The FUV detector for the Cosmic Origins Spectrograph on the Hubble Space Telescope

J. Vallerga, J. Zaninovich, B. Welsh, O. Siegmund, J. McPhate
J. Hull, G. Gaines and D. Buzasi

Space Science Laboratory, University of California, Berkeley
Berkeley, CA 94720-7450
USA

Reference #68
Corresponding Author: J. Vallerga, jvv@ssl.berkeley.edu, 510-643-5666, 510-643-9729 (Fax)

Abstract

The Cosmic Origins Spectrograph (COS) is a high throughput spectrometer that will be placed on the Hubble Space Telescope (HST) during the last servicing mission in the year 2003. COS will be the most sensitive UV spectrograph ever flown aboard HST and will investigate such fundamental issues as the ionization and baryon content of the intergalactic medium and the origin of large scale structure of the Universe. The driving design goal for COS is to maximize throughput at a moderate spectral resolution of ≥ 20,000 using optics with very few reflections and detectors with high quantum efficiency in two bandpass channels: FUV (1150-1775Å) and NUV (1750-3200Å).

The COS FUV detector, a windowless microchannel plate (MCP) detector, consists of two segments each 85 mm x 10 mm concatenated end to end with a 9 mm gap between them. The design is based on the Far Ultraviolet Spectroscopic Explorer (FUSE) detectors with identical format and front surface radius of curvature that matches the grating focal plane of the spectrograph. However, enhancements have been made in the design and fabrication of the MCPs, the photocathode, the delay line anode and the readout electronics. Below we discuss these design enhancements and their significance.

Key Words: Microchannel Plates, UV Detectors, Cosmic Origins Spectrograph, Hubble Space Telescope

1. COS FUV Detector Design and the FUSE Heritage

When the Cosmic Origins Spectrograph (COS)[1] was proposed to NASA as a replacement instrument on the Hubble Space Telescope (HST), the Far Ultraviolet Spectroscopic Explorer (FUSE) was well into integration testing with two space qualified detectors. In the proposal (a collaboration between University of Colorado, Boulder, University of California, Berkeley and Ball Aerospace), a copy of the FUSE detector was chosen as the spectrometer detector, with minimal changes. This design met the scientific requirements of the COS mission. But more importantly, working, space-qualified FUSE detectors existed, and would minimize the resources and time required to develop a new detector for an HST servicing mission in 2003. Using an existing detector design also reduced risk factors. Time saved in development could go into increased calibration and testing of the detector.

Each FUSE detector (Fig. 1) consists of a kovar-ceramic brazed body that holds two "segments" of three MCPs each in a Z stack configuration over two helical double delay line (HDDL) anodes. [2] Each segment has an independent high voltage bias and electronic readout and can be operated independently. The MCPs are curved (via a thermal slumping technique) to a concave radius of 826 mm to match the focal plane of the spectrometers. A quantum detection efficiency (QDE) enhancement grid is placed six mm above the MCPs and is curved to provide a uniform electric field. The grid increases the QDE by ~ 30% by propelling photoelectrons produced on the web area of the plate into the microchannels. The FUSE MCP detectors are optimized for the wavelength regime of 905 to 1190Å and therefore operate windowless with a KBr photocathode [3] deposited directly on the input surface of the top MCP. The dispersion direction of the spectrograph is aligned with the long "X" dimension of the detector which uses a helical delay line, fast (100MHz) amplifiers and a time to digital converter to produce an X location of each photon event with 14 bit precision. The cross dispersion ("Y") position of each event is determined using a charge division scheme between upper and lower wedges on the DDL anode which are read out with slower (1 MHz) charge amplifiers and digitized to 10 bits. The resulting full pixel scale of one FUSE detector segment is 16384 x 1024 with a spatial resolution in the X dimension of ~ 25 µm FWHM.

Based on our extensive testing and experience with the FUSE detectors (which are now operating in orbit) we have made changes to the FUSE design for the COS FUV detector which will result in performance improvements and decreased schedule risk.

2. Photocathode and Microchannel Plates

Due to its higher QDE in the bandpass of interest, CsI was chosen as the photocathode material for COS over the KBr used on FUSE. Both cathodes have similar QDEs at the shorter wavelengths near 1200Å, but the QDE of KBr drops off much faster than CsI at the wavelengths above 1400Å. [3,4] Both cathodes are robust and can handle short exposures to clean, dry laboratory air and both have extensive in-orbit qualifications.

The MCP stack for FUSE consist of 3 plates in a Z configuration with a format of 95 mm x 20 mm, 80:1 channel length to diameter ratio and a 13° bias angle. The top and bottom plates have 10 µm holes on 12 µm centers (manufactured by Photonis) while the center plate is 12µm holes on 15 µm centers (manufactured by Galileo Inc.). These two different microchannel pitches were chosen to reduce fixed pattern noise in the resultant flat field. This pattern was caused by a Moiré beating between the hexagonal arrays of microchannels of the different plates in the electron amplification process. There was evidence of this Moiré distortion in flat fields taken with the detectors on the Extreme Ultraviolet Explorer 10 years ago [5], but the higher spatial resolution of the FUSE detectors made the Moiré beat pattern much more evident, and problematic. Models of Moiré beating between two hexagonal arrays predict that the amplitude of the effect is minimized when one hexagonal pattern is rotated with respect to another by 30°, and this has been verified by experiment[6]. Unfortunately for FUSE, rectangular plates cannot be rotated at an arbitrary angle, so some residual Moiré modulation exists in the flat fields, especially for segment 2B.

The COS plates have the same format and thickness as the FUSE plates, but the MCPs have been cut from the boule differently such that the middle plate hexagonal pattern is rotated 30° from the top and bottom MCP pattern. The change in microchannel pitch inside the stack from 12 μm to 15 μm to 12 μm used by FUSE has been retained in the COS design. The bias angle of the microchannels with respect to the surface normal is increased to 19° to improve the QDE at longer wavelengths [4]. Preliminary testing of a candidate flight COS MCP stack from Photonis has shown excellent pulse height distribution, good QDE and no evidence of a Moiré pattern.

3. Delay Line Anode

The FUSE detectors used a helical double delay line anode (HDDL) [2] consisting of two separate helical delay lines in the X direction, with each of them having wedge shaped “fingers” interleaved under the active MCP output to collect the charge and insert it into the delay line. The Y position is determined by the charge ratio collected by the two delay lines while the X coordinate is determined by the time difference of the fast pulses at each end of the delay line with both delay lines coupled together at the preamp.

The need for high spectral resolution required a large delay on the FUSE anode. Spatial constraints demanded this be achieved with a fine delay line pitch (0.5 mm) which proved to be difficult to fabricate. Also, the requirement for a Y resolution of 25 μm FWHM was difficult to achieve using the wedge-wedge charge division scheme because of the large capacitance of the high dielectric constant substrate. The spatial non-linearity in the Y direction depended on the X position, most likely due to the precision in the etching of the tips of the very narrow wedges. And finally, to achieve good spatial resolution using charge division requires a slower amplification process, which increased the deadtime of the FUSE electronics.

Given these difficulties with the FUSE anode, a different scheme was selected for COS using a multilayer anode. This scheme is similar in certain respects to those used in the SOHO mission [7] and the upcoming GALEX mission [8]. The X dimension is readout using a single helical delay line positioned directly under the MCPs. Collection of the signal charge is direct onto the delay line. The elimination of the fingers should also improve the transmission line characteristics of the delay line.

The anodes are produced by photolithographically etching the pattern into conductor layers deposited on low loss flexible microwave substrates (6010 RT Duroid, ceramic doped PTFE, $\varepsilon = 10.2$). On top of the helical delay line is a set of very long (90 mm) fingers in the X direction (Fig. 2). These fingers collect approximately 35% of the charge and transfer it to a short delay line which is used to measure the Y dimension. Each finger is made of 4 layers. First a polyimide insulating layer, then a conductive layer acting as a ground plane to minimize cross talk between X and Y, then another polyimide layer and finally a top copper conductive layer carrying the Y signal. A photoetch technique is used to remove the sputtered copper between the fingers while the excess polyimide is removed by laser ablation. Though the fabrication of a multi-layer anode appears complex, the relaxation of the pitch specification to 630 μm has ameliorated the most difficult fabrication step on the FUSE anodes: connecting the top and bottom of the helical pattern through the substrate using Cu plated through holes. Spatial linearity should improve, especially in the Y direction and the Y offset and scale should no longer be a function of the X position. Initial spatial resolution results using a prototype COS anode give < 20 μm FWHM and are shown in figure 3.

4. Detector Readout Electronics

One of the first dividends from the conversion to delay lines in both X and Y dimensions is that both now use virtually identical electronic chains, differing only in scale and offset resistors and capacitors. Dropping the charge signal conversion also decreased the digitization time required per photon event. Figure 4 shows the FUSE measured livetime curve (events in vs. events out) and the expected COS curve.

Thermal models predicted that the COS electronics would run hotter than FUSE, which constitutes a problem as power dissipation near the detector has to be minimized. Because of their high voltage requirement, timing amplifiers on FUSE draw appreciable power and their number on COS is twice that of FUSE. We therefore redesigned the timing amplifier using the heritage of the FUSE design but substituting a low noise, low power part (Hewlett Packard MSA-0670 amplifier, 50 Ohm, 20 dB gain).

The amplified Start and Stop signals from either end of the anode enter the Time to Digital converter (TDC) which converts the time difference of the signal to a digital location. The COS TDC design is nearly identical to that of FUSE except for a modified front end discriminator and a baseline restoration circuit to improve accuracy at higher input rates. The new discriminators are based on a design by Turko and Smith [9] which has excellent walk characteristics over a large dynamic range and does not require the usual spool of delay line cable like the FUSE constant fraction discriminators. Pulser tests on the bench have been excellent (5.5 ps rms with walk of 3 ps over 16 dB dynamic range), though tests with the actual flight anodes have not yet taken place. We have left space on the printed circuit boards to use the FUSE discriminator design if necessary.

Inside the TDC, a precision current source discharges a capacitor for a time difference between the Start and Stop ECL logic signals. The resultant voltage is then digitized and represents the event position. It was observed on the FUSE electronics that when this capacitor was reset to a reference voltage after the digitization, it retained a residual small voltage memory of the previous pulse that decayed away with a long time constant. If rates were high enough, the position of the next event would be shifted by a small amount, depending on the position of the previous event and the time between events. A uniformly illuminated detector would then degrade the resolution of an input point source. For the COS electronics, we have therefore added a baseline restoration circuit that samples the capacitor voltage right before the capacitor begins to discharge, and subtracts it (analog) from the resultant event current integration.

Acknowledgements

This work was supported by NASA under contract NAS 5-98043

References

1. J. A. Morse, et al, Proc. SPIE., 3356, (1998), 361.

2. O.H.W. Siegmund, et al., Proc. SPIE, 3114, (1997), 283

3. D. Marsh, O.H.W. Siegmund, and J. Stock, Proc. SPIE, 2006, (1993) 51.

4. O.H.W. Siegmund, E. Everman, J. Vallerga, M Lampton, Appl. Optics, 27, (1988), 1568

5. J.V. Vallerga, O.H.W. Siegmund, P.W. Vedder, J.L Gibson,. Nucl. Instr. and Meth. A 310 (1991), 317.

6. A.S. Tremsin, O.H.W. Siegmund, M.A. Gummin, P.N. Jelinsky and J.M. Stock, Applied Optics, 38, (1999), 2240.

7. O.H.W. Siegmund et al., Proc. SPIE, 2518, (1995), 344

8. O.H.W. Siegmund et al., Proc. SPIE, 3765 (1999), in press

9. B.T. Turko and R.C. Smith, IEEE Trans. Nucl. Sci. 39, (1991) 1311.

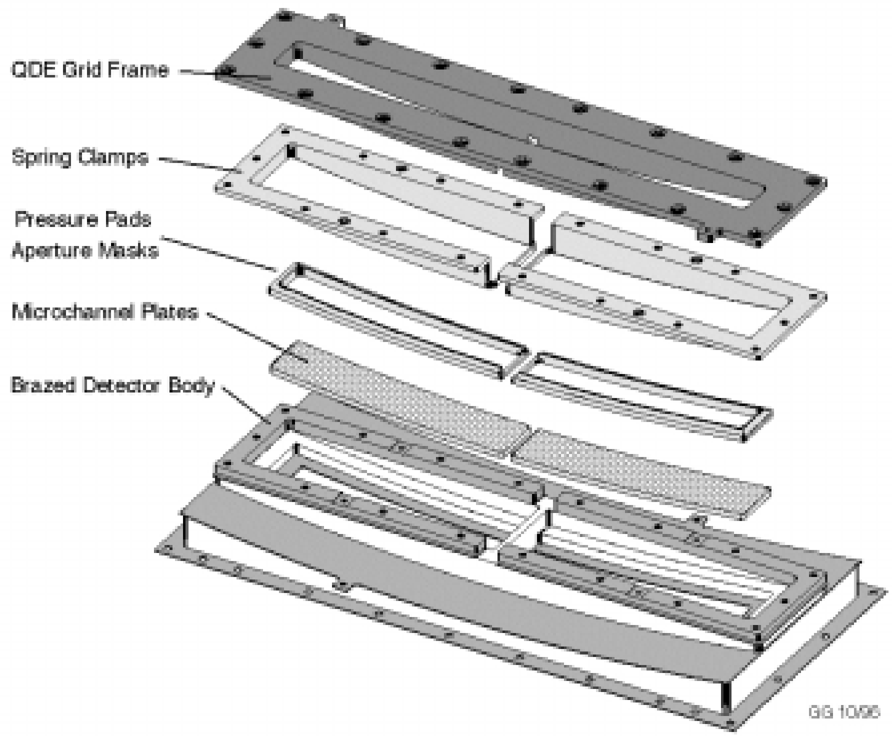

Figure 1. Exploded view of the COS FUV detector. The two MCP stacks are 95 mm by 20 mm.

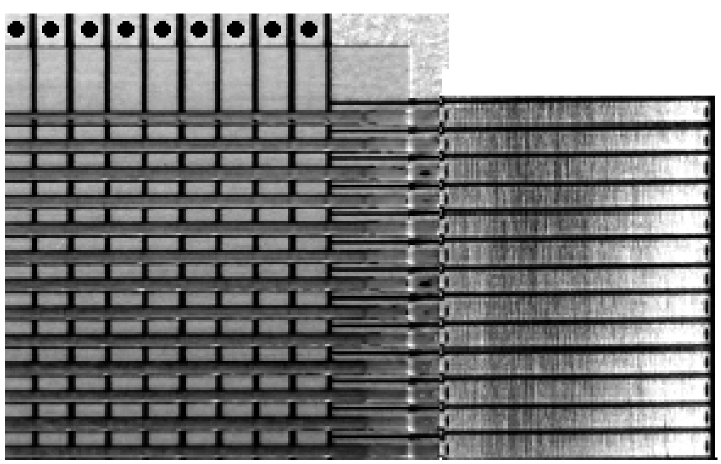

Figure 2. Top right corner of a prototype COS anode. The wide vertical traces are the Cu helical delay line that senses the X position of an MCP event. The narrow horizontal traces on the left are the Y "fingers" that collect ~35% of the event charge and inject it into the small Y helical delay line on the right. The pattern period in the X direction is 0.63 mm.

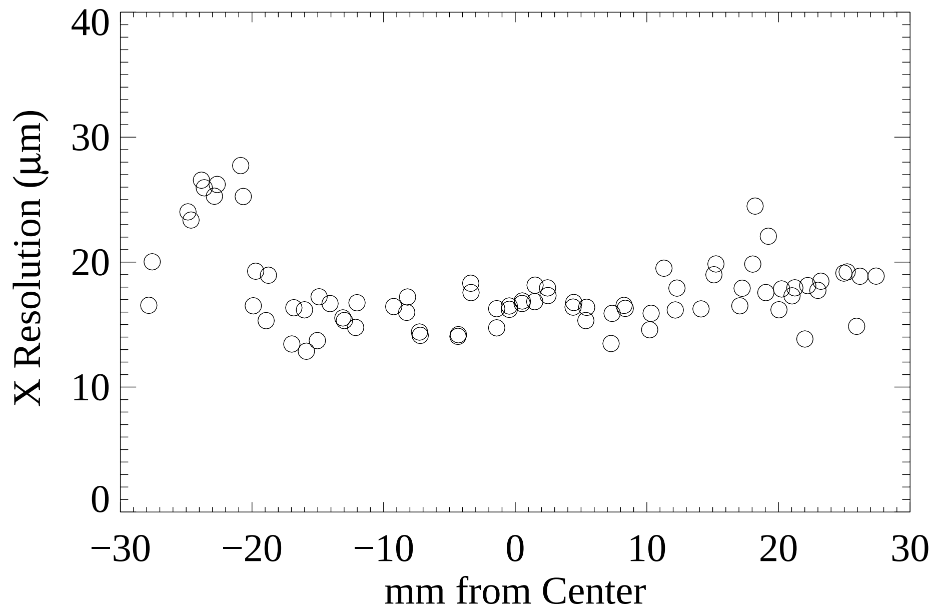

Figure 3. Measurement of spatial resolution in the X direction (FWHM) as a function of X position using the COS prototype anode. The pinhole mask used to define the UV input had 10 μm holes. The COS requirement is 25 μm FWHM.

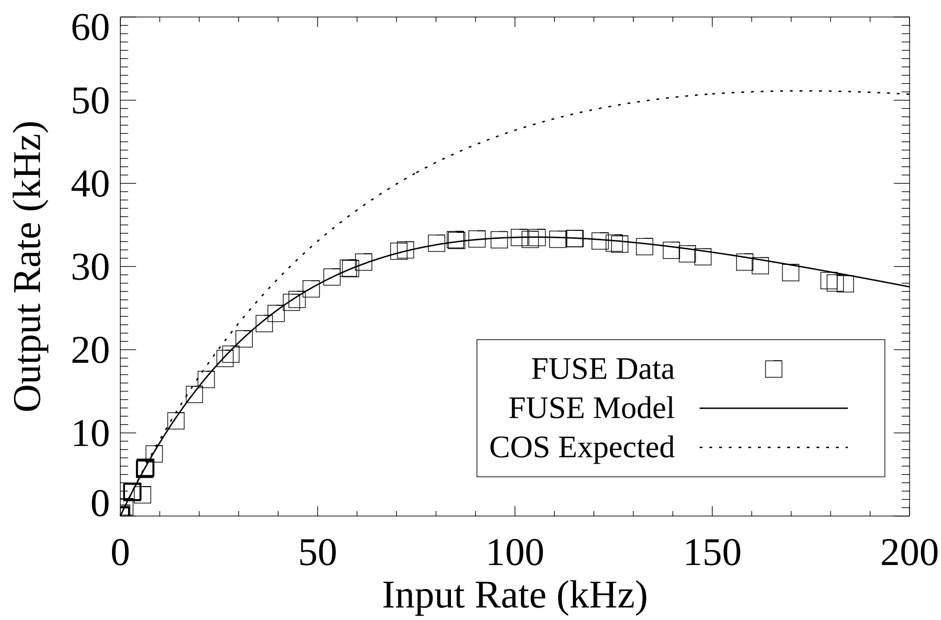

Figure 4. A comparison of the measured FUSE digitizer livetime vs. the expected livetime of the COS design. The livetime at 100 kHz will increase from 33% to 47%.