Radiation Response on the Mercury Iodide Crystals Grown by the Physical Vapor Transport

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ABSTRACT

This paper describes the establishment of techniques for preparing HgI_2 crystals to be used as HgI_2 semiconductor detectors, operating at room temperature. The HgI_2 crystals were grown by physical vapor transport (PVT) technique, using two different procedures: (a) using vapor growth of HgI2 precipitated from KI and acetone solution and (b) using dimethylsulfoxide solution as a complexing agent . The obtained crystals for both methods were characterized and the results obtained were analyzed considering the following properties: plan of the crystal orientation, resistivity and response to the radiation.

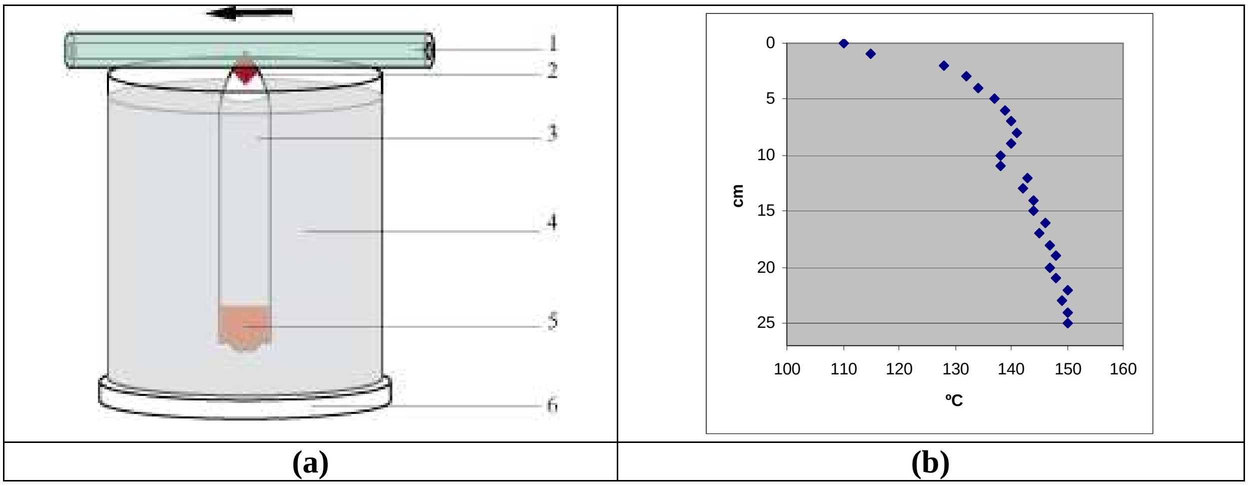
1. Introduction

There have been attempts to develop room-temperature X- and gamma ray semiconductor detectors for various applications. The main physical semiconductor properties required for fabrication of room temperature semiconductor detectors are: (1) high atomic number; (2) high density; (3) high absorption coefficient; (4) a band gap large enough to keep leakage currents low, at room temperature and (5) large electron and hole mobility-lifetime products, for an efficient charge collection [1, 2]. Among these types of detectors, HgI_2 has emerged as a particularly interesting material in view of its wide band gap (2.13 eV) and its large density (7.5 g/cm^3). HgI_2 crystals are composed of high atomic number elements (Z_{Hg}=80 and Z_I=53) and with high resistivity (>10^{14} Ωcm). These are important factors in applications where compact and small thickness detectors are necessary for X- and gamma rays measurements. However, the applications of HgI_2 are limited by the difficulty in obtaining high-quality single crystals and the long-term reliability problems in devices made from crystals [2]. Crystallization from the vapor transport has been used to grow HgI_2 crystals [3]. In this work, HgI_2 crystals were grown using vapor growth of HgI_2 precipitated from acetone and dimethylsulfoxide complexes [4].

2. Experimental Procedure

The commercially available HgI_2 powder (Fluka Chemika), with nominal purity of 99.9 %, was used as the starting material for growing crystals intended for detector applications.

The schematic diagram of the oil-bath furnace, used for HgI_2 crystal growth from PVT, and the typical temperature profile are shown in Fig. 1. The system consists of a lard oil bath, controlled by a controllable heating plate; an external heating piece was placed on the top of the growth ampoule, made of Pyrex glass. The growth was carried out in an inverted gradient, from source material residing at the ampoule bottom, using as seed of the initial nucleation obtained in the ampoule conic bottom. HgI_2 crystals were grown using two types of solutions: (1) from vapor growth of HgI_2 precipitated from KI and acetone solutions with the crystal pulled from the vapor phase at 120°C and (2) from solution at 25-50°C, using the dimethylsulfoxide as a complexing agent [4]



(a) **(b)**

Figure 1 – Schematic diagram of the oil-bath furnace used HgI_2 crystal growth from PVT technique: 1 Cold finger, 2 crystal, 3 ampoule, 4 oil bath, 5 HgI_2 powder and 6 heater (a) and typical temperature profile (b).

The crystalline quality and structural characterization of the HgI2 crystal were analyzed by X-ray diffraction (XRD); X-ray diffraction patterns were obtained in a Siemens (D5005) Diffactrometer, using CuKα radiation (2θ ranging from 5° to 70º).

In order to be prepared as a radiation detector, the electric contact was applied with conductive graphite painting on both sides of the wafers. Fig. 2 shows a schematic diagram of the detector and its connection to the preamplifier.

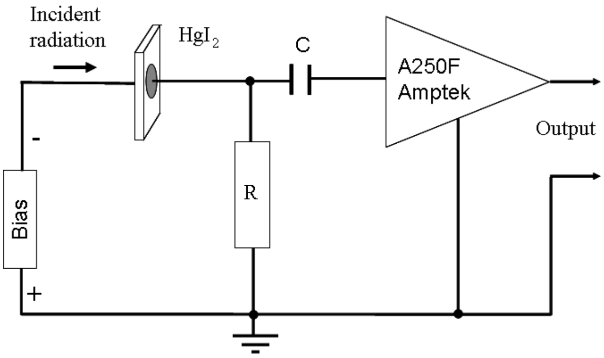
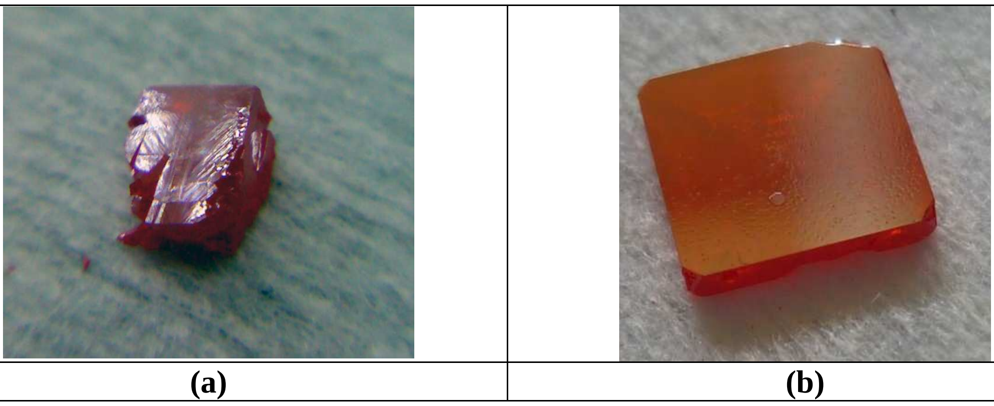


Figure 2 – HgI_2 detector and preamplifier connection.

The radiation response of the detectors was studied using the conventional nuclear electronic setup including the voltage power supply, charge sensitive preamplifier, a linear amplifier and an oscilloscope. The pulse height spectra were evaluated using an ORTEC model 918A multichannel analyzer, using a ^{241}Am gamma radiation source [5].

3. Results and Discussion

Fig. 3 shows the HgI_2 crystals grown by PVT method using HgI_2 precipitated from KI and acetone solutions and dimethylsulfoxide complexes. As it can be observed in this figure, the crystal grown from acetone (4a) presented a brilliant darker color, being more accentuated in the upper section. The crystal grown from dimethylsulfoxide complexes provided a square crystal, in the dimensions of a 1 cm^2 and 0.3 cm thick, visually more uniform and transparent (4b).



(a) (b)

Figure 3 - HgI_2 crystal grown by PVT from acetone (a) and dimethylsulfoxide (b) solutions

Fig. 4 shows the typical X-ray diffraction pattern of the HgI_2 crystals obtained. No significant difference was observed in the diffractograms between the crystals grown from both methods. The results show that the crystals have a similar structure to the tetragonal crystalline pattern of the HgI_2. The diffractogram indicates that the crystal is, preferentially, oriented in the (001) direction.

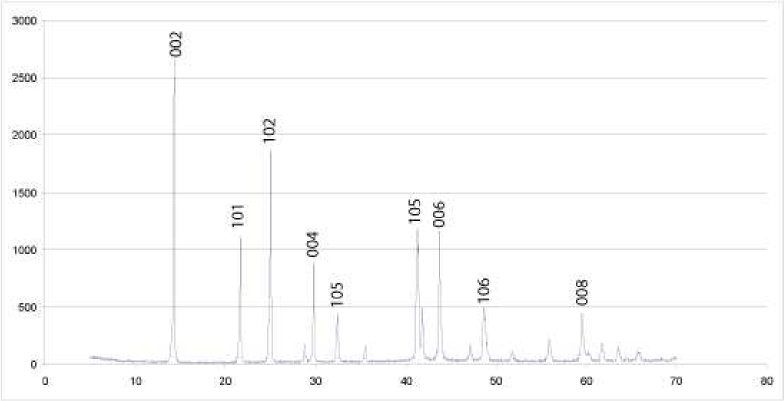
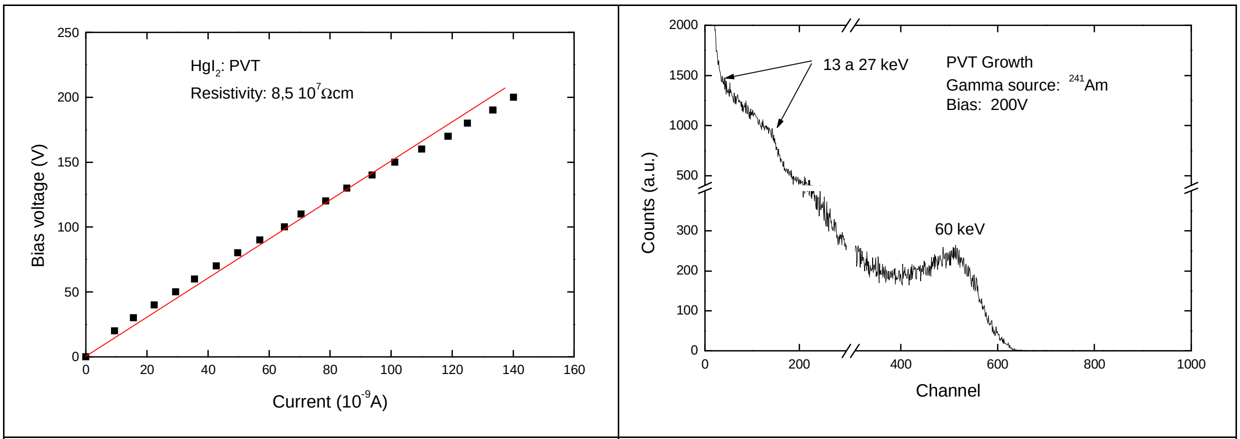


Figure 4 - X-ray diffractogram of HgI_2 grown by PVT method

Fig. 5 (a) shows the results of the leakage current, as a function of the applied bias for the crystal grown by PVT from the KI and acetone solution, while Fig.5 (b) illustrates the pulse height spectrum obtained, using a gamma ^{241}Am source for the crystal excitation. From the results of Fig 5 (a), the resistivity value for this crystal was inferred as being $8.5x10^7$ Ωcm. As it can be observed from the Fig. 5 (b), this detector presented good radiation response and pulse height with recognizable features under gamma ray excitation, although the resolution was poor. To obtain a better resolution is necessary to improve the charge collection [6]; to achieve this goal, purification should be carried out in order to decrease the impurities and, consequently, reduce the charge traps.

For the HgI_2 crystal grown by PVT from dimethylulfoxide, no radiation response was observed when excited with gamma radiation, probably due to the interference of the high leakage current in the occasional radiation signal detection. It was possible to observe the radiation response only under alpha ^{241}Am radiation (5.4 MeV) in the current mode. The detection, in the pulse mode, was not observed due to a low radiation response and a high noise signal. Further studies should be made to evaluate the influence of the crystals impurities and crystalline in the detector performance.



(a)_ **(b)**

Figure 5 - Current versus voltage of HgI_2 detectors (a) and energy spectrum with gamma rays from ^{241}Am prepared with crystal grown by PVT method from acetone solution

4. Conclusion

Preliminary results indicated that the technique the PVT from acetone solution present better performance as a radiation detector compared to PVT from dimethylsulfoxide solution. The HgI_2 crystal grown by PVT from acetone solution presented pulse height with recognizable features under gamma ray excitation, although the resolution was poor. On the other hand, for the HgI_2 crystal grown by PVT from dimethylsulfoxide solution no radiation response was observed under gamma ray excitation.

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