GRANT
IN-89-CR
180214
P- 8

DEVELOPMENT OF HIGH RESOLUTION IMAGING DETECTORS FOR X-RAY ASTRONOMY

NASA Grant NAG5-605

Final Report

For the Period 1 May 1982 through 30 June 1991

Principal Investigator
Dr. S.S. Murray and Dr. D.A. Schwartz

April 1992

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia 23337

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this grant is Larry J. Early, NASA, Code 840.0, Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, Virginia 23337.

1 Introduction

This Final report summarizes our past activities that were conducted under NASA Grant NAG5-605. This report discusses the work performed over the period of 1 April 1990 through 1 April 1991. A detailed description of the work done up to this report can be found in the sixteen Semiannual Progress Reports previously submitted.

2 Research Program

Our program consisted of research and development in three major areas,

1. X-ray optics,
2. soft x-ray (0.1 - 10 KeV) imaging detector,
3. hard X-ray (10 - 300 KeV) imaging detectors,

2.1 X-ray Optics

Over the past year, we have investigated the use MCP's as soft x-ray focusing devices. It had already been demonstrated that passive MCP's can be used as collecting devices for soft x-rays (Wilkins et. al. 1989) and that the MCP inner channel surfaces are smooth enough to reflect the soft x-rays efficiently. If these devices can be used to focus x-rays with a high efficiency and good angular resolution, they will revolutionize the field of x-ray optics. We have constructed preliminary ray tracing models that are being used to determine the radius of curvature and L/D ratio to optimize such an optic. The work done by Wilkens and colleagues used standard circular pore MCPs. They have pointed out that square pore devices should be an order of magnitude more efficient in reflecting x-rays. We obtained a section of a square pore MCP from Philips-Mullard for X-ray testing. Figure $2-1$ shows a SEM image of the front MCP surface. This MCP has a L/D ratio of 40:1 with a pore size of 80μ (100μ center-to-center spacing).

Using our AXAF and ROSAT high resolution x-ray cameras, we have obtained an image of a point-like x-ray source viewed through the square pore MCP collector. The experimental set up is indicated in Figure $2-2$. An optical photograph of the aperatured 3 x 16 array of square MCP pores along with the "first light" x-ray image is show in Figure $2-3$. This data has compared favorablly with our ray tracing model for the MCP. Initial analysis of this image demonstrates the feasibility of MCP optics for soft x-rays. We have begun discussions with MCP manufacturers (Galileo and Philips) about the possibilities of constructing large area square pore curved MCP for this activity. A spherically curved MCP, using the same manufacturing techniques developed for focal plane detectors such as the ROSAT Wide Field Camera, EUVE and ALEXIS should result in arcminute resolution performance. This possibility has been described in the work of

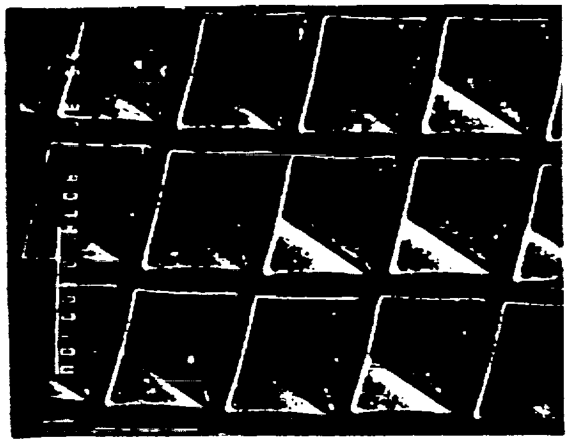

Figure 2 – 1: SEM photograph of the front surface of a square pore MCP from Philips-Mullard. Channels are 100μ center-to-center

Chapman et al (1990) in the context of x-ray concentrators and x-ray microscopes. We have extended their work as the basis of our ray trace models in the context of x-ray telescopes.

2.2 Soft X-ray Imaging Detectors

We have continuing our work in optimizing the performance of our soft x-ray MCP imaging detectors. This work involves improved MCP readout devices, defect removal in MCP's and photocathode optimization. Figure 2 – 4 shows a schematic diagram of our basic MCP imaging detector. This detector has the highest spatial resolution of any MCP x-ray imaging system. The spatial resolution is limited by the MCP pore size (sigma=10.4μ, FWHM=25μ), and remains constant over the full size of the detector. We have built devices ranging in size from 36 mm in diameter to 100 mm x 100 mm square.

2.2.1 Readout Technology

Thin Film Crossed Grid Readouts: We have developed a thin film readout device to replace our current generation of free standing cross grid charge detectors (CGCD). These devices consist of two planes of thin film wires separated by an insulating layer. These devices were prototyped in a joint venture with Bell Labs (Holmdel NJ), where the basic microfabrication processes were developed and tested. We then contracted a local manufacture (Thin Films Research Inc.) to produce these devices using the mask sets and processing techniques we developed at Bell Labs. Thin Films Research has modified these processes to improve yield and the first set of of 36mm devices has just been delivered for testing. These readouts have 128 wires per plane, which corresponds to over 16,000 intersections of top and bottom plane wires, each of which must be electrically isolated. A single electrical short circuit between the top and bottom planes of the

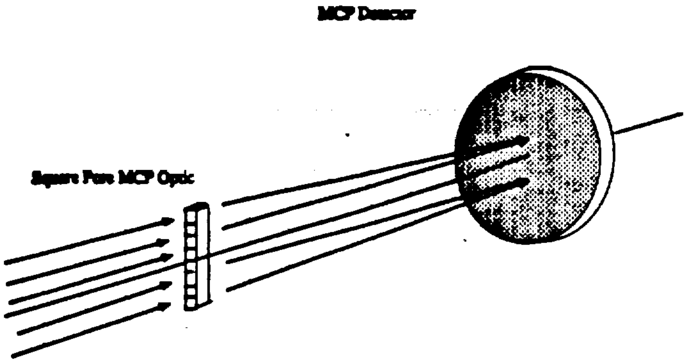

Figure 2 – 2: Schematic of experimental setup for imaging a point source through a section of a flat square pore MCP onto a high resolution x-ray camera.

Figure 2 – 3: a: Photograph showing 3 x 16 pore region of square channel MCP
b: X-ray image of point source through aperature.

readout makes the device inoperable. Our intial screening tests shows that Thin Films Research has succeeded in avoiding this type of fault.

Figure 2 – 5 is an optical microscope photograph of a section of the grid. The diced wafer is mounted to a printed circuit card with an external block of thin film resistors wirebonded to the grid. This device has been assembled into an HRI camera head including MCPs and readout electronics. We are in the process of characterizing these devices with respect to image quality, stability, and material compatibility. These devices should be more robust than the standard GGCD readout, and they will also provide a substantial reduction in cost, weight, and complexity in our MCP readout system. If these small area devices prove successful, we will next develop thin film readout devices for our large area (100 mm x 100 mm) MCP's.

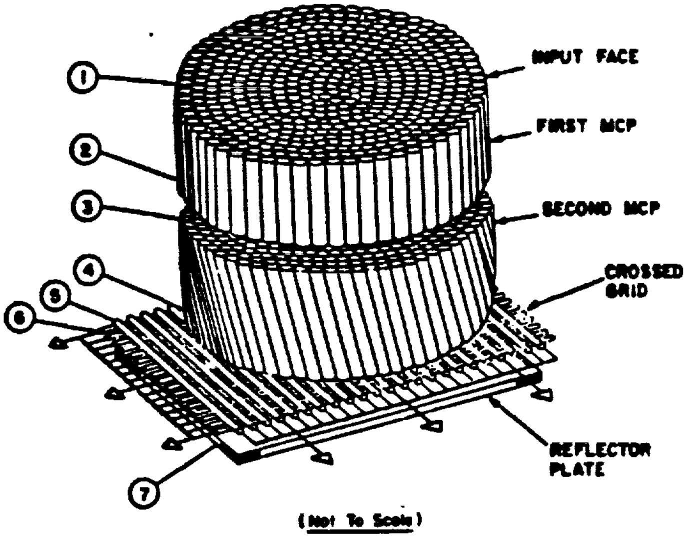

Figure 2 – 4: Schematic diagram of high resolution MCP imaging detector.

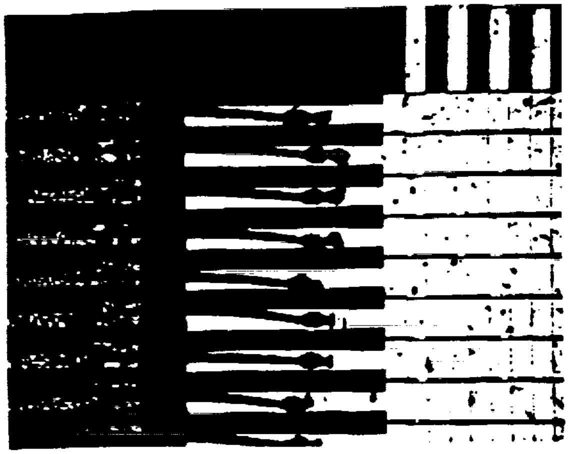

Figure 2 – 5: Photomicrograph of a thin film crossed grid readout mounted on a printed circuit card with external resistors wirebonded to thin file wires.

Curved Readouts: The introduction of "wide field" x-ray optics (Giacconi et al. in preparation) prompted us to investigate high resolution detectors that are better matched to the focal plane. For example, in the case of the AXAF mirrors, curving the detector to match the focal plane would improve the off-axis angular resolution by a factor of two. More importantly, a better match of the detector to the focal plane dramatically increases the solid angle of sky over which arcsecond imaging can be achieved. This permits more efficient use of telescope time for certain classes of observations (surveys, objective spectroscopy of dense fields, etc.), and gives better x-ray positions for serendipitus sources which greatly helps in their identification.

We have begun studies of high resolution readout devices for curved MCPs. We have measured the spatial distortions that arise when using a simulated curved MCP with a flat CGCD readout device. In this test a flat MCP and CGCD was constructed such that the separation distance between the two varied linearly from 1mm to 5mm. We are currently in the process of deriving the deconvolution factors needed to remove the image distortion. We will continue this work by analyzing the corrected image to quantify its limitations.

Resistive Sheet Readouts: Over the past year we have fabricated a thin film resistive sheet readout device for use in our long term MCP and photocathode storage investigations (discussed below). This device uses a NiCr resistive sheet to collect the charge from the MCP stack. The charge is collected on a square geometry and read out from the four corners. We elected to use these modest resolution readouts for the long term monitoring of MCP's since they are low cost, easily fabricated, and can be operated with a PC based event processor with simple electronics. Our use of these readouts will be to monitor the long term stability of MCPs and photocathodes in various environments. We need only modest resolution imaging for this purpose, but we plan to have a large number of test configurations of MCPs and photocathodes. A low cost, and simple readout such as the resistive sheet allows us to carry out these important tests without impacting other activities.

2.2.2 Photocathode Development

We have continued our work in optimizing and characterizing x-ray photocathodes. We have developed deposition techniques that allow us to evaporate several photocathode materials on a single MCP. The test photocathode materials are deposited in quadrants. Detailed quantum efficiencies measurements as a function of energy, angle, and deposition parameters are made of all four areas simultaneously so that relative effects are accurately measured. We have produced a quadrant coated MCP (Bare, CsI, CsBr, CsI+CsBr), and measured its characteristics (Martin et al 1990). Figure $2-6$ shows a plot of the relative quantum efficiencies of each quadrant at selected energies. Other materials (e.g., KBr) and combinations of materials are currently being studied using this method.

As part of the characterization of x-ray photocathodes, we have constructed a long term

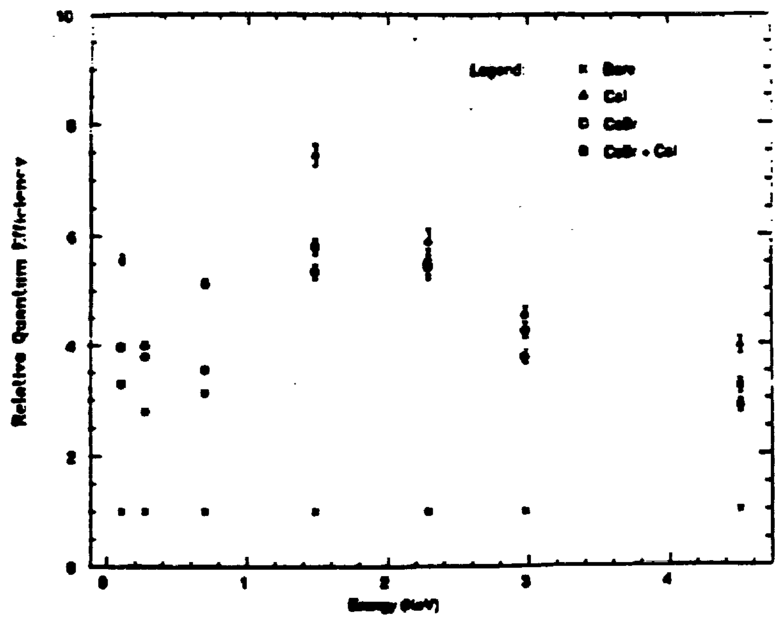

Figure 2 – 6: Relative quantum efficiency versus energy for CsI, CsBr, and CsI+CsBr photocathodes compared to a bare MCP.

storage test facility. In this facility we can investigate MCP and photocathode degradation as a function of time for various storage environments ranging from vacuum to nitrogen backfill. Several photocathode materials will be deposited on a single MCP (see above) and mated with a resistive sheet readout device. The MCP detector then will be attached to the pump cart for storage. The system is designed such that the MCP detector can be connected to a PC based event processor for periodic measurement of background, and detection of image defects. In addition, the detector assembly can be removed under vacuum and attached to our existing x-ray facility for quantum efficiency measurements. The key point of this facility is that once assembled, the test articles are not physically disturbed, and that measurements can be made easily and often.

2.3 High Energy Imager (HEI)

Recent advances in developing x-ray optics for the 10 - 40 KeV range suggest that moderate to high resolution imaging will be possible in this energy band (Elvis, Spektrosat Workshop Schliersee, Nov. 1987). We have modified an existing soft x-ray MCP detector to include a free standing photocathode suspended in front of the top MCP. High energy photons absorbed in this photocathode and the ejected photoelectrons areaccelerated into the MCP detector below. The photocathode has been designed such that it is thick enough to absorb high energy x-rays and still allow the photoelectrons to escape into the top MCP. To have reasonable quantum efficiencies over this energy range, a CsI photocathode thickness of 10 to 100 μ is required. We have developed two different techniques for producing such photocathodes.

The first method involves vacuum depositing a thick film of CsI on a strong back (which will actually be the x-ray facing side of the detector). We have developed deposition techniques that produce polycrystalline columnar structures as shown in Figure 2 – 7. To date we have produced films up to ~ 40 μ in thickness with an aspect ratio of ~1000:1. This type of photocathode structure

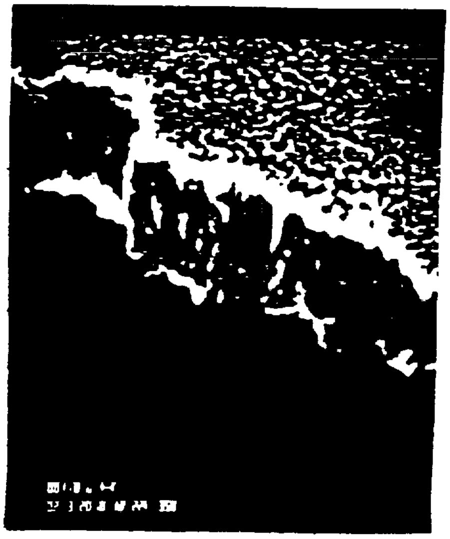

Figure 2 – 7: Polycrystalline columnar structure of evaporated CsI on a silicon strongback. CsI is 40μ thick with 1000:1 aspect ratio (height to width).

allows for long x-ray absorption path lengths along the crystal column, and short photoelectron escape path lengths across the cloumn. Since the photoelectrons do not have a strongly forward peaked emission direction, a large fraction of these electrons will escape from the CsI and be electrostatically drawn to the MCP below.

The second method involves producing a converter device that takes the place of the photocathode. This converter consists of a solid crystal of CsI that is structured like a MCP. The converter is ~ 1mm thick with open circular channels through the crystal. We have made several small converters (~1 cm2) that have channels diameters ~ 100μ with ~ 50% open area. In this case the incident x-ray strikes the CsI channel at grazing incidence (just as in the low energy detector the x-rays strike the CsI coated MCP at grazing incidence) and thus have a long path length through the converter. Photoelectrons (which are nearly isotropic) have a short pathlength to the CsI surface and escape to the vacuum and are detected by the MCP below.