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High Spatial Resolution Investigations of Microchannel Plate Imaging Properties for UV Detectors

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Introduction

Microchannel plate (MCP) photon counting detectors are currently being used with great success on many of the recent NASA/ESA ultraviolet (UV) astrophysics missions that make observations in the 100Å - 1600Å range. These include HUT, the Wide Field Camera on ROSAT, EUVE, ALEXIS, ORFEUS, and SOHO. These devices have also been chosen to fly on future UV astrophysics missions such as FUSE, FUVITA, IMAGE, and both the HST STIS and Advanced Camera instruments. During the period of this award we have fabricated a dual-chamber vacuum test facility (described below) to carry out laboratory testing of detector resolution, image stability and linearity, and flat field performance to enable us to characterize the performance of MCPs and their associated read-out architectures. We have also fabricated and tested a laboratory "test-bed" delay line detector, which can accommodate MCP's with a wide range of formats and run at high data rates, to continue our studies of MCP image fixed pattern noise, and particularly for new small pore MCP's which have recently come onto the market. These tests were mainly focussed on the assessment of cross delay-line (XDL) and double delay line (DDL) anode read-out schemes, with particular attention being focussed on flat-field and spatial resolution performance.

Microchannel plate developments

Standard MCP's provide good detector performance, with pore sizes of 10 to 12µm, gains $>10^7$, pulse height distributions (PHD's) of <40% FWHM, gain variations <20%, background rates <0.3 events sec^{-1} cm^{-2}, fixed pattern noise of <15%, and curved surfaces down to <7cm radius. Future missions such as FUSE and IRIS/LITE demand high resolution large area formats (>5 x 5cm and 10 x 1cm), low levels of fixed pattern noise and high image stability, along with lower background rates and high local event rate dynamic range. In this work we have sought to promote the development of, and evaluate the performance of smaller pore (5µm to 7µm) MCP's, large format MCP's, very low background rate MCP's (<0.03 events cm^{-2} sec^{-1}), high counting rate (>100 events $pore^{-1}$ sec^{-1}) with good stability, and techniques to reduce the MCP fixed pattern noise.

(a) High resolution MCP's

High spatial resolution (<≈15µm) is essential for future high resolution imaging (IRIS/LITE) and spectroscopy applications (FUSE). Currently, the size of the MCP pores is a significant issue. With helical DDL anodes and 10µm pore mcps we have now achieved resolutions of ~15µm FWHM and <1µm electronic binning (Fig 1 & 2), and we can observe the pore position "quantization" effects for MCP's with the standard pore sizes of 10µm (12µm center-center) or 12.5µm (15µm center-center) (Siegmund *et al* 1993). Smaller pore size MCP's are needed to reduce these position and resolution modulations due to the pores and satisfy the needs for future high resolution small and large format detectors.

MCP's with pore sizes in the range 5µm to 8µm are now being made, but they are not generally available and are of limited size. We have samples of Galileo 8µm and 5µm MCP's, and several Philips 7µm (25mm) MCP's. We have tested a 4 MCP "W" stack of the Philips 7µm pore 50:1 L/D MCP's and achieved gains $>2\times10^7$ with PHD's of <40% FWHM (Fig.5), and background rates of <0.4 events sec^{-1} cm^{-2} (Siegmund *et al* 1996). In initial tests we have also found that the 8µm Galileo MCP QDE is the same as regular 10µm pore MCP's. To evaluate the limiting resolution of small pores we have illuminated 12µm and 5µm MCP's with visible light through an Air Force resolution test mask (Fig. 3 & 4. The 5µm MCP's easily resolve <8µm patterns, also note the multifiber boundary in the 5µm MCP image, and pore misalignments at mutifiber boundaries (Group 5:6).

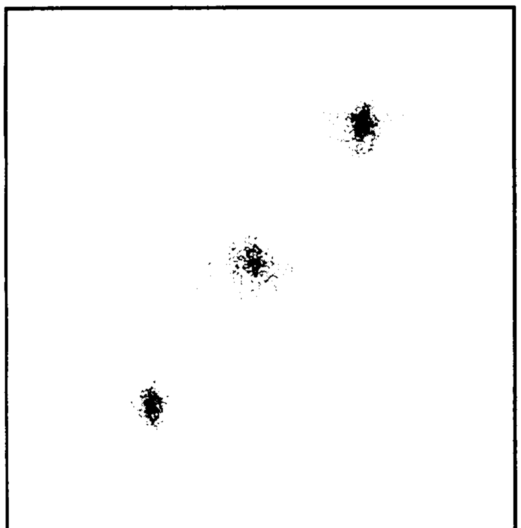

Figure 1 Images of three 10µm pinholes obtained with a 10µm pore MCP Z stack and a 90mm x 15mm HDDL anode readout.

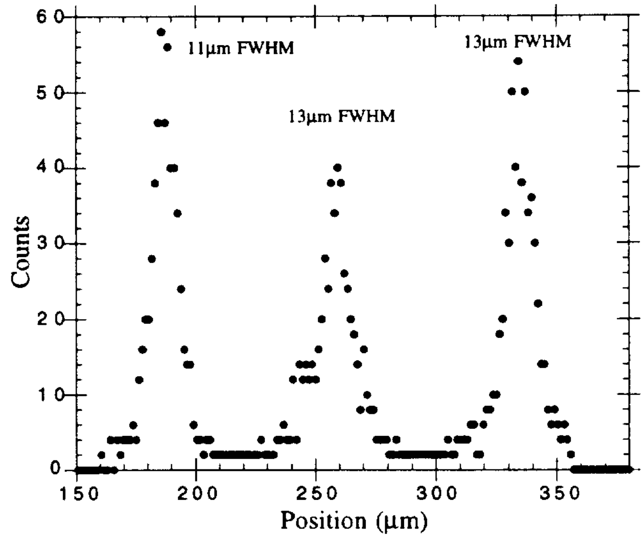

Figure 2 Histogram of the pinhole images in Figure 1 showing the point spread functions, & structure of one peak due to discrete pore locations.

8µm bars ↓ Group 6:1 ↓

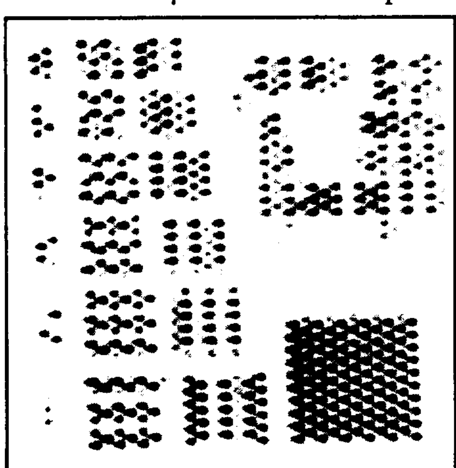

Figure 3. Philips 12µm pore MCP illuminated with an Air Force test mask pattern.

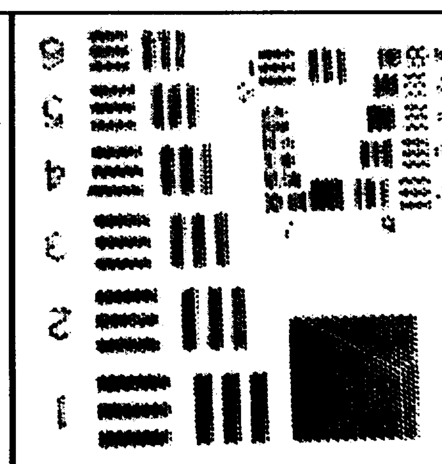

Figure 4. Galileo 5µm pore MCP illuminated withan Air Force test mask pattern.

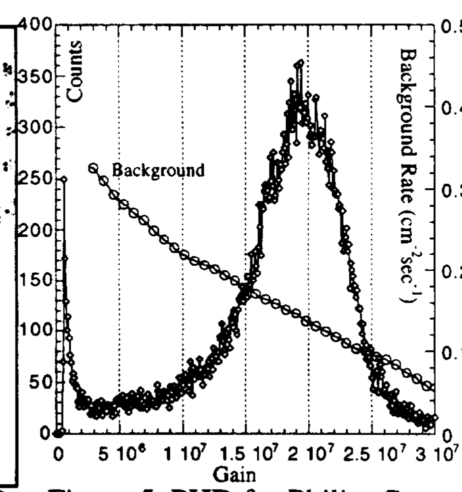

Figure 5. PHD for Philips 7µm pore MCP 4 x 50:1 L/D stack & background rate vs threshold

(b) MCP fixed pattern noise

Future generations of soft X-ray imaging detectors will probably require an understanding the MCP flat field structure and stability at the level of individual MCP pores. Doing on-orbit high statistics flat fields at high resolution (<20µm) for large format detectors would require a prohibitive amount of time and memory. Since relatively low counting rates are normally expected a practical alternative is to first calibrate the high resolution flat field and then employ image deconvolution techniques in orbit. For this scheme to work the flat field fixed pattern modulation should be stable so that it is possible to apply flat field corrections to the data, or to "dither" the images. To confirm this approach we need good statistical data (<3%) on various MCP's with high resolution <20μm and small scale electronic binning <<10μm so that the small scale structure and stability can be evaluated.

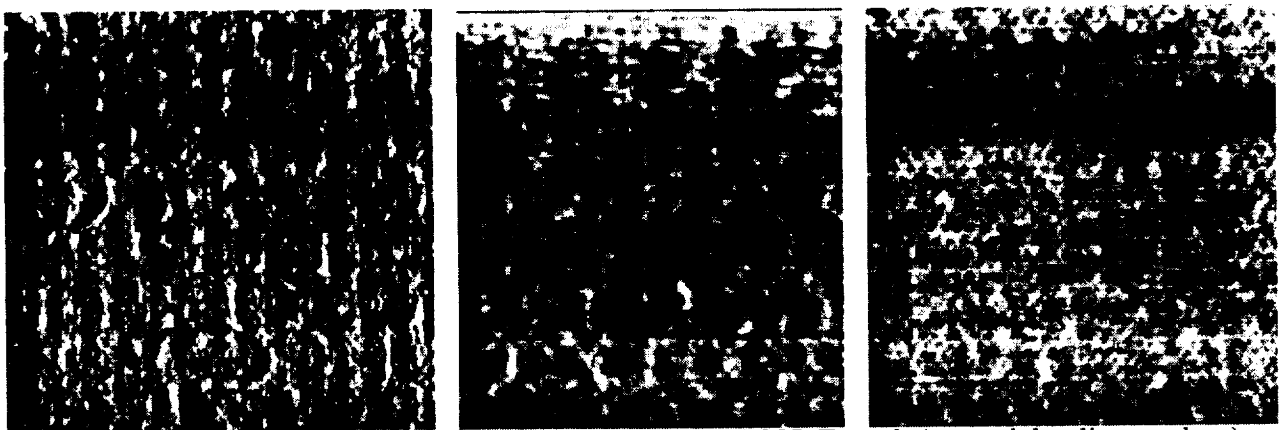

Figure 6. High resolution flat field images of 12.5μm pore MCP Z stack (cross delay line readout).
a) Multifibers aligned b) Multifibers rotated 7.3° c) Multifibers rotated 20°

During the period of this grant we have made significant progress in understanding the nature of flat field modulations for microchannel plate stacks. High resolution (<25μm) imaging with delay line image readouts has proven instructive in probing the small scale structures of MCP flat field modulations that were not visible at moderate resolution (50-100μm). Images with various MCP configurations clearly show several kinds of fixed pattern modulation. These include dark spots, multifiber modulation ('chicken wire') with periodicity of ≤1mm and small scale intensity variations (, and in some cases Moire modulation (Fig.6). Our studies of these effects show that flat field intensity multifiber modulation is accompanied by slight gain modulation, and can be attributed to the rear MCP of a stack [Vallerga *et al* 1989]. This is probably due to distortions and deflections of the charge cloud at multifiber boundaries at the output of the MCP. Dark spots are often blocked channels or distortions and fractures of small groups of fibers. We have also found that Moire modulation can be severe for high resolution imaging. Preliminary data (Fig. 6) indicates that the relative rotation of the top and middle MCP's of a Z stack determine the Moire modulation. If the MCP multifibers are aligned the Moire effect is not evident , but at a 20° rotation severe mottling (10-20% modulation) occurs. This suggests care is needed in specification of MCP stacks for high resolution applications so that this effect does not complicate image deconvolution.

Cross delay line anodes

For large format two dimensional imaging tasks we have devised a monolithic crossed delay line anode (XDL) scheme. This scheme has two orthogonal sets of fingers (Figs. 7, 8) in the charge collection area. The two sets are separated by a ground plane set of fingers and two thin, low ε layers (polyimide) with the same geometry as the upper finger set. The fingers in each axis are connected to "external" serpentine delay lines etched onto Cu on a high ε base substrate. This scheme allows the ratio of finger widths, and the size of the active area to be varied independently from the delay line design optimization. Anodes of this type with a 25 x 10mm format have now been extensively tested and provide ≈25μm resolution with good stability and linearity [Siegmund *et al*, 1995] and were used successfully on the SOHO satellite.

During the period of this grant, we have continued our developments of large format XDL anodes, specifically a 65 x 65mm format anode (Fig. 8). Bench tests show that this has similar delay and propagation characteristics to the more conventional double delay-line (DDL) anode electrodes and thus should perform in a similar way. The tests indicate that resolutions of the order <25μm should be attainable for the current anode configuration.

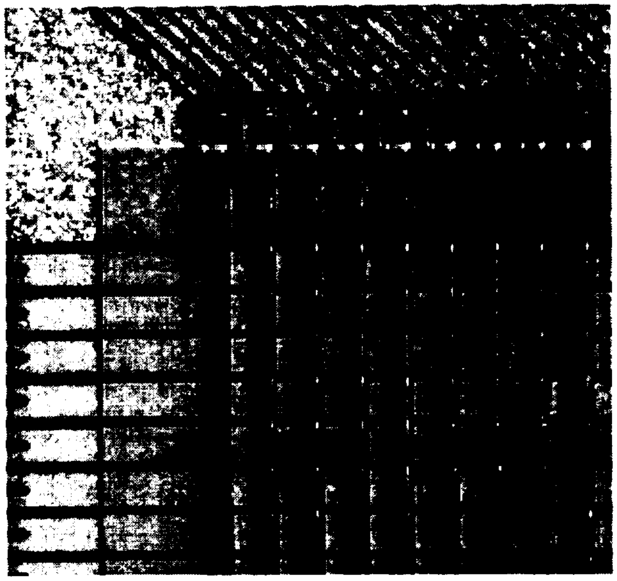

Figure 7. Close up of the corner of an XDL anode showing the external X and Y delay lines, and the X (lower) and Y (upper) charge collection fingers.

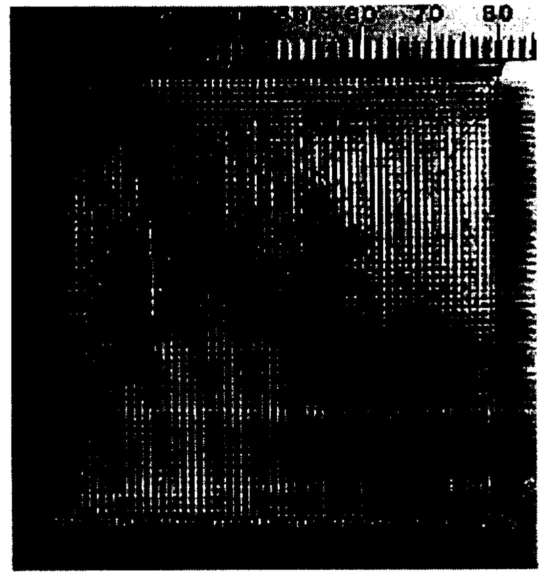

Figure 8. Photo of a 65mm x 65mm format XDL anode with external X and Y delay lines that is currently in test,

Test Facilities

Over the past 3 years we have built up an extensive test facility for the evaluation and calibration of MCP detector systems. A class 1000 clean room has been fabricated, adjacent to the vacuum test facility, which is used for MCP handling and detector assembly. A dual-chamber vacuum tank with associated "test-bed" detector systems has been fabricated under the terms of this award for the testing and evaluation of MCP's, photocathode lifetesting, and the test of delay-line readout schemes.

The dual- chamber has been fabricated such that it can carry out both the detector resolution, linearity and flat-field tests, and has been configured to have the ability to carry out the MCP bake-out and burn-in procedures using a thermostatically controlled thermal blanket in order to obtain heating up to ~ 300°C. By fabricating 2 test chambers on a common vacuum pump, detector tests can be carried out on multiple detectors in an independent and time efficient manner.

Each test chamber shares a high vacuum pumping system (consisting of a rough pump, cryo-pump and associated pressure gauges) capable of obtaining a vacuum pressure of << 10^{-6} Torr. They contain FUV (MgF2, LiF and quartz) windows to allow detector stimulation by various calibration lamps. The vacuum chambers, MCP's and anode structures are assembled in a controlled, clean environment within a Class 1000 clean room tent with associated Class 100 detector assembly flow benches. The test chamber is supported by various laboratory rack-mounted electronics for control and display of detector peformance parameters, with the rack being interfaced to both Macintosh and SUN Sparc computers for subsequent data analysis functions.

MCP Preconditioning Studies

The gain and pulse amplitude distribution of MCP's is not constant with long term use. Our program of life tests of MCP's has shown that there is an initial sharp drop in the gain, followed by a slow decrease towards a plateau region of stable operation (Siegmund *et al* 1989) The initial gain drop is associated with outgassing of the channel walls, while the slow stabilization is thought to relate to migration of alkali metals in the MCP glass. An established technique is to "precondition" the MCP's to stabilize their performance. This preconditioning and processing of MCPs consists of a sequence of cleaming, baking, depositing a photocathode, and then finally scrubbing the MCP stack. During the last 3 years we have systematically refined and improved this preconditioning process.

Extensive laboratory testing of many different sets of MCPs has shown that optimal plate cleaning is gained using a series of isopropyl and methyl alcohol ultrasonic baths. After a detector is assembled and initial MCP functional tests have been performed, the entire detector assembly is vacuum baked at temperatures chosen to fall below the softening point of the MCP glass (normally at 120°C for 6 hours). Typically, a vacuum pressure of << 10^{-6} Torr is established before detector bake-out. The pressure and the partial pressure of gases are then monitored during the bake such that volatiles may be identified using residual gas analysis, and hence the effectiveness of the bake can be ascertained. This procedure was best achieved using a controlled insulated heating collar on the vacuum chamber that established a limited rate, and duration, of heating which prevented any fracturing of components due to severe thermal differentials. Subsequent to the bake-out, the detector gain, pulse height spectrum, and other characteristics were measured to determine the optimum bake procedure required to ensure constant detector operational parameters. An example of the bake-out procedure carried out on the SOHO MCPs is given in Siegmund *et al* (1995).

After photocathode deposition on the MCPs, a high flux "burn in" or "scrub" is preformed to stabilize the overal MCP gain. The scrub procedure involves illumination of the detector with light from an Hg vapor lamp (the principal UV emission lines being 1879Å and 2537Å). It was determined that best results are gained when the detectors are operated during the scub with an overall voltage of ~ 700V below the nominal operating range. The DC current from the MCPs is continually monitored during the scub (typically 1 μA), such that the total charge extraction (~ 0.05 - 0.1 C cm^{-2}) can be determined. We found that for the SOHO MCPs the scrub behavior of the plates was unusual in that some MCP stacks did not show significant gain drop with charge extractions up to a level of 0.1 C cm^{-2} . This anomalous behavior has been observed for scrubs performed at different times for two different boules of MCP glass, and on MCP areas both with and without photocathodes (Siegmund *et al* 1995).

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