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Development and Characterization of a Single Line of Sight Framing Camera

D. K. Bradley, P. M. Bell, A. K. L. Dymoke-Bradshaw, J. D. Hares, R. E. Bahr, V. A. Smalyuk

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Development and characterization of a single line of sight framing camera*

D. K. Bradley, and P. M. Bell
Lawrence Livermore National Laboratory,
P.O. Box 808, Livermore CA 94550
A. K. L. Dymoke-Bradshaw, and J. D. Hares
Kentech Instruments Ltd.,
South Moreton, Didcot, Oxon OX11 9AG, UK
R. E. Bahr, and V. A. Smalyuk
University of Rochester Lab. For Laser Energetics
250 E River Rd, Rochester, NY 14623

Abstract

We present initial characterization data from a new single line of sight (SLOS) x-ray framing camera. The instrument uses an image dissecting structure inside an electron optic tube to produce up to four simultaneous DC images from a single image incident on the cathode and a microchannel plate based device to provide the temporal gating of those images. A series of gated images have been obtained using a short pulse UV laser source, and the spatial resolution of those images is compared to those obtained using a more traditional MCP based system.

Introduction

High-speed x-ray framing cameras are important diagnostics in the field of inertial confinement fusion (ICF). Gate times better than 100 ps are needed to image, with minimal motional blurring plasmas that can be typically moving at > 10^7 cm/sec. The dominant type of framing camera currently in use at large-scale laser fusion facilities is a proximity-focused device based on the gating of a microchannel plate (MCP)[1]. These instruments are simple and robust, and have been demonstrated to be capable of gate times as short as 30 ps.[2,3] [4] However, they are not true framing cameras in that each image has to be produced by a separate optical element (e.g. pinhole), each with a slightly different line of sight to the source. For many applications this is not a problem, but for experiments that use a remote backlighter source [5] or that need to look along a long line of sight[6], there can be potentially severe parallax problems. In addition, there is the potential for great expense if an expensive optic is being used to image the plasma, since each image would require a separate optic.

High-speed framing cameras based on image converter tubes can give multiple frames from a single line of sight[7-10], but have traditionally suffered from degradation in spatial resolution for short gate times, and the blanking of images between frames has also been a problem. In this paper we present preliminary data from a new type of hybrid camera that uses an electron optic tube to produce up to four simultaneous DC images from a single image incident on the cathode and a microchannel plate based device to provide the temporal gating of those images. We show time integrated data recorded using a dc x-ray source, and gated images recorded using a short pulse UV laser source and show how the measured spatial resolutions compare with that of a conventional MCP detector.

The image dissector

In a typical electron optic tube photons (x-rays) are incident on a photocathode and produce photoelectrons. The resulting secondary electrons are extracted from the cathode using a charged mesh or slot, are imaged by a set of focusing electrodes, are accelerated through an anode aperture and eventually hit a phosphor screen, producing an inverted image of the light hitting the cathode. In order to produce the image the electrons all pass through a small crossover region close to (typically just behind) the anode aperture. In a streak camera, a slit is placed in front of the photocathode, and the image on the phosphor is swept in the direction perpendicular to the slit by a ramp potential applied to deflection plates situated at the crossover point. In one typical framing camera design the deflection plates sweep the image past a second aperture plate with a second pair of corrector plates to compensate for the motion of the beam as it passes through the aperture, in another a staircase potential is applied at the crossover. In both cases it is difficult to keep the beam stable at short exposure time, with resulting loss in spatial resolution.

The image dissector concept discussed in this paper uses the fact that the electron crossover point is actually a Fourier transform plane of the input and final images. As a result any splitting carried out in this plane should have equal contributions from all parts of the image. Figure 1 shows a schematic of the design. Photoelectrons are produced at the photocathode with a range of initial energies and emission angles. Electrons with different radial velocities will arrive at different radial positions at the crossover point. It is this spread in velocities that allows the image splitting to be carried out. A pair of deflector structures is placed at the crossover point, as shown in fig 2. Each structure consists of a grounded center electrode, with a pair of positively charged electrodes to either side. The center electrode is designed to intersect the axis of the tube, and the net effect of the structure is to bisect the beam and deflect each half away from the axis. The second electrode triplet is rotated 90° around the tube axis so that the deflection from it is orthogonal to the first. The net effect of the pair of structures is that electrons travelling through the crossover will be deflected twice, once in each orthogonal direction such that four images are eventually produced at the image, or phosphor plane as shown in fig 2. In principle, since the tube is axi-symmetric, the four images should be identical, but in practice the splitter is not quite in the Fourier plane and the two orthogonal splits occur at slightly different axial positions. A photograph of the splitter assembly is shown in fig 3. Balanced (equal brightness) images are produced only when the assembly is located in the center of the crossover point. The radial position of the structure is adjusted by sliding the rear half of the tube relative to the front half. Great care has to be taken to minimize the effects of stray magnetic fields that will tend to move the position of the crossover.

The four images produced by the tube are continuous images and in order to run the instrument as a framing camera they must be gated. This has been achieved by replacing the phosphor that is normally at the image plane with a gated MCP system. This system operates in the same way as a traditional MCP framing camera ([1]), except in this case the incident image is being formed by electrons, instead of x-rays. Gating is produced by sending a negative (~1KeV) voltage pulse along four parallel microstrips coated onto the input side of the MCP. We were concerned that the fields caused by this pulse may have a defocusing effect on the electrons in the dissector tube, so we initially added a mesh 4 mm from the MCP to serve as a planar grounding surface for the electron tube, as in fig 4.

Measurements

The camera was initially tested with the rear MCP operated in a cw mode, using a dc x-ray source, with a Ti anode running at 10 KeV. The deflector assembly was adjusted to balance the image, and the electron tube voltages were adjusted in an attempt to optimize both the image focus and the uniformity of the dissected images. Images were recorded using a fiber-optically-coupled 4096 x 4096 pixel CCD camera system with 9-μm pixels[11]. This camera has been shown to be capable of recording data from MCP based framing cameras with no loss in resolution [12]. Fig 5 shows a set of images recorded using a mask in front of the photocathode consisting of a series of 75-μm bars separated by 1.5 mm. *The dissector tube was rotated with respect to the MCP detector such that each of the 4 images would appear on one of the four microstrips on the MCP.* The four images are fairly well balanced in intensity over several mm of photocathode area, although in this case the focus is not optimized in all the images.

The camera was then tested in gated mode using a 100 fs frequency quadrupled Ti-Sapphire laser system at a wavelength of 200 nm. The electrical gate pulses sent to the MCP system were 750 ps in duration, resulting in an actual gate width of 240 ps. The photocathode used for these tests consisted of 1200 A of CsI coated onto a 1000 A formvar substrate with ~100 nm of Al to provide electical conductivity. This cathode was optimized for use in the x-ray, rather than UV region, but since the dissector relies on analyzing the radial velocity spectrum of the photoelectrons, we wanted to use the same photocathode material for all the measurements. Fig 6 shows a set of gated images recorded using the UV laser system. In this case all 4 microstrips were timed simultaneously. We confirmed that if a microstrip were timed more than one gate width away from the others then no image would appear on that strip. The grounding mesh situated in front of the MCP detector can clearly be seen in all the images. For these measurements a ~2mm x 2mm aperture was placed in front of the photocathode and this allowed a measurement of the modulation transfer function (MTF) of the framing camera to be made by analyzing the edge response of the system, as shown in fig 7. Also shown in fig 7 is the measured edge response and MTF of a typical MCP-based x-ray-framing camera[12]. As can be seen from the figure, the MTF of the dissector system is slightly worse than that of the MCP system alone, but is comparable to measurements taken with streak camera tubes equipped with internal MCP's. It is also possible that since the camera was focused and balanced by eye for these measurements, it may not have been fully optimized.

The presence of the shadow of the grounding mesh in figs 5 and 6 is clearly detrimental to the use of the camera as an imager, so measurements were made of the performance of the tube without it present. Since the ground plane of the electron tube would now be slightly different from before, the tube was refocused without the mesh. A gated image recorded without the mesh, together with the measured MTF is shown in Fig 8. The measured resolution is actually better than with the mesh (possibly due to the tube being refocused), indicating that the electron beam is probably stiff enough that it is not affected too much by the transient field on the MCP. However, it is possible that distortions may occur towards the edge of the strip, which is not seen with the 2-mm square aperture.

Summary

We have presented the results of the initial tests of a single line of sight framing camera based on an electron-optic image dissector coupled to a traditional MCP-based framing camera system. The dissector/splitter part of the instrument has been shown to be capable of producing four reasonably balanced images over field of several mm, but a more careful study to check for possible image distortions still needs to be carried out. A full study of image quality as a function of electron tube potentials should also be carried out. A saturation study of the tube also needs to be carried out. Since the initial image is split into 4 at the crossover point it is likely that saturation and non-linearity effects will occur at output signal levels one quarter of those encountered in a regular tube, with resulting losses in dynamic range.

A series of gated images have been obtained using a short pulse UV laser source. The spatial resolution of those images is slightly worse than that obtained from an MCP framing camera alone. The presence of a grounding mesh in front of the MCP appears to have little effect on spatial resolution. Future measurements will be carried out using a laser produced plasma x-ray source.

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Figure captions

Fig. 1 Schematic of the splitter design

Fig. 2 A pair of orthogonal deflection structures at the crossover, or Fourier plane splits the initial image into four identical copies

Fig. 3 Photograph of the rear half of the tube, showing the dissector plates and the rear aperture

Fig. 4 Schematic of the electron tube, showing the position of the microchannel plate and the grounding mesh.

Fig. 5 Set of images recorded using a dc x-ray source. The dissector tube was rotated with respect to the MCP detector such that each of the 4 images would appear on one of the four microstrips on the MCP.

Fig. 6 Set of gated images recorded using a 100 fs UV laser source.

Fig. 7 Edge response and MTF of system compared with MCP system alone.

Fig. 8 Gated image and MTF recorded without the grounding mesh

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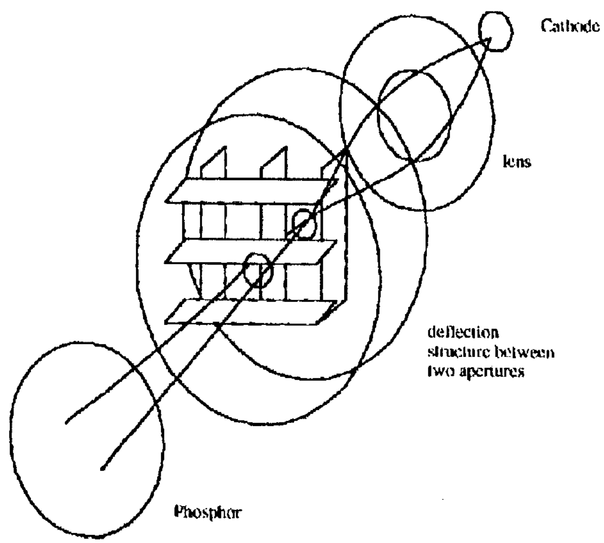
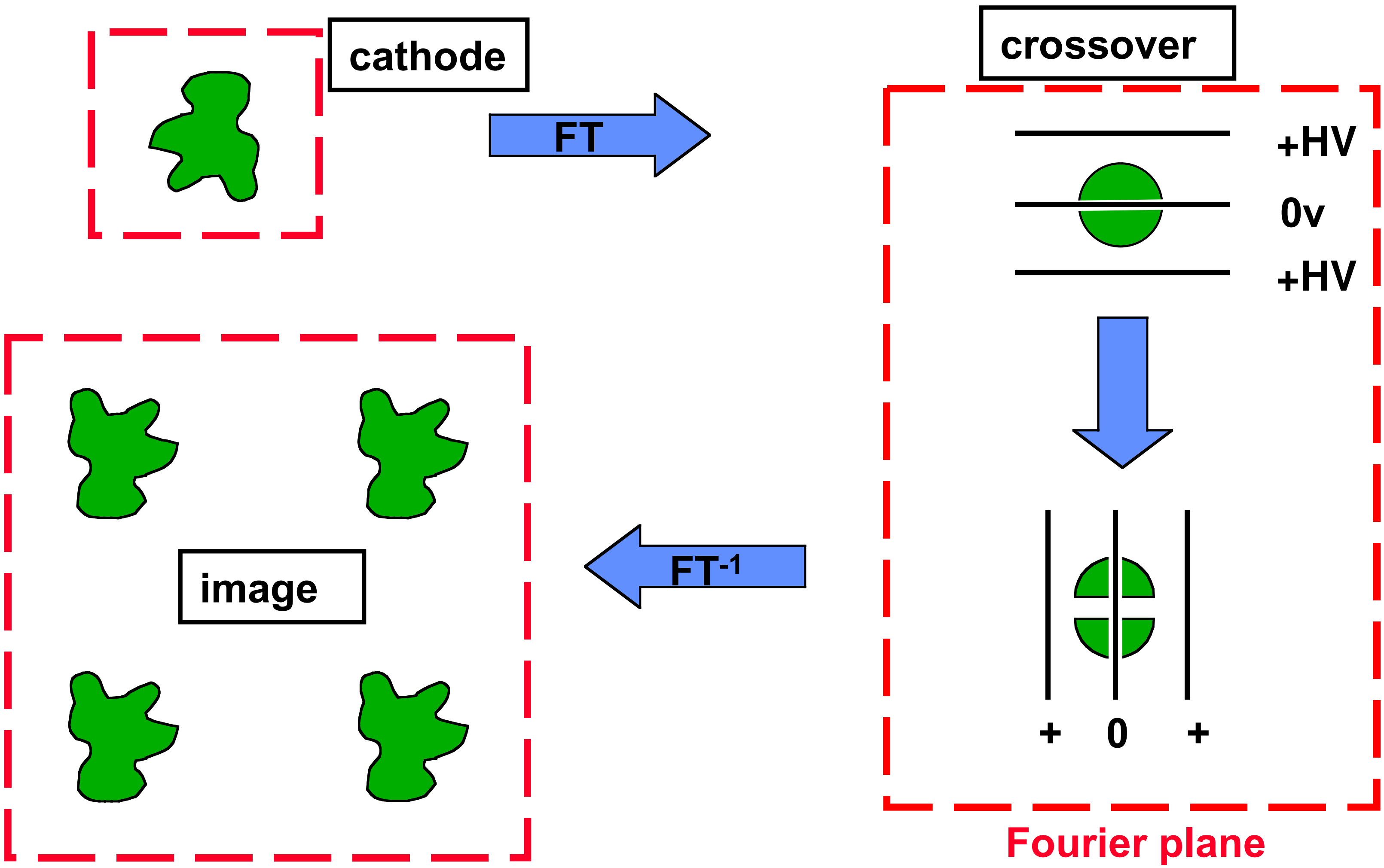
Tube uses a deflection structure to form 4 images at the phosphor plane

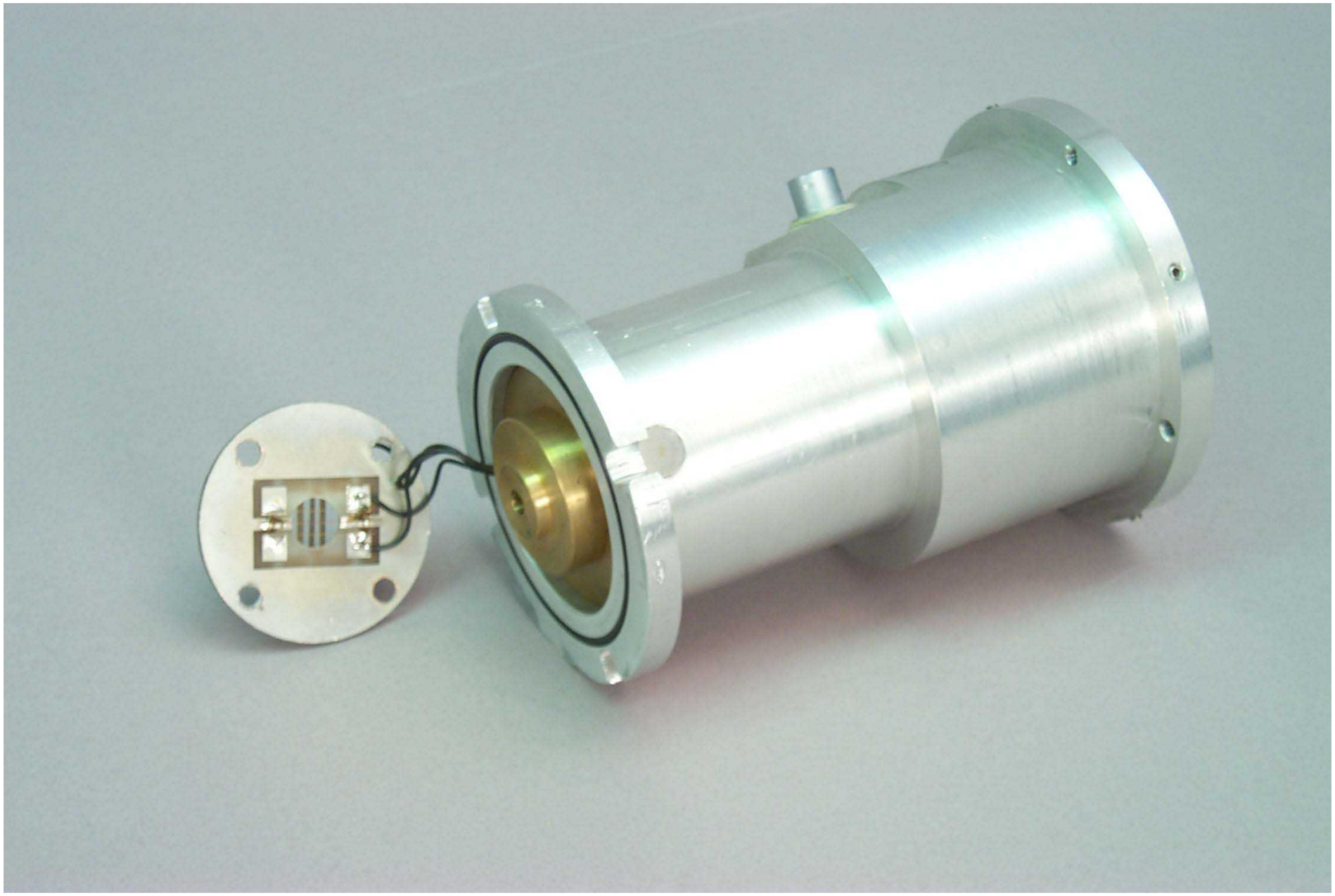


Phosphor is replaced by microchannel plate with pulsed microstrips for gated operation

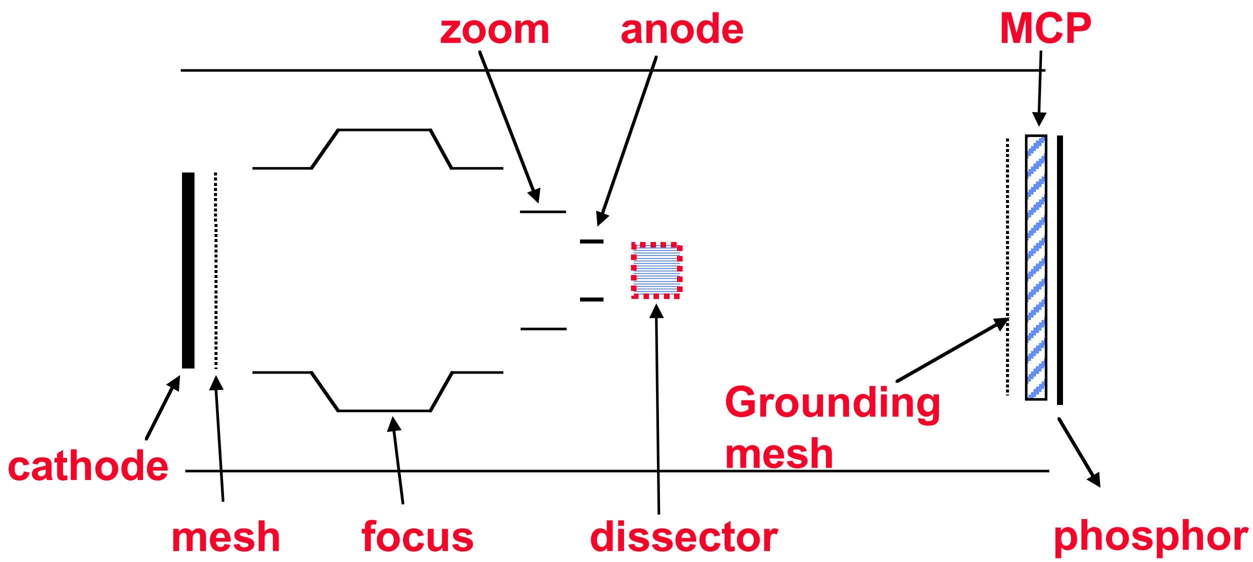
The electron image is split into 4 at the crossover, or Fourier plane.



Rear part of tube and dissector assembly.



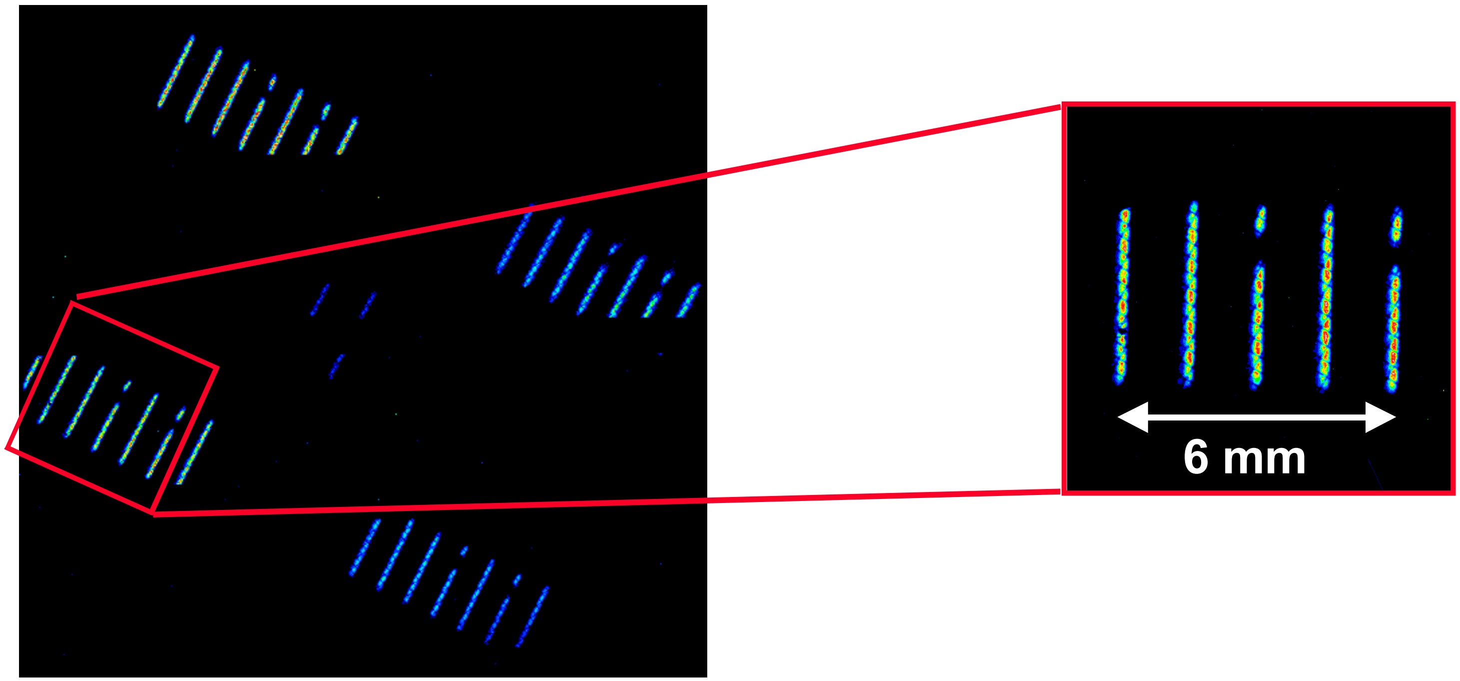
Electron images were gated using a michrochannel plate based framing camera at original phosphor position.



Mesh was placed in front of MCP to provide a ground plane for the electron tube (gathering requires propagation of negative pulse along MCP).

Framing camera was rotated so that one image appeared on each strip.

DC x-ray images of 1.5 mm period grid show individual images in focus over several mm.

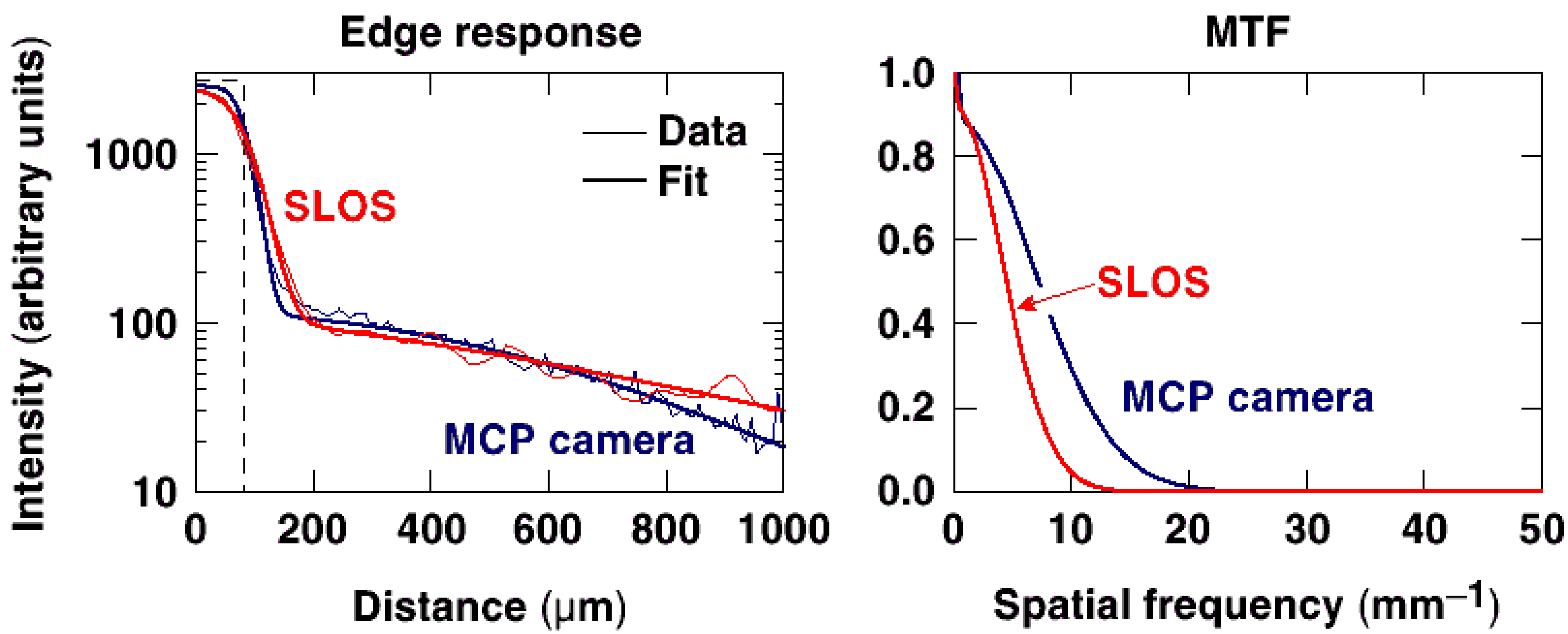


The camera has successfully produced four gated images using short pulse laser source.

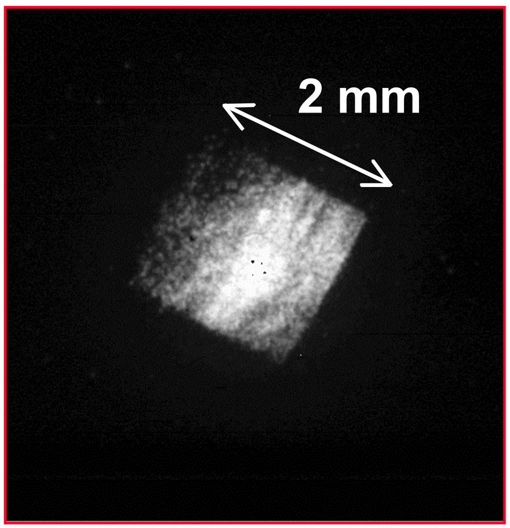
- Gate width is ~240 ps

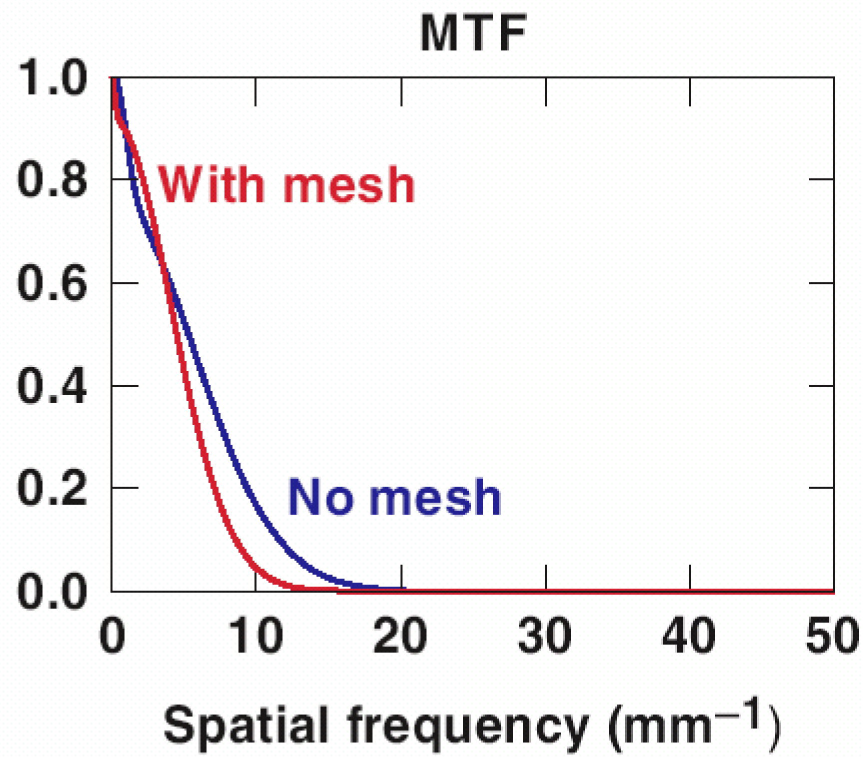
- 100fs 200 nm laser incident on 2mm square aperture on photocathode
- Strips were gated simultaneously in this image
- Structure from grounding mesh is very clear in images

Edge data from SLOS camera shows slightly worse resolution than traditional MCP camera.



Edge response from exposure without grounding mesh shows slightly better resolution.*





* camera was refocused before this data was taken