shows the amplified signal, which is shown as the number of counts, and CS presents the spatial encoded output for image signal.

The microchannel intensifier is a glass wafer, perforated by millions of electron multiplying plates, which can be designed in two configurations. The first is the proximity-focused, and the second one an electrostatically focused image tube as shown in Fig.1. The electrons emitted by the photocathode cross a short gap to microchannel plate, where they are accelerated and multiplied. In the first design, the electrons emerging from MCP strike the anode, again across a short gap. In this geometry the spatial organization of the imaged preserved because the two gaps are small enough to minimize the electron dispersion effect. In the second geometry photons enter the tube through fiber-optics window and hit the photocathode. The generated electron shower is focused by an electric field on the fluorescent plate located at a longer distance. This focusing is indicated in Fig.1, which is accomplished by two field rings. By focusing the electrons with either electric or magnetic field it is possible to increase the gap in order to operate at higher voltages that increase the gain. MCPs image tubes have been used in many laboratory instruments such as high-speed oscilloscopes, transmission electron microscopy, field-ion microscopes, and mass spectrometers. Such device makes possible the recording of extremely brief, faint or low-contrast features. Figure 2 shows schematical diagram for a typical conventional application of MCP in UV/VIS optical photon detection and imaging. In order to obtain higher sensitivity the array detector is placed behind an MCP as shown in Fig. 2. The arrangement is such that the spectrum illuminates a photocathode in which electrons are released due to photoelectric effect. The emitted electrons from the photocathode are then guided into the narrow channel of the MCP. The MCP channels are covered with a material emitting secondary electrons and multiplication occurs as electrons cascade along the channel, propelled by the applied electric field. The showers of electrons, there are spatially arranged corresponding to the primary spectrum, can impinge on a phosphor screen to produce encoded signal of the original spectrum. The light is then transferred to the diode array with retained spatial information. The output signals of the photodiode arrays are then converted by A/D module to a digital signal in MCA. The final spectrum is shown as photon counts in each channel of MCA. The high voltage for the channel-plate operation can be pulsed rapidly, and therefore the whole detector assembly can be gated to be sensitive during time intervals down to 5 ns. This type of operation is of great interest for background rejection in connection with the spectroscopy using short laser pulses.

MICROCHANNEL PLATE DETECTORS

The MCP detector types are devices with the more tradional circular, square, or hexagonal cross sections. Geometrical parameters involve channel wall thickness, and channel diameter. The composional parameters consist of the Pb oxide, Silicon oxide, and different compounds of alkali metals. Quantum efficiency depends on the X-ray and electron absorption coefficients, and the average path of the electron from the point of generation to the channel surface. These factors depends on the chemical composition of the MCP material and the X-ray energy.

MCP based X-ray Detectors

There are three principal ways in which the X-ray photons interact with matter that include, photoelectric effect, Compton scattering, and the Auger effect. All three processes produce moving electrons in matter, which can be detected directly or can initiate other electrons to obtain an electric charge pulse. These processes strongly depend upon the energy of the photon and the atomic number of the material (Z). The probability of scattering to a particular angle is a function of energy and angle. The photoelectric is the process in which a photon is absorbed by an atom and emits an electron. This probability increases strongly with Z and is less important at higher energies. The probability of interacting with matter in one of these processes can be expressed as absorption cross-section or absorption coefficient. At energies in the range up to 100 keV, the photoelectric effect is dominant; Compton scattering varies from a minor effect at 10 keV to being more important near 100 keV. If we consider the influence of Pb K-edge on detection efficiency, for the X-ray energies soon after Pb K-edge (88 keV) the photoelectron energy is near zero and they cannot enter the channel. In this case the detection efficiency is determined by the contribution of Auger electrons. Further increasing of the X-ray energy increases the energy of photoelectrons and the detection efficiency increases again.

For X-ray detection based on MCP a silicon photocathode is usually used in connection with a metal anode as a readout device [3]. The detection of the X-ray in such material is based on the surface layer of the detector. The same device shown in Fig.1 but without photocathode is used for direct detection of X-ray photons. In this arrangement MCP can be used as the X- and γ-ray detectors. In design of an MCP detector the channel type, geometrical factors, composional parameters of the active layer, and the incident X-ray energy should be considered.

For soft X-rays, photons interact within a thin surface layer of the silica-like, which has been depleted of Pb and enriched with K during the final stage of MCP processing [3]. The energy range for the soft X-ray range is about 0.02-10 keV and photon energy higher than 10 keV is considered as Hard X-ray. This activated layer here determines the MCP gain and the compositional change in this layer is responsible for the gain degradation. Typical MCPs of that kind are discs of diameter 25-55 mm with the straight channel of circular cross-section, hexagonally packed to a very high degree of uniformity. Square channel MCPs [3] provide a larger open area compared with the circular ones. The hard X-ray detection model can be based on MCP parameters and such a modeling is reported by Shikhaliev [4]. It is shown that at higher X-ray energies the quantum detection efficiency can be composed of uniformity. Square channel MCPs [3] provide a larger open area compared with the circular ones. The hard X-ray detection model can be based on MCP parameters and such a modeling is reported by Shikhaliev [4]. It is shown that at higher X-ray energies the quantum detection efficiency can be composed of the four probability functions such as

$$P=P_1P_2P_3\,P_4. \qquad (1)$$

The described model considers the X-ray interaction probability (P_1, X-ray absorption efficiency), the probability that primary electron reaches the channel (P_2, electron decay probability), the probability of producing an avalanche by the primary electron (P_3), and finally the probability of detecting such electron avalanche by an electronic devices (P_4, gain factor). This study assume P_3P_4 product is optimized to one and mainly concerns with the first two functions that depend on the geometrical parameters, composition of the material, and the X-ray energy range given by

$$P=\{1-\exp[-\mu L(1-a/(1+w/d)^2)]\}\,\exp[k(bw(2+w/d)+cd)] \qquad (2)$$

Where a, b, c determine the kind of MCP, L (thickness), d (opening width), w (wall thickness) are geometrical parameters of the MCP, $\mu(E)$ and k(E) are X-ray and electron absorption coefficients of the MCP material. These two parameters depend on the chemical composition of the MCP material and the X-ray energy. Detection model is based on photoelectric effect, Auger electrons, and the Compton effect depending on the X-ray photon energy. The soft X-ray interact with the input surface of an MCP, while a hard X-ray photon penetrates more into an MCP and the detection process is determined by the ray interaction in the MCP bulk. Photoelectron results in electrons in Pb and silicon while Auger electron results at energies higher than 400 keV. For the MCP detectors the hard X-ray detection mechanism differs from that of the charged particles and soft X-ray. In this case the primary electrons can consists of photoelectrons produced in the lead atoms, another produced in the silicon atoms. Other groups corresponding Auger and Compton electrons. However, most of the electrons are because of photoelectron in lead atoms due to the higher photoeffect interaction probability. Quantum detection efficiency is a figure of merit, which depends on the geometrical, composional parameters, and quantum energy range.

The geometrical probability functions that provide optimum quantum detection efficiency are described in this study. A limitation of a channel multiplier is the surface area of the entrances to the channel, which is usually less than the surface area of the entrance plate. For this reason, MCPs with the circular, square, and hexagonal channels are examined. Fig.3 shows the variation of geometric efficiency as a function of wall thickness for such given geometries.

As can be seen in Fig. 3 for square and hexagonal type, at X-ray energy of E=25keV, there is an optimum wall thickness w that maximizes this efficiency, while for the circular channel efficiency decreases exponentially. The geometrical efficiency as a function of the wall thickness for different thickness values is presented in Fig.4. The computation of this efficiency is based on Eq. (2) in which the cross section is considered to be a square with a width of d=15 μm. As can be seen in Fig. 4, for a given X-ray energy of E=40 keV (μ, and k are calculated) for this MCP, an optimum w can be obtained for each L value. For L=1 mm, the maximum detection efficiency is at w=0.5 μm, while for L=3 μmm this optimum value corresponds to w=0.2 μm. this comparison also indicates that as we increase L from 1 to 3 mm the geometric efficiency is increased from about 35% to 60%.

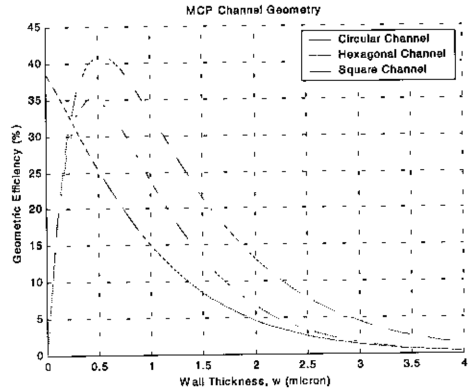

Figure 3. Geometric efficiency as a function of the wall thickness for different channel geometries. For a X-ray energy of E=25 keV, an optimum w can be obtained for square and hexagonal channels.

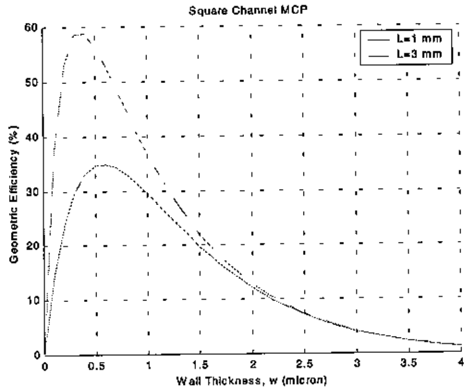

Figure 4. Geometric efficiency as a function of the wall thickness for different lengths L. For a X-ray energy of E=40 keV, an optimum w can be obtained for each L value. For L=1 mm, the maximum detection efficiency is at w=0.5 μm, while for L=3 μmm this optimum value corresponds to w=0.2 μm. Increasing L from 1 to 3 mm, the geometric efficiency increases from about 35% to 60%.

In a similar study the variation of the geometric efficiency as a function of the open width, d, for different L values is shown in Fig.5. As described in the previous case for each L value there exists an optimum d value for a channel thickness of w=1μm. Other parameters are fixed in this study. As expected for such energy range the geometric efficiency is increased as we increase MCP thickness. For L=1 mm the optimum efficiency is about 48% while for L=3 mm the optimum value as high as 57% can be theoretically obtained as noted from Fig.5, the optimum d value for L=1 mm is about 2m and for L=3 mm is shifted to d=4m while other parameters are kept constant. In comparing Fig.4 and Fig.5 for the same L values the reason that we get two different w/d values is that we considered two different energies and as a result μ and k are different for two figures.

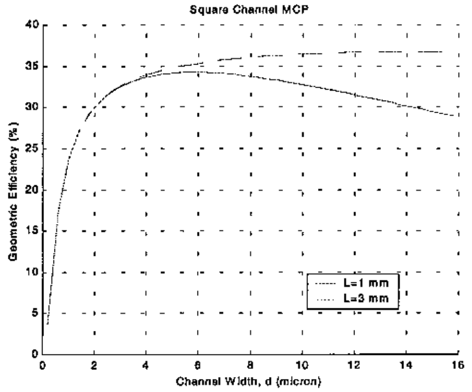

Figure 5. Variation of geometric efficiency as a function of the channel open width for different lengths. For a X-ray energy of E= 40 keV, an optimum d can be obtained for each L value. For L=1 mm, the maximum detection efficiency is at d=6 μm, while for L=3 μmm this efficiency is highest for a value of d=8 μm. Increasing L from 1 to 3 mm the geometric efficiency increases from about 33% to 37%.

MCP X-ray Position Sensitive Detectors

High amplification can be obtained in a dynode multiplier structure, but only at the expense of spatial resolution. The geometry of a dynode does not ensure that the electrons travel in a straight line; as a result, electrons emitted from a given region of the photocathode do not necessarily land in the corresponding region of the anode. The MCP is a device, which combines the spatial resolution of an image intensifier, and each multiplier corresponds to a single pixel, or picture element. The intensified image is a pattern of fine dots of varying brightness.

The output of an MCP need not to be registered on a fluorescent screen and can be detected by an appropriate readout device In this combination an anode instead of the phosphor screen is placed behind the MCP. This acts a detector for the MCP and can be in different forms. Here anode registers the position of a pulse of electrons emerging from a MCP so that data can be stored or manipulated. A microchannel photomultiplier can be designed so that the position of anode can be decoded electrically. The position encoding can be accomplished by two methods of analog and digital readout circuits. The simplest way to accomplish this is to provide each pixel with its own anode and detecting circuit. In order to reduce the number of the trigger circuits each pulse can be detected simultaneously on overlapping grids of vertical and horizontal wires. Another kind of position sensing anode encode the coordinates of the electron pulse in an analog or continuous manner. A number of one- and two –dimensional electronic position encoders have been used to exploit MCP's imaging potential [6]. These position sensitive anodes may include an array of separate anodes, wire anode grids, anodes providing binary output, capacitor strings, resistive plate, a quadrant or a wedge-strip anode geometries. Low-distortion resistive anodes for two-dimensional position –sensitive MCP systems are reported in [5]. Capacitive and resistive charge divisors method can be used to determine charge position. Charge sharing encoders can be used as a position encoder. Anodes for this purpose can be in the form of four-quadrant, Backgammon, wedge-and-strip (WS) [7], and graded density (GD) grid anode. Although the four quadrants is the simplest of class of low-noise position encoder, but WS and GD anodes provide lower nonlinearity. In each case the ratios of the charge detected by the various circuit can give the position of a pulse of the MCP to within a few thousands of the diameter of the field of view. Charge ratios must be calculated in both the horizontal and vertical directions so that the spatial coordinates of the pulse can be determined. In digital readout the position of the pulse can be encoded as a binary number.

PARAMETER CONSIDERATIONS

Table 1 shows the basic characteristics and requirements for the more efficient MCPs. The surface layer of the processed glass becomes a semiconductor with resistivity of 10^8 to 10^{14} ohms per square. There are three main fabrication methods for MCP construction including metal core process (coated glass on a fine wire), grooved-plate process (parallel grooves are etched photolithography, and the two-draw process (glass cylinder and hexagonal bundle of fibers). High uniformity in the diameter of the channels play important role and an MCP with very uniform channels was first fabricated in Mullard research laboratory.

The quantum efficiency of bare MCPs for VUV and soft X-ray detections are low (10%) depending on the photon energies. This efficiency normally decreases by increasing the photon energy and also shows decrease by increasing the photon incident angle. A material of relatively high photoelectric yield can be deposited on the MCPs front surface and channel walls in order to enhance the soft X-ray sensitivity. Practically, MgF_2 and CsI are used for the wavelength range of 8.3-67 A and EUV for the range of 200-2000A. MCP quantum efficiency is usually reported at a certain incidence angle. At energy range of 0.28-1.5 keV corresponding to the K absorption line of C and Al, respectively, a coating thickness of 1400 A CsI shows an efficiency of about 60% at the normal incident angle. MCP soft X-ray quantum detection efficiency is independent of channel diameter and pitch. Some important parameters of the MCP for the soft X-ray detection and imaging are shown in Table 2. For a single photon or charged particles counting MCPs is used in a high gain configuration that provides a saturated (peak) pulse height distribution (phd).

Such case has a gain of 106-108 with a small fwhm ΔG/G of (<50%). Table 3 shows the major parameters, which are important in design and operation of the MCP based position sensitive detectors. These include readout geometry; anode material and shape; position sensing method, nonlinearity and distortion in output, and finally the image quality.

For the case of detectors for the hard X-rays, as mentioned the detection process passes from a single channel mode to a bulk absorber mode in which the thick MCPs with thin channel walls provide the best detection efficiencies. It is found that a thicker MCP with thin channel wall, small septal thickness provides the highest detection efficiency. It is shown that for a given X-ray energy, and thickness value, there is an optimum wall thinness to opening ratio, which is different for each geometry. In spite of the several advantages of MCPs they have four major physical constraints that limit their performance. Table 4 lists major physical constraints for MCP construction. First, the average output signal that can be sustained in the walls of the MCP. When the flux of electrons is too great, electric charge removed from the glass is not replaced immediately and the trend is modified; as a result the average gain of the channel is reduced.

The second limitation of a channel multiplier is a phenomenon called " ion feedback". When the channel is operating at high gain, gas atoms in the channel can be ionized by collisions with the cathode electrons. Ions formed in this way are accelerated by the electric field toward the input end of the tube, where it may strike the channel wall and initiate a new cascade. Moreover the ions that strike the photocathode can shorten its lifetime, although a thin film of aluminum oxide now prevents damage of this kind over the entrance face of the plate. One way to minimize ion feedback is to make the channel curve or zigzag. Electrons easily cascade toward the anode, but the ions are inhabited from moving toward the photocathode by collisions with the walls.

A third limitation of a channel multiplier is charge density of the electrons in the channel, which is called the "space charge". The forth limitation of the microchannel plate governs its efficiency. The surface area of the entrances to the channel is normally less than the surface area of the entrance plate. If circular channels are employed, the ratio of the total channel cross section to the plate area is less than 91% owing to geometric constraints; because of the thickness of the channel walls the ratio in most MCPs is only about 55%. This number is half of the input flux strikes the metal-plated web area between the channel entrances. Certain strategies can be adopted to reduce this loss. If a strong electrostatic field is applied to the front of the plate, the electrons emitted from the web areas can be pulled into an adjoining channel and so initiate a cascade. The entrances to the channels can also be made funnel-shaped by etching the wafer, raising the ratio of channel area to total surface area. Several designers are experimenting with square or hexagonal channels, which pack together more efficiently than channels with a circular cross section.

Table 1: Basic characteristics and requirements for the MCPs.

1.	**Channel Material,** wall channels must emit more electrons than absorb, many glasses emit an average of two electrons for each incident electron
2.	**Electrical Conductivity,** electrical conductivity of the glass material must be predictable and controllable, in a glass electric current can be conducted by the diffusion of either free electrons or of ions
3.	**Material Type,** most successful material is a mixture of 40% silicon dioxide, 50% of lead oxide, and smaller quantities of several alkali oxides.
4.	**Material Resistivity,** surface resistivity of the material should be in the range of 10^8 to 10^{14} ohm per square
5.	**Amplifying Elements,** to produce high-quality image many amplifying elements are required, as many as 5000 channels packed with the 0.15 mm spacing between the channels.
6.	**Production Method,** there are basically three manufacturing production methods. The metal-core process, the grooved-plate, and the two-draw process. The second and third methods give better results.

Table 2: Important parameters in the MCP soft X-ray detector design and operations.

PARAMETER	DESCRIPTION
plate surface	Plano-concave, bi-concave
Gain fatigue	Useful gain lifetime at constant bias voltage ($6x10^7$ counts mm^{-2} at $G=10^7$)
Gain degradation	Compositional change in active layer, charge depleted from the wall
Initial gain G_0	2×10^2-1.2×10^7
MCP type	Single curved channel, strip, ring-shape, single Mullard, Type X,Y chevron
Image hotspots	Dust particles on the surface, poor voltage contacts, plate imperfections
Operational mode	Pulse saturated, poorly saturated, current unsaturated (linear mode)
Dynamic range	Operating energy range, soft (0.2-10 keV) and hard X-rays(>10 keV)
Length/Diameter	Length to channel diameter ratio, L/D=80-120 (D=10-50 μm)
Lifetime	Abstracted charge/channel (10^{-9}-10^{-5}C)
Count rates	10-1000 (#/s)
Efficiency	Higher efficiency for soft X-rays
Dark noise	Field emission from channel defects (1 counts $cm^{-2}s^{-1}$)

Table 3: Important parameters in the MCP based position sensitive detector.

PARAMETER: DESCRIPTION
Readout geometry: Discrete counter patterns and a continuous charge measuring output
Anode material: Resistive (charged particles, photons) and silicon (X- ray)
Anode shape: Square, circular or special shape
Position sensing: Wire grid, capacitor strings, four quadrant, graded density grid, wedge strip
Nonlinearity: Determines the nonlinearity of the output signal
Distortion: Determines the image similarity to input spectrum
Image Quality: Need for image with a good spatial resolution and quality

Table 4: Major physical constraints for MCP construction for X-rays.

1.	**Gain Degradation:** When the flux of electrons is too great, electric charge removed from the glass is not replaced immediately and as a result the average gain of the channel is reduced.
2.	**Feedback:** When the channel is operating at high gain, gas atoms in the channel can be ionized by collisions with the cathode electrons. Ions formed in this way are accelerated by the electric field toward the input end of the tube, where it may strike the channel wall and initiate a new cascade.
3.	**Space Charge:** When the channel is operating at high gain. Charge density of the electrons in the channel produces a disturbing field that limits the gain.
4.	**Efficiency:** Geometrical efficiency defined by the open area to total area. Depends on the geometry, for hexagonal channel is higher (50%).
5.	**Fabrication:** High Quantum efficiency requires small wall thickness and opening, but MCPs with d<10 μm and w<1 μm are hard to construct.

CONCLUSION

It has been shown that the quantum detection efficiency depends on four probability functions. As we notice from Figs 4 and Fig. 5, for every value of X-ray energy an optimum combination of L, d, w exists. To improve the detection efficiency of hard X-ray with energy E>100 keV increasing of L and optimizing w/d is required. For the energy range E<60 keV decreasing of d and w and optimization of w/d is also helpful. The characteristic efficiency of MCP depends on parameters is predetermined by the physical conditions described in this study, some corrections in the detection model after precise experiments are possible. Some of the MCP parameters can be easily varied for optimization of MCP quantum efficiency. For example, the described model shows that the higher thickness offers higher efficiencies, and practically we can fabricate devices with higher thickness. The standard channel wall thickness is small for the X-ray energy range E> 150 keV. This correction can be made because decreasing of the lead concentration and increasing the wall thickness is not limited practically. On the contrarily, decreasing of the channel diameter and wall thickness is strongly limited, and MCPs with d<10 μm and w<1 μm are hard to construct. For soft x-ray detection there has been a tendency to decrease the channel diameter, which improves the MCP position resolution, and to increase the MCP open area fraction, which increases the MCP sensivity and the image quality. Some special clues given in this study can be used to optimize hard X-ray detectors comparable with the scintillation detector efficiencies and preserve the high position resolution of MCP.

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