

THICK FILMS OF POLYCRYSTALLINE MERCURY IODIDE DETECTORS

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Polycrystalline HgI₂ thick film detectors are among the leading semiconductor materials to be used as direct converters in X-ray digital radiography. Their properties along with a survey of the properties of alternative materials such as PbI₂ and A-Se will also be given. The preparation of HgI₂ detector plates, using direct sublimation will be described. The microstructure of the thick films showing a columnar morphology, as determined by SEM measurements will be shown. The X-ray response to radiological X-ray generators of 60 and 80 kVp using the current integration mode will be reported. Finally some actual X-ray images taken at Xerox-Parc using HgI₂ polycrystalline detectors will be shown.

Keywords: HgI₂ detectors, Thick films, Semiconductors, Polycrystalline, X-ray digital radiography

1. Introduction

Polycrystalline HgI₂ thick film detectors are one of the promising candidate semiconductor materials to be used as direct converters in X-ray digital radiography. The detection capability of polycrystalline HgI₂ has been studied and reported, in particular one of the methods of preparation: the screen print (SP) technology [1-11]. The SP method in the current integration mode gives reduced sensitivity but has a much lower dark current. Much greater sensitivity can be obtained for X-ray imaging by using detectors produced by direct physical vapor deposition (PVD). Some of the first results were published recently comparing single crystals of HgI₂ with the polycrystalline PVD-HgI₂ [12,13].

2. Detector material deposition

Due to the low deposition temperature of less than 100°C, any ASIC substrate containing bottom pixel electrodes can be used, provided it has non-reacting electrodes, such as In-Sn-Oxide (ITO), gold, platinum, palladium, chromium or nickel. If other electrodes such as Ti-W alloys are used, an intermediate passivation layer must be used to prevent a chemical reaction with the detector plate.

Our present results deal with two kinds of cases: 1) polycrystalline HgI₂ acting as the photoconductor material, is evaporated on a-Si direct conversion X-ray image sensors, produced by Xerox-Palo Alto Research Center. 2) Glass substrates having an area of up to 5x5 cm² on which were predeposited continuous gold or ITO electrodes and on which polycrystalline HgI₂ is deposited, acting as the photoconductor material.. If we use a polymer layer which acts as a dielectric capacitor which can store charges then some polarization problems do occur. we studied the gold or ITO electrode samples, both with and without the polymer layer. The samples were prepared in a deposition system similar to the one published earlier [12-13].

Typical growth rate of the poly-HgI₂ layers is 200 to 1000 μm/h. Thickness can be controlled accordingly and films of 20-500μm were fabricated. Very high uniformity of the layer thickness over the entire substrate surface was achieved. The common range of layer thickness we tried to obtain was 100 to 200 μm with a deviation which did not exceed ±5 μm, and in some cases was only ±2-3 μm. Measurements of the layer thickness and grain size were carried out by optical microscopy with accuracy of 2-3 μm. Fig. 1 shows typical cross-sectional SEM micrograph on a polycrystalline layer. The layer exhibits a columnar type morphology with mean grain size of 20μm by 60μm by 150μm on the X, Y and Z-axis respectively. It was found that such columnar layers had a higher sensitivity as well as a much lower leakage current.

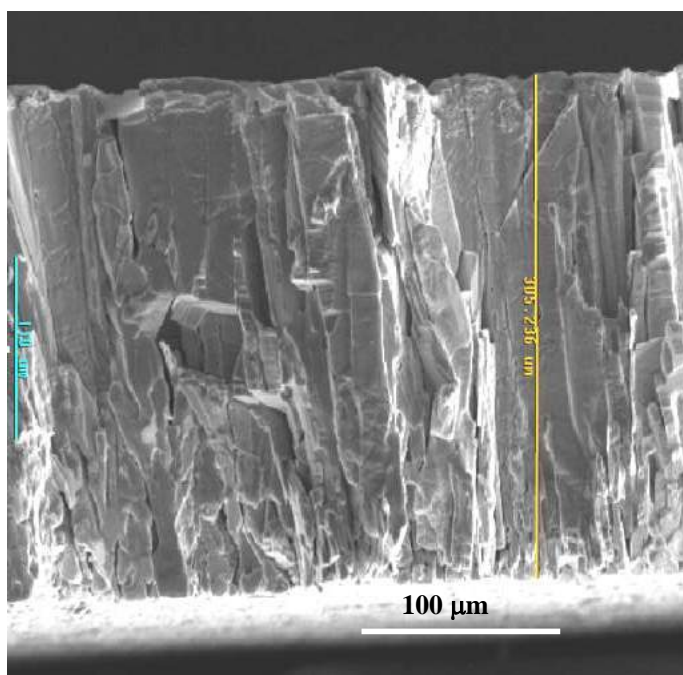


Fig. 1. Cross-sectional Scanning Electron Microscope picture of Polycrystalline HgI₂ layer.

One can also see that the columnar morphology has a pronounced orientation of the crystals with C axis perpendicular to the substrate. It was confirmed by the X-ray diffraction method and it was determined that more than 50% of the crystallites grow perpendicularly to the C axis. After deposition of the thick film of HgI₂ on the substrate, we proceeded to cover this film with a conductive electrode. The upper contacts were deposited by direct evaporation of gold or palladium.

3. X-Ray sensitivity measurements

The X-ray sensitivity experimental setup consists of a lead shielded test box and a dental X-ray generator, tubes biased at 65 and 85 kVp. For data acquisition we have used TEKTRONIX TDS 220 digital oscilloscope to acquire the 50 Hz X-ray pulses readout. For real-time calibration of the X-ray output, an a-Si p-i-n detector was used in parallel with the HgI₂ sample measured. Exposure time for each test was limited to a period of 4 seconds; the distance between X-ray source and sample was set to 30 cm in most cases. Since temperature is a factor in the amount of dark current produced, the box had to be temperature regulated to 25°C. The test box and the sample holder have three directional moving capabilities. A pinhole collimator has also been used in order to spatially map the HgI₂ film. The I-V characteristic of the HgI₂ films has been measured by using a Keithley 485 picoammeter.

4. Polarization studies

Polarization can be defined as the onset of an opposing electrical field due to trapping and release of electrical charges, which practically diminish the outside applied electrical field, causing a diminishing of the signal created by X-ray radiation. Since we used a dielectric passivation layer on top of the Ti-W alloy pixel detectors to protect it from reacting with HgI₂, we wanted to see its influence on signal decay. We used two methods to study the signal decay during switch off period: Irradiation by light and irradiation by X-rays (85 kVp 50Hz). Light pulses were generated with a chopper rotating in front of the light radiation source, which exposes the polycrystalline HgI₂ detector to 30-500 ms light pulses and with 10% of dark periods. The results are shown in Figs 2 and 3 respectively. One can see that in Fig. 2 the detector having no polymer shows a signal decay of only 5% at 30 ms, i.e., the residual signal is 95% from its original value. This was synchronized with a silicon detector for reference shown in the lower curve of the inset. The lag shows the appearance of the signal in subsequent periods after X-ray exposure. Clearly, the lag with polymer as shown in Fig. 3, is larger than without the polymer. Use of a polymer layer requires operating the detector at a higher bias in order to obtain similar sensitivity. The results of exposures to X-rays are shown in Fig. 4 and will be discussed next section.

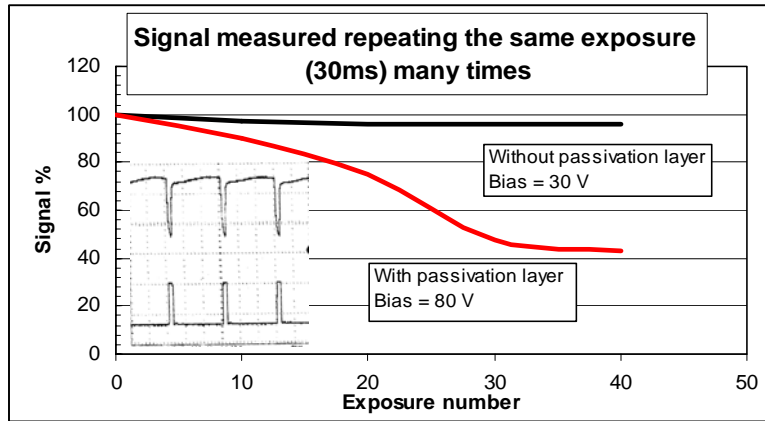


Fig. 2. Decay of the electrical response of poly-HgI₂ with and without passivation layer at 30 frames/sec light irradiation. The inset on the left side shows the actual response of Poly HgI₂ without passivation (upper waveform) and Si photodiode as reference (lower) to the light pulses, pulse: interval ratio is 10:1.

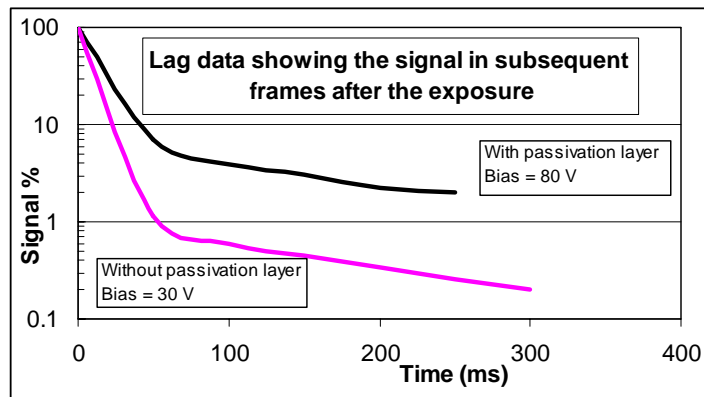


Fig. 3. Image lag data of Polycrystalline-HgI₂ with and without passivation layer.

5. Dark current and sensitivity studies

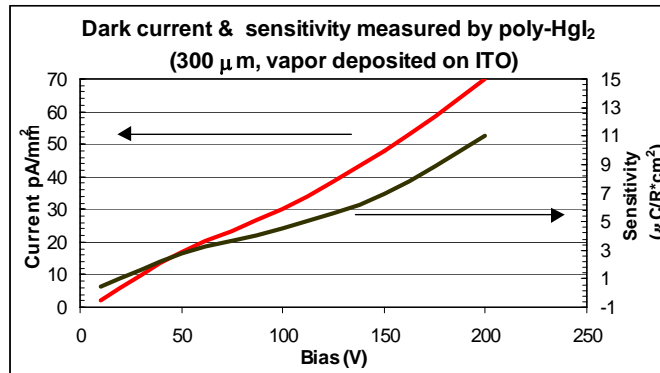


Fig. 4. Dark current and sensitivity measured by poly-HgI₂ without passivation layer.

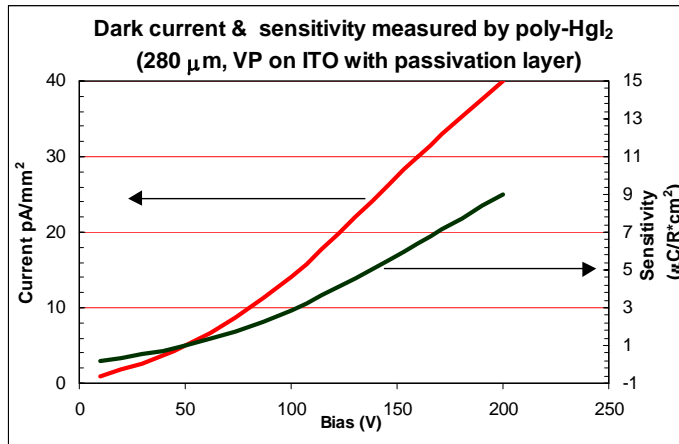


Fig. 5. Dark current and sensitivity measured by poly-HgI₂ with 1 μm passivation layer.

Figs. 4 and 5 compare two similar polycrystalline detectors with ITO electrodes, where one has passivation layer on the ITO. Note that dark current is significantly reduced on the film protected with the passivation layer, however the sensitivity does not change significantly especially at higher bias.

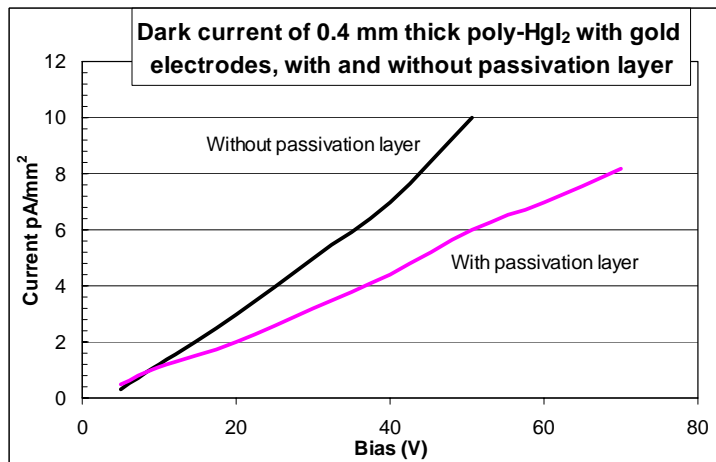


Fig. 6. Dark current measured on poly-HgI₂ deposited on gold electrodes. One sample was also deposited with a passivation layer.

In order to check the influence of the passivation layer, two gold electrode detectors with and without polymer passivation layers were investigated. Fig. 6 shows the dependence of HgI_2 dark current. It can be seen that use of a polymer layer decreases the dark current. A detector containing gold electrodes was also checked for long-range stability of the sensitivity and dark current. Fig. 7 shows that sensitivity is practically unchanged after seven months-- approximately $17\text{--}18 \mu\text{C/R}\cdot\text{cm}^2$. The dark current shows a good stability around 20 pA/mm^2 , as also shown in Fig. 7.

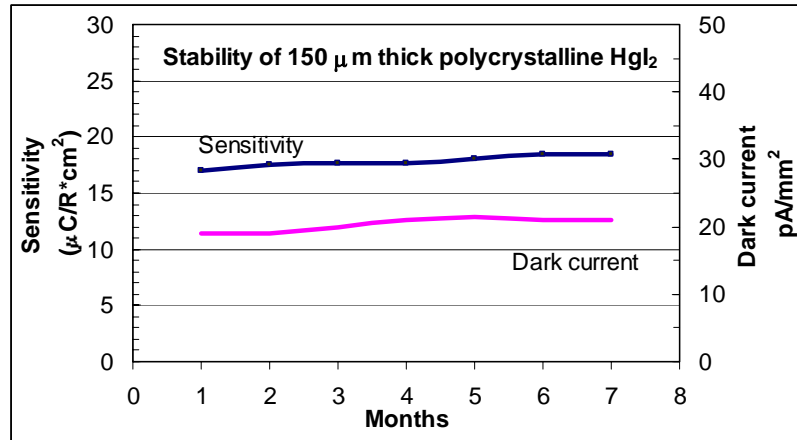


Fig. 7. Long term stability of polycrystalline- HgI_2 detector for dark current (right) and sensitivity (left).

6. Conclusions

The paper presents direct conversion X-ray images obtained with thick films of HgI_2 . The sensitivity has proven to be very high relative to other direct conversion X-ray detectors as shown in Fig.8, giving HgI_2 the highest value compared to published data on competing materials [15-18], demonstrating its great potential for radiological and fluoroscopy applications. As previously indicated, the image lag is not significant and efforts are being made to improve the results. It is shown here, that by adding a passivation layer, HgI_2 film can be deposited on top of the metallic pixel electrodes and bus lines without fear of corrosion by the HgI_2 , the passivation layer also enabled us to improve significantly the signal to noise ratio of poly- HgI_2 detectors.

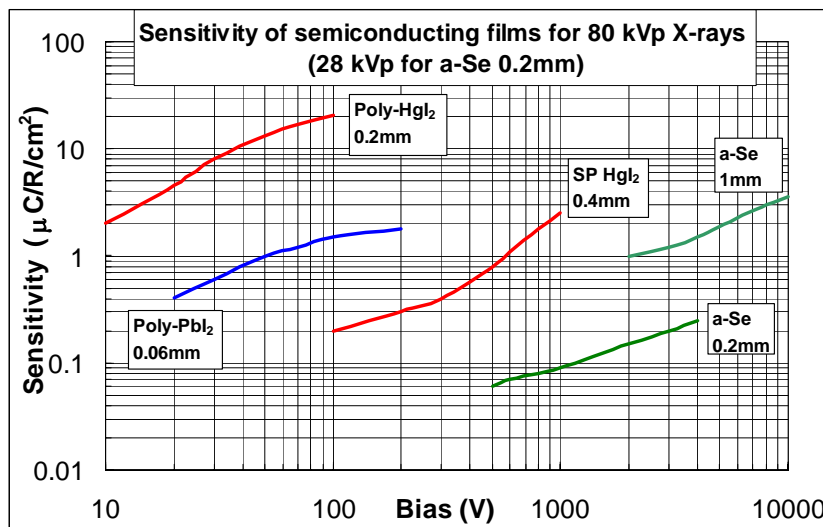


Fig. 8. Comparison of the sensitivity of PVD poly- HgI_2 and SP HgI_2 as compared to other semiconductor materials.

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