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Imaging Detectors for 20-100 keV X-ray Backlighters in HEDES Petawatt Experiments

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ABSTRACT

We are developing a petawatt laser for use as a high energy backlighter source in the 20 ~ 100 keV range. High energy x-ray backlighters will be essential for radiographing High-Energy-Density Experimental Science (HEDES) targets for NIF projects especially to probe implosions and high areal density planar samples. For these experiments we are employing two types of detectors: a columnar grown CsI scintillator coupled to a 2K x 2K CCD camera and a CdTe crystal with a special ASIC readout electronics in a 508 x 512 format array. We have characterized these sensors using radioactive sources. In addition, we utilized them to measure the Sm Kα source size generated by the short pulse laser, JanUSP, at LLNL. This paper will present the results of our characterizations of these detectors.

I. INTRODUCTION

Detectors capable of imaging in the 20 ~ 100 keV range will be essential for use in high-energy density experiments. X-ray radiography has been a valuable tool for inertial confinement fusion research (Ref 1). However, until now most experiments radiograph targets with <10 keV x-ray sources. As many NIF experiments require probing thicker and higher density targets, the need for 20~100 keV backlighter became essential. We are constructing the NIF petawatt laser to produce high energy x-rays. The characteristics of high energy Ka sources are presented elsewhere (Ref 2,3). In conjunction with laser construction, we are also developing imaging detectors that can be used for these experiments.

The medical imaging community has sustained a large development effort on hard x-ray imaging. Medical radiography applications require >50 keV x-ray sources and detectors. The imaging detectors in use today include large flat panel detectors, x-ray films, imaging plates, and CsI/CCD detectors. However, these detectors typically are tuned for large flux x-ray machines and the typical detector noise and spatial resolution is much larger than our requirements. The total number of photons from laser experiments are limited; we need low noise detectors for better signal to noise ratio imaging. The laser experiment targets are generally very small (>2 mm) so we need high spatial resolution detectors. We utilize commercial technology as much as we can while attempting to construct research grade detectors.

II. CSI/CCD CAMERA

***Assembly*:** We made a custom CsI camera that directly coupled to a backthinned CCD. We utilized an existing SI800 camera and hired Spectral Instruments to glue a Hammamatsu CsI scintillator screen directly onto the EEV42-40 2048 x 2048 backthinned CCD. For initial testing, we used a circular CsI screen (1” dia) to fit within the new EEV CCD because it was readily available commercially.

Figure 1 shows an image taken with the new SI800-CsI camera exposed to a Cd109 22 keV x-ray source for 60 sec. The area of the CsI screen and the bare CCD area is clearly distinguishable.

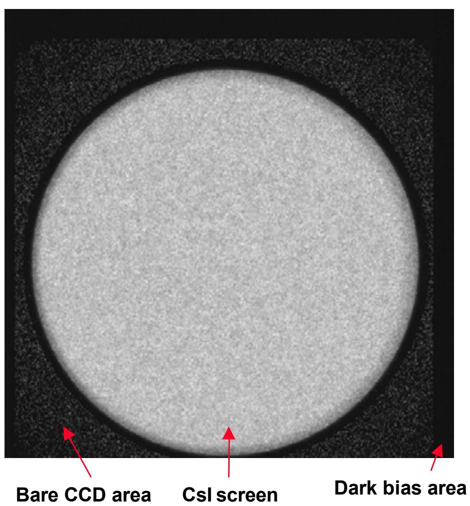

Figure 1. An image by the new SI800-CsI camera exposed 60 sec to the Cd109 22 keV x-ray source

Dark noise and Radiometric Sensitivity: Dark noise information is measured from the pixel ADU distribution from a difference image taken at 0 sec integration times. Figure 2 shows the dark noise distributions for this camera. In this figure, the 1-σ dark noise is 5.6 ADU’s. Dark current is the dark noise accumulation as a function of the CCD integration time. This is mainly caused by the thermal noise in the CCD. This new camera can be cooled down to –40°C; thus its dark current noise is very small. Figure 2 on the right panel shows the measured dark current for this camera; the slope is 0.0057±0.067 ADU’s/sec.

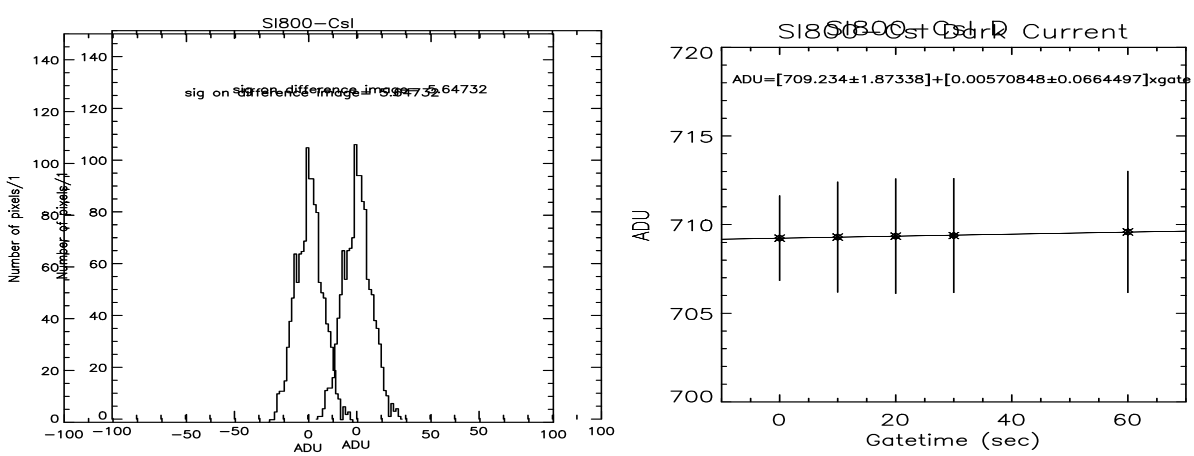

Figure 2. Left Panel: Pixel distribution of a difference image between two 0 sec dark exposures. The sigma of this histogram represents a measure of readout noise. Right Panel: Dark current measurement

The x-ray sensitivity, ADU's/x ray, is measured using a Cd109 source. Figure 3 shows the camera response as function of integration time to a Cd109 source placed 20 cm away from the CsI/CCD plane. From the fit, we calculate an ADU value of 255 for a 100 sec integration time. Knowing the strength of the Cd109 source (1.4 mCi), the number of x rays hitting one pixel (13.5 μm x 13.5 μm) is calculated to be 1.4 x rays. From this number we estimate the absolute x-ray response is 182 ADU's/x ray. The biggest uncertainty in this number comes from the following sources: 1) uncertainty in absolute source flux level (at least ±30%); 2) manual shuttering of the source by a hand-held Ta screen (at least ±10%); 3) uncertainty in the distance measurement between the source and the CsI/CCD plane (at least ±10%). The estimate of the overall error on this number is ±30%.

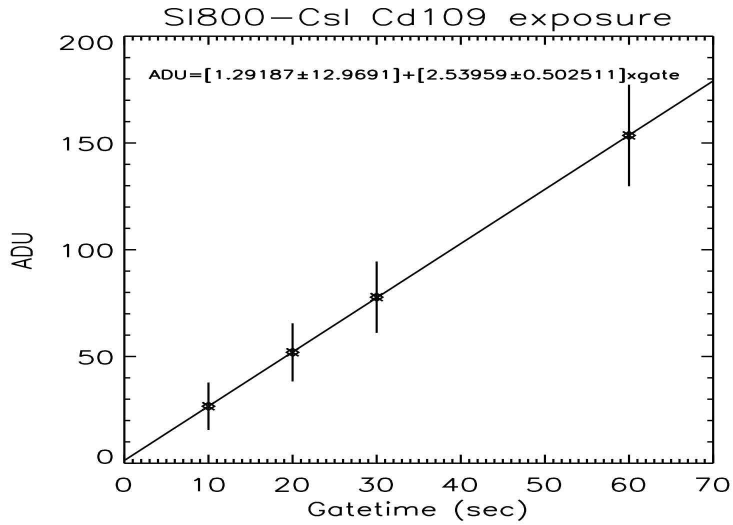

Figure 3. CsI/CCD response as function of gatetime to the Cd109 source at 20 cm away. From this measurement, the CsI x-ray response is 182 ADU's/x-ray.

Spatial Resolution: The spatial resolution of the CsI/CCD is measured again using the Cd109 source. Because the source strength is weak, we had to expose the camera for 10 minutes to accumulate enough photons to measure the resolution. The target is a resolution pattern made of 12 μm thick Au foil. Since the mean-free-path at 22 keV for Au is 8.5 μm, we expect 25% transmission through the foil side. The Fig 4 shows an image of this resolution pattern and the measured contrast function. With this columnal grown CsI scintillator we measure a spatial resolution better than 9 lpm at 50% contrast.

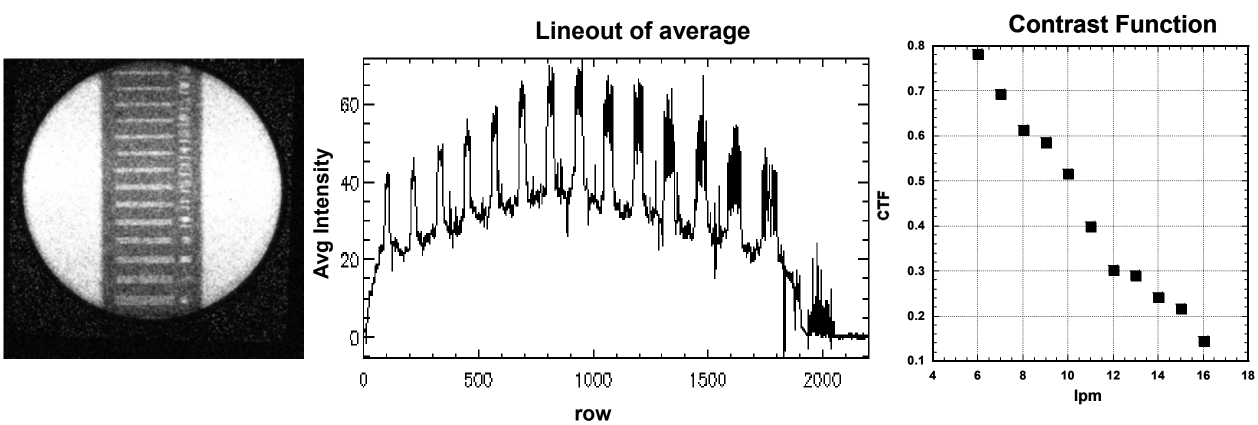

Fig 4. CsI/CCD spatial resolution measurement using Cd109 source and Au resolution pattern. We measure that the 50% contrast is approximately 9 lpm.

III. CdTe CAMERA

The second camera used in this experiment was a new CdTe device allowing direct detection of x-rays in the 20 to 100 keV range. The camera consists of 8 hybrids bump bonded to custom CMOS ASIC's. The camera consists of a 508 X 512 array of 100 μm^2 pixels, and can operate at up to 50 frames per second. For initial testing purpose, we procured a commercially available unit from Ajat Oy Ltd, Finland. Fig 5. shows an exploded view of this camera module. This detector runs at room temperature and is mainly used for medical imaging. Since most of medical imaging facilities have large-flux x-ray machines, this unit has low gain (14000 e^-s/ADU) with a 12 bit digitizer. The measured noise was 2~3 ADU's. With this noise level, it was difficult to utilize it as a single photon counting detector; but it was acceptable as an imaging detector. Since the direct detection of x-ray photons generally has much higher sensitivity and the robustness of CMOS electronics in high radiation environment is attractive, we plan to continuously work towards enhancing its performance to fit to our applications.

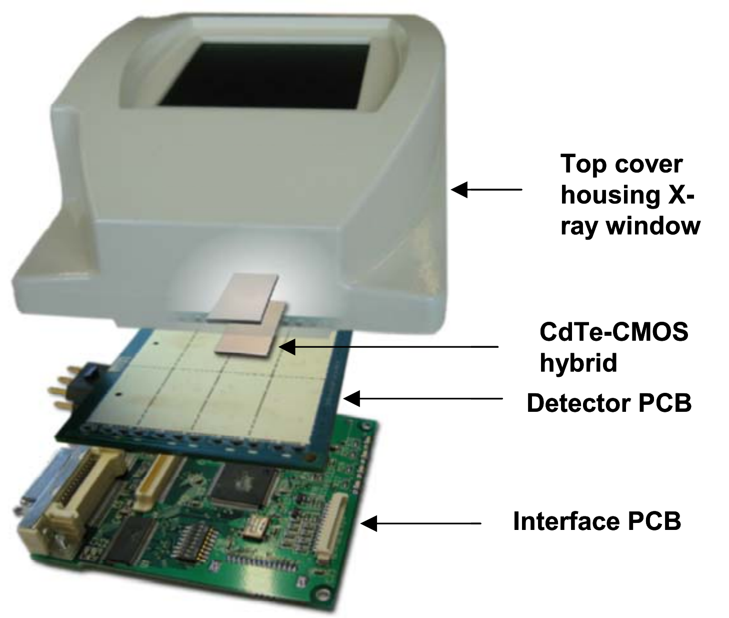

Fig 5. Unfolded view of DIC100T camera module

IV. HIGH ENERGY X-RAY SOURCE LASER EXPERIMENT

We utilized these detectors for a short pulse laser experiment at LLNL using the JanUSP laser. The goal of this experiment was to measure 40 keV Sm Kα source size from knife-edge images. Since our current experimental set-up cannot exclude the higher energy Bremsstrahlung background, the source we are measuring is a broad-band source. We used a 3 mm thick sharp edge Ta plate as the knife-edge. The experimental setup is show in Fig. 6. In the figure, d_{CdTe} and d_{CsI} are the distances from tantalum knife-edge to the CdTe and CsI cameras respectively. The geometry of the system was such that the CsI camera had a magnification of 4.5, and the CdTe camera had a magnification of 13.

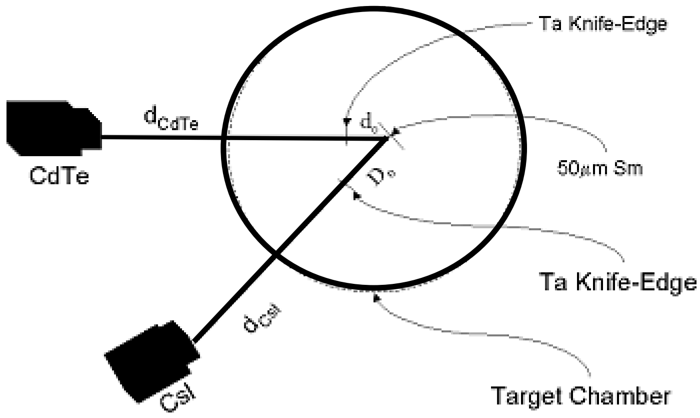

Fig. 6. CsI/CCD and CdTe detectors are utilized for an JanUSP laser experiment to measure Sm 40 keV Kα source size. dCdTe = 1m, do = 0.08 m, dcsI = 1m and do = 0.24 m producing mag(CdTe)=4.5 and mag(CdTe) = 13.

The resulting knife-edge images for both cameras are shown in Fig 7: The CdTe camera image on the left and CsI camera image on the right, respectively. The CsI/CCD camera image is noisier than the CdTe camera image because of its high magnification and smaller pixel size which result in a smaller number of the x-ray photons per pixel. Nonetheless, we can deduce the source size from the lineouts of the edge response, the resulting measured source size is ~60 µm.

V. CONCLUSION

Two types of imaging detectors have been fielded for high energy x-ray backlighter experiments. The CsI camera performed well, allowing a measurement of the Sm Kα source size. Calibration of the CsI camera has shown that it has low noise and good resolution. The new CdTe camera performed well, however some modifications to the camera will be necessary in order to meet the needs of future hard x-ray experiments. Modifications that are currently being pursued are a resolution to the horizontal MTF problem, and the addition of a cooling system to reduce the noise. Both cameras show considerable promise as diagnostic tools for future high energy x-ray backlighters for the NIF HEDES experiments.

VI. ACKNOWLEDGEMENT

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VI. REFRENCES

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3. Ka source paper - Park