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The decrease of fringe effect on mercuric iodide film arrays based on one-step mask method

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ABSTRACT

Polycrystalline α-phase mercuric iodide (α-HgI_2) film arrays have been prepared on ITO-coated glass substrates by hot-wall physical vapor deposition (HWPVD) method with the mask of 4 × 4 arrays. Film arrays are prepared based on one-step mask method. It is found that there exist differences between central parts and marginal parts of arrays in two aspects including surface morphology and electrical performance. The size distribution of grains in the edge is not uniform and grain boundaries are not clear, but the size distribution in the centre is consistent in morphology. In the aspect of electrical performance, the lowest leakage current of marginal parts and central parts is 4.95×10^{-8} A and 1.01×10^{-8} A respectively. The phenomenon of fringe effect demonstrates that the former is five times as large as the latter. Polishing method is also applied in order to decrease fringe effect of α-HgI_2 film arrays. Signal-noise ratios (SNR) of devices are investigated at room temperature irradiated by 5.5 MeV ^{241}Am source.

1. Introduction

Nuclear irradiation detectors have always been developed since scintillation counters, electronic count technology, gas detectors to semiconductor detectors [1,2]. But there exist several disadvantages in detectors mentioned above. Such as poor energy resolution of scintillation crystal detectors, great size of gas ionization detectors, and high requirements to temperature of semiconductor detectors [3]. Mercuric iodide (HgI_2) raised more and more attention because of its excellent characteristics for operating in room temperature, high detection efficiency, high electrical resistivity and so on [4]. This kind of semiconductor nuclear irradiation detector is supposed to ideal detectors for good energy resolution, small size, and portability. They have been used in different areas such as environmental monitoring, nuclear medicine and space detection [5,6].

Compared to other semiconductor materials, for instance, cadmium zinc telluride (CZT), HgI_2 is illustrated favored properties such as high atomic number ($Z_{Hg} = 80, Z_I = 53$), large optical band-gap (Eg = 2.13eV), high resistivity ($10^{13}\,\Omega$ cm) and high mass density ($6.4\ g\ cm^{-3}$) [7–9]. Though $\mu_h \cdot \tau_h$ value for CZT (5×10^{-5}) is slightly higher than for HgI_2(1×10^{-5}), this is compensated by the much lower growth temperature (< 100 °C for HgI_2 and > 600 °C for CZT). In addition, the preparation of CZT for large area is more difficult than HgI_2 so that the latter can be prepared for scale production [10–12].

Properties of HgI_2 films have great influence on detectors, Xu et al. [13] prepared detectors through growing high purity monocrystalline iodide mercury by both physical method and chemical sublimation [14]. Because of high cost of monocrystalline HgI_2 and the limitation of large area production, the research of polycrystalline α-phase HgI_2 is focused [15–18]. Burger [19] and Xu [20] grow α-HgI_2 by thermal vapor transport and epitaxial growth method. Now the most effective method is physical vapor deposition (PVD) [21]. The research of fringe effect in array devices is also getting increasing attention. Wei [22] has found that there exists an interaction between fringe fields and interactive fields in diode emitter arrays. And the interaction would influence the emission uniformity of emitter array. Sun [23] studied fringe effect of an ERT (electrical resistance tomography) sensor. He put forward that the phenomenon would cause measurement errors and image distortion. So it is necessary to study fringe effect and decrease it. The introduction of array detectors can improve the spatial resolution and make it apply in imaging area especially digital mammography of medical. It can also benefit on preparing large-area flat panel detectors for general radiography. Improving uniformity and adjusting non-uniformity of array detectors benefit the imaging integrity of digital radiation imaging. At present, Xu [24] et al. fabricate polycrystalline HgI_2 thick film detectors with 256 × 256 pixels on TFT substrate by PVD method, and obtain high resolution of X-ray imaging performance. Li [25] et al. found that there exists screening effect of CZT imaging detectors through experimental and simulation research. If the fringe effect can be solved, polycrystalline HgI_2 films will be promising to be

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new composite semiconductor detectors operating in room temperature. However, particularly in medical applications, HgI_2 detectors for large area couldn't satisfy demand [26]. Therefore the objects of this paper are exploring one-step mask method to prepare α-HgI_2 film arrays and improve crystal uniformity and electrical properties in order to decrease fringe effect, which is benefit to improve the spatial resolution mentioned above.

In our previous work, α-HgI_2 film arrays are prepared by hot wall physical vapor deposition (HWPVD) method on indium tin oxide (ITO) glass through using the mask of 4 × 4 arrays. This paper aims at research on growing character, growth velocity of α-HgI_2 film arrays, and reducing fringe effect effectively to improve signal-noise ratio (SNR). Investigating on the law of α-HgI_2 film growth, excellent detectors-grade α-HgI_2 film arrays will be more applicable in medical and environmental area.

2. Experimental details

2.1. Purification of α-HgI_2

Purity of raw material mercuric iodide is just 99.99%. So it was purified by physical vapor deposition at least two times in this paper. Higher purity of α-HgI_2 finally can be got which was used to fabricate α-HgI_2 film arrays devices.

2.2. Fabrication of α-HgI_2 film arrays

Deionized water and acetone were used to clean ITO glass substrates in an ultrasonic bath made by KUDOS firstly. Then α-HgI_2 film arrays were deposited on ITO glass substrates in different temperature with the thickness about 0.2 mm–0.5 mm. The diameter of film arrays were around 30 mm with 4 × 4 arrays mask in a modified oil bath system of HWPVD. Deposition temperature of the source between 75 °C and 90 °C was used respectively. Film arrays were grown from 2 g of refined HgI_2 powder at vacuum pressure of 10^{-3}Pa. Those α-HgI_2 film arrays prepared on ITO glass substrate have been shown in Fig. 1(a). The schematic model of preparation by one-step mask method has been displayed in Fig. 1(b). The source of HgI_2 solid powders can be sublimed to gases by vacuum evaporation. When HgI_2 gas particles arrive at the substrate, α-HgI_2 films arrays are deposited through mask by HWPVD according to chemical formula:

$$HgI_2(S) \xrightarrow{\text{sublimation}} HgI_2(g) \xrightarrow{\text{deposition}} HgI_2(S)$$

2.3. Polishing and passivation

In order to get more clean and uniform surface of the α-HgI_2 film, it was dealt with chemical surface passivation. It was etched chemically by 15% KI solution for around 1 min at room temperature in order to separate grain boundaries. Then the surface of film arrays was polished physically for about 60 min. Then deionized water was used to wash the surface of film arrays repeatedly. Ag electrode was deposited on the surface of film arrays after about 1 min by vacuum thermal evaporation.

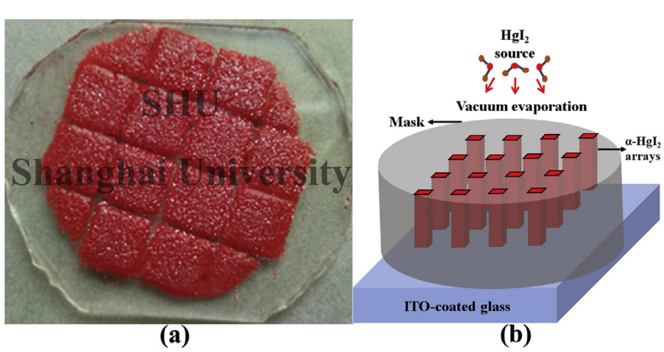

Fig. 1. (A) The α-HgI_2 film arrays prepared on ITO glass substrate (b) The schematic model of preparation by one-step mask method.

2.4. Characterization methods of α-HgI_2 film arrays and devices

Structure and morphology characterizations of α-HgI_2 film arrays were shown by Raman spectra and Scanning Electron Microscope (SEM). Raman spectrum was tested by Jobin Yvon Lab RAM HR 800UV spectrograph with argon ion laser wavelength of 514 nm. SEM figure was characterized by Hitachi SU1510. Electrical properties including I-V characteristics and current-time curves were measured by Keithley 2400 semiconductor measurement system.

3. Results and discussions

3.1. Structural characterization

Raman spectrum of α-HgI_2 film arrays were tested by Jobin Yvon Lab RAM HR 800UV spectrograph. Energy of the laser was 20 mW, harmless on the sample.

Those obvious and sharp Raman shifts around 111 cm^{-1} and 137 cm^{-1} after fitting process could be observed in Fig. 2. Sample 1–3 were prepared in different temperatures at 80, 85 and 90 °C respectively. It hasn't been reported that Raman shifts of α-HgI_2 film. But Raman shifts of monocrystalline HgI_2 are 18, 28, 113 cm^{-1}, respectively. The shifts of 18 and 28 cm^{-1} represent α-HgI_2 while the shift of 113 cm^{-1} is regarded as mix of α-HgI_2 and Hg_2I_2. From Fig. 2, the Raman shift of 111 cm^{-1} appears because of existence of (001) oriental structure in α-HgI_2 results in movement of the shift. From Fig. 2, Raman shifts of 111 and 137 cm^{-1} are regarded as long-range order characteristic peak position of α-HgI_2 in (001) orientation. There are also some differences between those three samples in Raman intensity because different thickness results from different growing conditions such as time and temperature in experiment.

Morphology characterization of α-HgI_2 film arrays is shown in Fig. 3. Fig. 3 **(a)** and **(b)** are of α-HgI_2 film arrays prepared in same experimental conditions. Fig. 3 (a) shows film arrays in the edge and Fig. 3 (b) is located in the centre. In Fig. 3 (a), the average size of grains is about 127 μm. Grain boundaries are not very clear between grains, and sizes of grains are not uniform. But it is also obvious that some of those grains grow aslant. In Fig. 3 (b), the average size is around 200 μm. Sizes are more uniform, grain boundaries are clear and grain orientation is fine. So shape of grains in Fig. 3 (b) is consistent. Uniformity is good as well, and compactness of the particles is also great.

Because HgI_2 film was prepared by HWPVD method, there exist

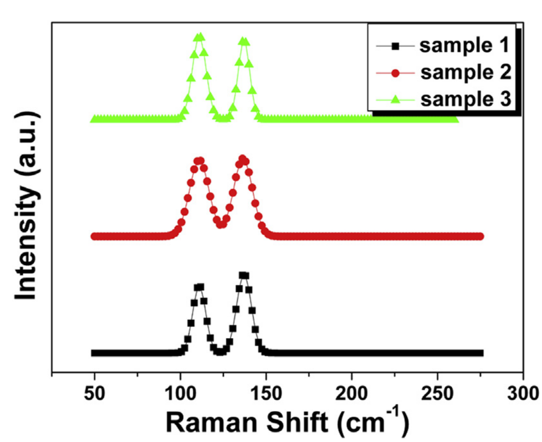

Fig. 2. Raman shifts of α-HgI_2 film arrays in different conditions.