Characterization of Mercuric Iodide Photoconductor for Radiographic and Fluoroscopic Imagers

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ABSTRACT

Photoconductive polycrystalline mercuric iodide deposited on flat panel thin film transistor (TFT) arrays is one of the best candidates for direct digital X-ray detectors for radiographic and fluoroscopic medical imaging.

The mercuric iodide is vacuum deposited by Physical Vapor Deposition (PVD). This deposition technology has been scaled up to the 20cmX25cm size required in common medical imaging applications. A TFT array with a pixel pitch of 127 microns is used for these imagers.

In addition to successful imager scale up, non-TFT based detectors were developed in order to improve analysis methods of the mercuric iodide photoconductor itself. These substrates consist of an array of palladium or ITO stripes on a glass substrate. Following deposit of the photoconductor, striped bias electrodes are deposited on top of the photoconductor at a 90 degree orientation to the bottom electrodes. These substrates provide more information than was previously available on the dark current and signal uniformity of the mercuric iodide photoconductor without the use of expensive TFT arrays. Mercuric iodide photoconductor thicknesses between 110 microns and 300 microns were tested with beam energy between 40 kVp and 120 kVp utilizing exposure ranges typical for both fluoroscopic and radiographic imaging.

Diagnostic quality radiographic and fluoroscopic images at up to 15 pulses per second were demonstrated. Resolution tests on resolution target phantoms were performed and performance close to the theoretical sinc function up to the Nyquist frequency of ~3.9 lp/mm is shown (127 micron pixel pitch).

Keywords: imaging, X-ray radiology, polycrystalline, mercuric iodide, imaging detectors, Flat-Panel imaging arrays.

1. INTRODUCTION

Direct detector materials must exhibit several attributes including high x-ray absorption, high charge collection efficiency, low dark current and good uniformity. These are difficult to achieve in a single material. Nevertheless because blurring due to spreading of light is eliminated, higher resolutions are possible with direct detectors than with detectors utilizing phosphor coatings.

Polycrystalline semiconductor HgI_2 films directly convert X-rays into electrical signals with high efficiency. This is due to the material's high atomic number, low energy requirement for generation of electron-hole pairs and the high mobility-lifetime product (μ-τ) of the charge carriers. The advantages of this photoconductor layer for digital radiography X-ray detectors have been demonstrated in previous papers[1-13].

This paper describes measurements performed on a specialized ITO electrode test array and on high-resolution image sensors using HgI_2 photoconducting layers in the direct detection mode of operation.

2. SAMPLE PREPARATION

2.1 Photoconductor Deposition

HgI_2 material deposition technique on small area substrates has been published earlier[1]. A full-scale 20x25cm imager has also been manufactured using mercuric iodide photoconductor layer[14]. Manufacture of such imagers required scale-up of the small reactors that have been used until now for production of 5cm x 5cm and 10cm x 10cm imagers. The substrates of the larger imagers are TFT arrays with 127μm x 127μm pixel size, 10cm x 10cm (768x768 pixels) and 20cm x 25cm (1536x1920 pixels) active area.

The reactor for mercuric iodide deposition is based upon a 14" (36cm) diameter glass reactor for smaller arrays and a 25" (63cm) diameter stainless steel vacuum vessel for large arrays. Highly purified mercuric iodide powder is loaded into evaporators in the base of the reactor. The TFT array is suspended over the evaporators. By proper choice of evaporator temperature and array temperature, a highly oriented (c-axis) and dense layer of polycrystalline mercuric iodide is deposited on the TFT array. These reactors have been used to deposit polycrystalline mercuric iodide layers in a thickness range of 40μm to 500μm.

After deposition of the mercuric iodide photoconductor, a bias electrode is deposited on top of the film followed by a polymer encapsulation layer.

3. EXPERIMENTAL RESULTS ON NON-TFT BASED PHOTOCONDUCTOR SAMPLES

3.1 Striped Electrode Detector

Measurements on mercuric iodide photoconductor were performed using a 69 x 4 electrode array on a 10cm x 10cm substrate (total of 276 measurement points). The array is formed by ITO stripes on the glass substrate, upon which the mercuric iodide is deposited, and then palladium stripes that are deposited on top of the mercuric iodide layer. These two sets of electrodes are oriented at 90 degrees to each other to create the measurement matrix. The design is similar to a palladium stripe electrode detector reported in Reference 14, but this design uses narrower electrodes (1.25mm) and smaller spacing between electrodes (20μ) compared to the earlier palladium striped electrode detector.

Figures 1 and 2 present typical photoconductor dark current results obtained using this characterization technique. Significant data on dark current and signal uniformity is obtained by this technique, without the need to use expensive TFT arrays for basic photoconductor characterization. The dark current looks uniform over the whole area within +-7% (relative standard deviation). Exclusion of the substrate edge (5mm) shows even better uniformity of +-4.5%.

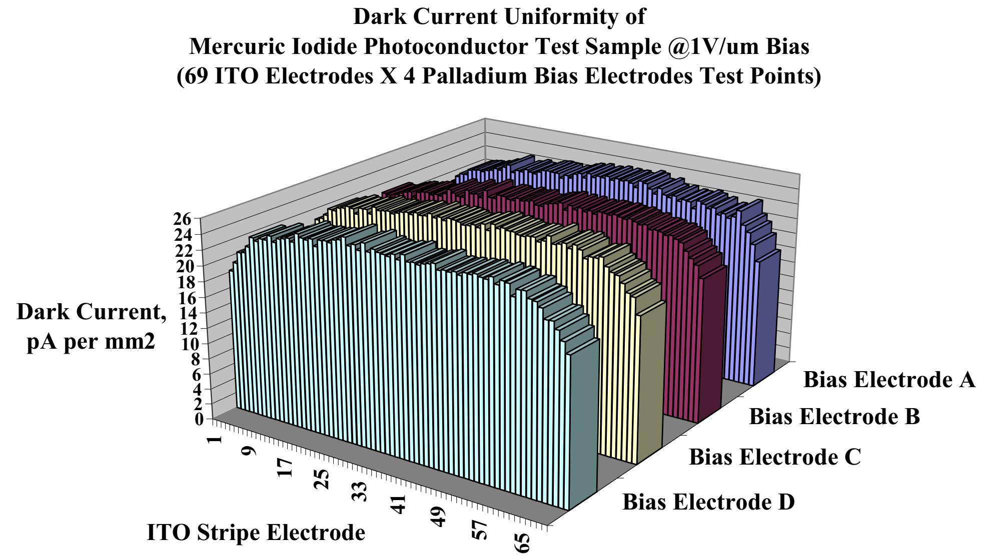

Figure 1: Dark Current uniformity of a mercuric iodide detector composed of ITO stripe electrodes. 1.0V/μ Bias on a 305μ thick photoconductor layer. Measurement at 25°C.

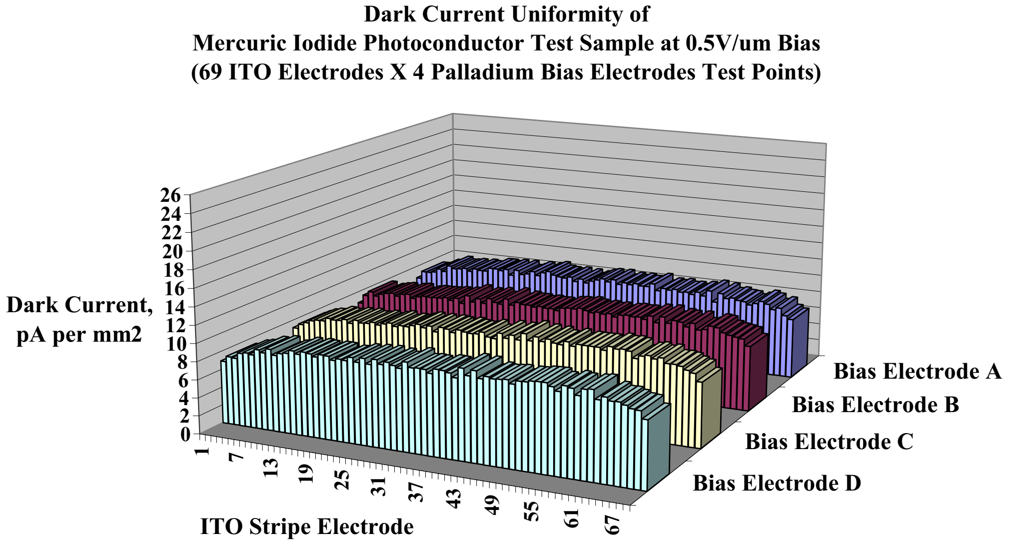

Figure 2: Dark Current uniformity of a mercuric iodide detector composed of ITO stripe electrodes. 0.5V/μ Bias on a 305μ thick photoconductor layer. Measurement at 25°C.

The striped electrode detector also provides significant data on temporal characteristics of the response of mercuric iodide photoconductor to X-ray exposure. Figure 3 shows polarization characteristics of the photocurrent when the photoconductor is biased at 0.5V/μm. However, when biased at 1.5V/μm, the photocurrent is very stable after the first 0.1 second of X-ray turn-on (see Figure 4). Radiographic X-ray exposure conditions are 29.73 mR during 5 seconds at 70kVp with 21mm of added aluminum filtration.

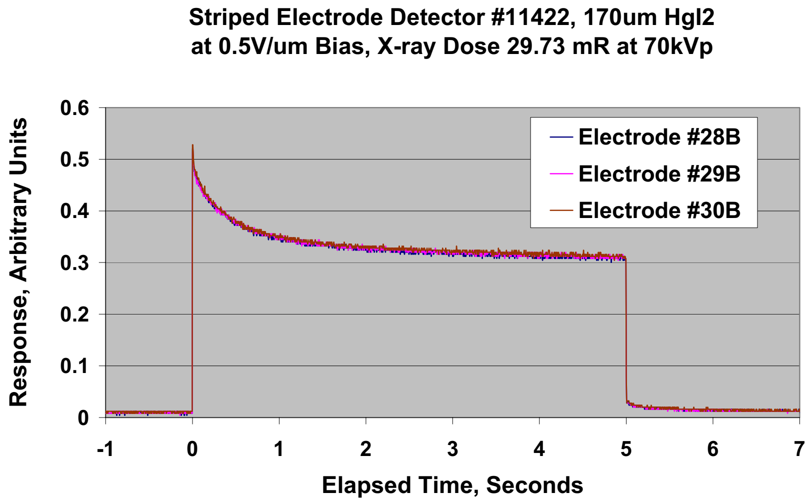

Figure 3: X-ray Response of HgI_2 Photoconductor under low bias showing polarization. X-ray conditions – 29.73 mR at 70kVp with 21 mm added aluminum filtration.

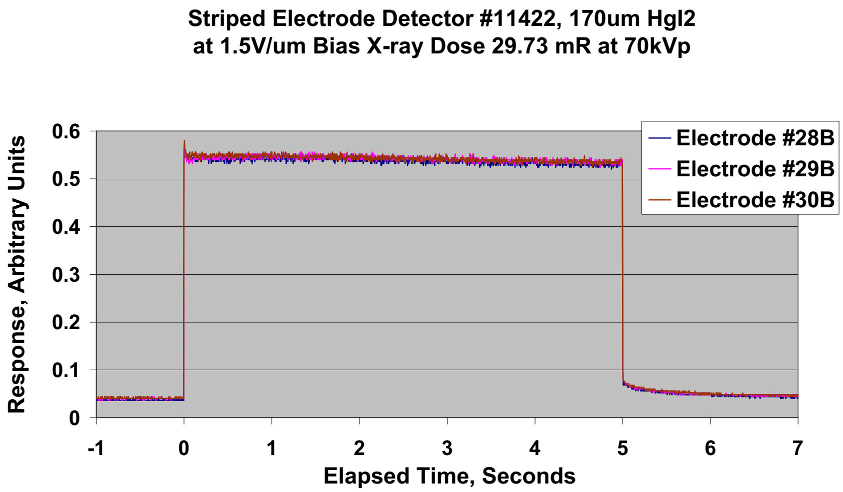

Figure 4: X-ray Response of HgI_2 Photoconductor under appropriate bias showing a stable response. X-ray conditions – 29.73 mR at 70kVp with 21 mm added Al filtration**.**

Sensitivity of this striped electrode detector was also evaluated as a function of X-ray energy (kVp). A bias field of 2.0V/μ was used to minimize polarization of the response over the 5-second radiographic exposure time, although it is noted that polarization does somewhat increase with increasing kVp even at this bias. Over the kVp range of 70kVp to 120kVp (added filtration of 21mm aluminum) and X-ray exposure of about 125 mR, sensitivity was found to moderately vary from 15.0μC/R/cm^2 to 12.4μC/R/cm^2, respectively. Variation of sensitivity as a function of X-ray energy would probably be even further reduced by use of greater photoconductor thickness, providing increased X-ray absorption at high kVp, and by use of higher bias to fully eliminate polarization.

Sensitivity of the striped electrode detector was then evaluated at a much lower X-ray dose rate, as shown in Figure 5. Polarization effects were decreased at this much lower dose rate. The variation in sensitivity as a function of X-ray kVp is further reduced compared to the high exposure test previously mentioned (125mR during 5-seconds), even when the bias is only 85V (0.5V/μ field).

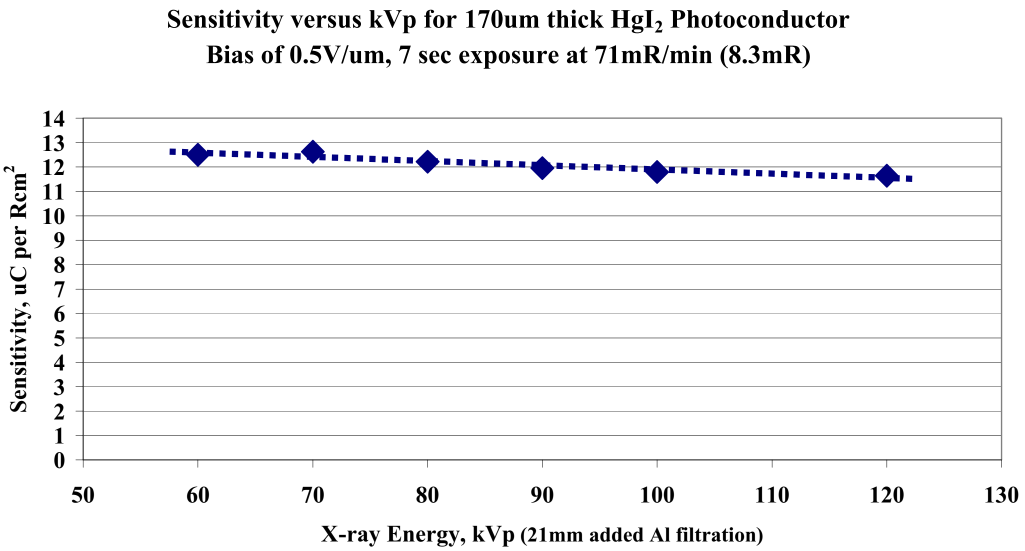

Figure 5: HgI_2 photoconductor sensitivity as a function of X-ray kVp at a 71mR/min exposure rate (7-sec exposure).

Response linearity of this detector was then further evaluated at low exposure rates using 70kVp tube voltage and 21mm added aluminum filter. Linearity is shown to be good as seen in Figure 6.

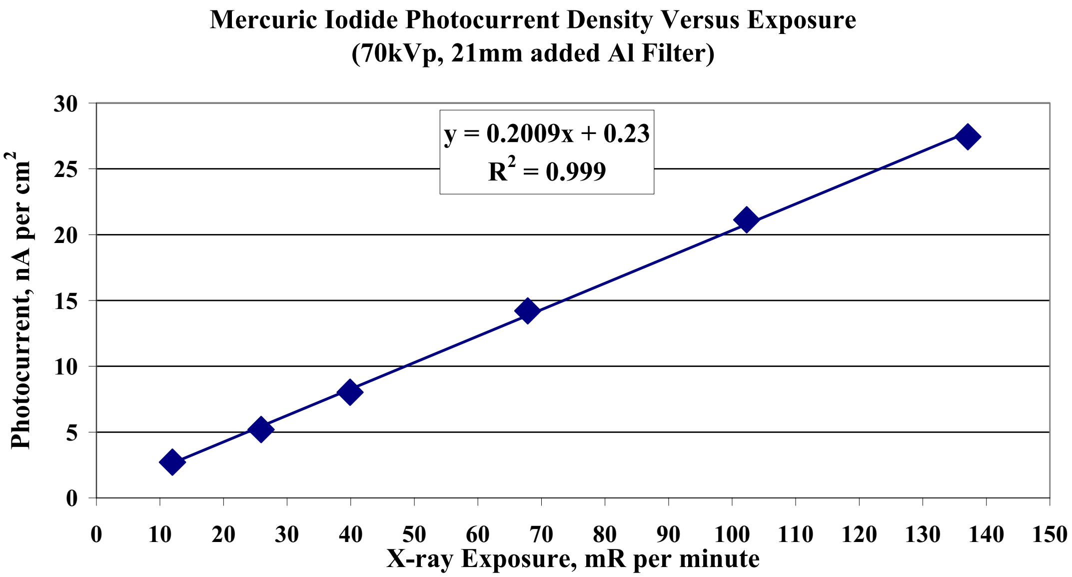

Figure 6: Response Linearity of 170μ thick HgI_2 Photoconductor with 1V/μ bias at 70kVp X-ray energy

In order to evaluate detector linearity at even lower exposures, it was necessary to cool the detector to 10°C. This reduced dark current by a factor of ~6 compared to operation at room temperature (~25°C). The lower dark current allowed very low photocurrents to be detected. Since it is not possible to reduce X-ray tube current below 0.5mA on our system, X-ray exposure was further reduced by adding 1 mm of copper filter to the 21 mm aluminum filter used in previous tests. Figure 7 shows that a good linear response was also obtained for these very low exposure rates.

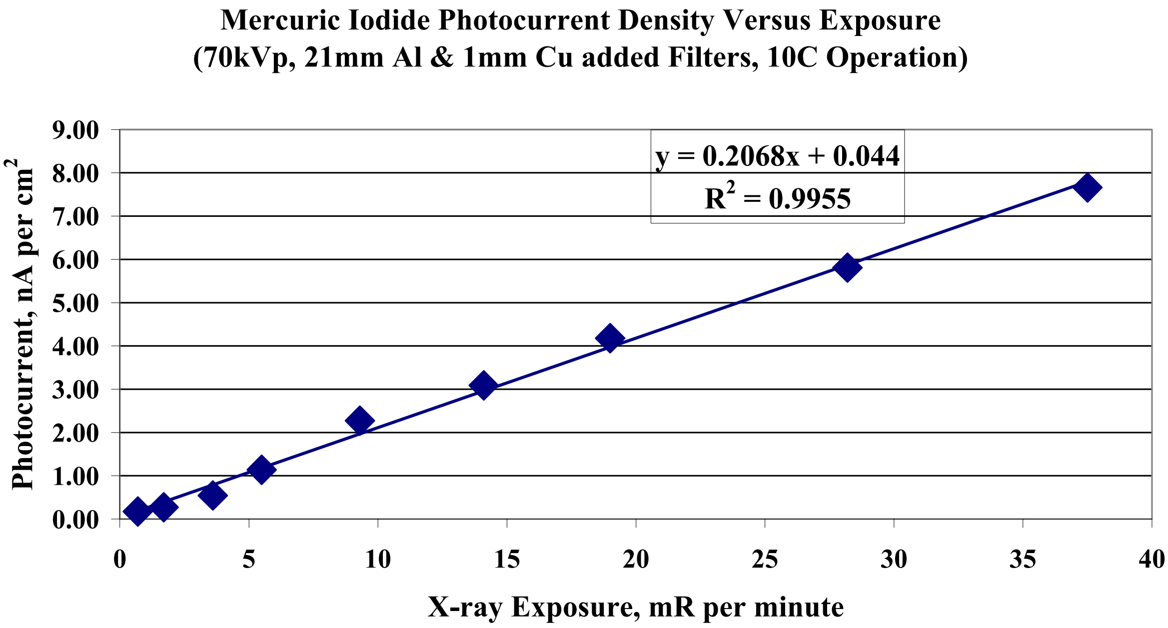

Figure 7: Response Linearity of 170µ thick HgI_2 Photoconductor with 1V/µ bias at very low X-ray exposure.

4. CHARACTERIZATION OF HgI_2 IMAGERS

The X-ray response uniformity and linearity were measured for HgI_2 X-ray imagers that are based upon TFT arrays. Imaging resolution was evaluated imaging a resolution test pattern. The measurements were made at 60kVp x-ray energy with 0.1mm Cu filtering. The imagers were tested in continuous fluoroscopic mode at 15fr/s frame rate.

4.1 Homogeneity of the Sensitivity

The pixel-to-pixel uniformity of the sensitivity was measured for imagers with various photoconductor thickness and X-ray energy (kVp). This study was done using 10cm x 10cm imagers. The values plotted are the standard deviation of the sensitivity relative to the average sensitivity (relative standard deviation of sensitivity). Figure 8 shows that a sensitivity variation of less than 12% is maintained over a large range of bias field for HgI_2 photoconductors of thicknesses 110µ and 250µ. Figure 9 shows that there is almost no effect of X-ray energy (40kVp and 60kVp) on the variation of sensitivity over the imager.

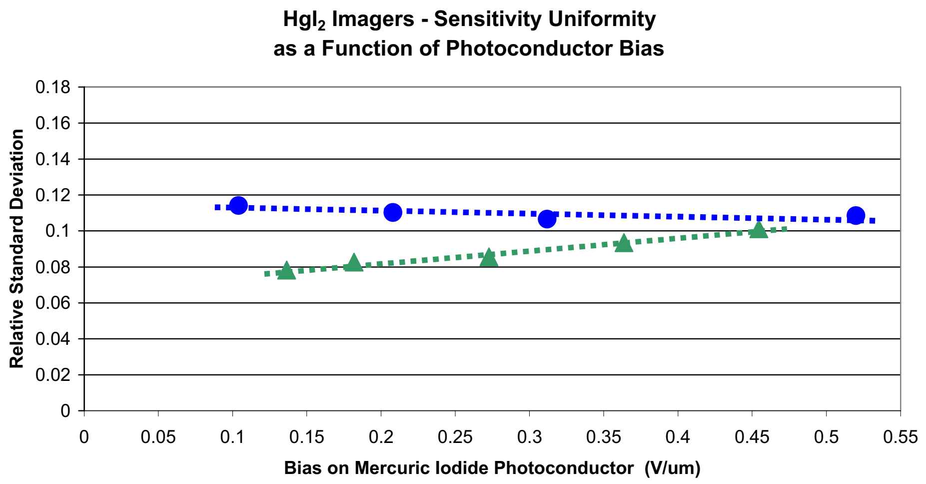

Fig. 8. Pixel to pixel of uniformity for two HgI_2 Imagers (10cmx10cm; 127µ pixel), 60kVp.Triangles – Imager with 110µ of HgI_2; Circles - Imager with 250µ of HgI_2

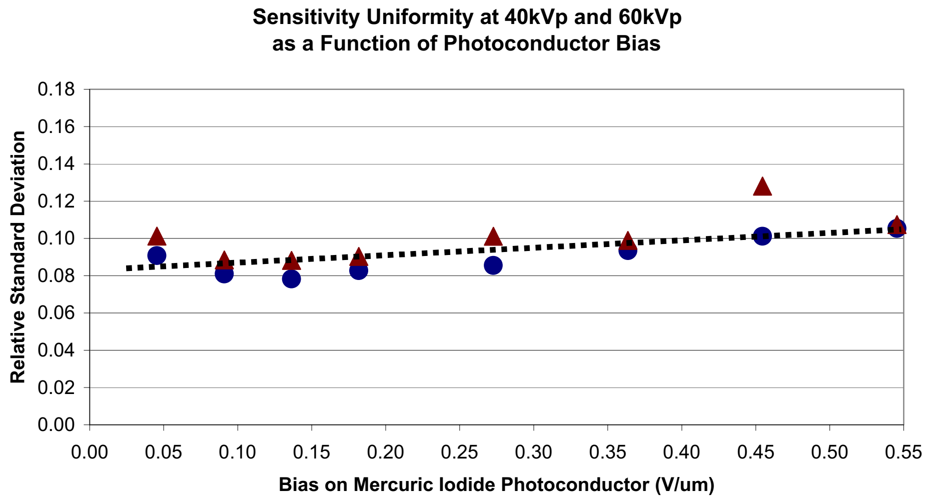

Fig. 9. Pixel to pixel uniformity of sensitivity for a HgI_2 Imager (10cm x 10cm; 127µ pixel; 110µ HgI_2 thickness) at 40kVp (triangles) and 60kVp (circles) X-ray tube voltage, 0.1mm Cu filter.

4.2 Imager Linearity

The linearity of a mercuric iodide imager was evaluated as a function of X-ray dose rate in fluoroscopic mode of operation (15 frames/second). These data were obtained on a 10cm x 10cm imager with 110µ of HgI_2 photoconductor. Exposure energy was 60kVp with 0.1mm added copper filtration. Excellent linearity was found over the entire range of 29mR/min to 601mR/min exposure intensity (Figure 10).

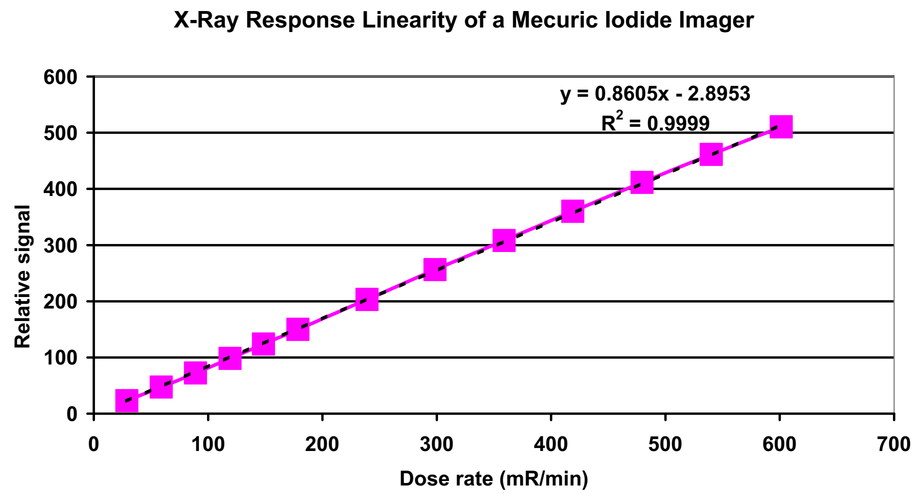

Fig. 10. X-Ray Response Linearity of a 10cm x 10cm Mercuric Iodide Imager with 110μ of HgI_2 photoconductor. X-ray Exposure Conditions - 60kVp with 0.1mm added copper filtration.

4.3 Imaging with Mercuric Iodide Arrays

The good uniformity and stable signal response achieved with polycrystalline HgI_2 layers allow excellent resolution to be achieved with mercuric iodide imagers. Figure 11 presents a lead resolution pattern imaged by 110μ thick HgI_2 photoconductor on a 127μ pixel array. Fluoroscopic exposure conditions are 60kVp with 0.1mm added copper filtration and exposure rate of 750mR/min. Readout rate is 15frames/second and bias on the photoconductor is 15V (0.14V/μ). Resolution is achieved up to the 3.93 line-pair/mm Nyquist frequency limit of the 127μ pixel size.

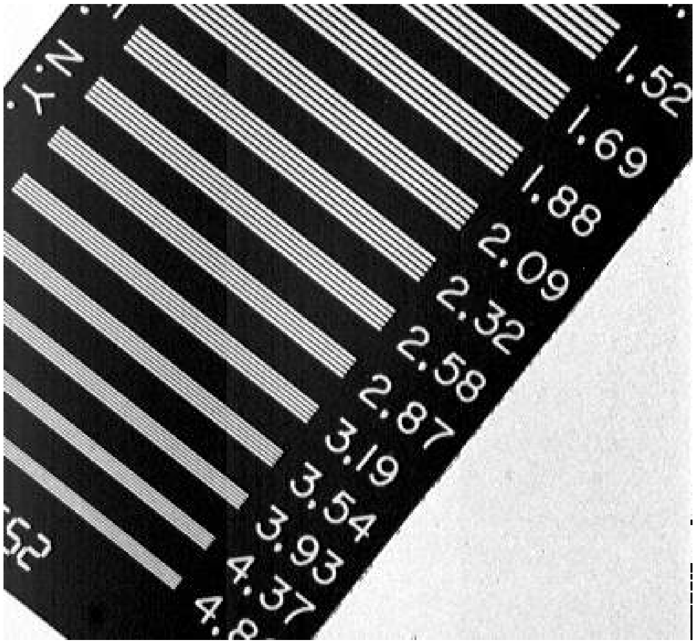

Fig. 11. Resolution pattern image taken by 10 cm x 10 cm imager with 110μ HgI_2 photoconductor

5. SUMMARY

Data were presented of measurements performed on mercuric iodide photoconductor detectors based upon striped electrodes (non-TFT) and upon TFT arrays (imagers). Both radiographic and fluoroscopic were used in these evaluations. Polycrystalline mercuric iodide photoconductor is shown to exhibit uniform, high sensitivity to X-rays, linearity and excellent spatial resolution.

6. ACKNOWLEDGEMENTS

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