Microchannel Plates

Microchannel plates (MCPs) are compact electron multipliers of high gain. They have been used in a wider range of particle and photon detection systems perhaps more than any other kind of detector.

A typical MCP consists of about 10,000,000 closely packed channels of common diameter which are formed by drawing, etching, or firing in hydrogen, a lead glass matrix. Typically, the diameter of each channel is ~ 10 microns. Each channel acts as an independent, continuous dinode photomultiplier. In astronomy, and in the many other fields that use MCPs, the detectors are generally used for distortionless imaging with very high spatial resolution.

Physical principles of MCP operation

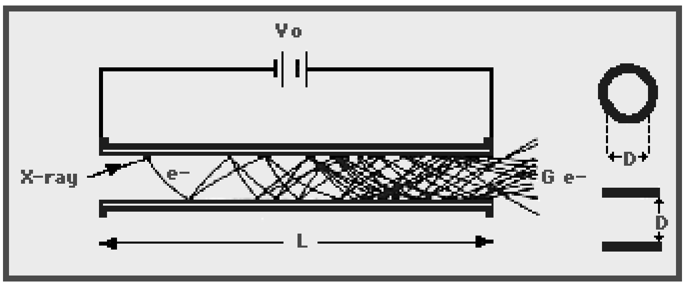
The fundamental physical principals of MCP detectors are gain, efficiency, energy resolution, spatial resolution, time resolution, and dark noise.

X-rays interact with the channel plate glass and electrodes (and with the associated photocathode material) via the photoelectric effect. For X-ray energies below about 5 keV, detection proceeds in a 'single channel mode'. That is, no significant fraction of the X-ray beam entering a given channel penetrates the channel wall to illuminate the neighboring channels. At higher energies, this 'channel crossing' phenomena becomes important.

Another important property of MCPs is their relative immunity to magnetic fields. A single plate with typical operating parameters is completely unaffected by being immersed in a 0.5 Tesla magnetic field. Stacks of plates in certain orientations are immune to much higher fields. This property has only just begun to be exploited in the space astronomy world.

Gain

For single photon or charged particle detection, MCPs are typically used in one of several "high-gain" configurations which produce a saturated (or peaked) output pulse height distribution. Gains of 10^6 - 10^8 are achievable. The governing physical parameter which determines gain is the L/D ratio (length to diameter of the individual channels). The higher the ratio, the higher the gain. Typical values are in the range 75:1 - 175:1. Also, the most commonly used configurations-- the chevron (or 'V' shaped arrangement) and the Z-plate configuration -- will not only produce 10^7 gain factors, but reduce the ion feedback.



The front plate of a chevron pair for use in X-ray astronomy usually has channels perpendicular to its front surface, since the X-rays emerging from a grazing incidence telescope do so along the surface of a cone. The channels of the rear plate are then at an angle of about 15 degrees. This arrangement, as far as we know, has never been proven to be optimal. It is just what is typically used. The gap between the plates is usually about 0. 1 mm. Often an intergap voltage field is also used. These two factors stop the electron cascade from spreading out, and thus reducing the spatial resolution of the detector system, as it crosses between the plates. Recently, other technologies (such as transparent metal meshes) have started to be used rather than the intergap field to produce the same result.

Theoretical and experimental evidence agree that the pulse height FWHM should decrease with decreasing channel diameter. Irrespective of geometry, however, minimal FWHM is achieved when (1) individual stages of the multiplier are independently operated in 'hard' saturation (the plate bias voltages independently exceed a level V_o where $V_o = (8.94(L/D) + 450)V$ and (2) the interplate potential difference is well chosen. The best FWHM from the curved single plate, the V configuration, and the Z configuration is around 30.

Quantum Detection Efficiency

The quantum detection efficiency in X-rays for a single "bare" MCP is a low 1-10%. It is strongly correlated with photon energy (the higher the E, the less the eff) and with the angle of incidence. The efficiency curve has strong peaks associated with angles of incidence which correspond with the critical angle of X-ray reflection from the glass substrate and tends to be zero at both normal (0 degrees) and grazing incidence.

To enhance the efficiency, a material of high photoelectric yield is deposited on the front surface and the channel walls of the MCP. This can increase the overall efficiency to over 30%. Other, more complicated techniques, have been found to push the efficiency to over 60% for the optimum angle of incidence.

Energy Resolution

Until recently, this section would have stated simply "has none". However, CsI-coated chevron MCP detectors have now been shown to possess a limited degree of energy resolution (at least in the soft X-ray region). This occurs, however, only if the bias voltage is well below the saturation voltage. Ultimately, the resolution achieved will be determined by the properties of the coating used on the channel walls.

Spatial Resolution

For any multistage MCP detector at the focus of a grazing incidence telescope, the FWHM spatial resolution is the sum of terms related to the geometry of the X-ray interactions and terms related to the readout element/signal processing chain. Since the functions of the detection/amplification and of position encoding are separable in MCP detectors, a wide range of detector geometries has evolved, each with its resolution dominated by a different term in the sum. However, in all cases, the fundamental resolution is the channel diameter.

Temporal Resolution

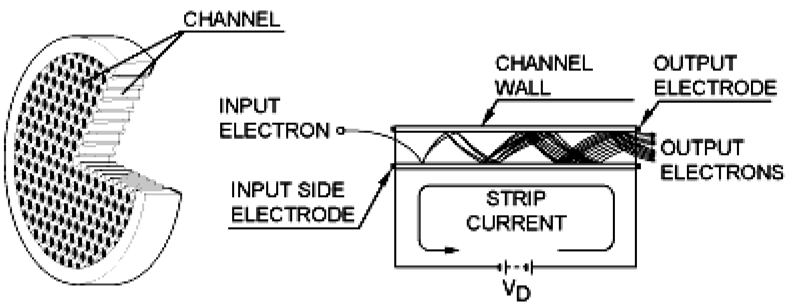
In general, the time resolution of a satellite-borne MCP detector is determined by the telemetry rate. MCPs are intrinsically very fast detectors. The pulse transit time through the intense electric field is of order 10^{-10} seconds. The transit time for a single plate with a length to diameter ratio of 40:1 operating under typical voltages is about 50 picoseconds.

Dark Noise

Usually, the internal background count, or dark noise, in the current generation of MCPs is uniformly distributed across the plate with a value of 0.2 cts/sec/sq-cm. This is rather high compared to rates seen in the most commonly used proportional counters. However, it is more indicative of the sophistication of scintillator rejection techniques and the ignorance of MCP noise than any intrinsic behavior. Also, contamination by potassium and rubidium cause the background to be higher in MCPs. Better manufacturing will therefore lead to reductions in the dark noise.

Microchannel Plates and Microchannel Plate Detectors

MCP is a specially fabricated plate that amplifies electron signal similar to secondary electron multiplier (SEM). Unlike SEM, MCP has several million independent channels and each channel works as independent electron multiplier. In other words, one can imagine MCP as an assembly of millions miniature SEMs. MCP consists of a two-dimensional periodic array of very-small diameter glass capillaries (channels) fused together and sliced in a thin plate. A single incident particle (ion, electron, photon etc.) enters a channel and emits an electron from the channel wall. Secondary electrons are accelerated by an electric field developed by a voltage applied across the both ends of the MCP. They travel along their parabolic trajectories until they in turn strike the channel surface, thus producing more secondary electrons. This process is repeated many times along the channel; as a result, this cascade process yields a cloud of several thousand electrons, which emerge from the rear of the plate. If two or more MCPs are operated in series, a single input event will generate a pulse of 10^8 or more electrons at the output.



Since the individual channels confine the pulse, the spatial pattern of electron pulses at the rear of the plate preserve the pattern (image) particles incident on the front surface. The output signals are typically collected in any of several ways, including metal or multimetal anodes, resistive anode (one- or two- dimensional), wedge and strip anode, Delay-Line Readout or on a phosphor screen deposited on a fiberoptic or other substrate.

Microchannel Plates have a combination of unique properties like high gain, high spatial resolution and high temporal resolution. They can be used in a large variety of applications including, imaging spectroscopy, electron spectroscopy and microscopy, mass spectrometry, astronomy, molecular and atomic collision studies, cluster physics etc. Most of these applications require only some of MCP properties, for example Time-of-Flight Mass Spectrometry require high temporal resolution of MCPs, imaging of single atoms in field ion microscopes or X-ray imaging of the Sun require mainly spatial resolution. Particle analysers may be produced by using a MCP detector at the output of a electrostatic and/or magnetic dispersion system. Very high sensitivity optical, UV and EUV and X-ray spectrometers can also be produced with appropriate filtering and dispersive elements. The same microchannel plate technology is used to make visible light image intensifiers for night vision goggles and binoculars.

Detectors based on Microchannel Plates have variety of designs depending on the type of particles detected, throughput (counts/second), time and position resolution, imaging area, linearity and sensitivity, signal to noise ratio and other requirements. It's a challenge to detector developer to optimize detector design for particular application.

In general, each detector that uses MCPs consists of three parts:

1) A Converter - a mechanism to convert initial particles in photons or electrons,

2) An Assembly of MCPs - a mechanism to amplify initial single electron or photon event into electron pulse and

3) A Readout Device - a mechanism to detect the electron avalanche.

1. A Converter is the part responsible for conversion of initial particles into electrons or photons that in turn efficiently interact with a Microchannel Plate. Photocathodes are used for visible and IR radiation. Open, windowless photocathodes of CsI or MgF_2 deposited on MCP operate well through the extreme UV and soft x-ray region. Specially formulated luminescent screens are used for neutrons, heavy ions and high-energy particles. The MCP is directly sensitive to ultraviolet rays (VUV, UV), X-rays, (-rays, charged particles, and neutrons, as well as electron beams, that's why no Converters are usually necessary for ion detection in mass-spectrometry applications and UV and VUV radiation.
2. An Assembly of MCPs consists of single, double (so-called Chevron or V-stack) or triple (Z-stack) MCPs adjacent to one another. Number of MCPs required depends on application. For example typical image intensifier for low-level light contains single MCP, typical TOF-MS ion detector has two MCP. A three plate (Z-stack) MCP Detector is used to detect (count) and image single particles.
3. The choice of electronic readout will depend upon requirements.
   For detection and particle counting applications where position resolution is not required, single metal anode can be used as a readout device. MCP detectors with metal anode are widely used in mass-spectrometry.
   For imaging applications with low temporal resolution phosphor screen (P20, P22, P46, etc.) coupled with CCD camera can be used. Gated versions as fast as 10 nanoseconds are also available.
   For imaging applications with moderate and high temporal resolution state-of-the art anode configurations have been developed that fall into the following classes:
   Resistive anodes (one and two dimensional)
   Wedge and strip designs
   Delay-Line-Readout
   The readout electronics should be matched to the anode configuration.

Del Mar Ventures supply Microchannel Plates, MCP assemblies as well as custom-made systems including mounting and readout device(s). This brochure describes Microchannel Plates, Open Microchannel Plates Detectors with Metal Anode and Open Imaging Detectors (Image Intensifiers).

Microchannel Plates

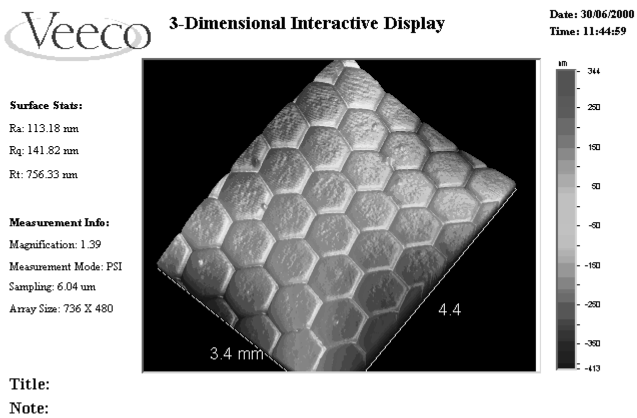
The microchannel plate is an open multiplier intended for registration of particles and radiations. MCPs represent 0.4-3.0 mm thick plates of round or rectangular shape. They have a honeycomb structure and contain in one square centimeter up to one million of separate channels of 5-15 μ m diameter. In addition to design simplicity, small dimensio and absence of external voltage divider, MCPs feature high time and spatial resolution capability.

Construction and Operation

A Microchannel Plate begins as a glass tube fitted with a solid, acid-etchable core and drawn via fiberoptic techniques to form single fibers. A number of these fibers are then stacked in a hexagonal array; the entire assembly is drawn again to form multi-fibers. The multi-fibers are then stacked together and fused at high temperature to form a boule.

The boule is sliced on a wafer saw to the required bias angle, edged to size, and then ground and polished to an optical finish. The individual slices are chemically processed to remove the solid core material, leaving a "honeycomb" structure of millions of tiny holes.

Through subsequent processing, this glass wafer is given its conductive and secondary emissive properties. Finally, a thin metal electrode (usually Inconel, Nichrome or chromium) is vacuum-deposited on both input and output surfaces of the wafer to electrically connect all the channels in parallel.



Honeycomb structure of Microchannel Plates.
For additional images of Microchannel Plate surface at different spatial resolution click here.

For normal operation, a bias of about 1000 Volts is applied across the microchannel plate, with the output at its most positive potential. The bias current flowing through the plate resistance is what supplies the electrons necessary to continue the secondary emission process. Electron multiplying process was described above. Below we consider most important properties of Microchannel Plates.

Shape and Size

Microchannel plate arrays may be fabricated in a wide variety of formats. The MCPs may range in size from 6mm to 100mm or larger, and they may be circular, rectangular, or virtually any other shape as required by the application or instrument geometry. In addition, a cylindrical or spherical radius of curvature may be provided to conform to the focal plane of an instrument.

A border glass area surrounds an effective area of MCP where channels are arrayed. Table below shows dimensions of standard MCPs, supplied by Del Mar Ventures.

MCP type (part #)	25-10E*	33-10E	34-10	46-12	56-15	43*63	70*90
Diameter, mm	24.8	32.8	34	46	56		
Length, mm						63	90
Width, mm						43	70
Effective Diameter, mm	18	25	30	40	50	38*58	65*85
Channel Diameter, μ m	10	10	10	12	15	15	15

MCP Thickness and Channel Diameter

The length of the channel of a MCP is virtually its thickness. The ratio of the channel length (L) to the channel diameter (d) L/d, as well as the inherent secondary emission factor of the channel wall material determines the gain of the MCP. The standard MCPs are fabricated with a L/d ratio about 40 to 80.

Channel Bias Angle

The channel bias angle is an angle formed by the channel axis and the vertical axis to plate surface. Channels are tilted to prevent incident particles from passing through the channels. The optimum angle is between 5° and 15° .

Open Area Ratio (OAR)

The OAR is the ratio of the open area to the total effective area of the MCP. For hexagonal arrays $OAR=(\pi *O\ 3/6)*(d/P)^2$ where d is a channel diameter and P is a pitch (period of the hexagonal structure, or c-c distance). For 10-12 structure (d=10μ m, P=12μ m) OAR=63%, for 12-15 it's 58%, for 15-18 it's 63%. OAR limits ultimate detection sensitivity of MCPs. Particles incident on the MCP between channels are not detected. In many applications it is desired to make OAR as large as possible for more efficient input of primary electrons. For this purpose, there are custom MCPs in which the glass channel walls on the input side have been etched to increase the OAR up to 70 to 80%.

Metal Coating (Electrodes)

Over the input and output surfaces of a MCP, Inconel, Ni-Cr or Cr is evaporated to form electrodes. The thickness of the electrodes is controlled to have a surface resistance of 100 to 200Ω between the MCP edge. In general, the electrodes are evaporated to uniformly penetrate into the channels. The penetration depth significantly affects the angular and energy distributions of the output electrons, and usually chosen to be in the range of the channel diameter multiplied by 0.5 to 2. In such demanding applications as image intensification where spatial resolution is of prime importance, the penetration depth of the electrodes is controlled to be deeper in order to collimate the output electrons.

Gain

The gain of an MCP, g, is given by the following equation using the length-to-diameter ratio of the channel: g= exp (G*(L/d), where G is the secondary emission characteristics of the channel called gain factor. This gain factor is an inherent characteristic of the channel wall material and represented by a function of the electric field intensity inside the channel. Generally, L/D is designed to be around 40, which produces a gain of 10^4 with an applied voltage of 1 kV.

When an even higher gain is required, two or three MCPs are used to configure the two-stage or three-stage MCP assembly. These stacked MCP detectors can offer higher gains up to 10^8-10^9. Multiple-stage MCP gains are not the simple multiplication of the gain of each MCP because of the gain saturation caused by space charge effect near the output region of channels.

In these configurations the spatial resolution is degraded to some extent because a multiplying electron current spreads into several channels as it enters the latter-stage MCP. On the other hand the saturation level increases by a factor equal to the number of those spread channels.

Pulse height distribution

When a single particle create a single electron event in MCP, the output pulse height distribution shows normally an exponential function. However, in the region where the gain is saturated due to space charge effect, the pulse height distribution becomes peaked. This phenomenon is observed in the MCPs operating at a high gain, for instance, stacked MCPs.

Pulse height distribution is usually characterized by the ratio of the half-width at peak (full width at half maximum: FWHM) to the peak value in the pulse height distribution: FWHM/A; it is normally expressed in percentage. In general, is shows 120% or less for two-stage MCPs and 80% or less for three-stage MCPs.

Transit time

The transit time of MCP assemblies is very small. Due to the shorter electron transit distance compared to the discrete dynode used in the conventional PMT or SEM, transit time of the electron avalanche in MCP channels is in 100 ps range. The width of the single event peak determined mainly by temporal characteristics of readout device and electronics. Ultimate time resolution can be achieved using anode configuration matched with 50 Ω connector cable.

Spatial Resolution

Since each channel of the MCP serves as an independent electron multiplier, the channel diameter and center-to-center (c-c) spacing determine MCP resolution. Channel diameters ranging from 5 μ m (6 μ m c-c) to 15 μ m (18 μ m c-c) are standard.

When the output from MCP is observed with a phosphor screen, the spatial resolution also depends on the MCP electrode depth penetrating into the channels, the space between the MCP and the phosphor screen, and the accelerating voltage. Typical spatial resolution of a MCP composed of 10 μ m diameter channels, which is observed with a phosphor screen, is about 40 l/mm. In the stacked MCP, the spatial resolution is less compared to that of a single MCP because it spreads into many channels as it enters the latter-stage MCP, and also because the increased gain makes greater the electrostatic repulsion in the space when the electrons are released from the MCP.

Dark Current

A typical MCP shows an exceptionally low dark current, less than 0.5pA/cm2 at an applied voltage of 1 kV. Even with a two or three-stage MCP, the dark count rate is low, less than 3 cps/cm2 at an applied voltage of 1 kV per stage.

Resistance

Glass composition and reduction processing conditions (time and temperature) can control the MCP resistance. Considering the output saturation, a lower resistance is desirable; however, there is a limitation in lowering the resistance as the MCP operating temperature rises due to higher power consumption.

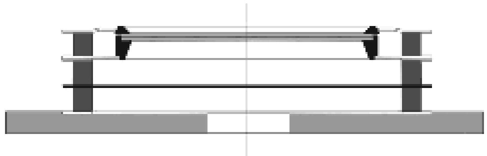
MCP resistance is typically in the range between 100 and 1000 MΩ . For applications requiring high output currents, low-resistance MCPs of 20 to 30 MΩ are available.

Microchannel Plate Detectors with Single Metal Anode (MCP-MA)

	DEL MAR VENTURES Microchannel Plate Detectors MCP-MA series are an open MCP detectors with one or more microchannel plates and a single metal anode. They are intended for time-resolved detection and make use of high-speed response properties of the MCPs. MCP-MA detectors are used for photons and particles detection in vacuum chambers or in the space.

The body of assembly is a metal-ceramic housing.

Drawing shows two matched MCPs in V-stack (Chevron) assembly (shown green), which are fixed in place using retainer ring (above MCPs). Metal anode shown blue. Ceramic insulator rings are shown red. Detector can be spot-welded or connected by screws to the support surface (shown grey).



All parts of the assembly are highest quality components. Metal parts are polished to avoid electric discharges. Two MCPs are connected to each other via thin (40 -50 µm) copper or stainless steel foil ring. Direction of channel bias angle in the first MCP is opposite to one in the second MCP (chevron assembly). Typical voltages necessary for a gain of 10^4, resistances and dark current densities of Microchannel Plates are shown in the table below. Each detector is supplied with individual MCP data.

Specifications:

	MCP-MA25	MCP-MA34	MCP-MA46
MCP detector body	metal-ceramic housing		
Effective area ? , min	18mm	25mm	40mm
MCP type	25-5, 24-10, 25-10 etc.	33-10 or 34-10	46-12
MCP Diameter, mm	24.2 or 24.8	32.8 or 34	46
MCP Thickness, mm	0.46	0.46	0.5
MCP channels pore-pitch, µm	5-6, or 10-12	10 –12	12-15
Typical Gain, (one MCP)	10^4 - 10^4		
(2 stack)	10^6 - 10^7		
(3 stack)	10^8 - 10^9		

Time resolution	< 1ns		
PHD (2 stack assembly)	FWHM/A<120%		
PHD (3 stack assembly)	FWHM/A<80%		
Output	Single metal anode		
Strip current	<20µA		
Outside diameter, mm	30.8	45	60
Detector height	11mm		

Operation conditions:

Wiring Methods

In general, MCP assemblies can be operated with any electrode (MCP-in, MCP-out or anode) at a ground potential.

1. Voltage Application

   When applying a voltage, do not apply the necessary voltage to the MCP at once. Slowly increase the applied voltage, with maximum 100 V step, until the optimum rating is reached, and verify if the MCP operates properly. In this procedure, also check the dark current by connecting an ammeter to the readout device. If there is an increase in the dark current, which might result from a small discharge, immediately turn off the applied voltage. After some time (depending on the situation) has passed, apply voltage to the MCP again in the same manner as described above. Note that the applied voltage to the MCP should be increased as slowly as possible even after normal operation has been verified.

2. Applied Voltage

Recommended and maximum applied voltage to MCPs and readout devices are as follows:

- Between MCP-in and MCP-out:

Set this voltage according to the required gain, 700 -1000V per MCP typical, 1100 V maximum, MCP out at positive polarity.

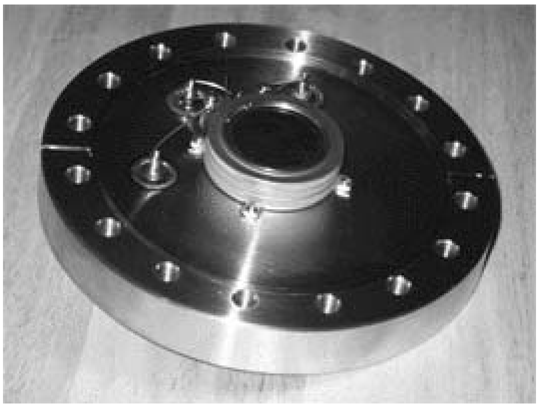
- Between MCP-out and single anode:

This is normally set at about 100 - 200 V.

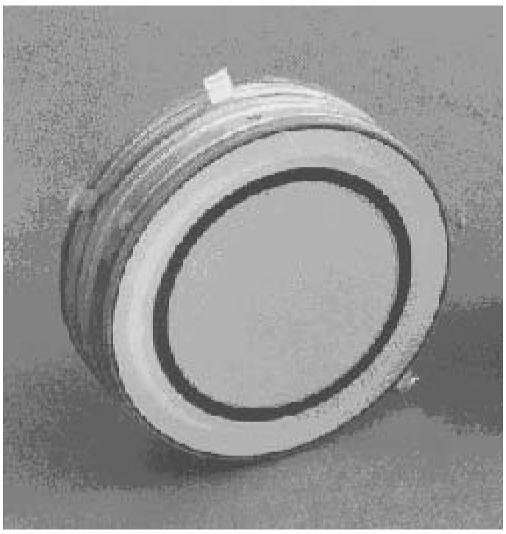
A system pressure better than $6.5*10^{-4}$ Pa ($5 *10^{-6}$ Torr) is necessary for proper operation. The MCP detector has to be degassed before applying the maximum voltage. Because the MCP is operated with a high voltage of about 1 kV per stage, a relatively high degree of vacuum must be required. If the MCP is operated at a deficient vacuum, not only will the noise increase due to the ion generation in the channels, but also the lifetime may be shortened. In the worst case, the MCP may be damaged by discharge. Therefore, it is recommended that the MCP be operated at a degree of vacuum as high as possible. When using a new MCP, it is recommended that before applying a voltage to it, the system be evacuated at a pressure of $6.5*10^{-4}$ Pa ($5*10^{-6}$ Torr) or below for more than 24 hours. If the evacuation time is short or the degree of vacuum is deficient, a discharge may occur.

MCP Detector Mounting

MCP-MA34 detector can be mounted on the standard vacuum flange or on any other substrate. It can be either spot-welded or connected with screws. Figure below shows MCP-MA34 mounted on the standard 6" ConFlat Flange.



Open Microchannel Plate Imaging Detectors (MCP-GPS and MCP-IFP)



Open Microchannel Plate Imaging Detectors have a design similar to MCP detectors with Metal Anode. Instead of simple metal anode an aluminized phosphor screen is used as a readout device. An electron cloud is drawn across a 0.7 mm gap by a high voltage onto micro-crystalline phosphor screen where the kinetic energy of the electrons is released as light.
Due to a high voltage electron image transferred to the visual image practically without distortions (this is called proximity focusing).

The phosphor screens deposited on a glass window are realized in MCP-GPS series and on a fiber-optic plate in MCP-IFP series. Drawing shows a cross-section of the imaging detector with a fiber-optic plate.

The optical image can be viewed directly, or coupled to a camera.

MCP-GPS and MCP-IFP imaging detectors are available in the same sizes and MCP-assembly options as MCP-MA detectors.

Open imaging detectors must be operated in pressures of less than $6.5*10^{-4}$ Pa ($5 *10^{-6}$ Torr).

Recommended and maximum applied voltage to MCPs and phosphor screen are as follows:

- Between MCP-in and MCP-out:

Set this voltage according to the required gain, 700 -1000V per MCP typical, 1100 V maximum, MCP out at positive polarity.

- Between MCP-out and phosphor screen:

A bias in the range 2.5-5 kV between MCP output and screen is required.