TECHNICAL INFORMATION

MCP ASSEMBLY

HAMAMATSU

CONTENTS

1. INTRODUCTION

Demands for instruments to detect and image charged particles such as ions, electrons, neutrons, X-rays, and UV rays has been steadily increasing in many applications including industrial measurement as well as various academic research fields.

A microchannel plate (MCP) consists of millions to tens of millions of ultra-thin conductive glass capillaries from 4 µm to 25 µm in diameter and 0.20 mm to 1.0 mm in length fused together and sliced in the shape of a thin plate. Each of these capillaries (or channels) functions as an independent secondary electron multiplier and they form together a two-dimensional secondary electron multiplier.

MCPs have mainly been used as electron multipliers in image intensifiers since they are highly sensitive to electrons and capable of two-dimensional electron multiplication. Recently, because of their high sensitivity to ions, subnanosecond time response, and compact size, they have been rapidlly applied to time-of-flight mass spectrometry (TOF-MS) that identifies ions by measuring the flight time of ions. Since the MCPs are also sensitive to UV to vacuum UV rays, soft X-rays, and neutrons, they are also proving useful in a variety of applications including academic research fields.

This technical manual describes basic structures and characteristics of the MCPs and their assemblies, in order to help users take full advantage of the superb features and characteristics in many applications. This manual also includes typical applications where our MCP assemblies are in actual use. Some applications being not described here due to space limitations, they are listed at the end of this manual and categorized by application field.

We hope this manual proves beneficial to users in developing new measurement equipment as well as upgrading existing equipment.

2. STRUCTURE AND OPERATING PRINCIPLE OF MCP

2-1 Operating Principle

Figure 1 shows a structure of a microchannel plate (MCP). As seen from the figure, the MCP consists of a two-dimensional array of many ultra-small diameter glass capillaries (channels), which are fused together and sliced in the shape of a thin disc. The inside wall of each channel is processed to have a specified resistance, forming an independent secondary electron multiplier. When an electron or radiation enters a channel, secondary electrons are emitted from the channel wall. Those electrons are accelerated by an electric field developed by a voltage V_D applied across the both end faces of the MCP and strike the opposite wall while traveling along their parabolic trajectories, and in this way produce further secondary electrons. This process is repeated many times along the channel and finally a large number of electrons are released from the output side.

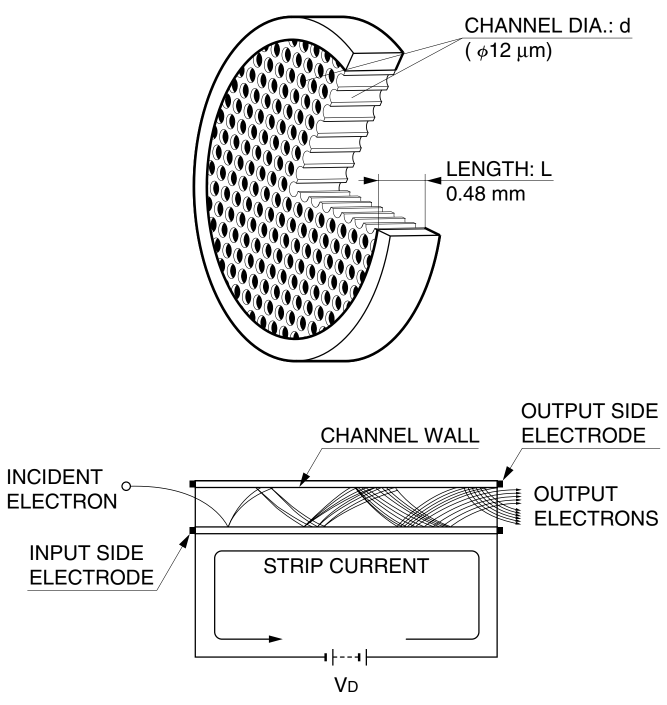


Figure 1: Structure and Operating Principle of MCP

2-2 Shape

The MCP is available in a variety of shapes and sizes, allowing users to choose an optimum type. The MCP is roughly categorized by shape into circular and rectangular types. Their respective dimensions are shown in Figures 2 and 3, and in Tables 1 and 2.

A typical MCP includes an effective area, where a multitude of channels are arrayed, and a border glass area enclosing that effective area. In the process for fabricating an MCP, many glass channels are first bundled very densely and fused into a hexagonal array called a multi-fiber. These multi-fibers are then arrayed to form an effective area. As seen in the figures and tables, an electrode is formed on the border glass that encloses the effective area.

MCPs specially configured with holes (apertures) in their centers are also available. These MCPs are mainly intended for use in electron microscopes in which a primary particle beam (such as an electron beam) is passed through the center hole to excite a sample and the reflected particles or secondary electrons emitted from the sample are then detected and multiplied by the MCP.

2-3 Thickness

The thickness of an MCP is nearly equal to length of the channels. The ratio of channel length (L) to channel diameter (d) is indicated by α (L/d). Gain of the MCP is determined by this α and the inherent secondary emission factor of the channel wall material. This means that MCPs made from the same material and with the same α value have the same gain, even if they are different in size. Standard MCPs are fabricated so that α is 40 to 60. The MCP thickness therefore varies according to the channel diameter, and is the value of the channel diameter multiplied by a figure of 40 to 60.

2-4 OAR (Open Area Ratio)

The OAR shows a ratio of the total open area to the entire effective area of an MCP. The OAR is typically about 60 %, but this ratio is preferably as large as possible to allow primary electrons to enter each channel more effectively. Custom MCPs, therefore, are manufactured with the glass channel walls etched to increase the OAR up to 70 % to 80 % on the input side.

2-5 Bias Angle

The bias angle is an angle formed by the channel axis and the axis perpendicular to the plate surface. This angle is chosen by taking the following factors into account: radiation detection efficiency, preventing effectiveness of incident particles from passing through the channels, ion trap efficiency and the spatial resolution when two or more MCPs are stacked. The optimum value is usually from 5 ° to 15 °.

2-6 Electrodes

Inconel (nickel-bases alloy) or Ni-Cr is evaporated on the input and output surfaces of an MCP to form the electrodes. The electrodes are processed to have a surface resistance of 100 Ω to 200 Ω across the both edges of the MCP surface. When the electrodes are evaporated, a portion of them in each channel is uniformly formed. The depth of these electrodes in each channel is usually manipulated to be within the range of the channel diameter (d) multiplied by a figure of 0.5 to 3.0, and significantly affects the angular and energy distributions of the output electron current. In applications of image intensifiers (I.I.s) where spatial resolution is of prime importance, the depth of the electrodes is controlled to be deeper in order to collimate the output electrons.

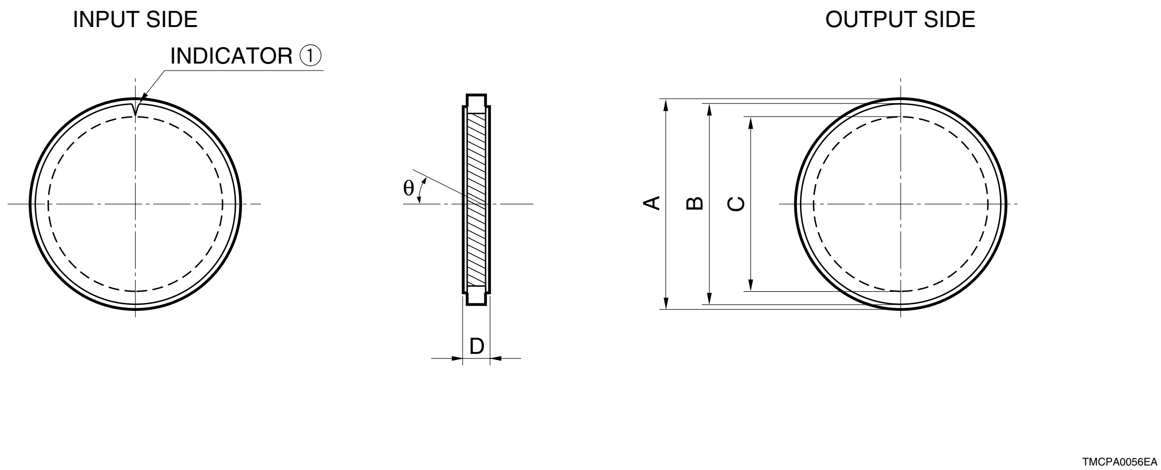


Figure 2: Dimensional Outlines of Circular MCP (Unit: mm)

Table 1: Dimensions and Characteristics of Circular MCPs

Type / Parameter	F1551-01	F1094 ② -01	F1094 ② -09	F6584-01 ③	F1552 ② -01	F1552 ② -09	F1208-01	F1217-01 ②	F1942-04	F2395-04	Unit
Outer Size A	ϕ17.9	ϕ24.8			ϕ32.8		ϕ38.4	ϕ49.9	ϕ86.7	ϕ113.9	mm
Electrode Area B	ϕ17	ϕ23.9			ϕ31.8		ϕ36.5	ϕ49	ϕ84.7	ϕ112	mm
Effective Area C	ϕ14.5	ϕ20			ϕ27		ϕ32	ϕ42	ϕ77	ϕ105	mm
Thickness D	0.48	0.48	0.41	0.48	0.48	0.41	0.48		1.00		mm
Channel Diameter	12	12	10	12	12	10	12		25		μm
Channel Pitch	15	15	12	15	15	12	15		31		μm
Bias Angle θ	8	5, 8, 15	5	8	8, 12		8				degrees
Open Area Ratio	60										%
Electrode Material	Inconel										—
Gain (Min.) ⑤	10^4										—
Resistance ⑤	100 to 700	50 to 500		2 to 30	30 to 300		20 to 200	10 to 200	10 to 100	5 to 50	MΩ
Dark Current (Max.) ⑤	0.5										pA·cm^{-2}
Maximum Linear Output ⑤	7 % of Strip Current ④										—
Supply Voltage ⑥	1.0										kV
Operating Ambient Temperature ⑥	-50 to +70										°C

NOTE: ①This mark indicates the MCP input side.
②Variant types with 6 μm channel diameter are also available.
③Wide dynamic range type designed to obtain high output current. (See the graph "MCP Saturation Characteristics" in the page 2.)
④The strip current is the current which flows along the channel wall when a voltage is applied between MCP IN and OUT. This is found by dividing the applied voltage by the MCP plate resistance.
⑤Supply voltage: 1.0 kV, vacuum: 1.3×10^{-4} Pa, operating ambient temperature: +25 °C
⑥Vacuum: 1.3×10^{-4} Pa

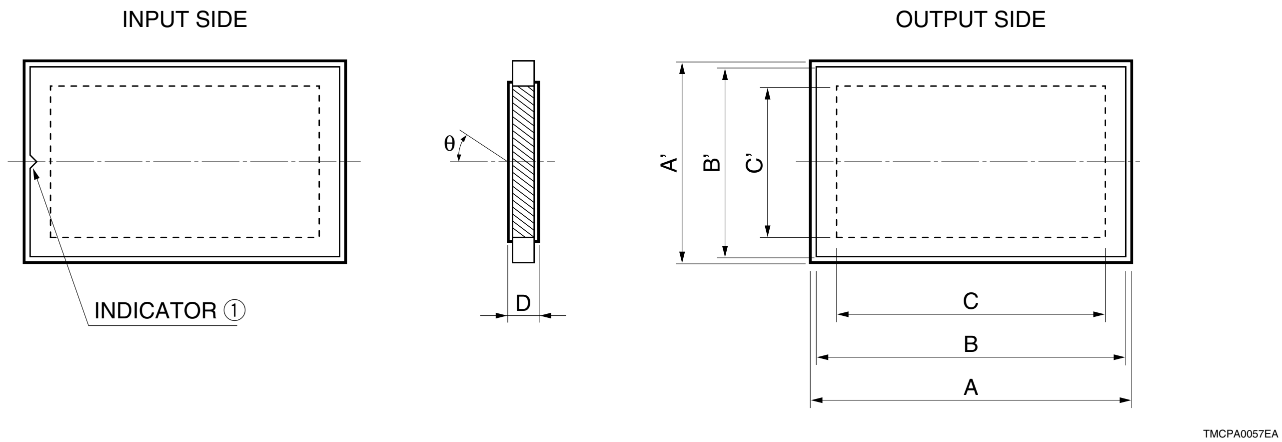


Figure 3: Dimensional Outlines of Rectangular MCP (Unit: mm)

Table 2: Dimensions and Characteristics of Rectangular MCPs

Parameter \ Type	F6492	F2370-01	F4772-01	F2806-01	F1943-02	F2805-03	F2396-04	Unit
Outer Size A×A'	139.9×8.9	15.9×9.4	61.9×13.9	49.9×39.9	87.9×37.9	59.9×59.9	96.9×78.9	mm
Electrode Size B×B'	138×8	15×8.5	61×13	49×39	87×37	58×58	95.6×77.3	mm
Effective Area C×C'	127×4	13×6.5	55×8	45×35	81×31	53×53	90×72	mm
Thickness D	0.48				0.60	0.80	1.00	mm
Channel Diameter	12				15	20	25	µm
Channel Pitch	15				19	25	31	µm
Bias Angle θ	8							degrees
Open Area Ratio	60							%
Electrode Material	Inconel							—
Gain (Min.) ⑤	10^4							—
Resistance ⑤	5 to 50	20 to 120	20 to 200				100 to 500	MΩ
Dark Current (Max.) ⑤	0.5							$pA \cdot cm^{-2}$
Maximum Linear Output ⑤	7 % of Strip Current ④							—
Supply Voltage ⑥	1.0							kV
Operating Ambient Temperature ⑥	-50 to +70							°C

NOTE: ①This mark indicates the MCP input side.
②Variant types with 6 µm channel diameter are also available.
③Wide dynamic range type designed to obtain high output current. (See the graph "MCP Saturation Characteristics" in the page 2.)
④The strip current is the current which flows along the channel wall when a voltage is applied between MCP IN and OUT. This is found by dividing the applied voltage by the MCP plate resistance.
⑤Supply voltage: 1.0 kV, vacuum: 1.3×10^{-4} Pa, operating ambient temperature: +25 °C
⑥Vacuum: 1.3×10^{-4} Pa

3. BASIC MCP CHARACTERISTICS

3-1 Gain and Pulse Height Distribution [1)]

The approximate gain (g) of an MCP is given by $g = \exp(G \cdot \alpha)$ using the length-to-diameter ratio α (=L/d) of the channel. Here, G is the secondary emission characteristics of the channel wall, called the 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. Figure 4 shows the gain characteristics of MCPs made from the same channel wall material but having different α, ranging from 40 to 80.

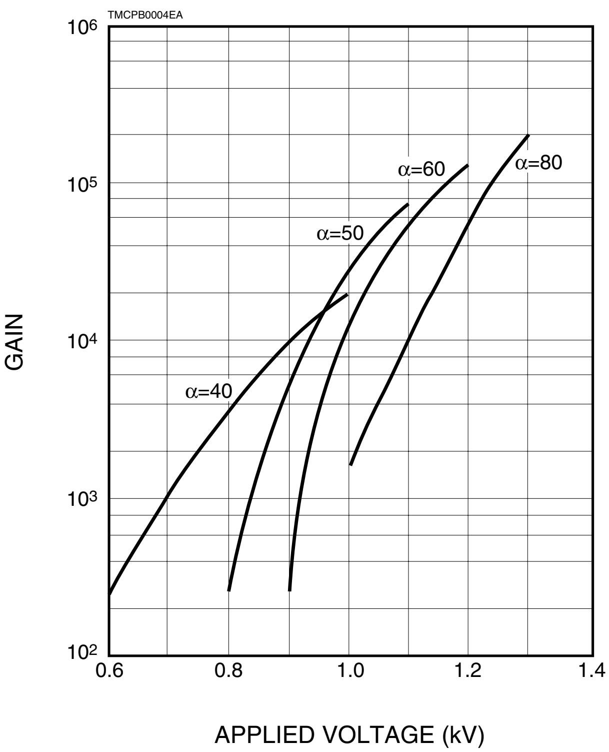


Figure 4: Gain Characteristics of MCPs with Different α (L/d)

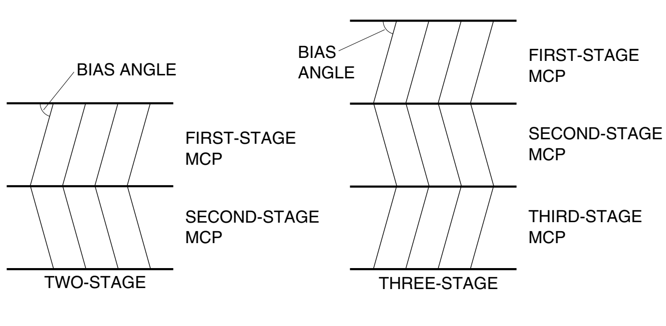


Figure 5: Cross section of 2-stage and 3-stage MCP assemblies

In general, when the α increase, the gain rises in the higher voltage region and get to the higher. However, when the gain exceeds 10^4, the noise increase caused by ion feedback becomes larger, consequentry it is not possible to make the gain of a single MCP infinitely large. The α is generally designed to be 40 to 60, and then the gain becomes 10^4 when the voltage 1 kV is supplied.

When the even higher gains are required, two or three MCPs are used in stacked configurations, newly two-stage or three-stage MCP. These stacked MCPs are useful in the pulse counting mode in which incident weak pulsed signals are converted into binary signals and measured in a way totally different from analog measurement. However, when the gain increases to a certain level, self-generated noises caused by ion feedback effects become a problem. This unwanted phenomenon occurs when residual gas molecules within the MCP channels are ionized by the multiplied electrons. The resultant ions travel back to the MCP input side along the electric field and produce false signals eventually degrading the S/N ratio. To minimize this phenomenon, two or three MCPs are stacked in proximity with their bias angles alternately opposing to each other as shown in Figure 5. This configuration reduces the noise caused by ion feedback effects because the ions generated from residual gases are absorbed at the junction between each MCP, allowing operation at an even higher gain.

Figure 6 shows typical gain characteristics of the single-stage, two-stage and three-stage MCP. As seen in the figure, gains higher than 10^4 are obtained with the single-stage MCP operated at a supply voltage of 1 keV. The two-stage MCP offers gains higher than 10^6 and the three-stage MCP higher than 10^7. In the case of both two and three stage MCP, the total gain is slightly lower than the multipled gain of each MCP because a charge loss occurs when charge moves through each MCP and also because saturation occurs by space charge effects inside the channels.

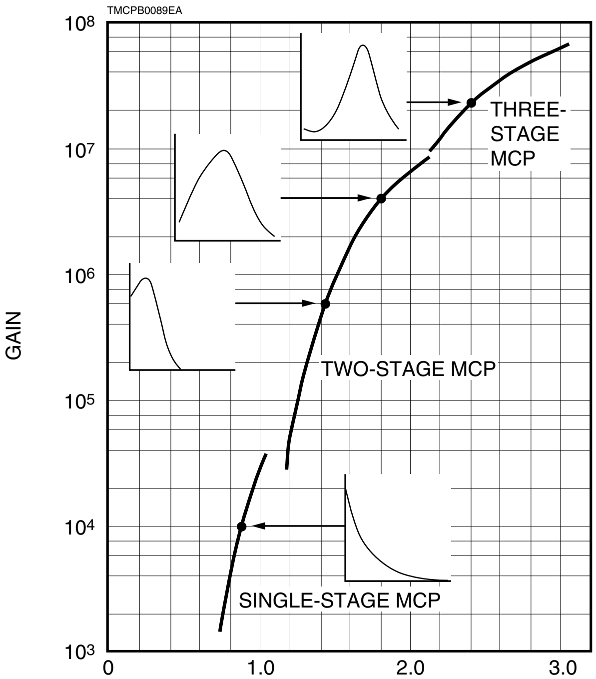


Figure 6: Gain Characteristics and PHD of MCPs with Different Number of Stages

Figure 7 shows typical pulse height distribution characteristics. It is well known that space charge saturation occurs when the MCP gain increases to a certain level. This is a gain saturation inside the channels and is caused by the electrostatic repulsion between the electrons produced inside the channels by the multiplication process and newly emitted secondary electrons. In a non-saturation region observed with the single-stage MCP, the pulse height distribution (PHD) falls off a nearly exponentially. However, in the region where the space charge saturation is predominant, the pulse height distribution becomes peaked with a smaller dispersion. The gain at which the charge saturation begins becomes lower as the channel diameter becomes smaller. For example, the gains become from 3×10^3 to 5×10^5 per channel for MCPs having a standard channel diameter of 12 µm. The pulse height resolution (PHR) is typically used as a measure to specify the dispersion of a pulse height distribution. As seen from Figure 7, the PHR is defined as the ratio of the full width half maximum (FWHM) to the peak channel value A in the pulse height distribution. The smaller the PHR value, the smaller the dispersion in the pulse height distribution.

PHR (%) = FWHM / A

This resolution depends on the MCP supply voltage, channel diameter, bias angle and distance between MCPs. Typically, it is 120 % for the two-stage MCP and 80 % for the three-stage MCP.

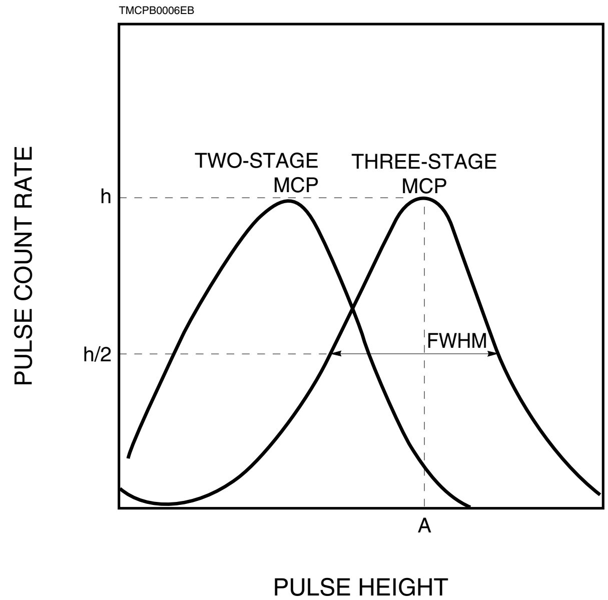


Figure 7: Pulse Height Distribution Characteristics

3-2 Dark Current

MCP dark current originates from the following factors; 1: electric field emission from the channel walls, 2: ionization of residual gases, 3: local discharge by a high electric field, and 4: photoelectron emission by photons produced by electric field scintillation of the MCP support parts. Sources of dark current caused by local discharge are eliminated by optimizing the MCP fabrication conditions and improving the assembly structure and materials. At any rate, typical MCPs exhibit a very low dark current which is less than 0.5 pA/cm^2 at a supply voltage of 1 kV. Even with the two-stage and three-stage MCP, the dark count is extremely low, and is less than 3 s^{-1}/cm^2 at a supply voltage of 1 kV per stage. Even so, in cases that the input signal level is extremely small, for example 10 s^{-1}, operating the MCP in gating mode (see section 4-3) will prove effective in reducing the dark signals since the MCP is operated only when the signals are input.

3-3 Resistance and Strip Current

The MCP resistance (R) can be controlled by material composition and manufacturing conditions used to fabricate MCPs. A lower resistance is desirable in view of the output saturation. However, the resistance can only be lowered a certain amount since the MCP operating temperature rises due to power consumption. Though MCP resistance differs from type to type, it is typically in a range between 100 MΩ and 1000 MΩ. Low-resistance MCPs of 5 MΩ to 30 MΩ prove useful in applications requiring high output current. Strip current (Is) is an inherent current flowing through the MCP surface and is given by the following equation:

$$I_s = V / R$$

where R is the MCP resistance and V is the operating voltage. From this equation, when the MCP resistance is 100 MΩ and the operating voltage is 1000 V, the strip current is 10 µA.

3-4 Output Linearity [2)]

When a large output current is drawn from an MCP, the channel walls near the output end are charged due to a large amount of secondary electron emissions. This phenomenon disturbs the potential distribution and weakens the electric field intensity, suppressing the subsequent multiplication. This charging effect is neutralized by the strip current flowing through the channel walls. However, this neutralization takes time because the strip current is small due to the high resistance of the channel walls. The time required for this neutralization is termed the dead time. This gain decrease is called the saturation effect, and begins when the output current reaches 5 % to 6 % of the strip one. Figure 8 shows typical saturation characteristics of a normal-resistance MCP (550 MΩ) and a low-resistance MCP (10.8 MΩ), and they both are operated in the DC mode. It is clear from Figure 8 that the saturation characteristics improve as the strip current increases with the reducing resistance. In other words, the saturation level is practically proportional to the strip current and is determined by the MCP resistance. In the case of the two and three-stage MCP operated in the counting mode, the same results are obtained. Figure 9 shows typical count rate characteristics of the two-stage MCP with different resistance values, in the counting mode. As can be seen from Figure 9, the count rate of the low-resistance MCP increases in proportion to the strip current in the DC mode.

A technique for making the channel diameter even smaller is recently the focus of much attention as a promising method for improving the count rate in the counting mode. For example, if the channel diameter is lowered to one half, then the number of channels that can occupy a unit area will be quadrupled. Likewise, if the channel diameter is lowered to one third, then the number of channels will increase by 9 times. This means that the probability that signals might enter the same channels is low even when the repetitive frequency of input signals is increased. This reduces dead time effects and is likely to improve the count rate. This is schematically illustrated in Figure 10.

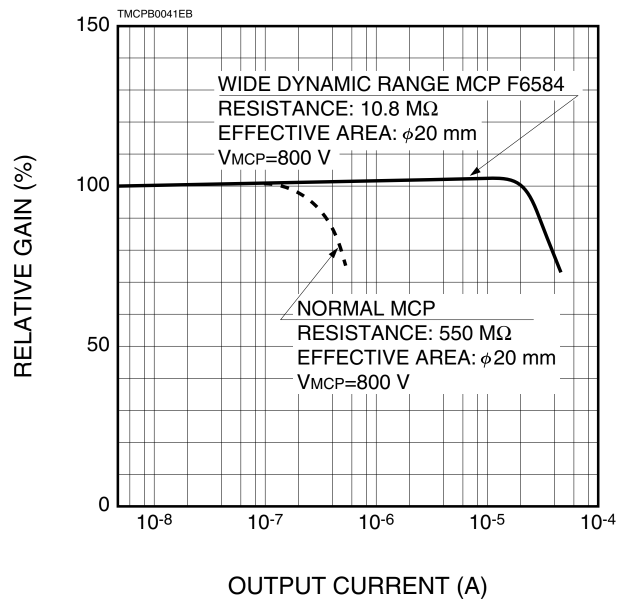


Figure 8: MCP Saturation Characteristics (analog mode)

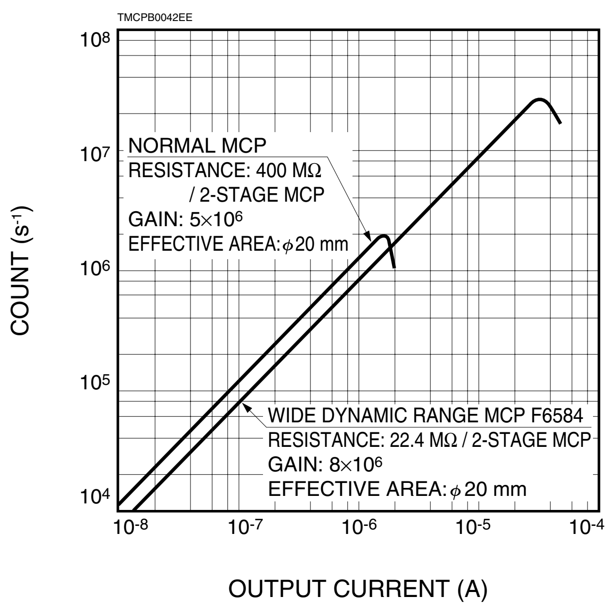


Figure 9: MCP Saturation Characteristics (counting mode)

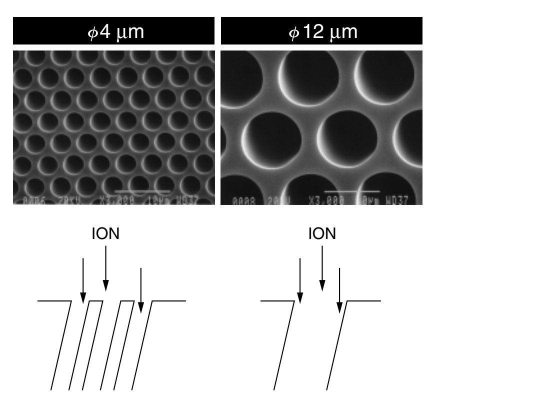
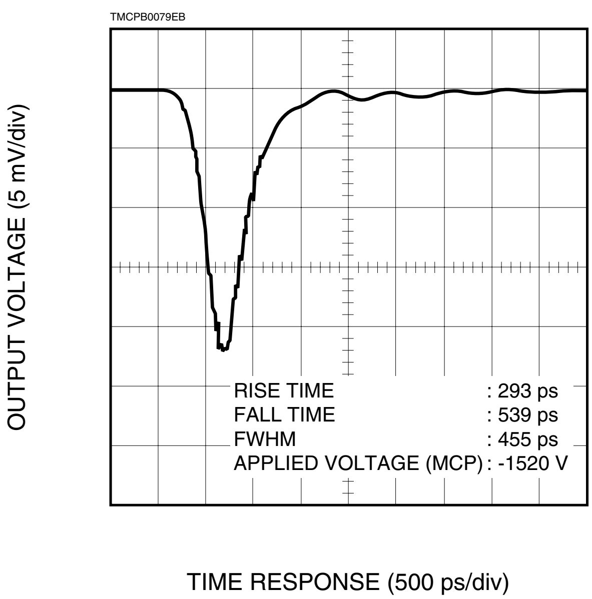


Figure 10: Improving the Count Rate by Reducing Channel Size

3-5 Time Response

Because the gain of an MCP is determined by α (=L/d), independent of the individual actual dimensions of d (channel diameter) and L (channel length), the size of the MCP can be reduced while the gain is kept at a constant value. Figure 11 shows an output waveform measured with a high-speed type MCP assembly F4655-13 (effective area: 14.5 mm diameter) and its dimensional outline. This assembly uses a two-stage MCP having 4 µm channel diameter. The thickness of the two-stage MCP is very amall (less than 0.5 mm), which corresponds to the electron transit distance. This therefore significantly shortens the electron transit time and achieves excellent time response characteristics of 293 ps rise time and 539 ps fall time.

a) Output Waveform



b) Dimensional Outline

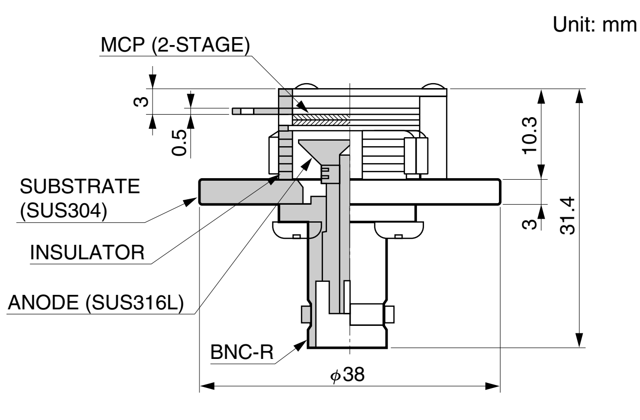


Figure 11: Output Waveform of High-speed MCP Assembly F4655-13 and Dimensional Outline

3-6 Spatial Resolution

Since individual channels of the MCP serve as independent electron multipliers, the spatial resolution of the MCP depends on the diameter and pitch of channels arrayed in two dimensions. When the output from the MCP is observed on a phosphor screen, the spatial resolution also depends on the MCP output electrode penetration depth into the channels, distance between the MCP and the phosphor screen, and the accelerating voltage.

Figure 12 shows a diagram of a measurement system used to evaluate the limiting resolution of an MCP (single stage) with a 6 µm channel diameter.

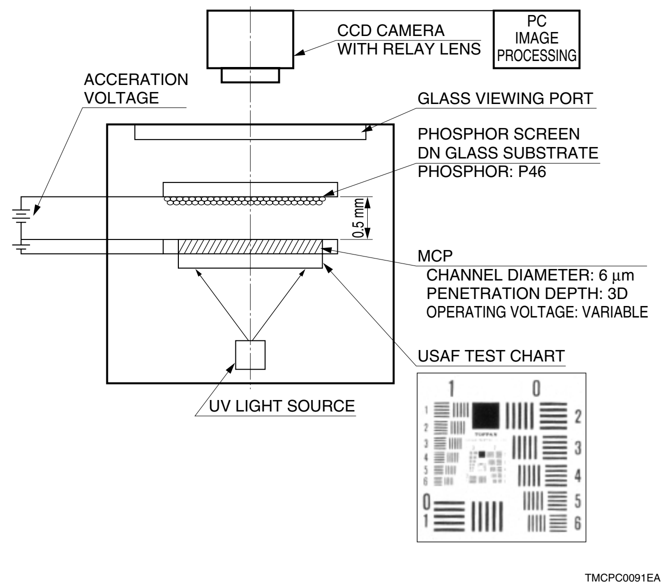


Figure 12: Schematic Diagram for Resolution Measurement

In the above measurement system, a USAF test chart whose pattern is formed on a glass plate is directly coupled to the input surface of the MCP and a UV light source is used to illuminate the test chart. Electrons multiplied by the MCP strike the phosphor screen where the electrons are converted into visible light. This is observed by a CCD camera and the limiting resolution is measured by identifying the smallest chart rank that can be clearly recognized. Under these conditions, a limiting resolution of 20 to 25 µm (40 to 50 lp/mm) was obtained at a gain of 1000.

In the case of a stacked MCP (2-stage MCP), the spatial resolution gets lower compared to that of a single MCP. The reason for this is that electrons multiplied in a channel of the first-stage MCP spread into several channels as they enter the latter-stage MCP. Another reason is that the charge density which increases when the electron flow is released from the MCP output side causes an increase in the electrostatic repulsion within the space, which in turn causes the electron spread to broaden between the MCP and phosphor screen.

3-7 Life Characteristics

Life characteristics of MCPs are basically proportional to the total amount of electric charge drawn from the MCP, though the ambient atmosphere such as the vacuum level also affects these life characteristics. Figure 13 shows a typical life characteristic of an MCP operated in the DC mode. This MCP is a single-stage one with a 6 µm channel diameter and is installed inside a vacuum chamber maintained at a vacuum level of 1.3×10^{-4} Pa. Life data was measured during continuous operation after the gain was stabilized by aging at approximately 0.1 C.

The degradation in gain can be thought of as results from an increased work function due to a lower density of alkali oxide (high δ substance contained in the MCP glass material) caused by electron collision with the channel walls. The gain degradation is also considered to be caused by deformation in the potential distribution that occurs as the resistance changes near the MCP output.

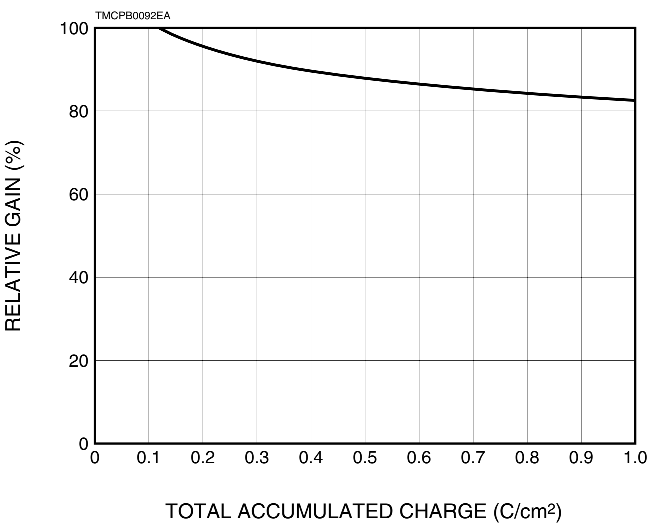


Figure 13: Life Characteristic

3-8 Detection Efficiency for Ions, Electrons, UV, VUV and Particle Beams

The MCP is directly sensitive to ultraviolet rays, X-rays, alpha-rays, charged particles, and neutrons as well as electron beams and ions. Table 3 summarizes previously published data on MCP sensitivity. Note that these results may differ depending on the MCP open area ratio (OAR), the angle and energy of incident beams, and whether or not the MCP surface is coated. Figure 14 [3] shows detection efficiency versus incident energy of an electron beam and Figure 15 [3] shows relative sensitivity measured by varying the incident electron beam angle. The maximum detection efficiency occurs in an electron energy range from 500 eV to 1000 eV. Although the sensitivity depends on the incident energy, the maximum sensitivity is obtained at an incident angle of 13 ° in that energy range.

Table 3: Detection Efficiency of MCP

Types of Radiation	Energy or Wavelength	Detection Efficiency (%)
Electron	0.2 keV to 2 keV	50 to 85
	2 keV to 50 keV	10 to 60
Ion (H^+, He^+, Ar^+)	0.5 keV to 2 keV	5 to 58
	2 keV to 50 keV	60 to 85
	50 keV to 200 keV	4 to 60
UV	300 Å to 1100 Å	5 to 15
	1100 Å to 1500 Å	1 to 5
Soft X-ray	2 Å to 50 Å	5 to 15
Hard X-ray	0.12 Å to 0.2 Å	to 1
High energy particle (ρ, π)	1 GeV to 10 GeV	to 95
Neutron	2.5 MeV to 14 MeV	0.14 to 0.64

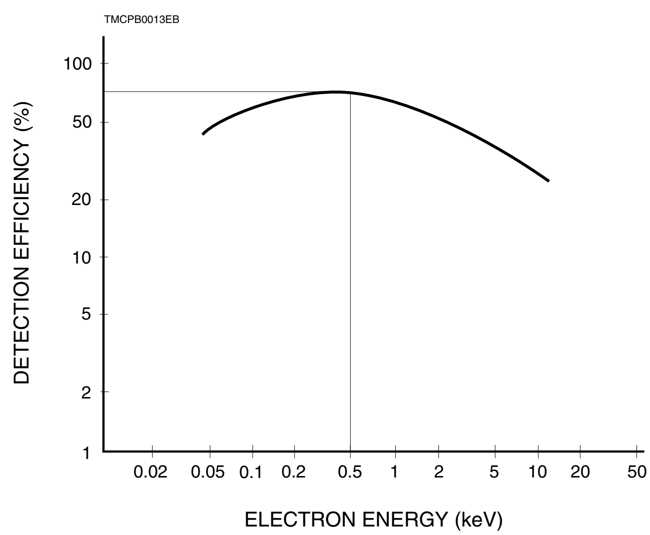


Figure 14: Detection Efficiency vs. Electron Beam Energy

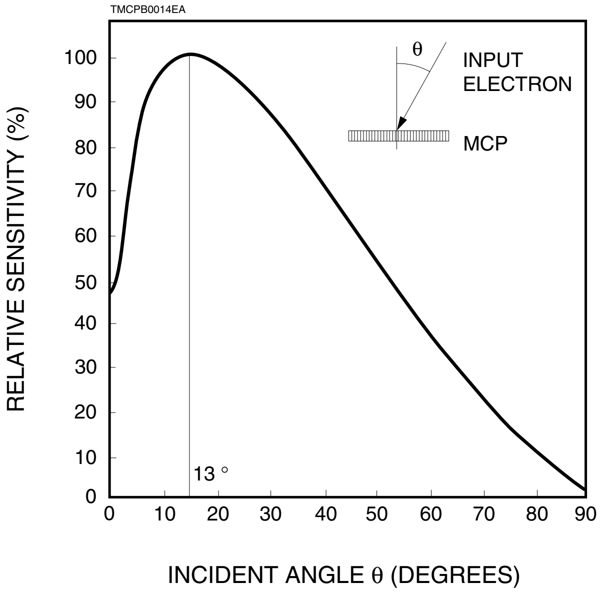


Figure 15: Relative Sensitivity vs. Incident Angle of Electron

Figure 16 shows detection efficiency [6] for He ions and He neutral particles. As seen from this figure, there is no significant difference in the detection efficiency between ions and neutral particles, and it indicate a high detection efficiency of about 50 % in the incident energy range from 1 keV to 10 keV. Figure 17 [6] shows PHD (pulse height distribution) data measured at 10 keV, 60 keV and 100 keV ion energy. These data prove that nearly the same results are obtained and are not dependent on the energy range. In an energy range of 1 keV to 100 keV, nearly the same detection efficiency will probably be obtained for He ions.

Figure 18 [7] shows typical detection efficiencies for ions with a mass number up to 10000 amu, measured by varying the post-accelation energy. In this figure, the upper line indicates the detection efficiency for metal cluster ions (Cr) and the lower line indicates detection efficiency for ions containing a large amount of hydrogen. This shows there is a tendency for the detection efficiency to increase as the ion accelerating energy becomes higher. For example, for ions with a mass number of 10000 amu, the detection efficiency is around 80 % at an accelerating voltage of 20 kV, but drops below 5 % at 5 kV. Compared to metal cluster ions, the detection efficiency for ions containing hydrogen tends to be lower even if the mass number is the same.

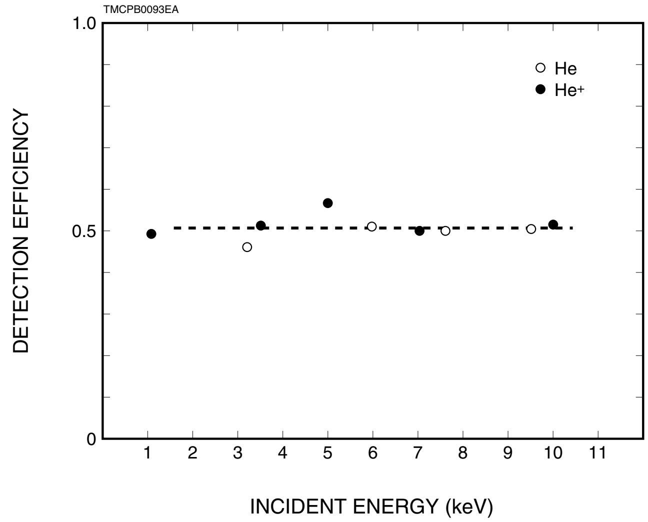


Figure 16: Detection Efficiency for He Ions and Neutral Particle vs. Incident Energy

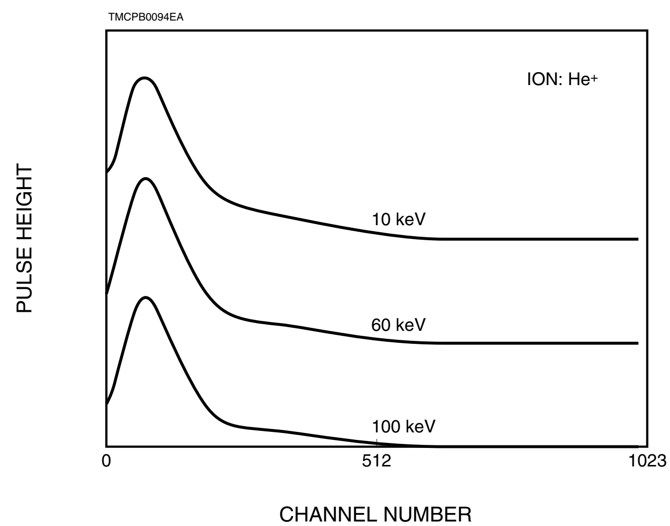


Figure 17: Pulse Height Distribution with He Ions at 10 keV, 60 keV and 100 keV

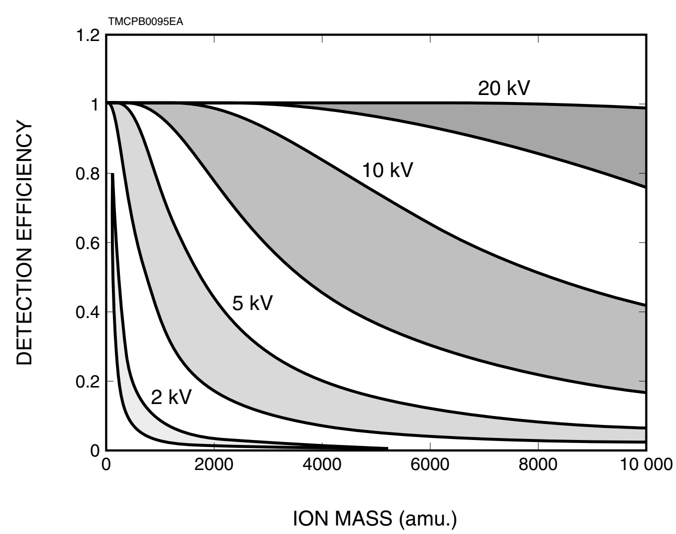


Figure 18: Detection Efficiency for Cr Cluster Ions (upper curve) and hydrocarbons (lower curve) for Post-acceleration Voltages between 2 kV and 20 kV

Figure 19 [8] and 20 [9] show relative detection efficiencies in the UV to hard X-ray region and detection efficiency versus soft X-ray photon energy respectively. As with the electrons, the detection efficiencies for these photons are angle-dependent, accordingly the angle at which the maximum detection occurs becomes shallow with increasing energy. This phenomenon is due to the relation between the position where secondary electrons are produced and their escape depths. The detection efficiency for UV rays is relatively low compared to electrons and ions. Coating a photoelectric material on the MCP input surface is effective in enhancing the detection efficiency. Typical photoelectric material are CsI, CuI, KBr and Au. Among these, CsI is most commonly used. Effects of CsI coating on the detection efficiency are shown in Figure 21 [10]. Alkali halide compounds like CsI are deliquescent materials that will react with moisture in the air and their characteristics may degrade in a short time. To prevent this, always keep those materials in a vacuum during storage. When taking them out of the vacuum, make sure the ambient humidity is sufficiently low and take particular care to handle them in as short a time as possible when in the air.

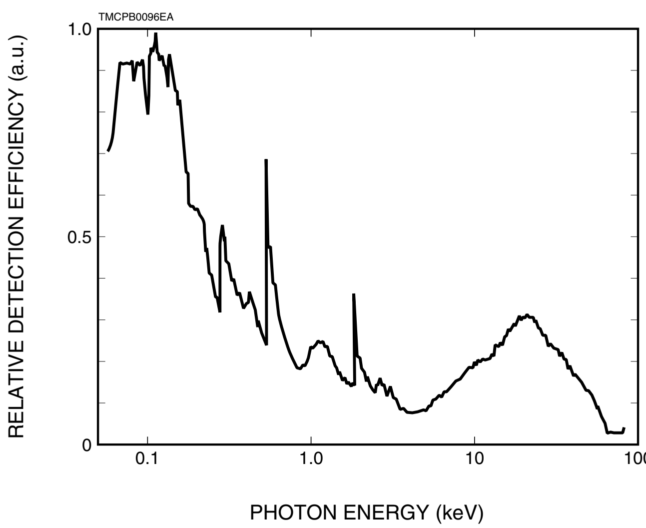


Figure 19: Detection Efficiency vs. Photon Energy in UV to Hard X-ray Region

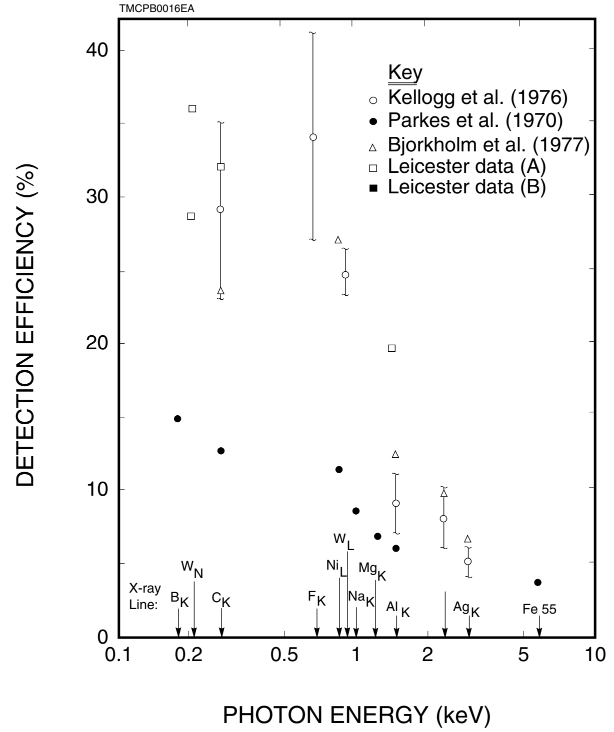


Figure 20: Detection Efficiency vs. Soft X-ray Photon Energy

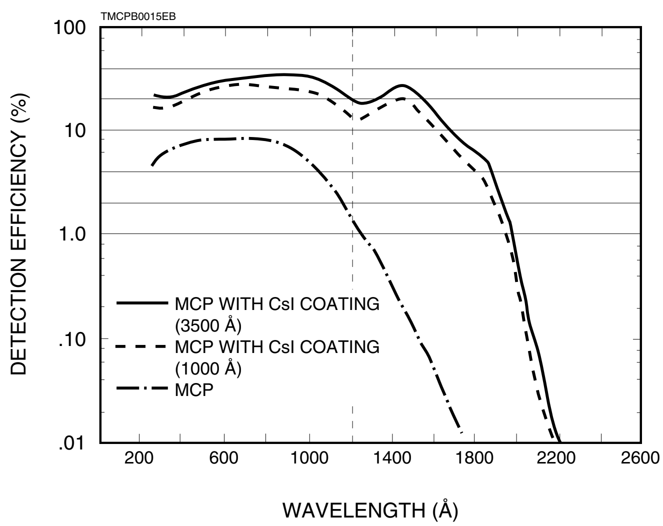


Figure 21: Detection Efficiency vs. UV Wavelength

3-9 Effects of Ambient Atmosphere [11]

3-9-1 Gain variation when used in magnetic field

The MCP is less susceptible to the presence of magnetic fields than the discrete dynodes used in ordinary photomultiplier tubes (PMTs). The magnitude of the magnetic effect depends on the direction of the magnetic field versus the MCP channel axis. Figure 22 shows output variations caused by magnetic fields, measured by exciting the MCP with UV rays and detecting its output using an anode positioned 3 mm away from the MCP output end.

When the magnetic field is perpendicular to the MCP channel axis, the MCP gain simply decreases as the intensity of the magnetic field becomes higher, because the flight range of the electron cycloid trajectories shortens and the electron impact energy lowers. In this case, some of the electrons emitted from the MCP are unable to reach the anode and return to the MCP, thus lowering the collection efficiency at the anode. The extent of this effect is more remarkable when the anode voltage is lower and/or the MCP-to-anode distance is longer.

When the magnetic field is parallel to the axis of the MCP channels, the electron trajectories rotate along the magnetic field. The mean flight range of electrons extends and increases the impact energy, causing the gain to increase. However, when the magnetic field becomes appreciably greater, the flight range of electrons begins to shorten due to the relation to the rotating radius and causes the gain to decrease.

As discussed above, when the MCP has to be operated in a magnetic field, the MCP channel axis should preferably be oriented parallel to the direction of the magnetic field.

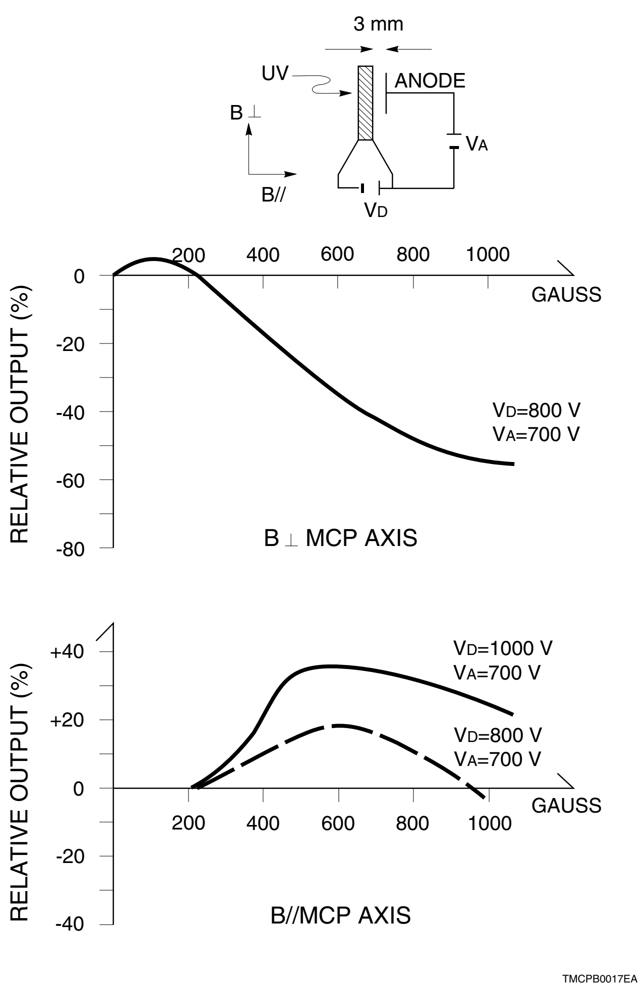


Figure 22: MCP Magnetic Characteristics

When an MCP has to be operated in strong magnetic fields higher than 1 T (Tesla), use a small channel diameter MCP and set it so that the channel axis is parallel to the magnetic field. This will allow use in magnetic fields up to 2 T without any problem.

Figure 23 [12] shows magnetic characteristics of an MCP-PMT that incorporates a two-stage MCP with 6 µm channel diameter.

When it is unavoidable to use the MCP in a magnetic field perpendicular to the channel axis, it is recommended to set the MCP to face diagonally so that the angle between the channel axis and magnetic field is smaller. This will minimize magnetic field effects on the MCP and prevent a loss of gain. [13]

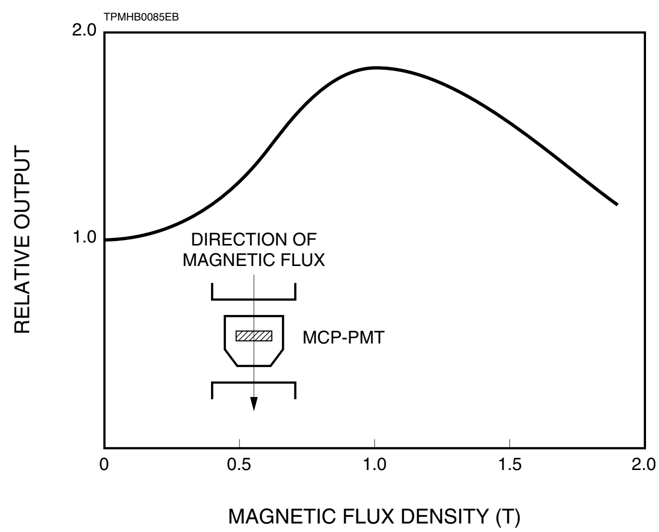


Figure 23: Typical Magnetic Characteristics of an MCP-PMT

3-9-2 Temperature effects

Since the MCP has a negative temperature coefficient, its resistance value decreases with an increasing ambient temperature. The MCP itself heats up due to Joule heat during operation, and its resistance decreases if operated at a high temperature. A decrease in resistance also produces further Joule heat, and the repeated process of heating and resistance decrease can cause thermal runaway, leading to significant damage in the MCP. To avoid this, the MCP must be operated at temperatures in the range from -50 °C to +70 °C.

3-9-3 Effects from the vacuum condition

Because the MCP is operated at a high voltage of about 1 kV per stage, a relatively high vacuum condition is required. If the MCP is operated at a poor vacuum, not only will noise increase due to the ion generation in the channels, but also the lifetime may shorten and, in the worst cases the MCP might be damaged by discharge. To avoid this problem, the vacuum level should be maintained at 1.3×10^{-4} Pa or higher during MCP operation.

4. APPLICATION BASICS

4-1 MCP Assemblies

To actually use an MCP, it must be assembled with leads, as well as a proper readout device and mounted on support parts. MCP assemblies are available in easy-to-handle configurations. They are roughly classified into a demountable type (Figure 24) and a non-demountable type (Figure 25).

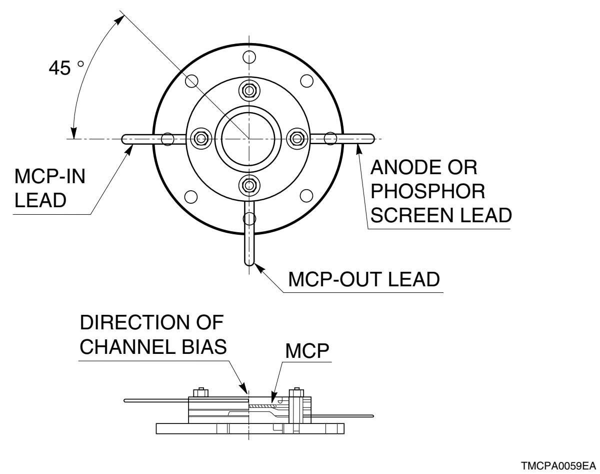


Figure 24: Demountable MCP Assembly

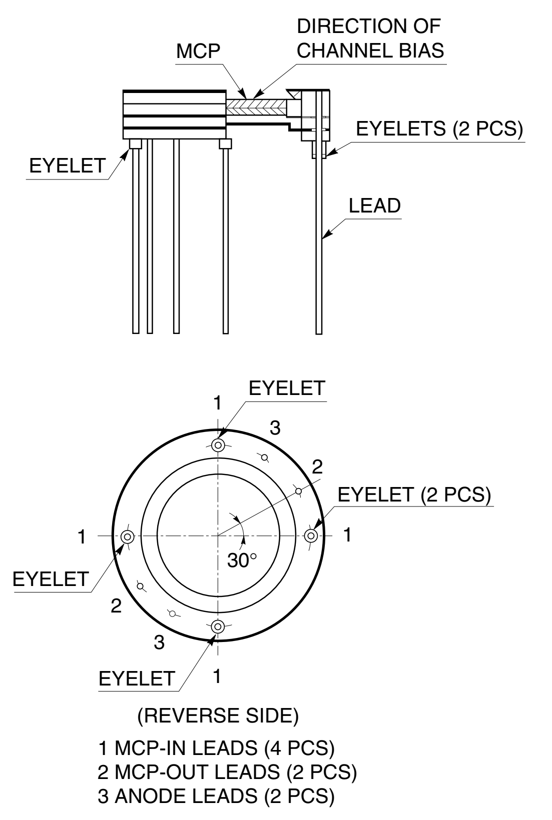


Figure 25: Non-demountable MCP Assembly

The demountable type allows easy replacements of both MCPs and the readout device. The non-demountable type on the other hand is more compact than the demountable type and requires less installation space, though the MCP and readout device cannot be replaced. Other MCP assemblies include a vacuum flange assembly type that allows to make direct connections to vacuum chamber of a equipment. See section 11, "MCP Assemblies (custom assemblies)".

4-2 Signal Readout Methods

The MCP detects one and two-dimensional information. However, since the MCP acts only as a multiplier, it must be used along with a proper readout device. Discussed below are the most commonly used readout devices and the wiring connection to a high voltage power supply that is needed to operate the MCP.

4-2-1 Single anode

A metal plate is generally used as a simple electron collector (anode). It is used for measurement in the analog and the counting modes where no position data are needed. The single anode offers high-speed measurement since it makes use of the fast response of the MCP. Figure 26 shows typical wiring of a single anode MCP assembly. There are two methods for supplying the voltage. One is to use two or more high-voltage power supplies to directly supply the required voltage. The other is to use a resistive voltage divider circuit. In view of the polarity of objects to be detected and the ion detection efficiency, method A is used to detect positive ions since it allows the MCP input side to be maintained at a negative high voltage, while method B is used to detect electrons or negative ions since it maintains the MCP input side at ground potential (or at a slightly positive high voltage). When detecting UV and soft X-rays where the polarity of the object for detection is not an issue, the method A is usually used because signal processing is easy.

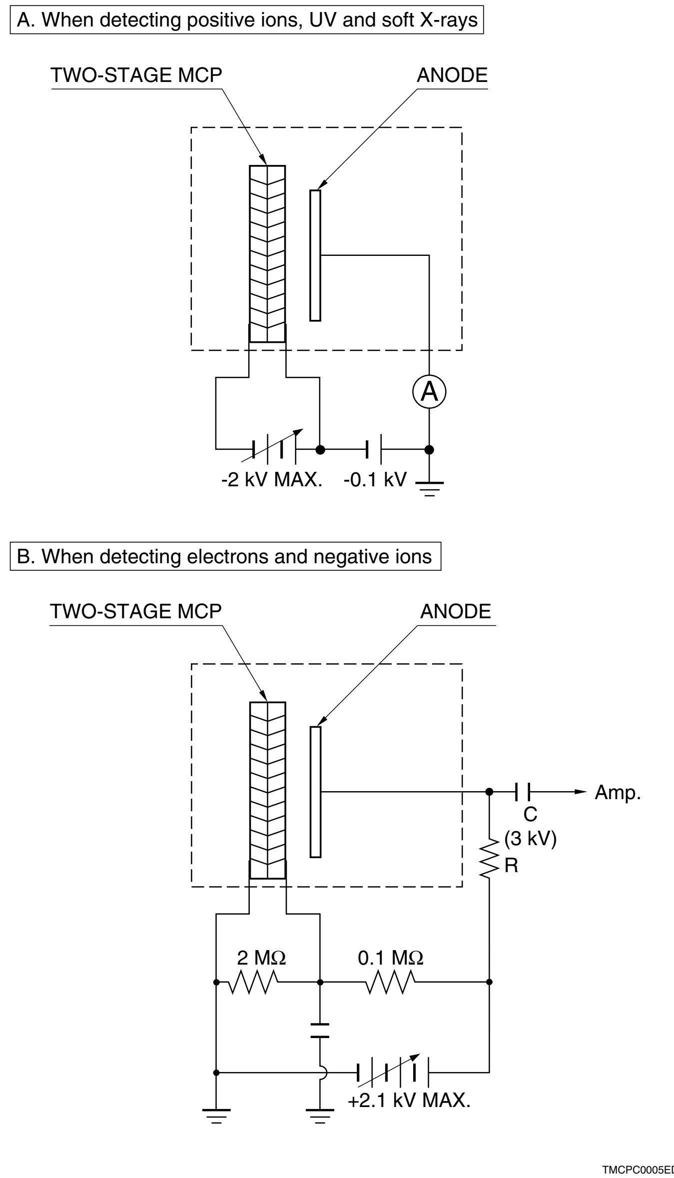


Figure 26: Wiring Example in Single-anode MCP Assemblies

4-2-2 Multianode

A single anode uses one anode, while a multianode consists of two or more independent anodes arrayed in one or two dimensions. As for the single anode, measurement can be made in both the analog and counting modes. Since each anode works independently, position data can be obtained according to the multianode pattern. Each anode is also able to measure simultaneously and readout paralleliy, at a high count rate. Spatial resolution is determined by the pitch of the anodes. However, it is not practical to make the pitch smaller than necessary since the crosstalk effect occus. The optimum pitch is around 2 mm.

Figure 27 shows a wiring example for the multianode MCP assembly. The distance between MCP-Out and the anode is kept as short as possible and a higher accelerating voltage is applied across them to reduce the crosstalk effects.

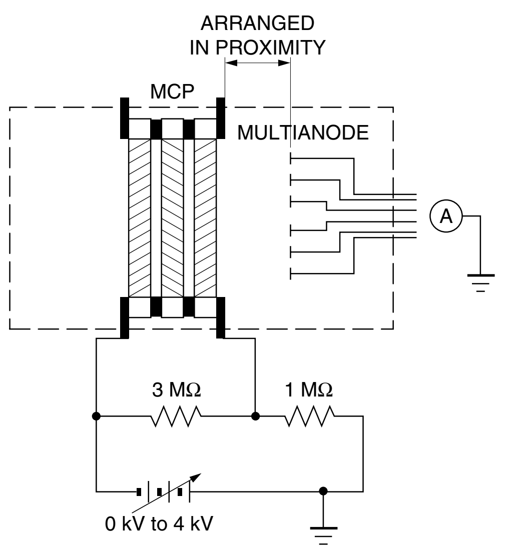


Figure 27: Wiring Example for a Multianode MCP Assembly

4-2-3 Phosphor screens (in combination with imaging devices)

The phosphor screen is made up of phosphor material coated onto a glass plate or an FOP (fiber optic plate) [14] and is used to convert output signals from an MCP into visible image, rather than detecting them as electrical signals. The phosphor screen is made up of granular phosphors of about 2 μm in diameter that are deposited on a glass plate at high density to form a phosphor layer whose thickness is equal to that of accumlated several particles. This phosphor screen is assembled in proximity (with about 1 mm of space) to the MCP output surface. A two dimensional image with high resolution can be attained by applying a high accelerating voltage (2 kV to 4 kV) across the MCP and phosphor screen. The resolution depends on the number of stacked MCPs. Spot sizes formed on the phosphor screen surface by single electron beams usually range from 40 μm to 50 μm in FWHM for single-stage MCPs and 80 μm to 100 μm for two-stage MCP.

The optical images converted on the phosphor screen can be observed with an imaging system using a CCD camera, as well as by direct visual viewing. Wiring examples of an MCP/phosphor screen assembly are shown in Figure 28.

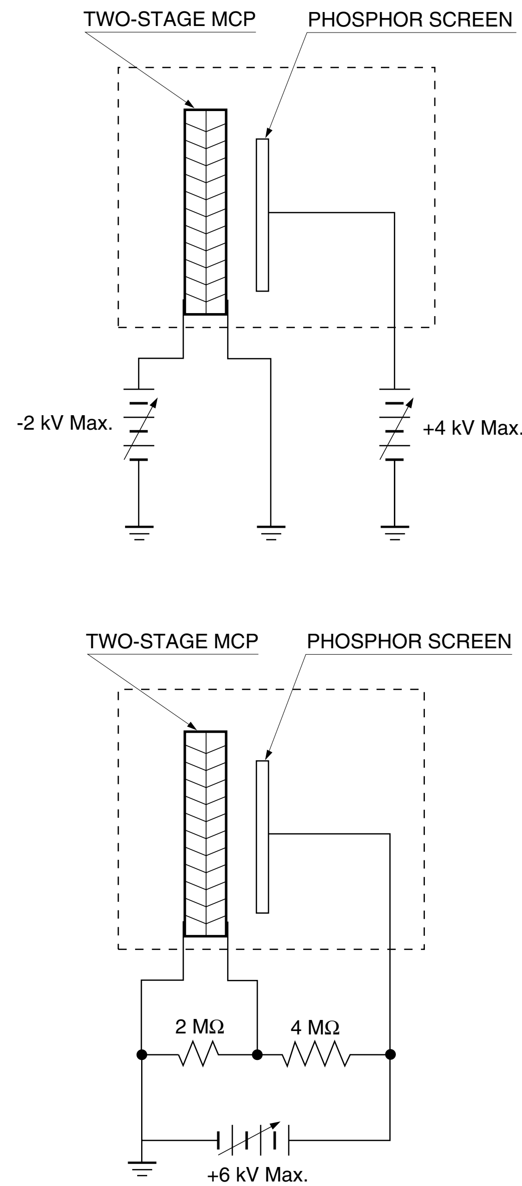


Figure 28: Wiring Examples of MCP/Phosphor Screen Assembly

Phosphor screens must be selected according to the application purposes. Figure 29 and 30 show typical spectral emission characteristics and decay characteristics of various phosphor, respectively. Major specifications for those phosphors are also listed in Table 4. When viewing with the naked eye, it is necessary to select a phosphor with longer decay time and spectrums that match the human eye's sensitivity. When viewing with a high-speed readout CCD camera, it is essential to select a phosphor with short decay time so that no afterglow remains in the next frame.

Phosphor screens can also be used in the same manner as a single anode (electrical signal detection), because an aluminum film called the metal-back is coated over the input surface of the phosphor screen or an ITO (a transparent conductive film) is applied on the substrate.

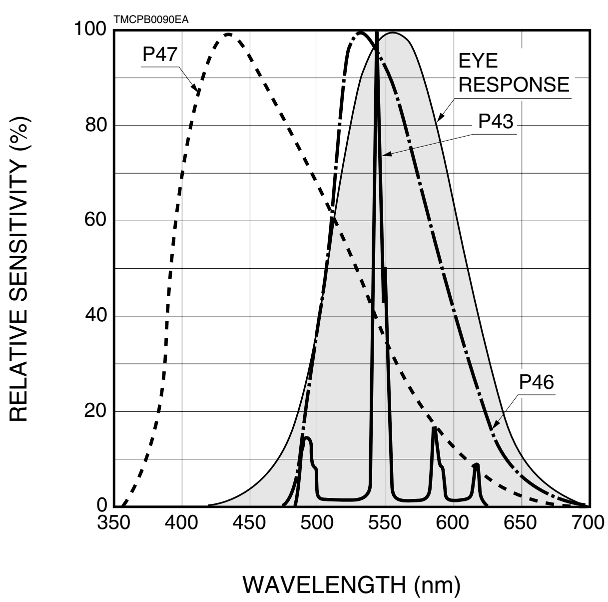
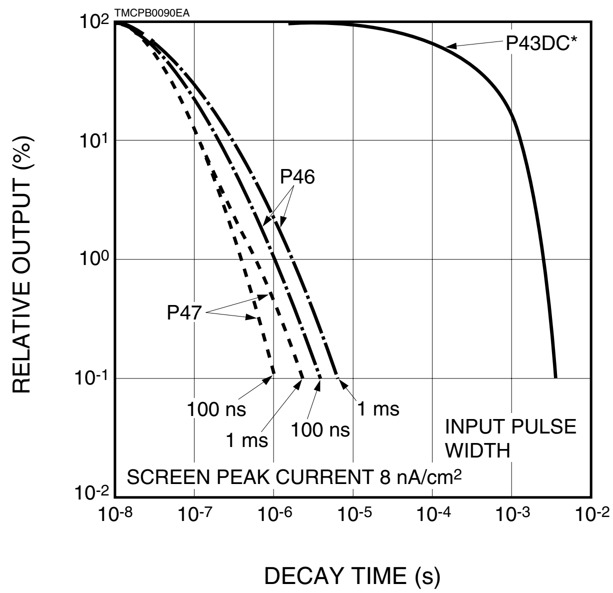


Figure 29: Spectral Emission Characteristics of Various Phosphors



* Decay characteristics of P43DC are measured after continuously input light is removed, while those of P46 and P47 are measured after pulsed input light (time indicates pulse width) is removed. (Both are measured as image intensifiers.)

Figure 30: Decay Characteristics of Various Phosphors

Table 4: Emission Characteristics of Various Phosphors

Types of Phosphor Screen	P43	P46	P47
Peak Emission Wavelength (nm)	545	530	430
Emission Color	Yellowish Green	Yellowish Green	Purplish Blue
Relative Power Efficiency Ⓐ	1	0.3	0.3
Decay Time 10 %	1 ms	0.2 µs to 0.4 µsⒷ	0.11 µs
Remarks	Standard	Shorter decay time	Shorter decay time

NOTE: ⒶAt supply voltage of 6 kV. Relative value with 1 being the output from P43.
ⒷDepends on the input pulse width.

4-2-4 CR-chain Anode

As Figure 31 shows, this readout device consists of independent multiple anodes, each connected in parallel to a capacitor and a resistor.

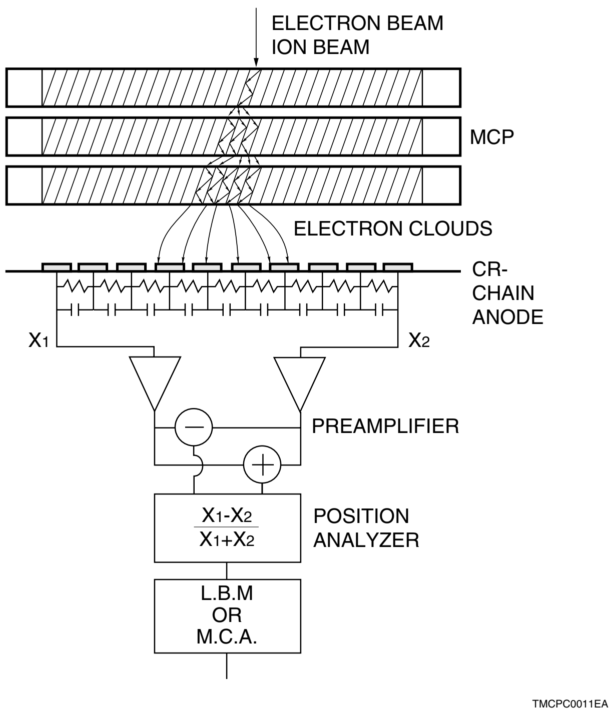


Figure 31: MCP assembly with CR-chain anode and its signal processing system

In this device, the electric charge multiplied by a three-stage MCP spreads onto adjacent several anodes. It is then divided by electrodes at both ends of each anode in proportion to the reciprocal of the resistance ratio corresponding to the distances between the incident position and each of the electrodes. An arithmetic operation with these divided charges gives the center-of-gravity position where the signal is incident, thus this device provides a resolution better than the anode pitch. This device is also superior in terms of quantitative analysis since incident signals can be counted one by one. Another advantage of this device is that the anode size can be made larger with keeping its capacitance relatively small at high counting rate. This device is therefore ideal for large-area detectors. Using anodes of 0.85 mm $\times$ 20 mm in size and 1.0 mm in pitch at the MCP gain of 10^7, a spatial resolution higher than 120 μm can be obtained as shown in Figure 32.[15)]

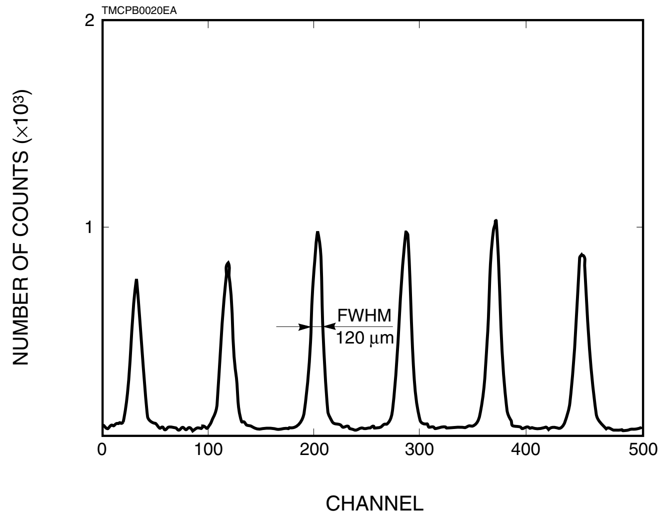


Figure 32: Spatial Resolution of MCP Assembly with the CR-chain Anode

4-3 MCP Gating Operation

Among measurement techniques, one type can only detects signals within a certain width of time. This is called "gating operation" and is used in time-resolved measurement for observing changes over time, as well as in high S/N ratio measurements of very-short phenomena under high background noise conditions. The gate method depends on the detector structure. Typical detectors using MCPs are described below.

4-3-1 Standard Gating

In this method, a gate voltage in the nanosecond to microsecond order is applied to the MCP. Figure 33 shows a structure of the gating MCP/phosphor screen assembly. This assembly, designated F2225-21PGFX, has a two-stage MCP with an effective area 40 mm diameter and a phosphor screen and is mounted on a vacuum flange with a viewing port. Two MCP-In leads are shown in the figure. One of them connects to a resistor (50 Ω) that prevents drive pulses from reflecting during high-speed gating less than 10 ns.

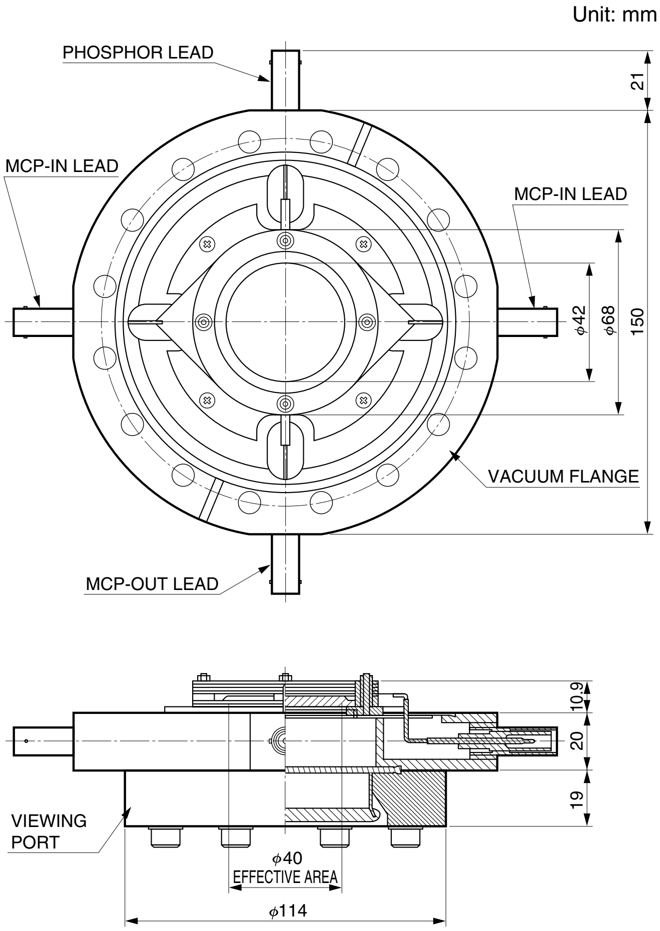


Figure 33: Gating MCP/Phosphor Screen Assembly Example

Figure 34 and 35 show a schematic diagram example for 2 ns gating operation a connection example to a gate pulser, respectively. For information on the head controller, please consult with us.

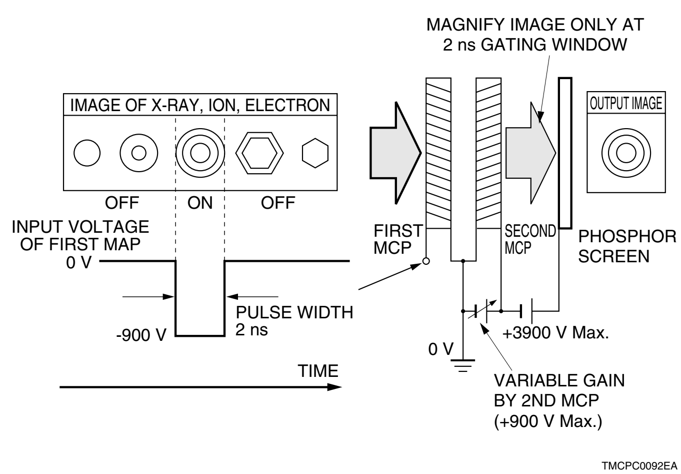


Figure 34: Schematic Diagram Example of Gating MCP Assembly

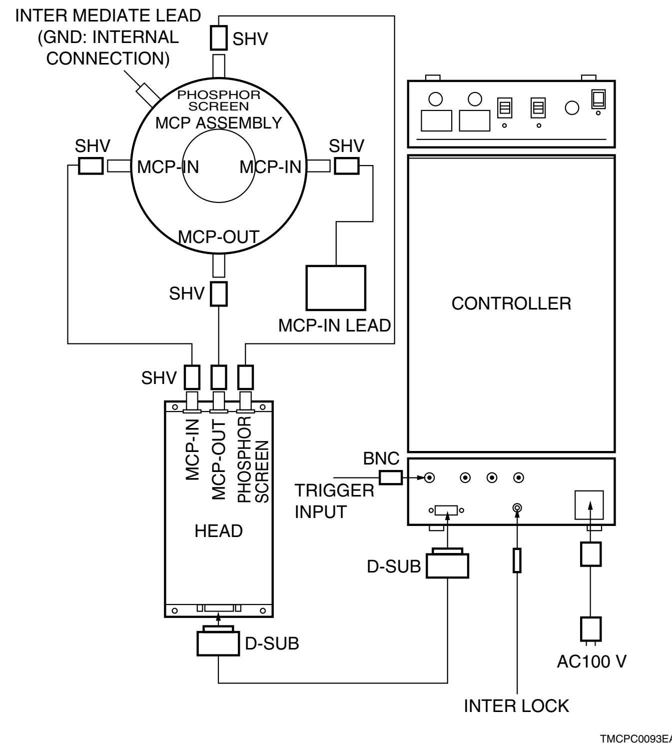


Figure 35: Connection Example of Gated MCP Assembly to High-voltage Gate Pulser

4-3-2 Strip Line Method

Soft X-ray measurement in research fields such as laser nuclear fusion reaction often requires the gate width as short as 100 ps. Standard gating is inadequate in such applications due to a voltage drop caused by impedance discontinuity in the gate voltage supply section. In such applications, gold is deposited on the input surface of the MCP to fabricate a photocathode strip line, which serves as a transmission line for high-speed gating pulses in subnanoseconds.

Multiple strip lines of gold are deposited over the MCP input surface in the same way to form multiple photocathode lines. Applying gating pulses to those strip lines at different timings allows acquiring several gated images (framing images). The examples show several images attained with one strip line by applying a delay time to the gate pulses transmitted along the transmission line. Figure 36 shows strip line dimensions formed on a rectangular MCP of 40 mm × 50 mm and the operating principle of an X-ray framing camera capable of acquiring 4 frames of images with the two strip lines. A framing camera using this gate scheme succeeded in obtaining time resolution of 100 ps and spatial resolution of 15 lp/mm.[16] A similar method using tapered strip lines is also being used to prevent attenuation during pulse voltage propagation.

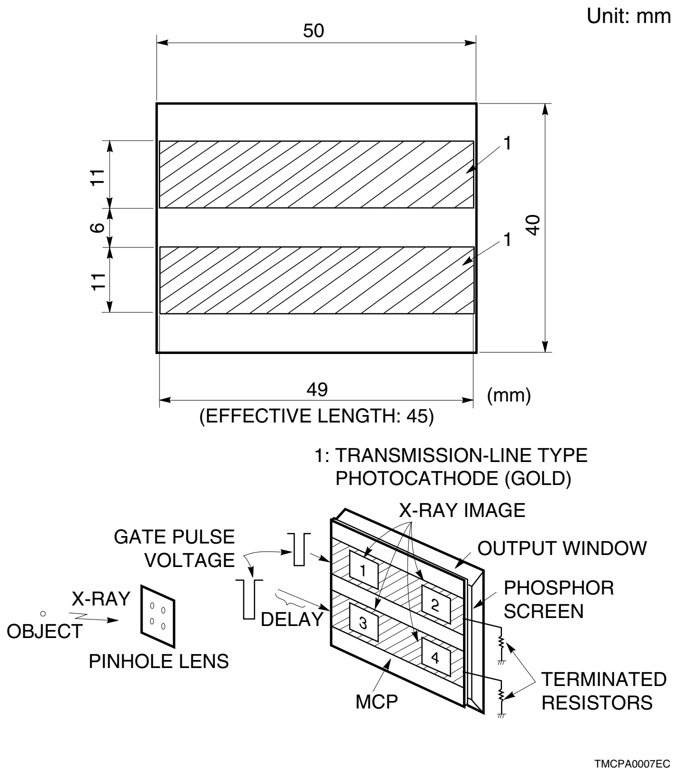


Figure 36: Principle of X-ray Framing Camera
(4 frames of shutter images)

5. MCP ASSEMBLY APPLICATIONS

MCP assemblies offer many advantages and are extensively used in various fields. For example, in medical, bio-science and semiconductor industries, MCP assemblies are used in TOF-MS (time-of-flight mass spectrometry) for developing new drugs, identifying biomolecules such as proteins for disease analysis, and also for performing semiconductor device measurement that is becoming very essential to keep pace with rapid advances in semiconductor lithography processes. MCP assemblies are also widely used in academic research fields for evaluating nanostructure devices using TOF techniques and accelerator physics experiments involving synchrotron radiation.
This section shows typical MCP assembly applications and information on the MCP assemblies actually used.

5-1 Time-of-Flight Mass Spectrometry (TOF-MS)

The time for an ion to travel from a test sample to the detector depends on the mass number of the ion. Making use of this principle, TOF-MS identifies the incident ions by measuring the time for the ions to travel from the ion source to the detector. TOF-MS detectors must have high-speed response and must detect ions as well with high efficiency. That is why these detectors mainly use MCPs. Figure 37 shows a schematic view of TOF-MS using an MCP.

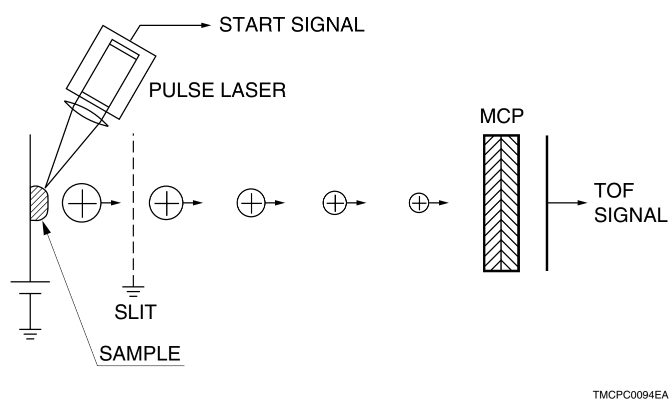
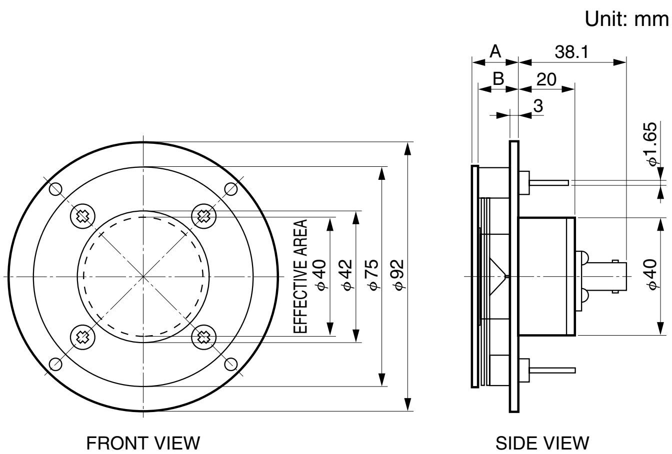


Figure 37: Schematic View of TOF-MS

Test molecules ionized by a laser or other means travel along the drift space at a certain speed while being accelerated by the potential difference developed between the grids, and reach the detector. When the electrical charge is constant, the smaller the mass number of the ion, the shorter this travel time and vice versa. In principle there is no limitation on the measurable mass range so that macromolecules such as proteins with molecular weights in several ten thousands to hundred thousands can be measured. Thanks to this feature, TOF-MS is now extensively used in research to discover new drugs as well as for DNA analysis.

TOF-MS detectors must have a fast output time with a rise time less than 2 ns and acquire good output waveforms with no ringing (signal reflection, etc.)

Figure 38 and 39 show dimensions of the F9892 series MCP assemblies designed for TOF-MS and a typical output waveform acquired with the F9892 series, respectively.



Type No.	A	B
F9892-11	16	14
F9892-12	15.6	13.6

TMCPA0054EA

Figure 38: MCP Assembly for TOF-MS

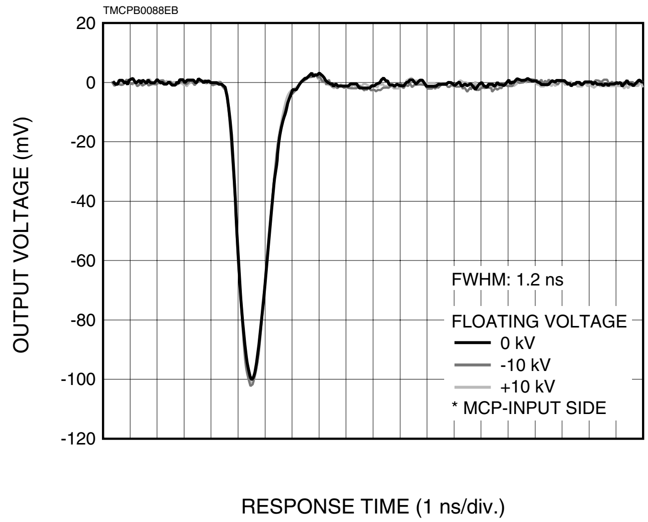


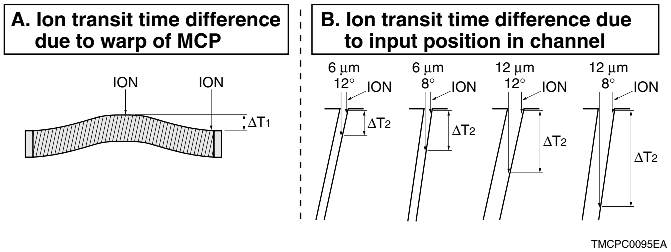
Figure 39: Typical Output Waveform

This MCP assembly has a large effective area of 40 mm diameter and a structure capable of operating in the floating mode with the input surface voltage up to ±10 kV. This allows to detect both positive and negative ions with high sensitivity, and to constantly maintain the output connector at ground potential because a high-voltage coupling capacitor is connected across the anode and connector.

The assembly structure is virtually optimized to obtain ideal high-speed waveforms with no ringing by using a high-frequency 50 Ω coaxial cable connector (BNC).

This assembly uses a small channel diameter MCP with a relatively large bias angle and a high degree of flatness in order to minimize the time jitter that affects mass resolution characteristics of TOF-MS instruments.

Figure 40 shows physical factors and calculated time jitters of the MCP. Figure 41 shows measurement data for the degree of flatness of this MCP.



Factor	**A**	**Warp (µm)**	20				200			
	B	**Channel Dia. (µm)**	6		12		6		12	
		Bias angle	12 °	8 °	12 °	8 °	12 °	8 °	12 °	8 °
Jitter	**A**	**ΔT1 (ns)**	0.5				4.6			
	B	**ΔT2 (ns)**	0.7	1.0	1.3	2.0	0.7	1.0	1.3	2.0
Sum (ns)			**0.84**	**1.12**	**1.39**	**2.06**	**4.65**	**4.71**	**4.78**	**5.02**

* Ion mass: 1000 u., Ion accelation voltage: 10 kV, calculation data

Figure 40: Time Jitter Comparison

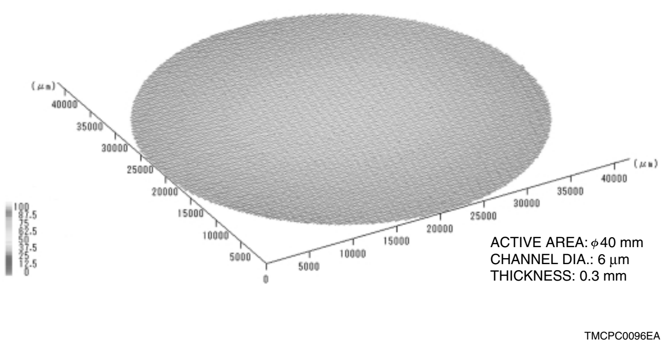


Figure 41: Flatness of MCP Surface (±10 µm)

5-2 SEM: Applied to Line Width Measurement

In a SEM (scanning electron microscope), the primary electron beam is focused and scanned over the sample and the subsequent secondary beam (reflected electrons or secondary electrons) is detected and multiplied by an MCP assembly. The secondary beam image from the sample can be obtained by processing these multiplied signals synchronously with the primary electron beam.

Utilizing this technique, the SEM is applied to line width measuring systems to detect fine mask patterns in semiconductor fabrication processes. Figure 42 shows an example of this application.

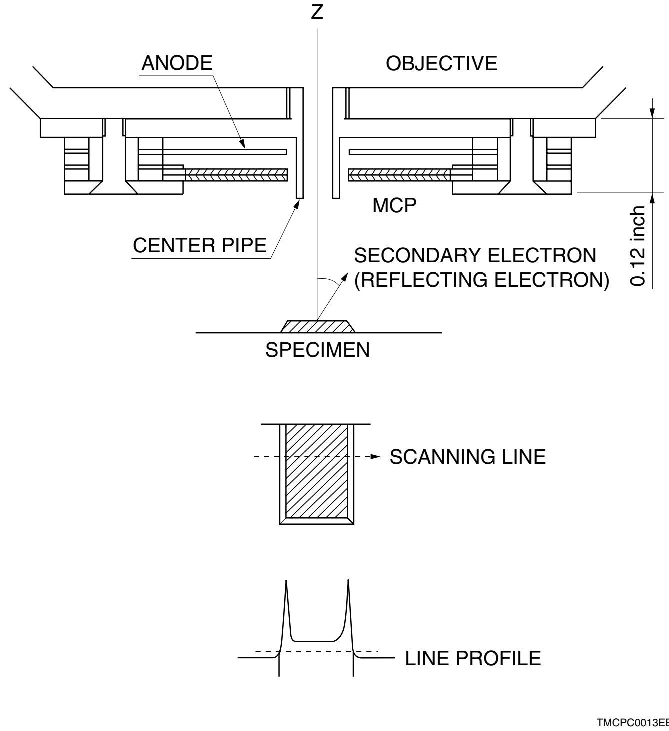


Figure 42: SEM for Line Width Measurement

MCP assemblies (F2223-21SH, etc.) used in this application have a thin, annular structure with a center hole for the primary electron beam passage. Detection of this assembly is performed symmetrically with the beam axis, thus the MCP assembly can be mounted in proximity to the sample. This greatly enhances secondary beam detection efficiency and improves the sensitivity and S/N ratio.[17] This also helps to reduce the amount of primary beam irradiations, consequently it minimizes damages to the sample and reduces charge-up effects.

5-3 RBS[18] (Rutherford Backscattering Spectrometry)

When surfaces of solid state material are irradiated with an ion beam, the ions are elastically scattered by the surface at speeds according to the mass numbers of the atoms. RBS makes use of this phenomenon when performing surface analysis.

In typical RBS, an ion beam focused down to the order of nanometer is irradiated onto the sample, and the travel time of the elastically scattered ions are measured to non-destructively analyze the three-dimensional compositions, the impurity distributions and the crystalline properties of the sample. RBS will prove a promising technique for evaluating semiconductor devices and nanostructure devices in the near future.

The detectors used in RBS must be highly sensitive to ions, of high-speed response, and compact. These are reasons why the MCP assembly with a center hole (e.g. F2223-21SH with an effective area of 27 mm diameter) is used.

Actual data acquired by TOF-RBS are shown in Figure 44.

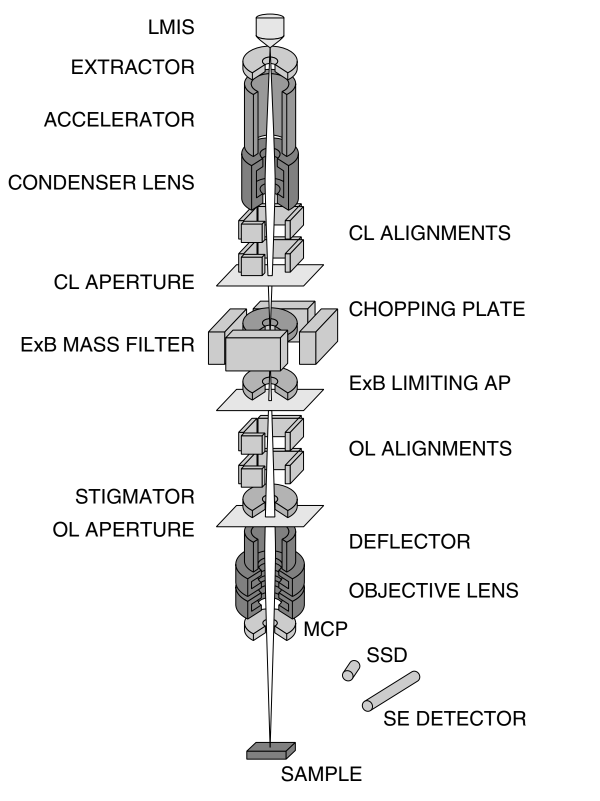


Figure 43: Schematic View of RBS Equipment Using Ion Nanoprobe

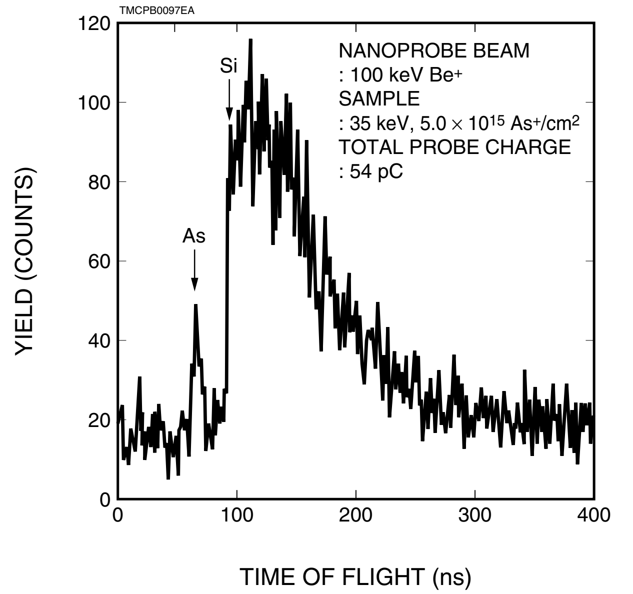


Figure 44: TOF-RBS Spectrum of As Injected into Si Substrate

5-4 ESCA (Electron Spectroscopy for Chemical Analysis)

ESCA is the most widely used surface analysis technique utilizing photoelectron spectroscopy.

In typical ESCA, the sample is irradiated with soft X-rays (MgK α rays or AlK α rays) at specified energies causing photoelectrons to be emitted from the sample surface. The kinetic energies of the emitted photoelectrons are measured by the energy analyzer to determine the binding energies. Elements on the surface of the sample can be identified from the binding energy levels of electrons inherent to the elements and their binding state. Counting the number of photoelectrons also allows measure the quantity of the elements.

Detectors for ESCA must have high sensitivity to electrons and be able to detect multiple spectra at one time, accordingly the multichannel type detector (e.g. F2225-21MX with an effective area of 40 mm diameter) is used. Figure 45 shows a schematic view of ESCA equipment using a multianode MCP assembly.

MCP assemblies that use a phosphor screen as a readout device rather than multianodes are increasingly used in recent years.

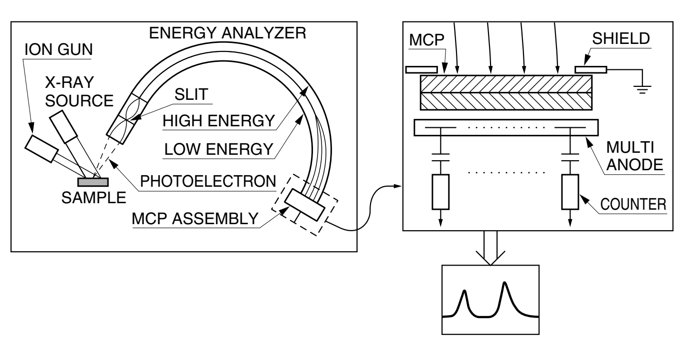


Figure 45: MCP Assembly Used in ESCA

5-5 Beam Profile Monitor Using Oxygen Gas Sheet [19)]

This beam profile monitor was designed for non-destructive, high-speed, two-dimensional measurement of the ion beam profile generated inside a synchrotron. An actual application of this monitor is described below.

At the National Institute of Radiological Sciences in Japan, a synchrotron accelerator called the HIMAC generates ion beams by accelerating ion species ranging from H to Xe at a maximum energy of 800 MeV/n. The beams generated by HIMAC are utilized in cancer treatment.

The HIMAC is operated in a high vacuum environment (10^{-8} Pa) and the generated beam intensity is relatively low (below 10^8 particles/bunch). The beam profile monitor installed in the HIMAC was developed for beam diagnosis in order to maintain stable beam operation. The detector layout of this beam profile monitor is shown in Figure 46.

The detector mainly consists of a two-stage MCP/phosphor screen assembly (F2395-24PX) and a gated ICCD (intensified CCD) camera. The MCP has an effective area of 100 mm diameter and the phosphor screen is the fast response type (P47 with a decay time of 80 ns). An oxygen gas sheet 1.3 mm thick is injected at a density of 1×10^{-4} Pa synchronously with the passage of the synchrotron beam to cause the gas sheet to collide with the beam. Oxygen ions generated by the collision with the beam are then input to the MCP by the electric field. The ions are multiplied by charge amplification in the MCP and converted into visible light on the phosphor screen, producing a two-dimensional beam profile image. This profile image is then acquired through the viewing port by an ICCD camera that is operated with a gating (typically 100 ns or more) synchronized with the beam.

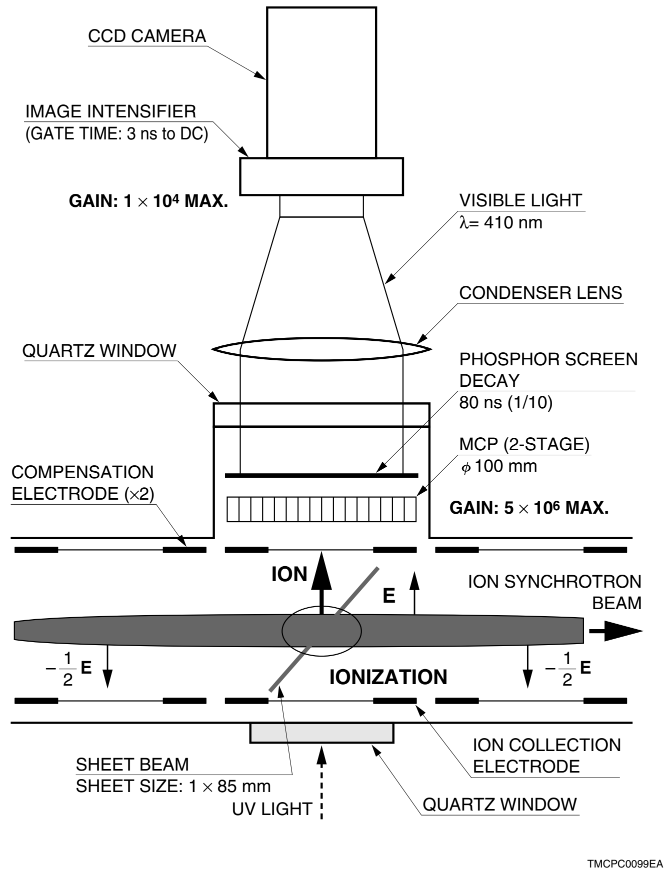


Figure 46: Layout of Beam Profile Detector

Figure 47 shows images representing changes in a carbon ion beam profile which correspond to the beam accelerating energy. Figure 48 shows changes in an argon ion beam profile during the electron cooling process and shows projection data in the horizontal direction.

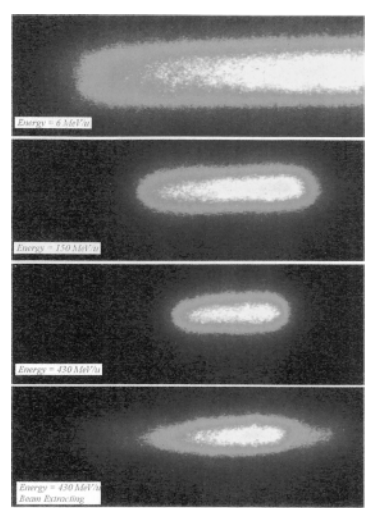


Figure 47: $^{12}C^{6+}$ Beam Profile from Injection to Extraction (6 to 430 MeV/n)

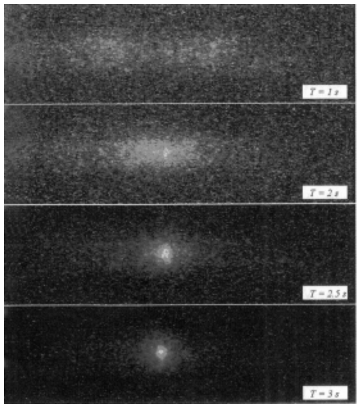


Figure 48: Beam Profile Changes in Full Strip Argon Ion Beam by Electron Cooling (Image Width: 58 mm)

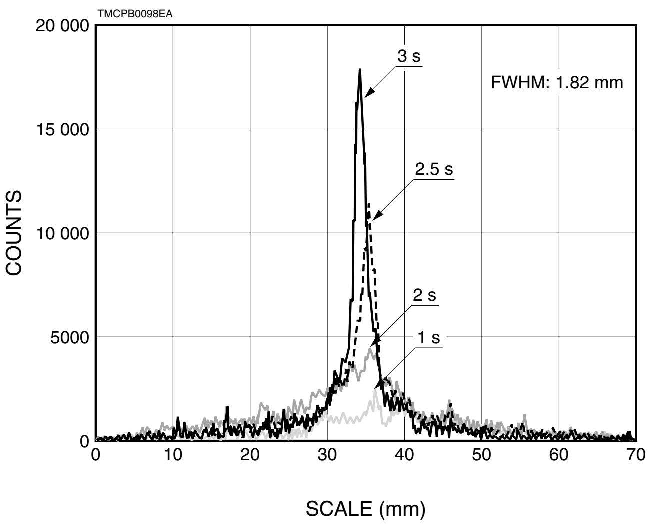


Figure 49: Horizontal Projection of Beam Profile of Figure 48

5-6 High-Order Harmonic Generator [20)]

By condensing a high-power ultra-short pulsed laser beam into a cell filled with argon gas, this equipment generates coherent short-pulsed light with extremely high intensity in the vacuum UV region (30 nm to 100 nm).

Compared to synchrotron radiation equipment which is well known as an instrument for generating highly intense light in the vacuum UV region, the high-order harmonic generator is much less costly yet produces ultra-short pulses of light with high peak intensities. It also features a compact table-top size, allowing to be used as a practical light source in small areas such as experimental labs. A schematic diagram of the high-order harmonic generator is shown in Figure 50.

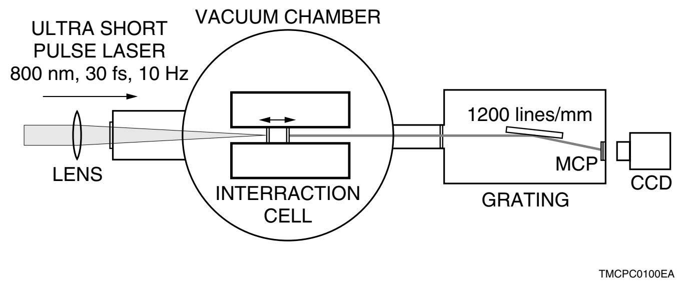


Figure 50: Schematic Diagram of High-order Harmonic Generator

This high-order harmonic generator uses an MCP/phosphor screen assembly mounted on a vacuum flange (F6959 with an effective area of 28 mm diameter) to observe vacuum UV images. Vacuum UV light emitted from the inside interactive cell is dispersed by the grating into a spectra which are then focused on the input surface of the MCP. The spectra, after being multiplied in the MCP, are converted into an optical image on the phosphor screen. The image is transferred through an FOP (fiber optic plate) to the atmosphere side to be observed with a CCD camera. Figure 51 shows the structure of the MCP assembly used here, the acquired vacuum UV image and the intensity dispersion in spectrum.

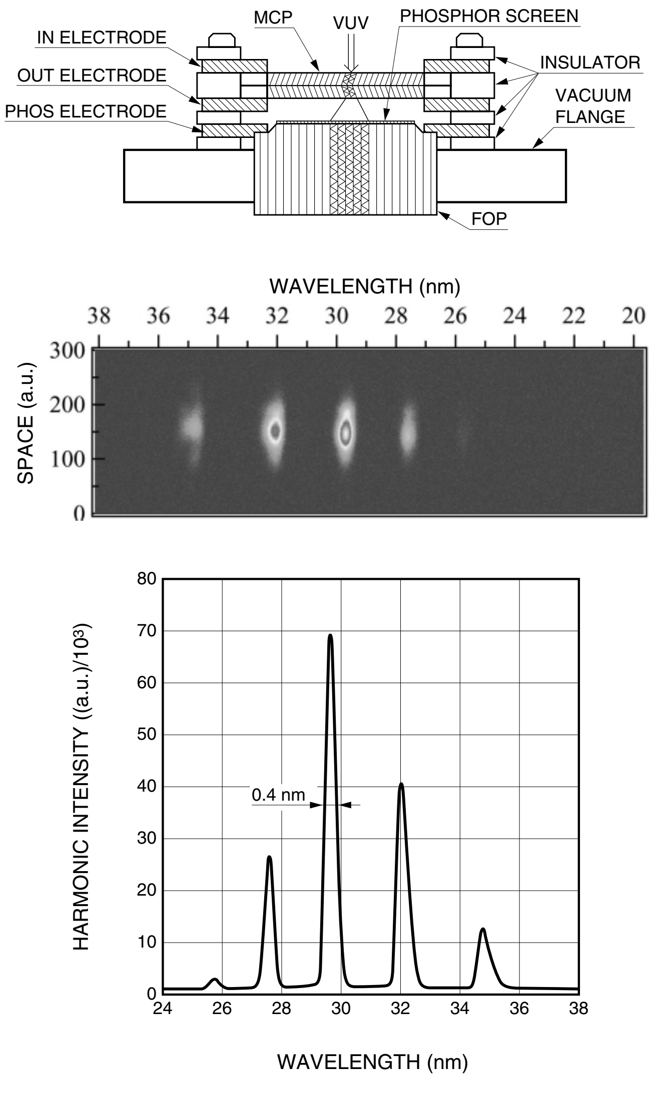


Figure 51: MCP/phosphor Screen Assembly Used in Vacuum UV Observation

6. HOW TO USE

Since MCPs and MCP assemblies are operated at high voltages in a vacuum, it is necessary to handle them with the same care as for high-vacuum materials. Refer to the following instructions to handle and operate MCPs and MCP assemblies correctly. If you have any questions, please contact us before use.

6-1 Handling Precautions

(1) Handling

Do not touch MCPs and MCP assemblies with bare hands. Failure to follow this instruction may cause contamination by oil and salt from your hands and fingers, possibly leading to an increase in dark current, discharges, and a decrease of gain. When handling, always wear clean vinyl gloves or polyethylene gloves. Never touch the effective area of the MCP and MCP assemblies even when wearing those gloves.

(2) Environments

The MCP surface is processed to be electronically active and the parts used in the assembly are also machine-finished for high vacuum use. Accordingly handle them in environments that conform as much as possible to clean room specifications which keep oily vapor, moisture and dust to a minimum. If dust or debris gets on an MCP or its assembly, blow it off with dry clean air or nitrogen gas. When doing this, check the surrounding area and blow at a pressure not so as to blow up other dust. Never use your own breath to blow dust off the MCP.

(3) Shock

MCP and MCP assemblies are made mostly from glass. Extreme care must be taken to protect them from excessive shocks. Scratches or nicks on MCP or assembled parts might increase dark current or cause discharge. In particular MCP/vacuum flange assemblies are equipped with high-voltage feedthroughs which lack mechanical strength, consequently even small shocks might cause vacuum leaks. Be especially careful when unpacking and mounting them on the equipment.

6-2 Storage

MCP and MCP assemblies are shipped in packages that are evacuated to a vacuum or filled with dry nitrogen gas. These packages are intended only for short-term storage during shipping, not for long-term one. When storing MCPs and MCP assemblies, take them out of their packages and keep them in a clean system under either of the following conditions, a) or b).

a) Store in a clean system at a vacuum pressure below 13 Pa and isolate from oil diffusion as much as possible.

b) Store in a clean system where dry nitrogen passed through a 0.45 µm or smaller filter constantly flows (humidity: 20 % or less).

6-3 Operation

(1) Vacuum Evacuation Before Use

Gas adsorption occurs when operating the MCP or MCP assembly for the first time or in re-operating after storage. Carry out degassing then under high vacuum conditions at a pressure below 1.3×10^{-4} Pa for more than 24 hours before attempting to operate it (before supplying the voltage to the MCP).

(2) Wiring

The supply voltage polarity and ratings differ depending on the MCP structure and the type of incident signals. Refer to the wiring examples shown in Figures 26, 27 and 28.

(3) Supply Voltage

Always maintain a high vacuum level at a pressure below 1.3×10^{-4} Pa during MCP or MCP assembly operation. When supplying a voltage to the MCP or MCP assembly and its output signal readout device (an anode or a phosphor screen), slowly increase the voltage by 100 V step (approx. 5 seconds per 100 V).

• Dark current

When the voltage is first supplied to the MCP or MCP assembly, connect an ammeter to the signal readout device to check the dark current without signal input to the MCP or MCP assembly. (See measurement conditions listed on the MCP assembly test sheet and check if the dark current is normal.)

Whenever there is an abnormal increase in the dark current, immediately lower the supply voltage and consult us for advice.

• Signal input

First make sure the input signal (electrons, ions, etc.) is uniform over the input surface of the MCP or MCP assembly. If the signal is only incident on a limited area, gas emissions might concentrate there and cause a discharge.

Next, after the signal is input, check operation by increasing the voltage until an output signal appears. During this procedure, connect an ammeter to the signal readout device (an anode, etc.) and monitor the output current. In the case of phosphor screen output, check the light emission state on the phosphor screen instead of monitoring the output current.

Whenever you notice an abnormal output current or an abnormal emission on the phosphor screen, then immediately lower the supply voltage and consult us for advice.

(4) Rated Supply Voltage

Supply voltages to MCPs and readout devices are as follows.

• Across MCP-In and MCP-Out:

Set this voltage according to the required gain.

1 kV Max. (single-stage MCP)
2 kV Max. (two-stage MCP)
3 kV Max. (three-stage MCP)

• Across MCP-Out and single anode:

This is normally set at about 100 V.

1 kV Max.

• Across MCP-Out and phosphor screen:

This is normally set between 2 kV and 4 kV.

4 kV Max.

• Across MCP-Out and multianode:

1 kV Max.

• Across MCP-Out and CR-chain anode:

This is usually set at about 100 V.

(5) Operating Procedures

The following explains specific procedures for supplying the voltage to a two-stage MCP/phosphor screen assembly with a vacuum flange.

1) Checking the MCP Electrical Continuity

After the system has been evacuated by the procedure explained in section 6-3 (1), check the MCP electrical continuity as follows. (See also Figure 52 below.)

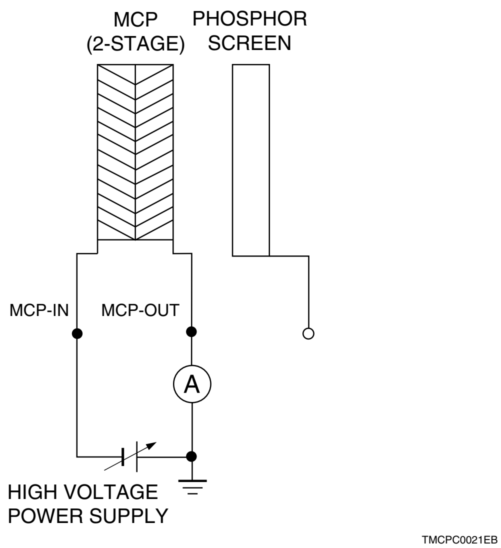


Figure 52: MCP Electrical Continuity Test Circuit

① Connect the MCP-In feedthrough to the terminal of a high-voltage power supply (either positive or negative high voltage).

② Connect an ammeter between the MCP-Out feedthrough and ground.

③ Turn on the high-voltage power supply connected in step 1, and slowly increase the voltage by 100 V step up to 500 V. At this time, make sure that the ammeter connected in the step ② gives indications proportional to the increasing voltage. The current that flows through the MCPs in this state is called the strip current (Is). The strip current is given simply as:

$$Is = \frac{V}{R_1+R_2} \ (\mu A)$$

Where R_1 and R_2 (MΩ) are resistances of the two MCPs. Make sure that this value is nearly equal to the resistance value given in the test sheet supplied with the MCP. However, the MCP resistance values in Hamamatsu test sheets are measured at V=1000 (V) applied to a single MCP, so that these may slightly differ from those measured at a low voltage.

2) Supplying the Voltage

After checking the MCP electric continuity in the preceding item 1), supply a high voltage to the MCP and phosphor screen while observing the light emission state on the phosphor screen. Follow the steps below to supply the high voltage.

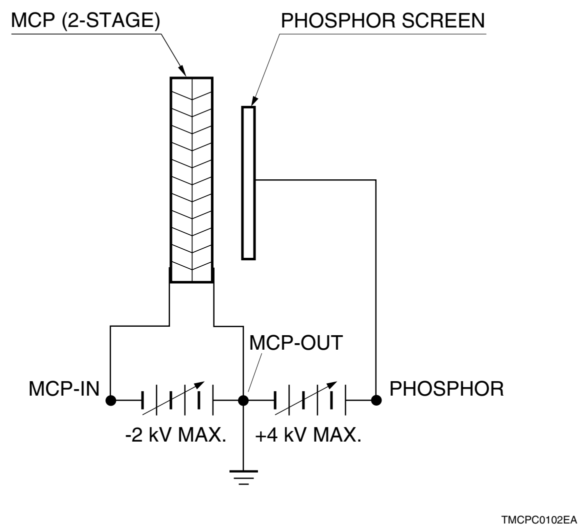


Figure 53: MCP Assembly Operation Test Circuit

① Connect the MCP-In, MCP-Out and phosphor screen terminals as shown in Figure 53.

② Supply +100 V to the phosphor screen.

③ Increase the voltage applied to the MCP-In slowly by 100 V step up to -2000 V at maximum.

④ Increase the voltage applied to the phosphor screen slowly from +100 V to +4000 V at maximum by 100 V step. During this procedure, view the phosphor screen under dark room illumination.

If light emission is seen on the phosphor screen, which is probably caused by a small discharge, immediately shut off the applied voltage. After making sure that the vacuum level has returned to the normal pressure (1.3×10^{-4} Pa or below), supply the voltage again as instructed above.

If this is the first time for this MCP assembly to be used, do not have to increase the voltage up to the maximum during actual operation. Images usually can be viewed on the phosphor screen by just supplying a voltage between -1000 V and -1600 V to the MCP and a voltage between +2000 V and +3000 V to the phosphor screen, and the supplying voltage depending on the amount of input signal fed to the MCP.

⑤ After supplying the voltage, gradually supply the input signal to the MCP while checking the light emission state on the phosphor screen. At this point, make sure that the input signal is uniform over the MCP. If the signal is incident only on a limited area, gas emission may concentrate there, and become the cause of a discharge.
To reduce the risk of the problems above, operating the MCP assembly at a minimum voltage is recommended as long as the desired brightness that suits your application is obtained.
If the brightness on the phosphor screen becomes too low or has decreased due to service life deterioration, increase the voltage applied to the MCP or the phosphor screen by 100 V step where needed.

⑥ The voltages have now been applied. Before entering on experiments, be sure to follow the instructions given in steps ① to ⑤. Avoid suddenly increasing the supply voltage.

6-4 Vacuum Baking

Vacuum baking is effective for degassing when using MCPs or MCP assemblies in an extremely high vacuum condition. Perform the vacuum baking at a temperature below 150 °C while keeping the exhaust system at a vacuum pressure below 1.3×10^{-4} Pa. Because the baking time depends on the amount of gases released from the exhaust system, decide the time while checking the vacuum level. If the baking temperature is too high, the MCP and MCP assembly gain might drop and the MCP resistance increase. Use caution with this.
Vacuum baking however cannot be performed on some types of MCP assemblies. Please consult us for detailed information before attempting vacuum baking. (Also see the test sheet that comes with the MCP assembly to check whether or not vacuum baking is possible.)

6-5 Excessive Output

Excessive output signals may increase gas emission from the inside MCP channels and may cause electrical discharge. The output signal must be kept within 7 % of the strip current flowing in the MCP or MCP assembly.

6-6 Problems with Peripheral Devices

Abnormal voltage caused by external induction or electrical discharge occurring in a power supply for peripheral devices or at high-voltage feedthroughs may cause irrecoverable damage to the MCPs or MCP assemblies.

6-7 Disposal Method

These products contain lead or lead compounds. When disposing of these products, take appropriate measures that comply with applicable regulations regarding waste disposal. Correctly dispose of them yourself or entrust proper disposal to a licensed industrial waste disposal company. In any case, be sure to comply with the regulations in your country or state.

7. DEALING WITH ABNORMAL CIRCUMSTANCES

①The dark current is high or dark current has increased.

- Check whether ions from a vacuum gauge and ion pump are entering the MCP. Use caution particularly when operating the MCP with the MCP-In at a high negative potential.
- Check whether the supply voltage to the MCP exceeds the maximum rating.
- Check whether foreign materials or dust are adhering to the MCP surface. If so, blow them away using dry nitrogen gas. If this is not effective, consult us for advice.
- Check whether excessive signals are being input to the MCP. If so, the dark current might increase due to the gas emission from the channel walls.
- When the MCP has been vacuum-baked, make sure that enough time has passed after the vacuum baking so that the MCP temperature has returned to the room temperature. Because thermal conductivity in a vacuum is lower than that in the air, it takes longer for the MCP to return to the room temperature. Leave the MCP unused all night or longer after vacuum baking.

②The MCP surface is contaminated by ions or oil from the diffusion pump.

- Consult us for advice.

③No signal output from the MCP.

- Check whether the correct voltage is applied to the MCP. The best way to check this is to measure the MCP strip current and calculate the resistance. In this case, if the MCP is at fault, applying a high voltage may cause the MCP to discharge. Then apply a low voltage (100 V to 200 V) to perform this method. If the calculated resistance matches the resistance listed in the MCP test sheet attached, the MCP is normal.
- Check that the anode connection is correct.
- Check that the signal is definitely incident on the MCP surface. If the MCP output signal appears in response to a test signal (for example, UV light), the MCP is operating normally.

④Gain has decreased or PHR is poor.

- Check that the MCP output is within the dynamic range. If the output exceeds the dynamic range, the gain will decrease and the PHR (pulse height resolution) will also deteriorate.
- Check whether the signal is incident on a limited area of the MCP surface. The localized output might exceed the dynamic range of this limited area, causing a drop in gain.
- Check whether excessive current was output from the MCP during operation. If an excessive output continues, it will shorten the MCP service life and hasten a loss of gain. It is inevitable as the MCP life elapses that the gain also gradually decreases over a long period of time. In either case, the MCP must be replaced when the gain has decreased.

⑤The multianode output signal fluctuates.

- The MCP gain may have dropped or partial discharge of the multianode may have occurred. Consult us for advice.

⑥The MCP has discharged.

- Immediately shut off the supply voltage and carefully check the MCP assembly. If any mark caused by discharge is found on the MCP surface or phosphor screen, immediately stop using the MCP and consult us for advice. If these are found to be normal, pump out the system for about one hour to evacuate gases produced by the discharge. Then, slowly increase the voltage while monitoring the dark current or while checking whether light emission occurs on the phosphor screen.

⑦Ringing appears with the output signal.

- Consider using a high-speed response MCP assembly designed to prevent ringing. (See also sections 3-5 and 5-1.) Please consult us for information on how to reduce ringing when using ordinary MCP assemblies.

8. FREQUENTLY ASKED QUESTIONS

QUESTIONS AND ANSWERS

①How should MCP assemblies be stored?

MCP assembles are shipped in packages which are filled with nitrogen gas or evacuated. However, these packages are not suitable for a long-term storage. Store them by the following instructions provided in section 6-2, "Storage".

②What precautions should be taken when installing an MCP assembly in equipment?

MCP assemblies are used in a high vacuum. Follow the instructions given in section 6-1, "Handling precautions". When installing an MCP assembly into equipment, handle it in an environment conforming to clean room specifications. If this is not possible, store the MCP assembly in a dust-proof case until the installation is ready. Complete the installation in as short a time as possible.

③Dust adhered to the surface of an MCP. How can it be removed?

In this case, blow off the dust using dry nitrogen gas passed through a 0.45 µm filter. Note that blowing the nitrogen gas in a normal environment might cause problems by penetrating ambient dust into the MCP. Always perform this procedure in a place conforming to clean room specifications.

④Should precautions be taken when using an MCP assembly in an evacuating system?

Oil from the evacuating system, if it gets on the MCP and assembly, might lower the gain and the breakdown voltage, and increase the dark current. Use an oil-free type evacuating system (cryo pumps, turbo molecular pumps, etc.). If using an oil-diffusion pump is unavoidable, always install an oil-trap. Should the MCP or assembly become contaminated by oil, consult us for advice. Never try to clean them yourself.

⑤I would like to use an MCP assembly at a lower vacuum level (higher pressure). At how low a vacuum level can the MCP be operated?

MCP assemblies must be operated in a high vacuum at a pressure suggested below.

- MCP/phosphor screen assemblies: 1.3×10^{-4} Pa or below
- Other MCP assemblies: 6.5×10^{-4} Pa or below.

Operating an MCP assembly at a pressure higher than these levels may cause discharge or breakdown.

⑥I hear that besides electrons, the MCP is also sensitive to UV and X-rays. What quantum efficiency do they have? Is there any method to enhance it?

See section 3-8 on detection efficiency for information on MCP sensitivity to UV and X-rays. One way to enhance this sensitivity is a CsI (cesium iodide) coating. However because CsI is such a deliquescent material that will react with moisture in the air, more care must be taken than for a normal MCP in order to avoid moisture. Even during storage, always keep it in a vacuum. The MCP assembly setup time should also be as short as possible so that the MCP is exposed to air only for a minimum time.

⑦I hear that the MCP output current will not saturate up to 7 % of the strip current. What is the specific value of the strip current?

The strip current is an intrinsic current that flows through the MCP during operation. See section 3-3 for detailed information. In an MCP having a resistance of 200 MΩ, for example, a strip current of 5 µA will flow when 1000 V is applied across the MCP. This means that a non-saturated or linear output (at 5 % loss) can be obtained up to 7 % (350 nA) of this strip current. If a greater output is required from the MCP, use an MCP having lower resistance. See section 3-4 to view the actual measurement data.

⑧An excessive signal was input to the MCP during operation. The area where the excessive signal was input shows a loss of gain. Is it possible to restore the original gain?

Basically, this is not possible. This is why the gain in the area where the excessive output was extracted has drastically dropped compared to the surrounding area due to MCP fatigue in that area. If the gain loss is small, aging the MCP with a signal uniformly input over the MCP surface might be effective, because the aging process decreases the overall MCP gain and minimizes the gain difference between the fatigue area and the surrounding area. However, if the loss in gain is drastic, it is impossible to restore the original state. The MCP assembly must then be replaced with a new one.

⑨There are only two electrodes in two-stage and three-stage MCP assemblies. Is it necessary to apply a voltage to each of the MCPs?

Two and three-stage MCP assemblies have only two electrodes, IN and OUT. In the fabrication process, each MCP is carefully assembled to have a resistance difference within ±10 %. The supply voltage applied across IN and OUT is properly distributed according to the resistance of each MCP, thus no intermediate electrodes are needed.

⑩Even when a signal was uniformly input over the MCP/phosphor assembly, there was a partial area with lower gain. Why?

Check whether or not the incident angle of the input beam is aligned with the bias angle of the MCP. If aligned, the input beam enters deep into the channels and does not contribute as much to multiplication, and this results in a loss of gain.

⑪What is ion feedback? How can I prevent it?

When an MCP is operated at high gain, the residual gases are ionized inside the channels and these ions travel backward to the MCP input side. This phenomenon is called ion feedback. If this occurs, a large secondary pulse may be generated as noise, eventually causing a discharge in the worst case. Effective techniques to prevent this are using a two-stage or three-stage MCP with opposing bias angles or coating a thin aluminum film over the input surface of the MCP.

⑫How should the potential distribution be established for an MCP assembly?

The supply voltage polarity and ratings differ depending on the MCP structure and the type of incident signals. Refer to the wiring examples shown in Figures 26, 27 and 28.

⑬I would like to use various types of readout devices on a demountable MCP assembly. Is it possible to replace them myself?

We do recommend that readout devices be replaced by Hamamatsu.

⑭Can the MCP resolve the energy of incident particles or photons?

The MCP itself is not capable of resolving energy when particles are input directly. If this capability is needed for charged particles, there is a technique for attaching a special mesh in front of the MCP assembly for energy discrimination.

⑮What determines the spatial resolution of an MCP and MCP assembly?

The spatial resolution depends greatly on the type of readout device. The number of stacked MCP and the channel pitch also affect the resolution. Typical spatial resolution for each readout type is described below.

①Phosphor screen type

This type has the following resolution (FWHM).

6 μm channel diameter: 25 μm for single-stage MCPs

12 μm channel diameter: 40 μm to 45 μm for single-stage MCP and 80 μm to 90 μm for two-stage MCP

②CR-chain anode type

This type has a resolution of about 120 μm by position data calculation.

9. REFERENCES

1)
S. Matsuura, S. Umebayashi, C. Okuyama, K. Oba: "Characteristics of the newly developed MCP and its assembly", IEEE Ttans., NS-32. 350 (1985)

2)
S. Matsuura, S. Umebayashi, C. Okuyama, K. Oba: "Current status of the microchannel prate", IEEE Trans., NS-31, 399 (1984)

3)
M. Galanti, R. Gott. J. F. Renaud: "A high resolution, high sensitivity channel plate image intensifier for use in particle spectrographs", Rev. Sci. Inst., 42, 12, 818 (1971)

4)
J. L. Wiza: "Microchannel plate detector", Nucl. Inst. and Meth., 162, P.587 (1979)

5)
K. Oba et al.: "High-gain microchannel plate multipliers for particle tracking or single photo-electron counting", IEEE Trans., NS-28, L, P.705 (1981)

6)
K. Tobita et al.: "Absolute Detection Efficiency of a Microchannel-Plate Detector for Ions and Neutrals", JOURNAL OF APPLIED PHYSICS, VOL 26, NO. 3, March, 1987, PP509-510

7)
IS Gilmore and MP. Seah: "ION DETECTION EFFICIENCY OF MICROCHANNEL PLATES" Int. J. Mass Spectrom. 202 (2000) 217

8)
N. Yamaguchi et al.:"X-ray detection characteristic of microchannel plates using synchrotron radiation in the energy range from 0.06 to 0.6 keV", Rev. Sci. Instrum. 61 (10), October 1990

9)
G. W. Fraser: "The soft x-ray quantum detection efficiency of Microchannel Plate", Nucl. Instrum. and Meth., 195, 523 (1982)

10)
C. Martin, S. Bowyer: "Quantum efficiency of opaque CsI photocathodes with channel electron multiplier arrays in the extreme and far ultraviolet", Appl. Opt., 21, 4206 (1982)

11)
"Characteristics and applications of microchannel plates", Technical information published by Hamamatsu Photonics K. K.

12)
"Photomultiplier Tubes - Basics and Applications", Technical handbook published by Hamamatsu Photonics K. K.

13)
K. Ishii et al.: "The characteristics of the newly designed microchannel plate detector in a strong magnetic field.", Rev. Sci.Inst., 70, 8, 3319 (1990)

14)
T. Nakayama, T. Sugawara, C. Okuyama, T. Kawai: "Fiber optic plates and their applications", Journal of the Institute of Television Engineers of Japan, 14, 53, 1(1999)

15)
"Trial production of one-dimensional PSD and its characteristics", Proceeding of the 48th Autumn Meeting (1987) of JSAP (Japan Society of Applied Physics)

16)
M. Katayama, M. Nakai, T. Yamanaka, Y. Izawa, S. Nakai: "Multi frame x-ray imaging system for temporally and spatially resolved measurements of imploding internal confinement fusion targets", Rev. Sci., 62, 1, 124 (1991)

17)
R. Mimura: "Problems with increasing the accuracy and dimensional miniaturization in electron beam measuring technology", Semicon News, 10, 44 (1987)

18)

By courtesy of Dr. Takai, The Center for Quantum Science and Technology under Extreme Conditions, Osaka University

19)

Y. Hashimoto et al.: "Oxygen Gas-Sheet Beam Profile Monitor for the Synchrotron and Storage Ring", Nuclear Instruments and Methods in Physics Research A527(2004) 289-300

20)

E. Takahashi et al.: "IEEE, J Select. Top, Quantum Electron", Vol. 10, PP1315-1328, 2004

10. REFERENCES BY APPLICATION

[Ions]

● **TOF-Resolved Mass Spectrometer (Multi-turn TOF-MS)**

M. Toyota, M. Ishihara, S. Yamaguchi, H. Ito, T. Matsuo, R. Roll and H. Rausenbauer: "Construction of a new multi-turn time of flight mass spectrometer", J. Mass Spectom. 35,163-167(2000)

● **Residual Gas Beam Profile Monitor**

R. Ishida, Y. Nakahama, H. Aihara, M. Iwasaki, H. Kakuno, H. Noumi, Y. Sato, A. Toyoda: "R & D of residual gas beam profile monitor", Nuclear Science Symposium Confrence Record, 2004 IEEE Vol.3 1798

● **Aerosol Analysis Using RE TOF-MS Technology**

Y. Matsumi, A. Takeuchi, K. Takahashi, N. Sugimoto, I. Matsui, A. Shimizu: "Real-time measurement of atmospheric aerosol using a mass spectrometer for laser-ionized individual particles", Laser Sensing Symposium (2004)

● **Coaxial Impact Collision Ion Scattering (CAICISS)**

M. Katayama, E. Nomura, N. Kanakama, H. Fukushima, M. Aono: "New material surface and interface evaluation table - Coaxial impact collision ion scattering (CAICISS)", Journal of the Vacuum Society of Japan, 31, 5, 377 (1988)

[Electrons and Positrons]

● **Femtosecond Photoelectron Image Spectrometer**

T. Suzuki: Journal of the Physical Society of Japan, 58, 765 (2003)

● **Electron Emission Microscope (MEEM, PEEM, LEEM)**

N. Ueno: "Metastable excited atom electron emission microscope", Journal of the Vacuum Society of Japan, 18(7)415-420 (2005)

● **Electron Emission Microscope (MEEM, PEEM, LEEM)**

H. Murata, T. Kimura, Y. Nishimura, H. Shimoyama, A. Mogami, Y. Sakai, M. Kudo, M. Kato, K. Betsui and K. Inoue: 9 "Development of electron optical instrument for evaluation of multi emitters — observation of operating conditions of multi emitters by LEEM, PEEM and FEEM —", Technical Digest of the 17th International Vacuum Nanoelectronics Conference (IVNC 2004), Cambridge, Massachusetts, USA, July, 2004, pp. 188-189

● **ULSI Test System Using SEM Technology**

M. Miyoshi, Y. Yamazaki, I. Nagahama, A. Onishi, and K. Okumura: "Electron beam inspection system based on the projection imaging electron microscope", J.Vac. Sci. Technol. B 19(6), Nov/Dec 2001

● **Electron–Ion Coincidence Spectroscopy**

K. Mase, E. Kobayashi, and K. Isari: "Development of New Apparatus for Coincidence Spectroscopy and Auger-Photoelectron Coincidence Electron - Polar-Angle-Resolved-Ion Spectroscopy", Correlation Spectroscopy of Surfaces, Thin Films and Nanostructures, Edited by. J. Barakdar and J. Kirschner (WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004.) Chap. 16, pp. 206-225.

● **High-speed Reflection Positron Diffraction**

A. Kawai, T. Ichinomiya: "Surface study by high-speed reflection positron diffraction", Surface Science Vol.24, No.3, pp.174-180, 2003

● **Electron Beam Diffraction (RMEED Pattern Observation)**

G. Shimaoka, M. Ono, J. Okubo, Y. Nakanishi, K. Matsuura. M. Murabayashi: "RMEED pattern observation by MCP", Journal of the Vacuum Society of Japan, 29, 5, 201(1988)

[UV, X-rays]

● **Time-space Measurement of Soft X-rays Emitted from AL Plasma**

Y. Okano, K. Oguri, T. Nishikawa, H. Nakano: "Soft X-ray imaging system for picosecond time-resolve absorption spectroscopy using a femtosecond-laser-plasma source", Rev. Sci. Instrum., 77, 046 105(2006)

● **X-ray Framing Camera**

K. Kondo, T. Haruki, H. Mita, Mitsuo Nakai, S. Nakai: "Development of a high-speed gating X-ray framing camera", TECHNICAL REPORT OF IEICE EID 95-3 (1995-06)

[Space Applications]

● **Evaluation of SELENE–MAP–PACE–IMA Sensor (Analysis of Lunar Atmospheric Ions, Research on Lunar Surface Material)**

S. Yokota, Y. Saito, K. Asamura and T. Mukai: "Development of an ion energy mass spectrometer for application on board three - axis stabilized space craft" REVIEW OF SCIENTIFIC INSTRUMENTS 76, 014501 (2005)

● **LEP-ESA/ISA Data Analysis Results (Aurora Electron Observation)**

H. Tanaka, Y. Saito, K. Asamura, S. Ishii and T. Mukai: "High time resolution measurement of multiple electron precipitation with energy time dispersion in high - latitude part of the cusp resion" JOURNAL OF GEOPHYSICALRESEACH, VOL. 110, A07204, doi: 10. 1029/2004JA010664,2005

11. DIMENSIONAL OUTLINES OF MCP ASSEMBLIES (CUSTOM MADE DEVICES)

* PCD (Pitch Circle Diameter)

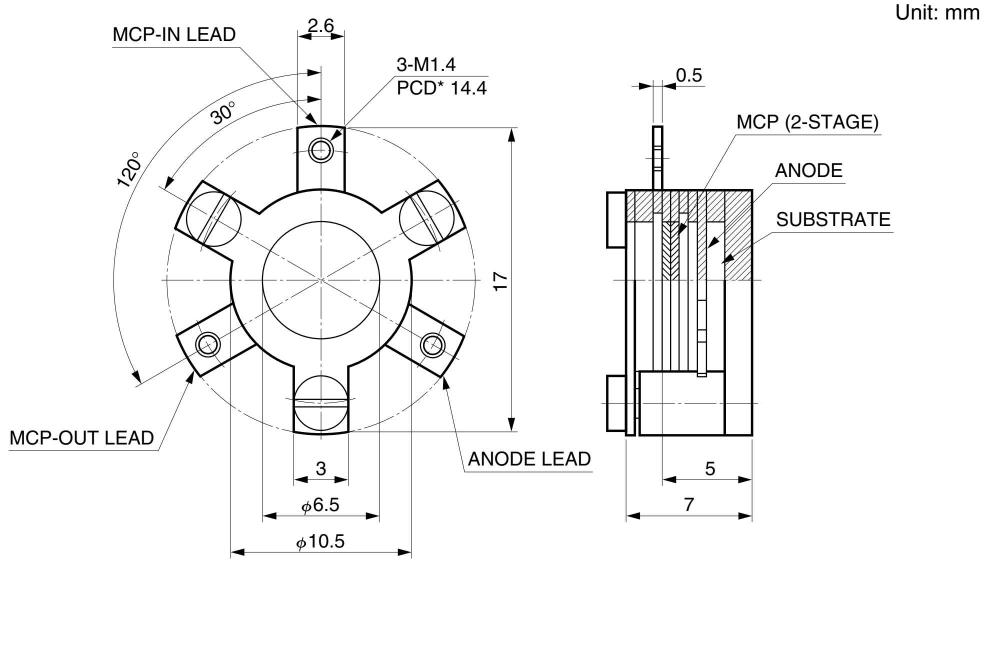


Figure 54: Compact MCP Assembly

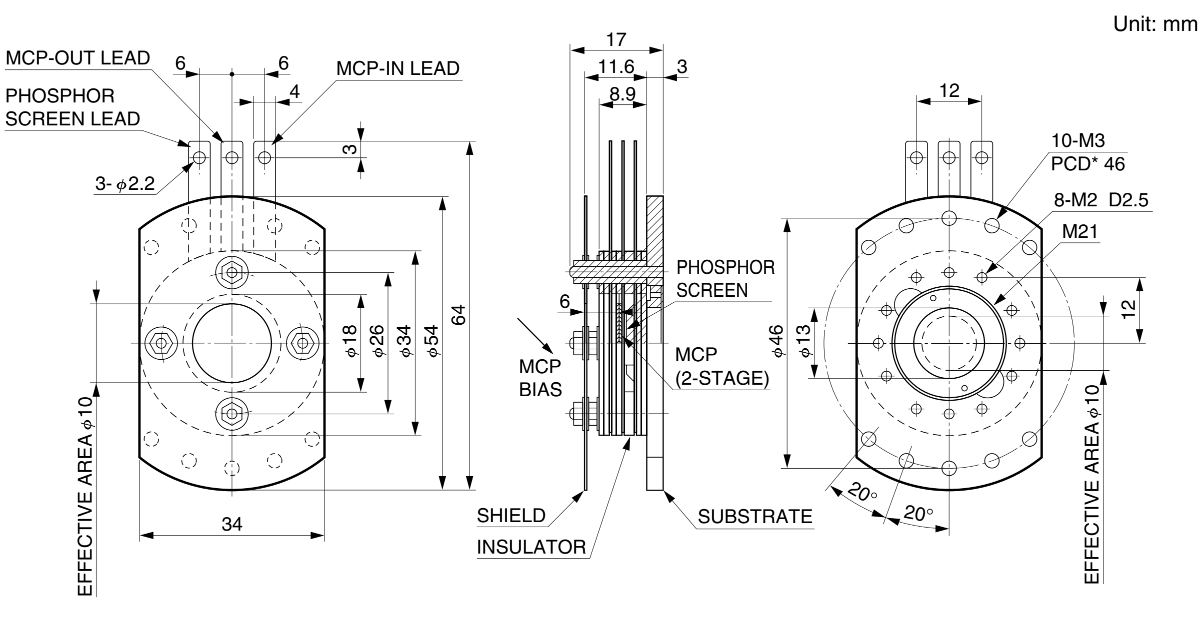


Figure 55: Compact (reduced size substrate) MCP/Phosphor Screen Assembly

Unit: mm

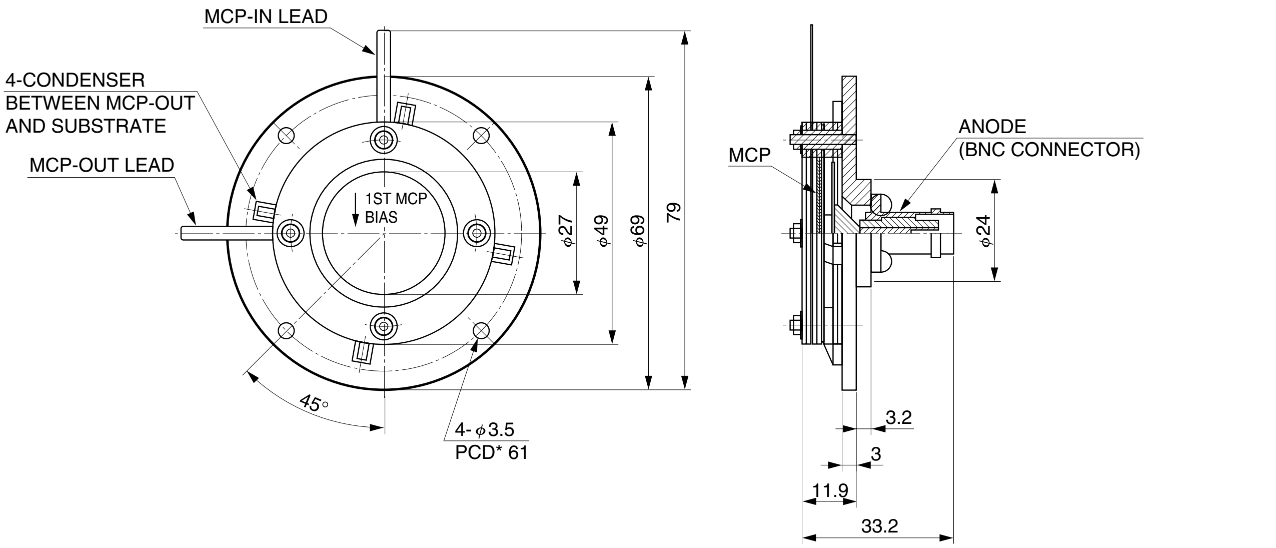


Figure 56: High-speed Response MCP Assembly

Unit: mm

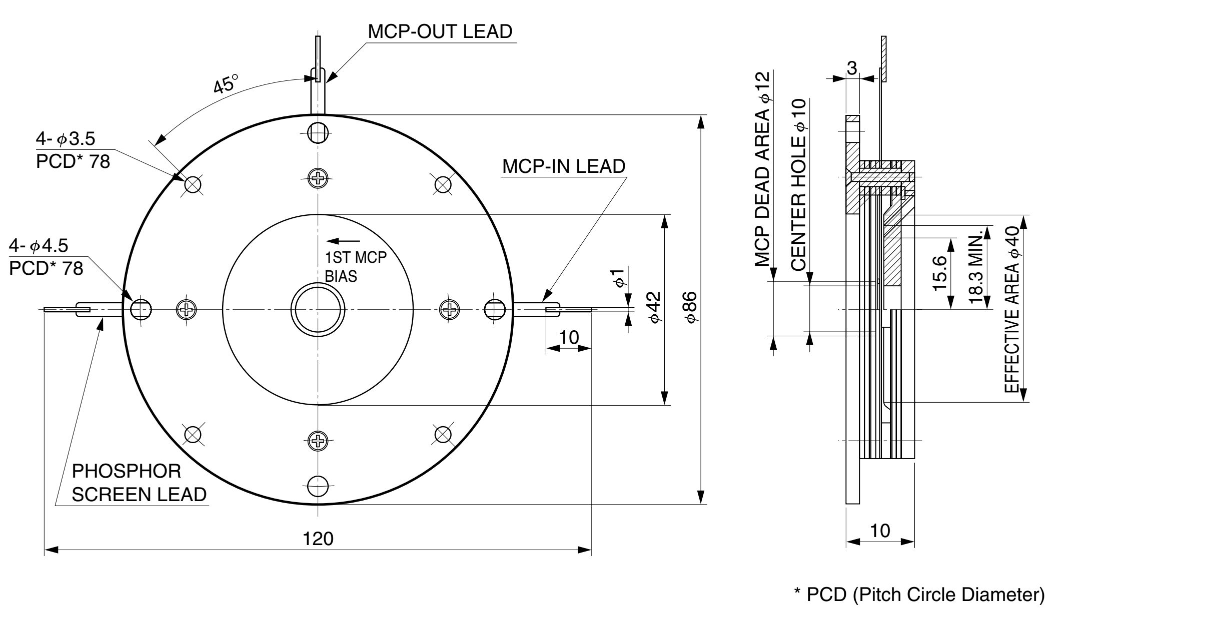


Figure 57: Center-holed MCP/Phosphor Screen Assembly

Unit: mm

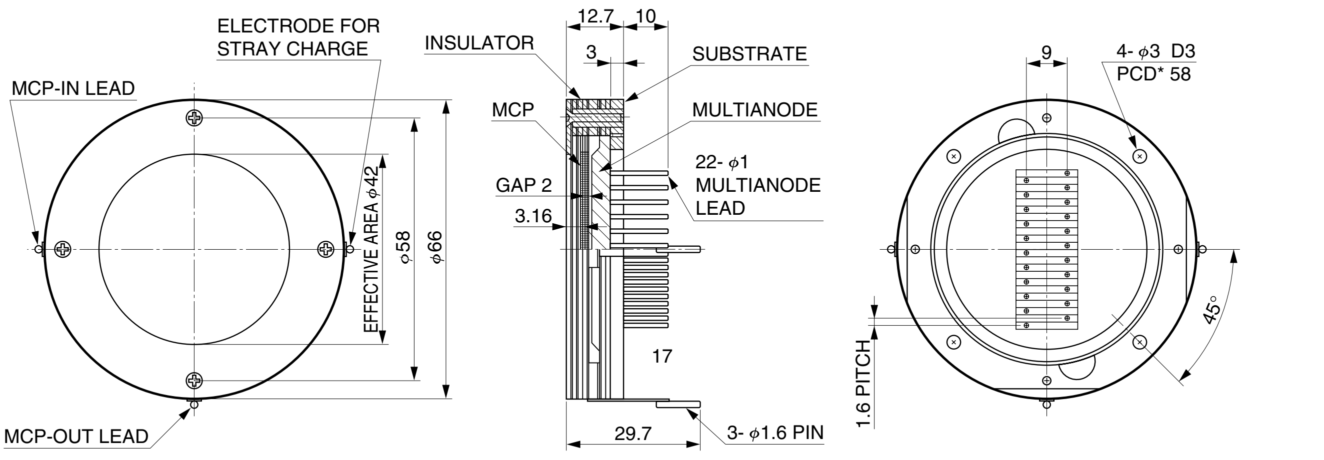


Figure 58: Multiande MCP Assembly

Unit: mm

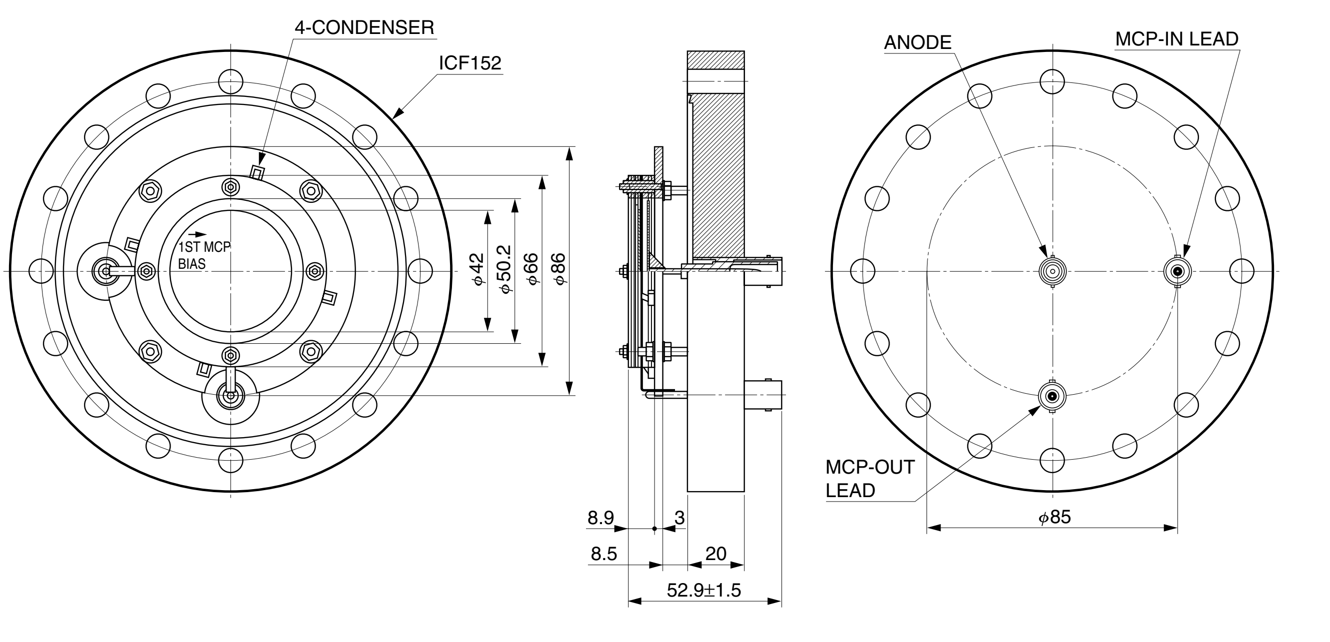


Figure 59: High-speed Response MCP/Vacuum Flange Assembly

Unit: mm

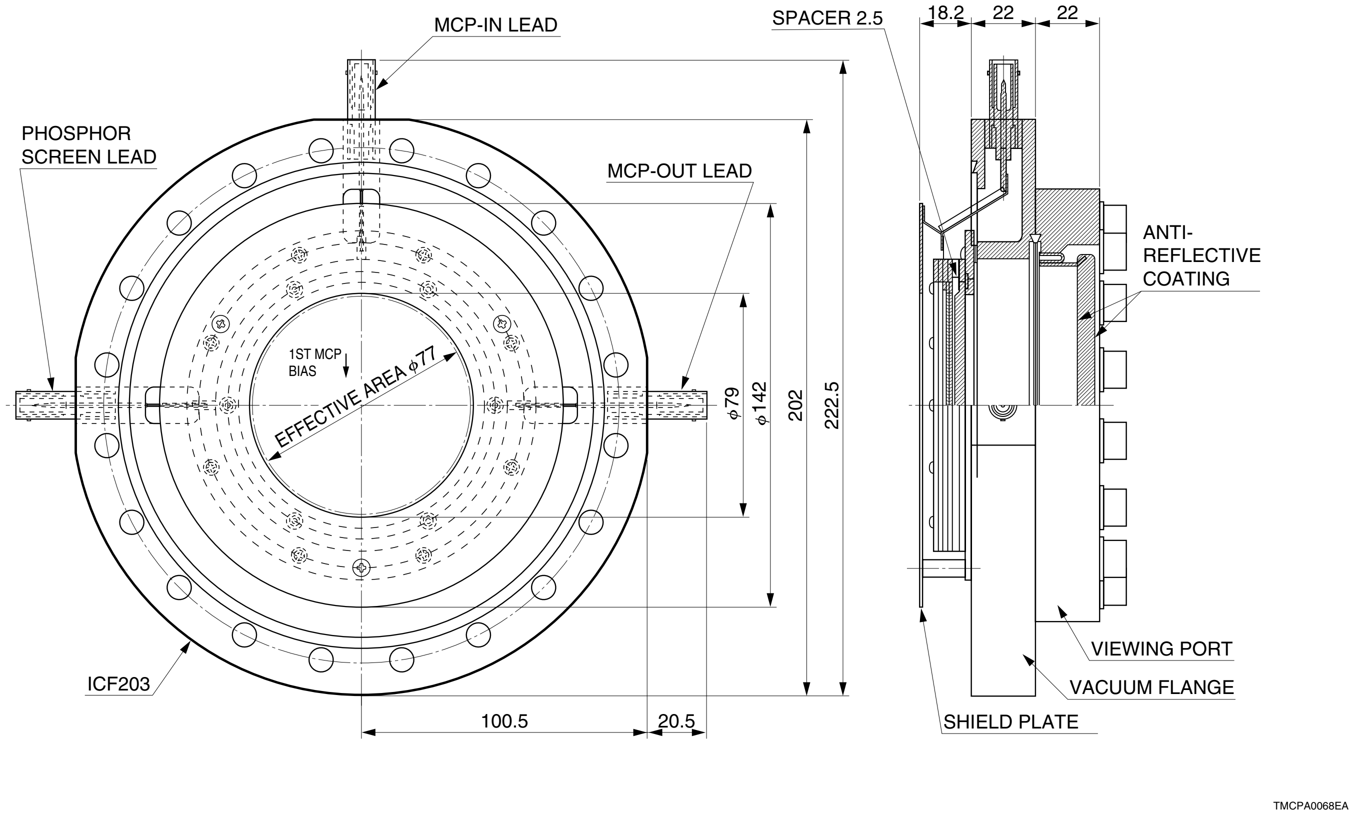


Figure 60: Large Area MCP/Phosphor Screen/Vacuum Flange Assembly

Unit: mm

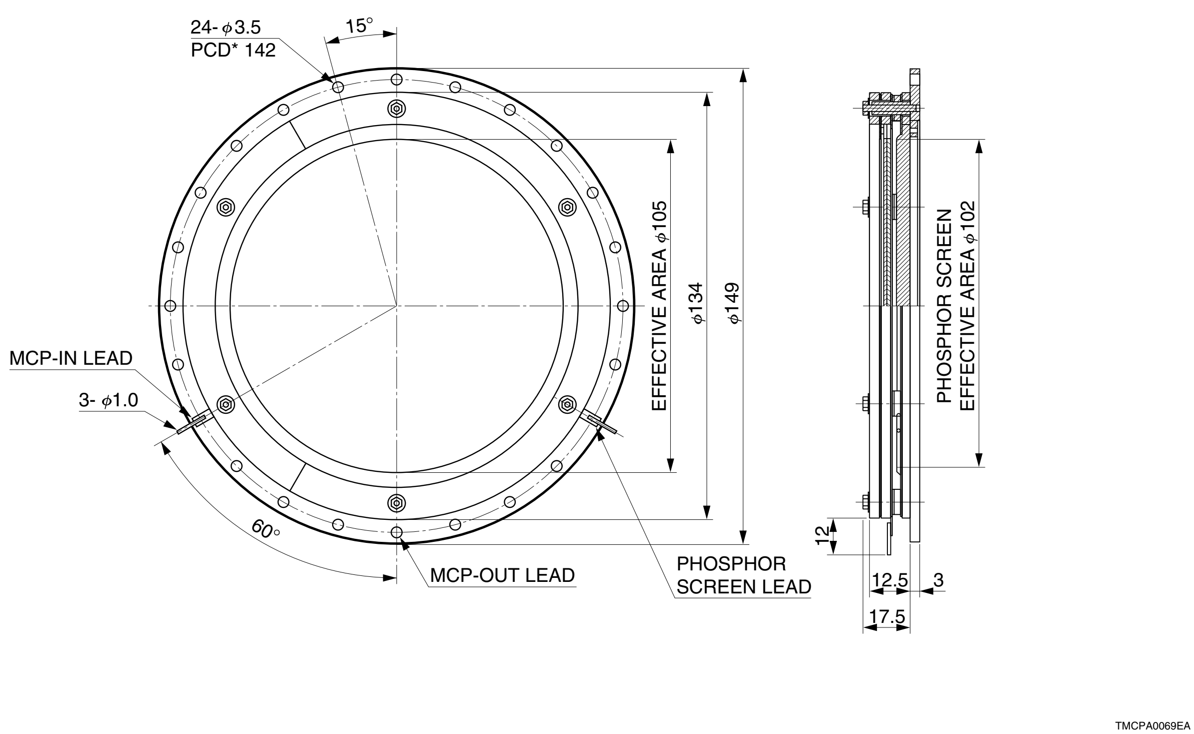


Figure 61: Large Area MCP/Phosphor Screen Assembly

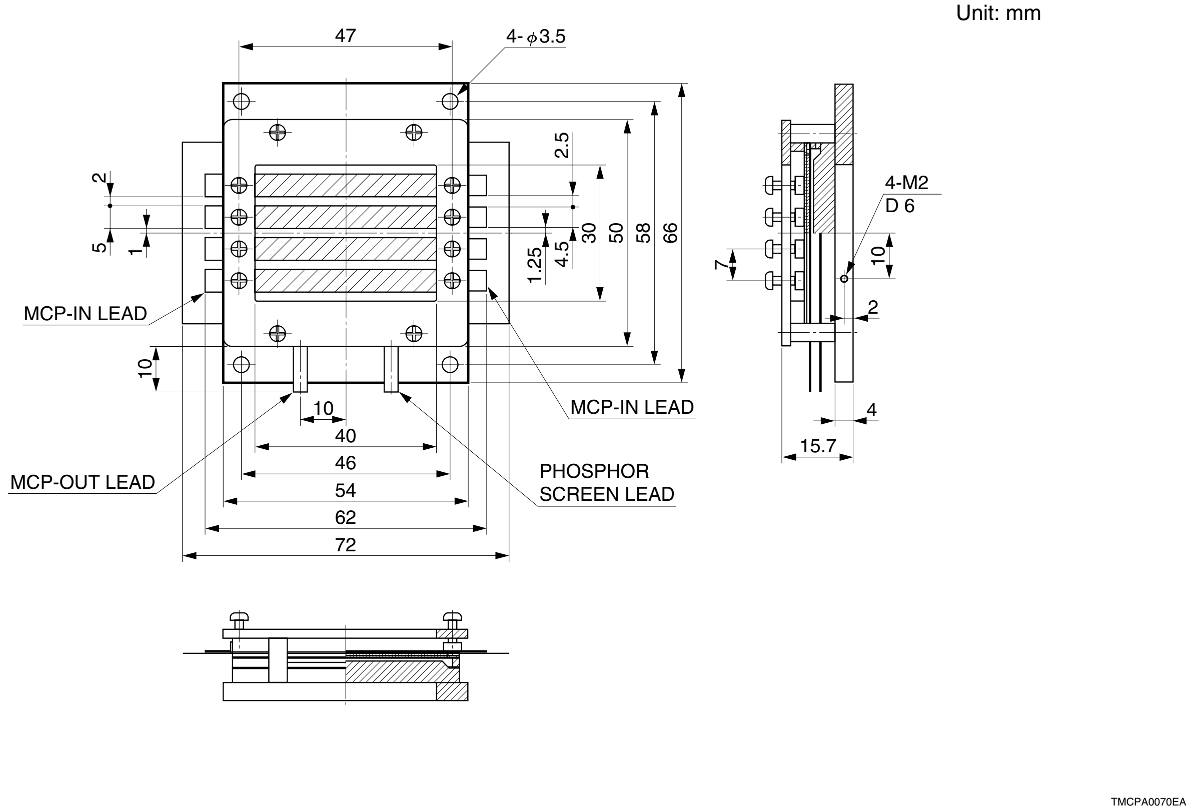


Figure 62: Strip Line MCP/Phosphor Screen Assembly

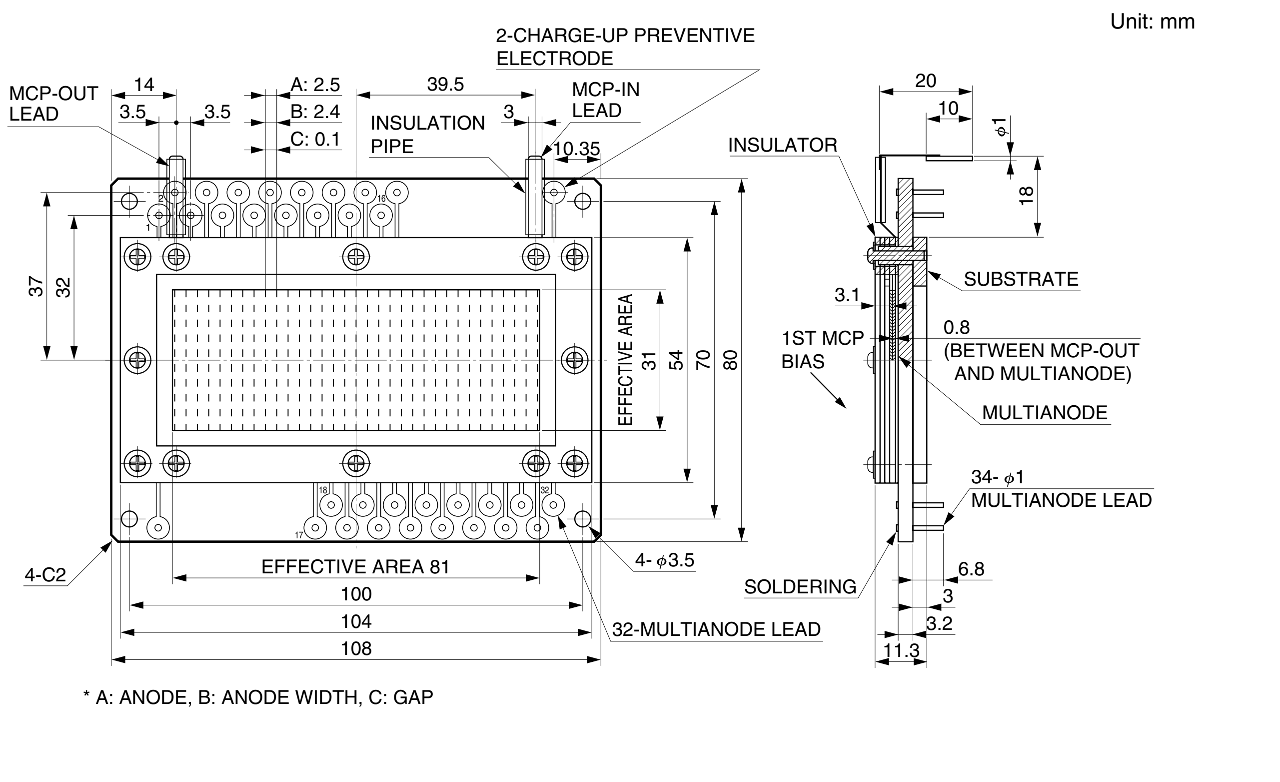


Figure 63: Multianode Rectangular MCP Assembly

HAMAMATSU WEB SITE www.hamamatsu.com
HAMAMATSU PHOTONICS K.K., Electron Tube Division
314-5, Shimokanzo, Iwata City, Shizuoka Pref., 438-0193, Japan, Telephone: (81)539/62-5248, Fax: (81)539/62-2205
U.S.A.: Hamamatsu Corporation: 360 Foothill Road, P. O. Box 6910, Bridgewater. N.J. 08807-0910, U.S.A., Telephone: (1)908-231-0960, Fax: (1)908-231-1218 E-mail: usa@hamamatsu.com
Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone: (49)8152-375-0, Fax: (49)8152-2658 E-mail: info@hamamatsu.de
France: Hamamatsu Photonics France S.A.R.L.: 19, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone: (33)1 69 53 71 00, Fax: (33)1 69 53 71 10 E-mail: infos@hamamatsu.fr
United Kingdom: Hamamatsu Photonics UK Limited: 2 Howard Court, 10 Tewin Road Welwyn Garden City Hertfordshire AL7 1BW, United Kingdom, Telephone: 44-(0)1707-294888, Fax: 44(0)1707-325777 E-mail: info@hamamatsu.co.uk
North Europe: Hamamatsu Photonics Norden AB: Smidesvägen 12, SE-171-41 SOLNA, Sweden, Telephone: (46)8-509-031-00, Fax: (46)8-509-031-01 E-mail: info@hamamatsu.se
Italy: Hamamatsu Photonics Italia: S.R.L.: Strada della Moia, 1/E, 20020 Arese, (Milano), Italy, Telephone: (39)02-935 81 733, Fax: (39)02-935 81 741 E-mail: info@hamamatsu.it

TMCP9002E01
SEPT. 2006 IP
Printed in Japan (1000)