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Section 6b. MATERIALS WITH TARGETED APPLICATIONS
Plenary Lecture

ADVANCES IN PHYSICAL VAPOR DEPOSITED POLYCRYSTALLINE-HgI_2 X-RAY IMAGING DETECTORS

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Physical Vapor Deposition deposited on A-Si TFT arrays, used for large area X-ray imaging detectors, reports improved properties for polycrystalline films of HgI_2. X-ray diffraction shows 100% c-Axis orientation of the polycrystalline films. The electrical charge transport properties were found to be similar to those of single crystals. Transient charge transport (TCT) with alpha particles measurements was used to evaluate the mobility, the trapping time and the surface recombination velocity of the samples. Typical Electron-, and hole mobility of high quality polycrystalline HgI_2 were $\mu_n = 88\,cm^2/V\cdot s$ and $\mu_p = 4.1\ cm^2/V\cdot s$, respectively. Trapping times were $\tau_n \cong 18\,\mu s$ and $\tau_p \cong 3.5\,\mu s$, and surface recombination velocities $s_n \cong 1.4\times10^5$ cm/s and $s_p \cong 3.7\times10^3$ cm/s. Bulk trapping-times and surface recombination velocities appear of the same order of magnitude as in the single crystal. The performances of these detectors as spectrometers in standard nuclear spectroscopy system were evaluated. We used a gamma source of ^{241}Am with a characteristic 59.6 keV gamma emission. The FWHM of the detector peaks depends on its charge transport properties. High quality polycrystalline HgI_2 detector gives a photo peak with FWHM = 70 keV, while lower quality polycrystalline HgI_2 detector doesn't give a photo peak at all.

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1. Introduction

Thick film polycrystalline HgI_2 is most promising as a direct photoconducting converter in x-ray digital radiography. It exhibits the highest x-ray sensitivity among the known polycrystalline or amorphous materials [1]. Physical vapor deposition (PVD) has been used [2] for preparation of these films. Description of preparation methods, characterization of detection capability, and first imaging results, were recently published [3]. The sensitivity and charge transport properties of PVD polycrystalline x-ray detectors are somewhat inferior to those of the single crystal [4]. Grain boundaries in the polycrystalline material are expected to be electrically active [5], for example by creating trapping levels within the forbidden gap. Their disturbance to charge collection includes the introduction of potential barriers between neighboring grains [6,7] and [8] and of electron-hole recombination and trapping centers.

The present work reviews the correlation between the transient charge transport properties using the transient charge technique (TCT), as described in references [8-10] and [11] and the quality of polycrystalline mercuric iodide layers prepared for x-ray detectors. We previously attempted the method on a single crystal, revealing, however, a new effect: the delayed emission of carriers initially generated in near-surface traps [8]. A similar effect was obtained for the polycrystalline layers.

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2. Experimetal procedure

The measured samples of the films of polycrystalline HgI_2 were prepared using the Physical Vapor Deposition, PVD, as described elsewhere [7]. The substrates were glass slides coated with ITO electrodes. After deposition the samples of polycrystalline HgI_2 films were covered with Aquadag, colloidal graphite electrodes with Pt wires attached to the bottom ITO and top Aquadag electrodes. The TCT method for the charge transport properties measurement, involved, the use of only a portion of the sample, thin ($\sim 1\mu m$), semitransparent layer of colloidal graphite (Aquadag by Acheson) painted as a front electrode, approximately $10\ mm^2$ in area. The radiation source was ^{241}Am alpha particles ($5.5\ MeV$), which induce near-surface carrier-generation events. A collimator of approximately $1\ mm^2$ in area in front of the detector served to limit the alpha incidence rate to less than $\sim 1{,}000$ per second. The alpha source was mounted at approximately $1.5\ mm$ distance from the front detector electrode.

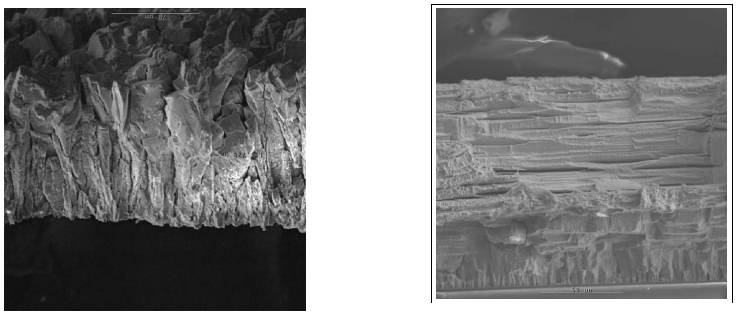

Fig. 1. SEM picture of a bad (left) and good (right) structured Poly- HgI_2 detector.

The set-up and typical electrical scheme for the transient voltage measurement is described elsewhere [11]. The high voltage across the detector was provided by a 240A type KEITHLEY power supply. The detector was shunted with a series resistance of the order of $100-1{,}000\ M\Omega$, depending on the long time-scale needed for measurement. Voltage signals across this resistor follow the alpha particle absorption. They are fed into the input of a source-follower preamplifier of approximately unity amplification, which serves for impedance matching, then into a Tektronix TDS210 digital oscilloscope. The time resolution exhibited by the circuitry at point B was approximately $0.02\ \mu s$. For low voltage bias, further pre-amplification was required, however at the cost of reduced time resolution. Pulse shapes were digitally recorded by a desktop personal computer, and displayed on the screen with the aid of WAVE-STAR software.

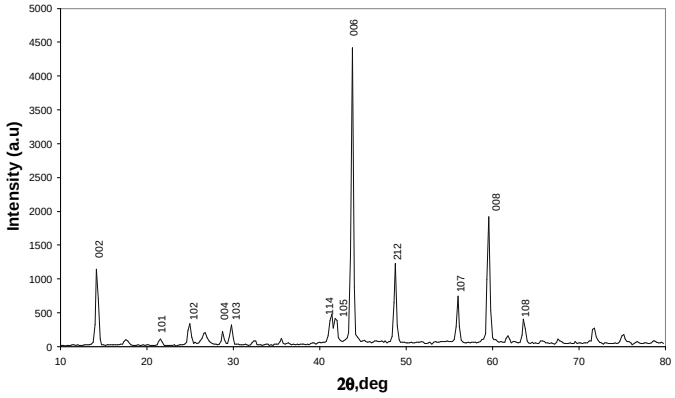

Fig. 2. XRD spectrum of a bad structured Poly- HgI_2 detector.

The setup for nuclear spectroscopy, consisted of a preamplifier, amplifier and Multichannel Analyzer, as is customary in nuclear Spectroscopy.

Two PVD films of polycrystalline HgI_2 samples, which had a bad and good microstructure, as determined by optical microscopy were also examined by X-ray Diffraction,XRD and by SEM measurement, and the results will be shown next relative to their respective electric charge properties and their nuclear spectroscopic results.

3. Results and discussions

The SEM and XRD results for the bad non textured and the good textured polycrystalline films of HgI_2 samples are shown in Figs.1-4.One can see in the SEM pictures shown in Figs. 1 and 2, that the bad Poly- HgI_2 sample has also a loosely packed columnar structure which can be seen in the cross section of the sample; whereas the good Poly-HgI_2 sample has a much better closed structure. The same is true with the XRD spectra shown in Figs. 3 and 4. The bad Poly-HgI_2 sample shows no preferred orientation whereas the good Poly- HgI_2 sample shows a fully c-axis oriented, well textured structure. We shall see next, how well the structural data correlate with electrical charge transport properties.

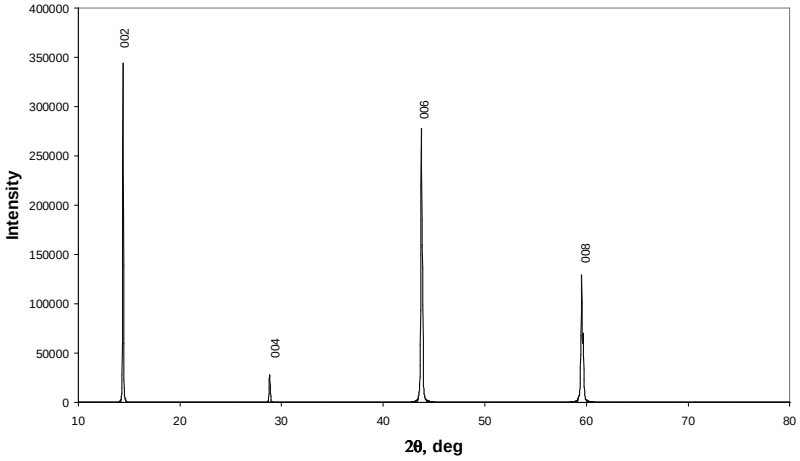

Fig. 3. XRD spectrum of a good structured Poly- HgI_2 detector.

Transient charge transport (TCT) with alpha particles measurements was used to evaluate the mobility, the trapping time and the surface recombination velocity of the samples. Typical electron-(n), and hole-(p) mobility of the bad and good polycrystalline HgI_2 vary from $\mu_n = 46-88\, cm^2/V\cdot s$ and $\mu_p = 3.8-4.1\ cm^2/V\cdot s$, respectively. Trapping times vary from $\tau_n \cong 4-18\,\mu s$ and $\tau_p \cong 2.8-3.5\,\mu s$, respectively. The better values shown here for the mobility and trapping-time and surface recombination velocity belong to the good samples, which appear to be of the same order of magnitude as in the single crystal. The lower values quoted above belong to the bad poly- HgI_2. However, there is a difference between the single and even the good polycrystalline HgI_2 detectors tested for their nuclear spectroscopic response.

The performance of the good and bad polycrystalline HgI_2 detectors as spectrometers in standard nuclear spectroscopy system was evaluated. We used a gamma source of ^{241}Am with the characteristic 59.6 keV gamma photo peak emission. The FWHM of the detector photo peaks depends on its charge transport properties. High quality polycrystalline HgI_2 detector has a photo peak with FWHM = 70 keV, while bad structured Poly- HgI_2 detectors do not show any energy resolution. Fig. 5 shows these results in which the nuclear spectroscopic response to a gamma source of ^{241}Am with the characteristic 59.6 keV gamma photo peak emission of (a) single crystal detector, (b) good structured Poly- HgI_2 detector and (c) bad structured Poly- HgI_2 detector are given. One can see that

the single crystal has the narrowest FWHM of the photo peak and is situated at the energy channel of about 60keV whereas the polycrystalline detectors have their photo peak with a much larger FWHM and placed at an energy channel, which is less than half than that of the single crystal.

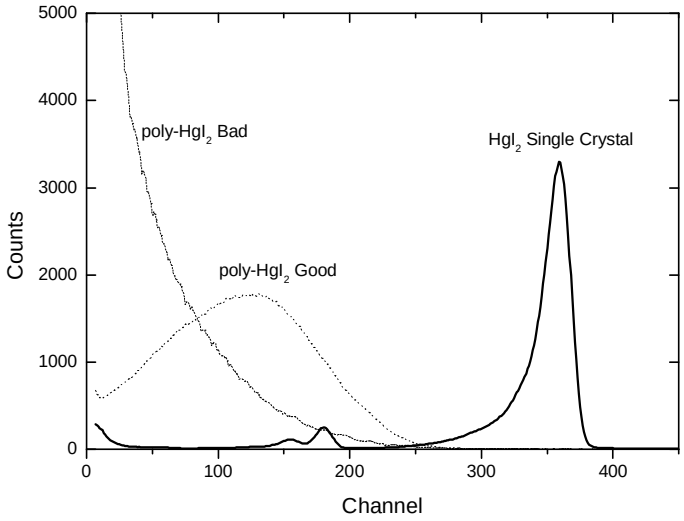

Fig. 4. Nuclear spectroscopic response to a gamma source of ^{241}Am with the characteristic 59.6 keV gamma photo peak emission of (a) single crystal detector, (b) good structured Poly-HgI_2 detector and (c) bad structured Poly- HgI_2 detector. The thickness of the detectors were, 400, 350 and 280 μm and the applied bias was 1V/μm for (a), (b) and (c) detectors, respectively.

The difference in the behavior of the polycrystalline as compared with the single crystal detectors regarding electrical charge transport properties, in which the results are almost similar and the nuclear spectroscopic response in which the polycrystalline detectors are much inferior, can be tentatively explained as follows: For electrical charge transport properties measured by alpha radiation which is mainly absorbed at the upper surface, the incident photons see in the good detector sample a single grain which may appear as a single crystal. Hence, the TCT results of the HgI_2 detector are almost identical with those of the single crystal detector. However in the case of the nuclear spectroscopic response, the gamma radiation, which is much more penetrating and the photons, may already see some non-aligned grains and grain boundaries. Therefore the FWHM, which represents the width of the histogram of the photoelectric events, is much larger. Also polarization occurs in the polycrystalline detectors, due to the large amount of grain boundaries, which trap many more charges than the single crystal detector, which after being filled create an opposing polarization field which pushes the photo peak to lower energy channels.

4. Conclusions

The present work shows that polycrystalline large area films of HgI_2 detectors, can be grown using the PVD method, also to be fully textured in the c-axis direction, with good closed interlayer structure. These HgI_2 textured detectors are called good-structured detectors. These good detectors were shown to have electrical charge transport properties.

As measured by the Transient charge transport (TCT) method with alpha particles to be similar to those of single crystals. The good polycrystalline large area films of HgI_2 detectors have also spectroscopic energy resolution at 60 keV, however the FWHM is much larger than for single

crystals and the photo peak appears at much lower energy channel due to polarization. The good polycrystalline large area films of HgI_2 are ideal imaging detectors as mentioned in the references of this paper.

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Note added in proofs:

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