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Photon counting with small pore microchannel plates

A. Martindale*, J.S. Lapington, G.W. Fraser

Space Research Centre, Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK

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Abstract

We describe the operation of microchannel plates (MCPs) with 3.2 μm diameter channels as photon counting detectors of soft X-rays. Gain and temporal resolution measurements are compared with theoretical scaling laws for channel diameter. A minimum pulse width of 264 ps is observed for a two stage multiplier at a total bias voltage of ~1930 V.

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Keywords: MCP; Microchannel plate; High speed; X-ray detector

1. Introduction

The time resolution, count rate capability, dark noise and spatial resolution of imaging microchannel plate (MCP) detectors are all fundamentally determined by the channel diameter, D, and the pitch of the channel array, p [1,2]. Manufacturers have progressively reduced D from 25 μm to the present limit of 2−4 μm [3,4], driven mainly by applications in night vision intensification and time of flight mass spectrometry, where any improvement in temporal resolution Δt translates into better mass resolution, particularly for ion analysers for space plasmas [5]. The detector parameter space around $\Delta t < 1$ ns, $\Delta x < 10$ μm in fact remains unoccupied except for microchannel plates, while the MCP's open window response in the extreme ultraviolet waveband remains unchallenged. In this paper, we present a preliminary account of the photon-counting properties of 3.2 μm channel MCPs in a high gain, two-stage "chevron" arrangement. Results from a parallel study of the same MCP format under pulsed laser stimulus, where many microchannels are excited simultaneously, are also described in these proceedings [6].

2. Small pore MCP detector

The detector reported here consisted of two solid edge, 18 mm diameter active area MCPs produced by Photonis SAS (Brive, France), mounted in direct contact. The channel aspect ratio L/D was 55:1 and the channel bias angle 6°. The open area fraction was 66%. The total thickness of the MCP pair was only 0.35 mm, requiring great care in assembly into the detector body. A circular copper disc, 20 mm in diameter and ~1.5 mm from the rear MCP surface, was used as the non-imaging readout electrode. This conducting plane was held at ground potential behind the MCP stack and connected through a 50 Ω impedance matched transmission line [3] to either a LeCroy Wavemaster 8600A (6 GHz) oscilloscope for fast timing measurements, or to a charge sensitive preamplifier for measurements of gain and dark noise. $C-K$ (0.28 keV) X-rays from an electron bombardment source were used to illuminate a ~2 mm diameter spot on the input MCP at normal incidence—an effective incident angle of 6° to the channel axes.

3. Results

Fig. 1 shows the peaked pulse height distribution measured at a total MCP bias of 1958 V i.e. 979 V/plate.

Fig. 2 summarises the variation of modal gain and full-width-at-half-maximum (FWHM) with bias voltage.

*Corresponding author. Tel.: +44 116 252 2650; fax: +44 116 252 2464.
E-mail address: am136@star.le.ac.uk (A. Martindale).

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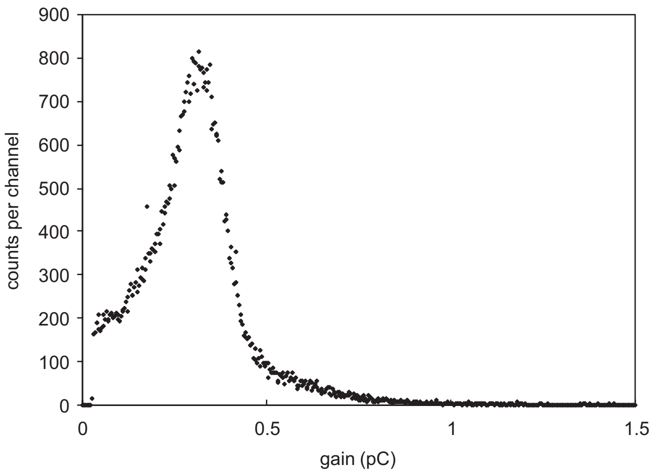

Fig. 1. MCP detector pulse height distribution with modal gain 0.32 pC and FWHM 64%.

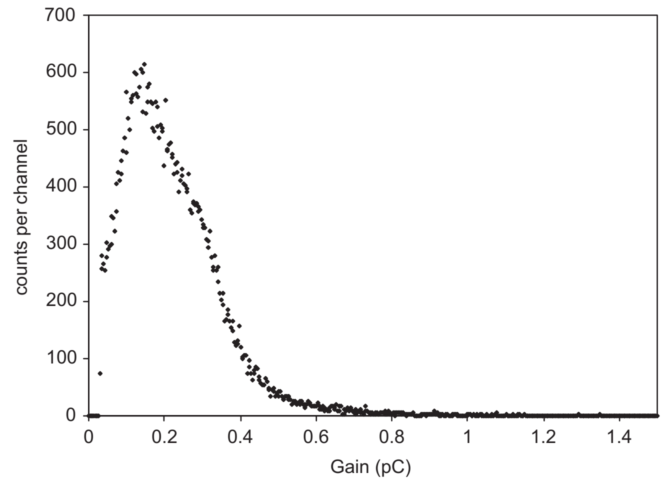

Fig. 3. Detector noise pulse height distribution.

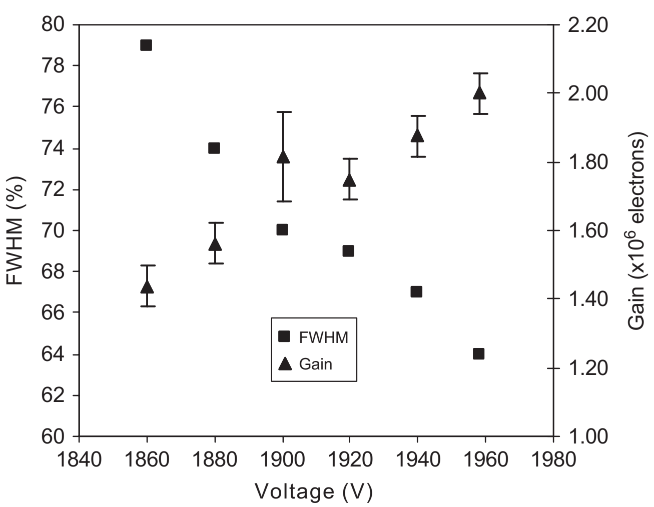

Fig. 2. Modal gain (triangles, right hand scale) and pulse height FWHM (squares; left hand scale) as functions of total MCP bias voltage.

The errors on the FWHM are negligible. However, the error in gain shows that the apparently anomalous point in the detector gain curve at 1900 V can be explained by the increased error on this reading, caused by a skewed shape to the peak of the pulse height distribution (Fig. 2).

Fig. 3 shows the results of a long integration ($\sim 2\times 10^4$ s) of detector dark noise. Based on the model of internal radioactivity due to ^{40}K content of the channel plate glass, the dark noise above a discriminator setting equal to (say) 10% of the modal gain should scale with channel diameter for a given aspect ratio. In fact, the measured rate is $\sim 0.9\,\mathrm{cm^{-2}\,s^{-1}}$, compared to about $\sim 0.4\,\mathrm{cm^{-2}\,s^{-1}}$ for plates with 10 μm diameter pores. This higher-than-expected rate may be due to gamma and beta emission from ^{40}K in the ceramic components in the detector body.

The operational field across these plates is of order $5.6\,\mathrm{kV\,mm^{-1}}$, compared to $\sim 2.5\,\mathrm{kV\,mm^{-1}}$ for standard 10 μm; 40:1 (L:D) plates. Despite this extremely high field the small pore MCPs exhibit stable operation with relatively low noise.

We have used the scaling laws given in Refs. [1,2] to scale the calculated 180 ps transit time and 35 ps transit time spread for a single 4 μm pore 80:1 aspect ratio plate to the channel geometry of current interest. The scaling laws are

$$t_f^{\mathrm{new}} = t_f^{\mathrm{old}}\frac{(L^2/D)_{\mathrm{new}}}{(L^2/D)_{\mathrm{old}}}$$

$$\Delta t_f^{\mathrm{new}} = \Delta t_f^{\mathrm{old}}\frac{L_{\mathrm{new}}}{L_{\mathrm{old}}},$$

where "new" indicates the current plates and "old" the published values. We obtain a transit time of 68 ps (a lower limit, because of gain saturation [2]) and a transit time spread, equivalent to pulse width, of only 19 ps for the front plate. A better approximation follows from adopting the pulse propagation velocity in hard saturation ($\sim$0.9 ps/μm [1]) for the second plate in the stack, giving a chevron transit time estimate of $(68\,\mathrm{ps} + (55\times 3.2\times 0.9)\,\mathrm{ps}) = 226\,\mathrm{ps}$. For the transit time spread, we should properly take into account the dispersion in pulse initiation positions due to the non-zero bias angle of the MCPs. Ignoring this, we add front and rear plate contributions to pulse dispersion (which are identical [1]) in quadrature to obtain an intrinsic transit time spread of 27 ps. Preliminary results indicate somewhat slower detector response.

The mean pulse width and rise time were recorded as a function of the voltage between the rear of the stack and the anode (Fig. 4). Hence, as a function of the rear field as the separation of the MCPs and anode is known ($\sim$1.5 mm). Acceleration of the pulses on to the anode by the rear potential reduces any further pulse broadening due to variation in output electron energy.

There is a clear change in the gradient of the pulse width curve (Fig. 4) at a rear voltage of $\sim$750 V. Fig. 5 indicates the change in the temporal pulse shape giving rise to this change in gradient. At low voltage, the pulses are single

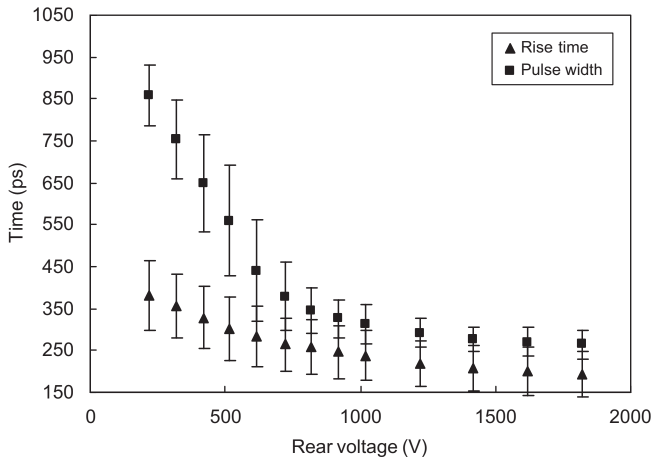

Fig. 4. Pulse width and rise time as a function of the voltage between the rear of the stack and the anode.

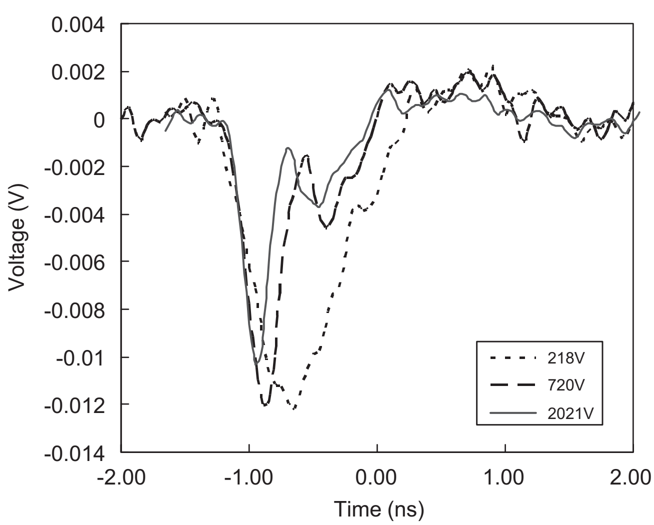

Fig. 5. Evolution of pulse shape with rear voltage.

peaked and wide, whereas at higher voltages the double-peaked nature of the pulse becomes apparent. Once the dip between the two peaks exceeds 50% of the peak amplitude, the calculation of pulse width by the LeCroy oscilloscope no longer takes account of the second peak. Hence, the pulse width is lower and no longer changes as rapidly with increasing field.

The average pulse rise time (10–90% of the peak) of the fastest detector configuration was found to be 189 ps when the rise time of the oscilloscope was subtracted by the method outlined in Ref. [3] the pulse width was 264 ps. These values compare to the 80 ps and 140 ps reported by Photek [7] for rise time and pulse width, respectively, of a similar detector configuration. However, the latter measurement was performed on an ensemble of pulses owing to measurement limitations.

4. Conclusions and further work

3.2 μm Photonis MCPs have been operated for the first time in X-ray photon counting mode. The pulse height distributions are well saturated and the MCPs operate stably at gains in excess of 10^6 electrons at a remarkably high internal electric field value of $5.6\,\mathrm{kV\,mm^{-1}}$.

A best rise time of ~190 ps, measured at low gain, was observed with a relatively large accelerating voltage (2 kV) between the stack and the anode. The rise time did not vary significantly with MCP gain. Other experimental results [6,7] and theoretical predictions herein and in Refs. [1,2] indicate that the plates should, when optimised, perform better.

The next stage of work will be to investigate and correct the factors contributing to the slower than expected timing response of the system. A number of possible mechanisms have been identified which may contribute to the higher than expected rise times.

Firstly, the net positive charge left on the MCP pore walls close to the charge exit aperture could couple on to MCP output electrode and readout anode. This would induce a positive signal with a slow decay, reducing the anode electron signal amplitude and increasing its rise time. A possible solution is to couple the MCP output electrode to ground using a capacitor with very high frequency response. Another solution, used for commercial high speed microchannel plate detectors, is to use a grid between MCP and anode to pre-accelerate the output electrons before they are detected by the anode, and serves to decouple the anode from induced signals from the MCP.

Secondly, the double peaked pulse (Fig. 5) seen at higher MCP to anode fields requires investigation. It is conjectured that this could be due to the following:

(a) Impedance mismatch in the electrical connection between anode and 50 Ω feedthrough causing ringing, as suggested by the baseline overshoot apparent after the pulse completion.
(b) Secondary electrons, emitted from the anode resulting from the primary charge cloud impact. Their later recollection on the anode would give rise to the after pulse.
(c) A double peaked electron energy distribution in the MCP output pulse giving rise to two distinct charge collection times on the anode, resulting from the collection of a fast electron component initially followed later by a slow electron component.

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