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Author(s)	Arata, Yoshiaki; Miyake, Shoji; Kishimoto, Hiroaki; Abe, Nobuyuki
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Multichannel Measurement of Soft X-ray with MCP and OMA System†

Yoshiaki ARATA*, Shoji MIYAKE**, Hiroaki KISHIMOTO*** and Nobuyuki ABE****

Abstract

Position sensitive multichannel measurement of 4keV soft x-ray was carried out using microchannel plate (MCP) and optical multichannel analyzer (OMA). X-ray image by MCP was converted to visible one through phosphor and detected by OMA as electrical signal. Dependence of sensitivity and spatial resolution of MCP on the x-ray incident angle was measured in detail and it was found that the latter was limited essentially by the electron divergence in the region between MCP and phosphor. Transparent photocathode was mounted in front of MCP to improve gain reduction for obliquely incident x-ray at a large angle. Favorable improvement in the sensitivity was obtained and its incident angle dependence was fairly removed without any reduction in the spatial resolution of the detection system.

KEY WORDS: (Microchannel Plate) (Multichannel Measurement) (Soft X-ray) (Transparent Photocathode)

1. Introduction

With the recent advance of spectroscopy in vacuum ultraviolet (VUV) and soft x-ray regions, availability of multichannel detection scheme is increasingly needed. Microchannel plate (MCP) is one of the well known multichannel devices to be used in these wavelength regions¹⁻³). It is a bundled miniature of channeltrons as the photomultiplier having continuous dynode and each channel independently has a function of electron amplification. So that MCP possesses the advantage to intensify an image in two-dimensional form. Due to its high gain of about 10^4 it is also applicable to the observation of very weak VUV and x-ray in space. Furthermore as it is hardly affected by magnetic field because of its high electric field provided in the channel, it is also effective to measure an x-ray from magnetically confined plasmas⁴).

MCP has a disadvantage, however, that when used as a detector for the grazing incidence spectroscopy, its sensitivity is decreased drastically because of a very low conversion efficiency of photons to electrons in the area of the channel wall at a large incident angle of the x-ray to the channel axis. In this study, we have applied a method to supplement the sensitivity reduction for obliquely incident x-ray. A transparent photocathode is placed just in front of MCP, so as photoelectrons emitted from the

photocathode by the injection of x-ray to be accelerated normally into MCP. In this case MCP works as an ordinary electron multiplier.

While x-ray image intensified by MCP is usually analyzed by two methods. One is the electrical output through various anodes as position sensitive detection⁵⁻⁸). Multi-wire anode, resistive anode, and cross-grid anode and so on are typically used. This method has a superiority for a single event detection. When, however, two-dimensional image or coincidental multi-events should be detected, it has lack of spatial resolution and digital processing system for analyzing the data is rather complex and expensive. The other method⁴) is to convert the image into visible one by accelerating electron flux from MCP on to the phosphor screen behind it. It is quite simple and easy to perform. Now we have many experiences^{9,10}) in the visible multichannel spectroscopy with commercially available analyzer system (OMA, PAR). With this system we already studied a pulsed high current arc plasma mainly in the spectral profiles of emitted lines. So that we have selected the latter method in this experiment and a visible image from the phosphor screen is focused by a lens on to the surface of OMA detector head to be analyzed and recorded electrically.

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* Professor

** Associate Professor

*** Graduate Student

**** Research Associate

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This paper reports on experimental results of the soft x-ray detection with MCP and OMA system. Special emphasis is given to the angular dependence of the intensity and the resolving power of the detection system and the application of a photocathode in front of MCP was made clear to be successful to supplement the gain reduction for an obliquely incident x-ray without worsening the spatial resolution.

2. Experimental apparatus

Scheme of the photometry system is shown in Fig. 1. Soft x-ray whose energy is about 4keV is irradiated on to the surface of MCP and/or photocathode with an x-ray tube (Type N1163, Hamamatsu TV) having a transparent-type Ti target. The soft x-ray image is then transformed into visible one by phosphor. Type of the phosphor used is P-11 and it is deposited on the fiber plate set at the back of MCP. Distance between MCP and phosphor is variable from 0.75 to 2mm. The photocathode is made of Au-layer sputtered on the Be-foil of $30\mu\text{m}$ in thickness. Thickness of the uniformly sputtered Au-layer is selected to be 3000A over the whole surface of 25mm in diameter and it has the optimal photoelectric conversion efficiency for 4keV x-ray¹¹⁾. X-ray tube, photocathode, MCP and fiber plate with phosphor are mounted in a vacuum chamber of 10^{-3} - 10^{-4} Pa. Visible image through the fiber plate is focused by a lens on the input surface of OMA detector (Model 1254, PAR) and is read out as electrical signal with the console (Model 1215/1216, PAR). OMA system is operated at real-time mode.

Schematic diagram of microchannel plate and of each channel is shown in Fig. 2. The form of MCP is a sliced bundle of capillary glass pipes which are called channel. Inner wall of each channel consists of the layer of a high resistance with high emission efficiency of secondary electrons. Each channel acts as a photomultiplier having continuous dynode. Front and rear surface of MCP are coated by metal so as to supply high voltage below 1kV to each channel. X-ray flux injected into the channel is converted to photoelectrons and they are multiplied repeatedly to reach to a gain of about 10^4 . Dimensions of MCP used (F1552-01, Hamamatsu TV) are as follows; channel diameter is $12\mu\text{m}$, channel pitch is $15\mu\text{m}$ and its length is 0.5mm. Active diameter usable for measurement is 25mm. Electron flux amplified by MCP is proximity focused on the phosphor screen. As stated earlier, electron signal is converted to visible light to be detected by OMA. Since the degree of focusing of amplified electron flux on to the phosphor affects directly the resolving power of the system, a high voltage below 5kV is needed

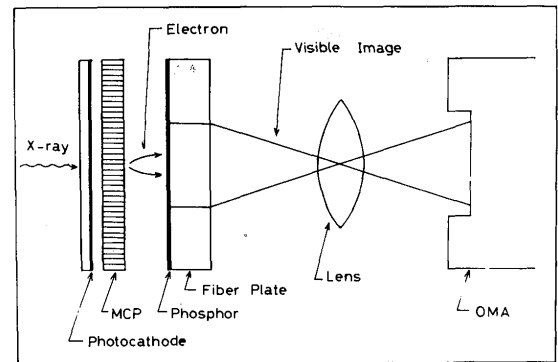


Fig. 1 Photometry system

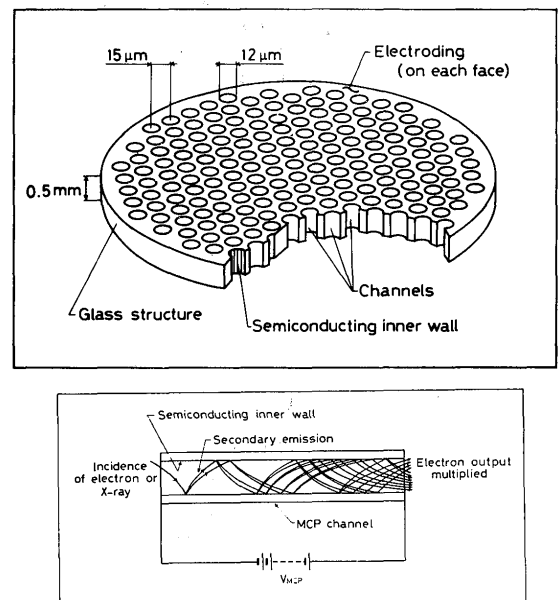


Fig. 2 Schematic diagram of MCP and of each channel.

between MCP and phosphor screen and their separation is required to be short enough without electrical breakdown.

3. Result and discussion

3-1 Resolving power without photocathode

Figure 3 shows the geometrical relation in front of the MCP used. A slit of $20\mu\text{m}$ in width is set in contact with the surface to limit the dimension of incident x-ray. It is made of razor blades. The angle θ in the figure corresponds to the direction of incident x-ray on to the slit and is called "incident angle". The angle ϕ is called "bias angle" which decides the inclination of the channel axis relative to the normal to the surface. It is originally provided to inhibit electrons incident on to the MCP surface

without any amplification. Here all the data described in this sub-section is brought at $\theta=0^\circ$ to evaluate the spatial resolving power from FWHM (full width at half maximum) of the intensity distribution of the slit image detected by OMA. The result is shown in Fig. 4.

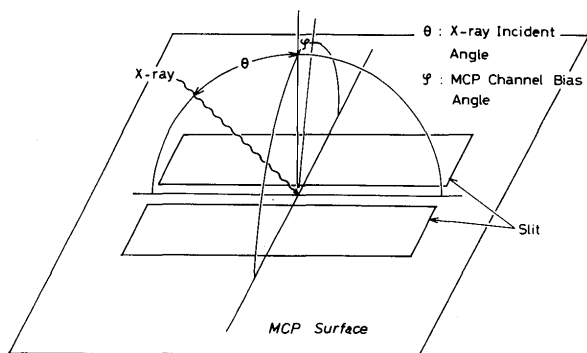


Fig. 3 Geometrical relation in front of the MCP with a slit provided on the surface.

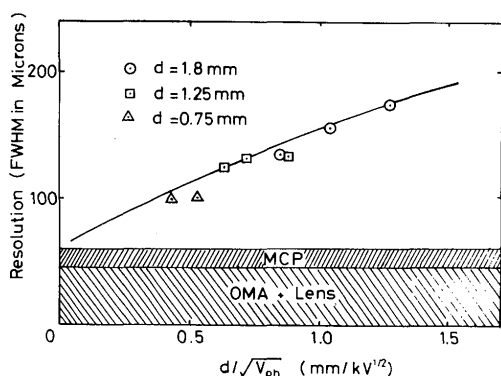


Fig. 4 Resolving power of the detection system without photocathode and in normal incidence of x-ray.

The abscissa is $d/\sqrt{V_{ph}}$ and the ordinate shows the resolution in FWHM, where d and V_{ph} are the distance and the applied voltage between MCP and phosphor, respectively. We have measured the resolution for $d=1.8, 1.25$ and 0.75 mm at various V_{ph} . For the detection system factors which contribute to the resolution inherently are geometrical dimension of channels and their assembly as MCP, degree of proximity focusing of electron flux between MCP and phosphor, focusing characteristics of the lens and the resolving power of OMA system. Contribution of the latter two factors was evaluated by replacing the slit on to the rear surface of the fiber plate and measuring the intensity distribution of the visible light from the phosphor screen with the OMA detector. While contribution of MCP geometrical factor is brought by channelpitch of $15\mu\text{m}$. All these factors are given in the figure by the shaded regions, which are, of course,

independent of d or V_{ph} . In the region between MCP and phosphor screen an electron trajectory shows a parabola during the proximity focusing by a strong electric field acceleration. Electrons are considered to be emitted from a channel with the effective angle α relative to the channel axis and with a mean initial velocity u . The diameter Y (FWHM) of the electron cloud on the phosphor is given by the following equation⁴⁾:

$$Y = 2 \sin 2\alpha \times \frac{ud}{V_{ph}} \left(\sqrt{1 + \frac{V_{ph}}{u \cos^2 \alpha}} - 1 \right).$$

It is nearly proportional to $d/\sqrt{V_{ph}}$ and the variation of d plays the dominant role. This factor contributes additionally to the resolution and is drawn in the figure by the curve of the calculated Y value for $\alpha=10.5^\circ$ and $u=30V^4)$. Experimental data well fits to the calculated curve. Fonck et al⁴⁾ has obtained a similar curve in the measurement for the wavelength region of 100-1500Å. From the viewpoint of spatial resolution it can be concluded that only the divergence of electron clouds between MCP and phosphor is of problem for the measurement of soft x-ray with MCP.

3-2 Application of transparent photocathode

A transparent photocathode was mounted in front of MCP and a dc potential of a few hundred volts was supplied between them on account of proximity focusing of the photoelectron on to the MCP. Sometimes photocathodes are also added^{12), 13)} for the observation of visible or ultraviolet light with MCP. In that case the transmission of the light through the photocathode is impossible. While, when it is to be applied to the grazing incidence spectroscopy of soft x-ray a partial transmission of the x-ray may affect the resolving power. We have checked this problem. As we can see in the upper-left

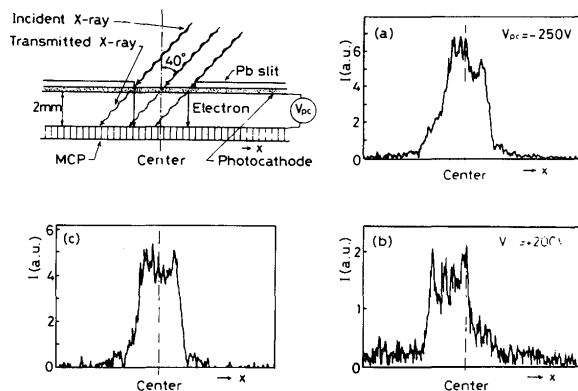


Fig. 5 Intensity distribution of the slit image with a photocathode separated from MCP for an obliquely incident x-ray.

part of Fig. 5, the photocathode was set with the separation of 2mm from the MCP and the slit on the photocathode with a width of 2mm was exposed by the x-ray whose incident angle θ was 40° . Fig. 5(a) shows the intensity distribution detected by the OMA detector when the dc potential V_{pc} on the photocathode was $-250V$ to MCP. In this case emitted photoelectrons are accelerated on to the MCP. The distribution is asymmetric and has some swelling on the left side. We may consider that partially transmitted x-ray through the photocathode has reached to and amplified by MCP at an off-centered position. In b) of the figure we show the data in case of $V_{pc} = +200V$ to MCP. This positive potential prevents the photoelectrons from reaching on to the MCP. In this case only the slit image by the transmitted x-ray through the photocathode could be detected at the off-centered position decided by the geometrical relation in the figure. Thus by subtracting the intensity distribution in b) from a) we have obtained a data as a true distribution only by the photoelectron as shown in c). Indeed a symmetrical distribution at the central position of the slit is obtained and we have made certain that the photocathode and the MCP should closely contact together to avoid degradation in the resolving power in case of oblique incidence of the x-ray. However when they are close together, no potential can be provided and the sensitivity may be lower than in case of $V_{pc} < 0$. Taking this in mind we have investigated the dependence of the spatial resolution and the sensitivity on the x-ray incident angle with the closely contact and transparent photocathode on the MCP.

3-3 Spatial resolution and sensitivity at an oblique incidence of the x-ray

With and without photocathode, resolving power of the above mentioned system was measured over various incident angle θ . By setting a slit of $20\mu\text{m}$ in width on the photocathode surface the data was taken in the same manner described in the sub-section 3-1. The result is shown in Fig. 6. The resolution with photocathode is almost the same with that without photocathode, and even in oblique incidence of the x-ray a good resolution is obtained as well as that of normal incidence.

Figure 7 shows the dependence of the sensitivity of the detection system on the incident angle with and without photocathode. The sensitivity is normalized by the value at $\theta=0^\circ$ and with photocathode. White symbol gives the raw data. In the oblique incidence of the x-ray, however, the intensity of the x-ray flux per unit area should be decreased with the angle and we have corrected the raw data dividing by $\cos\theta$, whose result is given by black symbols. From this result we may conclude that by

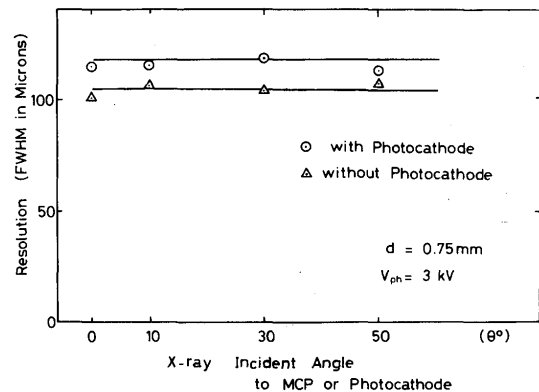


Fig. 6 Dependence of the resolving power of the detection system on the x-ray incident angle.

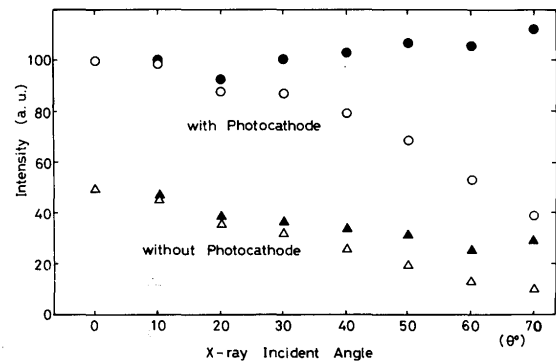


Fig. 7 Variation of sensitivity on the x-ray incident angle with and without photocathode.

converting the x-ray to photoelectrons before injecting on to MCP we can obtain an increased sensitivity even though it is impossible to provide a potential V_{pc} because of the close contact between photocathode and MCP. Furthermore, the sensitivity is not lowered with the incident angle partly due to the normal incidence of photoelectrons on to the MCP and also to efficient conversion of photons to electrons. We here note that without photocathode it seems that sensitivity degradation in oblique incidence is not so large. In this experiment the MCP has a bias angle of $\phi=11^\circ$. When we consider the angle ψ between the x-ray incident direction and the channel axis, the minimum ψ of 11° at $\theta=0^\circ$ is obtained. In the detailed analysis by G.W. Frazer¹⁴⁾, it is found that the sensitivity for the x-ray energy of 4keV has a maximum at $\psi=1^\circ$ and decreases steeply over this angle. So that in this experiment the sensitivity is already in the strongly lowered region for ψ , where $\theta=0^\circ$ and 70° give $\psi=11^\circ$ and 70.4° , respectively.

4. Conclusion

As an efficient extension on the availability of the visible position sensitive detection system into the soft x-ray region, microchannel plate (MCP) and optical multichannel analyzer (OMA) system were coupled to measure a soft x-ray with the energy of 4keV. The characteristic x-ray was emitted from the transparent-type x-ray tube with Ti-target. X-ray image by a slit of 20 μ m in width was intensified in MCP and converted into visible one with phosphor screen. It was then focused on to the inlet of OMA detector head and was analyzed by the controller and the micro-processor included in OMA system.

Sensitivity and spatial resolution of MCP to the x-ray were measured in detail and the latter was found to be limited by the electron divergence in the region between MCP and phosphor screen.

To remove strong gain reduction in MCP to an obliquely incident x-ray, a transparent photocathode was mounted at close contact with the front face of MCP. Favorable increase in the sensitivity was obtained and its dependence on the incident angle of the x-ray was appropriately removed without any reduction in the resolving power.

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