RECENT PROGRESS WITH MULTI-ANODE MICROCHANNEL ARRAY DETECTOR SYSTEMS

J. Gethyn Timothy
Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, Colorado 80309 USA

ABSTRACT

The Multi-Anode Microchannel Arrays (MAMAs) are a family of photo-electric, photon-counting array detectors that are being developed specifically for use in instruments on space-borne and ground-based telescopes. In this paper we review briefly the construction and modes-of-operation of the MAMA detectors and describe the current development status of the different detector systems.

INTRODUCTION

The Multi-Anode Microchannel Arrays (MAMAs) are a family of photo-electric, photon-counting array detectors that are being developed specifically for use in instruments on ground-based and space-borne telescopes. These detectors combine the high sensitivity and photo-metric stability of a conventional channel electron multiplier (CEM) with a high-resolution imaging capability. A number of detector systems with different readout array formats to meet the requirements of specific imaging and spectroscopic applications are currently in use or under development. A number of successful ground-based observing programs using visible-light (1 x 1024)-pixel MAMA detectors have recently been completed, and MAMA detectors with formats as large as 256 x 1024 pixels are currently being fabricated for both space and ground-based applications. MAMA detectors with formats of 1024 x 1024 pixels and larger will be fabricated during the next three years.

MULTI-ANODE MICROCHANNEL ARRAYS

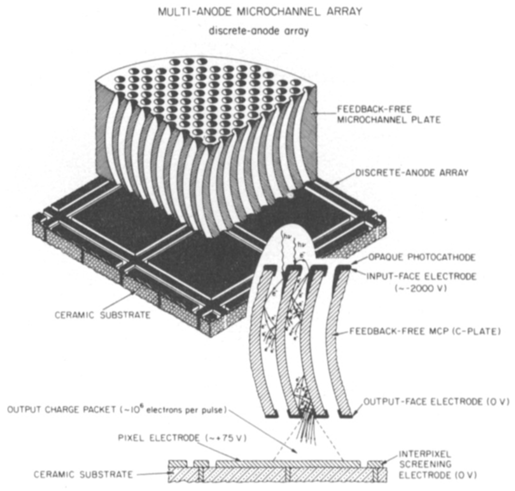
Two types of Multi-Anode Microchannel Array (MAMA) detector systems have been developed as shown in the schematics in Fig. 1. The discrete anode MAMA detector (Fig. 1a) consists of a tube assembly (sealed or open) containing an array of metal anodes and a single curved-channel microchannel plate (MCP) with the appropriate photocathode

C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 251–258.

https://doi.org/10.1017/S0252921100083615 Published online by Cambridge University Press

material deposited on the front face. The detector resolution elements (pixels) are defined solely by the physical dimensions of the electrodes in the anode array which is mounted in proximity focus with the output face of the MCP. The photocathode material defines the spectral range of the detector and the curved-channel MCP provides the high gain and narrow output pulse-height distribution required for pulse-counting operation with a noise level determined solely by the statistics of the photon detection rate.

a.



b.

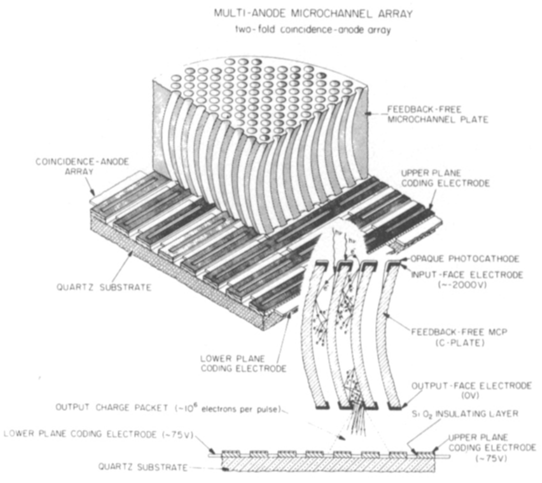


Figure 1. Schematics of Multi-Anode Microchannel Array Detectors.
a. Discrete-anode array. b. Coincidence-anode array.

A charge-amplifier and discriminator circuit which issues a logic pulse for each output charge pulse from the MCP that exceeds the preset threshhold is connected to each anode. These pulses are accumulated in a set of counting circuits for a pre-determined exposure time. The number of events recorded in each counting circuit is proportional to the number of photons incident upon that part of the front face of the MCP that corresponds spatially to the anode location.

Since the number of pixels in a discrete-anode array is limited to about 500 by the currently available connector and electronic technologies, we have developed the coincidence-anode MAMA detector which employs two sets of anode electrodes insulated from each other but exposed to the output face of the MCP as shown in Fig. 1b. In the coincidence-anode MAMA detector the spatial location of the event is determined by the simultaneous detection of a charge pulse on the two sets of anode electrodes. Using this technique, a total of a x b pixels can be uniquely defined using only a total of a + b sets of anode electrodes. A (1 x 1024)-pixel array for example which has a total of 32 x 32 pixels requires only 32 + 32 sets of anode electrodes. A charge-amplifier and discriminator circuit which issues a logic pulse for each output charge pulse in the MCP that exceeds a preset threshhold is connected to each set of anode electrodes. Any valid combination of coincident logic pulses is decoded to determine the spatial location of an event. The number of events occurring in each spatial location is stored in the corresponding word of a random access memory (RAM). This decoding and storage process is repeated at a maximum rate determined by the pulse-pair resolution of the electronics. A number of discrete- and coincidence-anode MAMA detectors have been fabricated or are under development at this time. The characteristics of these detectors are listed in Table 1 and details of the configurations of these different anode arrays may be found in the literature (Timothy et al., 1981; Timothy and Bybee, 1981).

	Tube Model	Pixel Format	Pixel Dimensions $(mm)^2$	Number of Amplifiers	Maximum Count Rate* (counts s^{-1}) Each Pixel	Total Array	Availability
Discrete-Anode	549-162 or	2 x 2	6.0 x 6.0	4	3.6×10^7	1.4×10^8	Now
	549-169	10 x 10	1.2 x 1.2	100	1.4×10^6	1.4×10^8	Now
	"	1 x 160	8 x 0.100	160	8×10^5	1.3×10^8	Now
Coincidence-Anode	"	1 x 512	8 x 0.025	48	2×10^5	10^6	Now
	"	1 x 1024	6.5 x 0.025	64	1.7×10^5	10^6	Now
	"	16 x 1024	0.380 x 0.025	80	9.7×10^3	10^6	Now
	"	24 x 1024	0.260 x 0.025	88	6.6×10^3	10^6	Now
	"	512 x 512	0.025 x 0.025	96	6.5×10^2	10^6	Now
	"	256 x 1024	0.025 x 0.025	96	6.5×10^2	10^6	Now
	549-172	1024 x 1024	0.028 x 0.028	128	7.8×10^2	10^6	1982

*Limits for 10% loss of detection efficiency with MCP providing 10^6 counts mm^{-2} s^{-1} and electronics dead time of 100 ns.

Table 1. Characteristics of MAMA Detector Arrays

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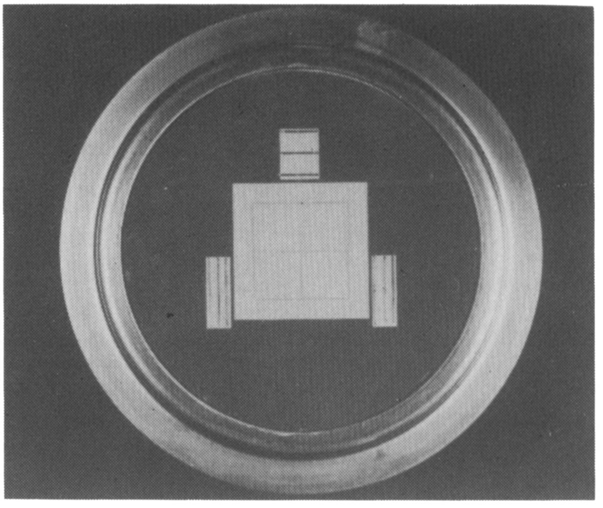
Two representative discrete-anode arrays are shown in Fig. 2. The first (Fig. 2a) is a (2 x 2)-pixel array with pixel dimensions of 6 x 6 mm^2 which will be employed as a quadrant photosensor for use in the fine guiding system of a high-resolution stellar ultraviolet rocket payload. The second (Fig. 2b) is a (1 x 160)-pixel array with pixel dimensions of 8mm in length by 100 microns in width which is being used as a high-dynamic-range spectroscopy array.

a.



b.

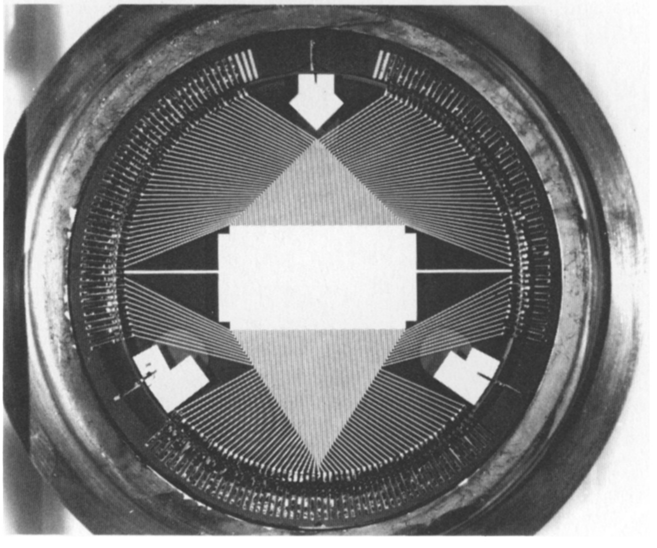


Figure 2. Discrete-anode arrays.
a) (2 x 2)-pixel quadrant array.
b) (1 x 160)-pixel linear array.

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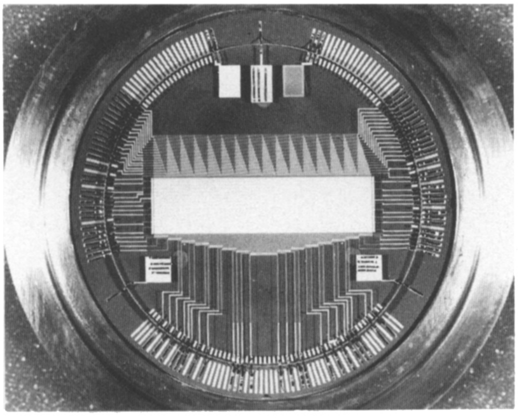
Two representative coincidence-anode arrays are shown in Fig. 3. In the (1 x 1024)-pixel array (Fig. 3a) a total of only 64 amplifiers and discriminator circuits is required to read out photometric data from the 1024 pixels. Each pixel in the array has dimensions of 6.5mm in height by 25 microns in width. The (1 x 1024)-pixel linear array has been extended to a two-dimensional format by fabricating an additional set of electrodes beneath the upper sets of coincidence-anode electrodes. The lower electrodes are insulated from the upper electrodes by means of an intermediate dielectric layer but exposed in the interstices to collect the low energy (order of 30 V) electrons from the MCP.

a.



b.

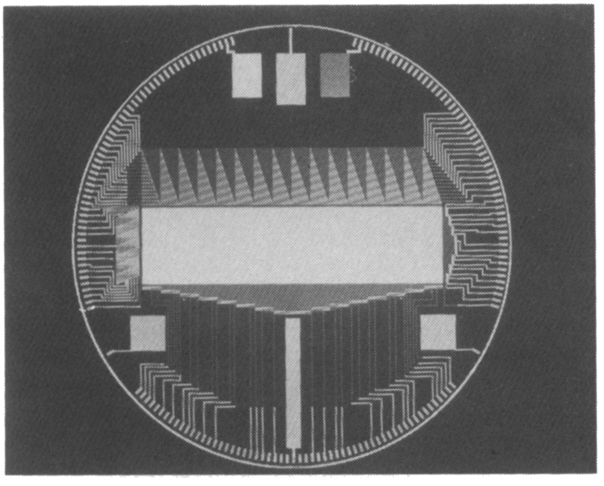


Figure 3. Coincidence-anode arrays.
a) (1 x 1024)-pixel linear array.
b) (256 x 1024)-pixel imaging array.

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A multi-layer imaging coincidence-anode array with 256 x 1024 pixels having dimensions of 25 x 25 microns^2 is shown in Fig. 3b. This array requires a total of 96 amplifiers and discriminator circuits to read out the photometric data from the 262,000 pixels.

A (1024 x 1024)-pixel array with pixel dimensions of 28 x 28 microns^2 will be fabricated within the next twelve months. The procedures used for the fabrication of this array will be capable of fabricating very large format arrays with up to 4096 x 4096 pixels on substrates 127mm in diameter within the next three years.

PERFORMANCE CHARACTERISTICS

The MAMA detectors offer a number of unique advantages over alternative photoelectric imaging systems currently under development for use in ground-based and space instruments. Among these are:

1) Low applied potential (<3 kV).
2) High gain (>10^6 electrons pulse^{-1}) which reduces susceptibility to external electronic noise.
3) Pulse-counting operation with zero readout noise.
4) Absolute event timing accuracy of 100ns or better.
5) A very long count lifetime (>2.5 x 10^{11} counts mm^{-2}).
6) Low power consumption (<30 W for a complete system).
7) Readout array format can be varied by command to optimize observing programs and data rates.
8) Proximity-focused operation eliminates complex and bulky magnetic or electrostatic focusing systems.
9) Immune to external magnetic fields of less than 500 Gauss.
10) No cooling of the multiplier is required for pulse-counting operation.

The key component of the MAMA detector system is the curved-channel MCP which represents a fundamental breakthrough in MCP technology. Details of the performance characteristics of the curved-channel MCPs have recently been presented in the literature (Timothy, 1981). We note here those aspects of the performance characteristics which are of critical importance for imaging and spectroscopic experiments on ground-based telescopes.

1) Only a single curved-channel MCP is required for operation in the pulse-counting mode. Since curved-channel MCPs with 12-micron-diameter channels on 15-micron-diameter centers are now available, the curved-channel MCP has the highest spatial resolution of any available pulse-counting MCP detector system.
2) The dark count rates of the curved-channel MCPs are now at the limit set by the intrinsic radioactivity of the glass and by the cosmic ray background (less than 0.01 counts mm^{-2} s^{-1}). The dark count rates of visible-light MAMA detector tubes are accordingly set solely by the characteristics of the bialkali or

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trialkali photocathode (typical dark count rates of the order of 0.1 to 1 counts mm^{-2} s^{-1}).

3) The curved-channel MCP has demonstrated the longest lifetime of any currently available MCP detector system (>2.5 x 10^{11} counts mm^{-2}).

4) The dynamic range of the curved-channel MCP meets the requirements for efficient flat-field calibration in any imagery or spectroscopy system (>10^5counts mm^{-2} s^{-1}).

5) The "plateau" in the high-voltage characteristic where the detection efficiency varies slowly as a function of the MCP voltage provides a stable photometric response without stringent requirements on the stability of the high voltage power supply. Flat-field calibration accordingly need only be undertaken at very infrequent intervals.

It is of particular importance to note that the MAMA detector system provides distortion-free imaging with a spatial resolution that is independent of time or of the signal level. Data recorded using a (1 x 1024)-pixel detector system have shown that the absolute linearity is of the order of ±2 microns over the 26-mm length of the array. The pixel-to-pixel crosstalk is calculated to be less than 0.4% and cannot be measured with our existing optical test facilities. Furthermore, image motions of a fraction of a pixel width (of the order of, or less than, 4 microns) can be distinguished easily with the MAMA detector. This characteristic is of particular importance for the determination of the absolute wavelengths of emission or absorption lines over long periods of time. Identical distortion-free imaging capabilities are obtained with the two-dimensional MAMA detectors.

As an example of the quality of data produced by the MAMA detector system, the spectrum in the region of the Ca H and K lines for the star

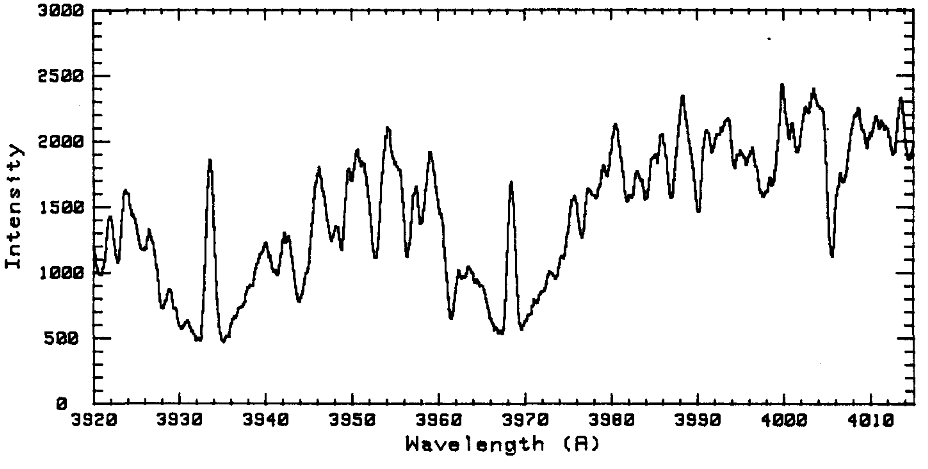

Figure 4. Ca H and K emission lines for the star λ And (HR 8961) recorded with (1 x 1024)-pixel visible-light MAMA detector.

https://doi.org/10.1017/S0252921100083615 Published online by Cambridge University Press

λ And (HR 8961), recorded using the coudé spectrograph of the 88-inch telescope at Mauna Kea with a dispersion of 4.5 Å/mm, is shown in Fig. 4.

It should further be noted that, unlike the photoconductive array detectors such as the Charge-Coupled Devices (CCDs), the readout noise of the MAMA detector is zero. The signal-to-noise ratio is, accordingly, set solely by the photon statistics and by the detector dark count rate, producing the optimum performance for low-light-level imaging and spectroscopy. The (1 x 1024)-pixel visible-light MAMA detectors have been used recently for a series of spectroscopic investigations covering topics as diverse as the diffuse interstellar band at 4430 Å, variations in the winds and mass-loss of O and B stars, and the detection of magnetic fields in cool stars from the measurement of magnetic-field-induced spectral-line broadening. This program of ground-based spectroscopy will be continued in the future and during the first half of 1982, the two-dimensional (16 x 1024)- and (256 x 1024)-pixel MAMA detectors will be used to initiate programs of faint-object Cassegrain spectroscopy and faint-object imaging. It is further intended that the fast timing characteristics of the MAMA detectors will be utilized in programs of "speckle" imaging and "speckle" spectroscopy. Finally, the fabrication and laboratory evaluation of very large format arrays with up to 4096 x 4096 pixels will be carried out during the next three years.

ACKNOWLEDGEMENTS

I am happy to acknowledge the efforts of a large number of people at the various subcontracting organizations with the development and fabrication of the MAMA detector systems. I am particularly grateful for the efforts of R.L. Bybee of Ball Aerospace Systems Division, who is the co-inventor of the MAMA detector system. I also wish to thank Dr. E.J. Weiler of NASA Headquarters for his continuing support of this detector-development program. This work was supported by NASA under grant NSG-7459 with the University of Colorado.

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