Conference Paper

Synthesis and Characterisation of Thin Films of Bismuth Triiodide for Semiconductor Radiation Detectors

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Bismuth iodide is a potentially active material for room temperature radiation detector, as it is well reported in the literature that it has both wide energy band gap and high atomic absorption coefficient. Crystalline films of high atomic number and high radiation absorption coefficient can absorb the X-rays and convert them directly into electrical charges which can be read by imaging devices. Therefore, it was proposed to grow thin films of Bismuth iodide on glass substrate using thermal evaporation technique in vacuum to avoid the inclusion of impurities in the films. The structural studies of the films were carried out using XRD and optical absorption measurement was carried out in the UV/VIS region using spectrophotometer. All Bismuth iodide films grown at room temperature are polycrystalline and show X-ray diffraction peaks at angles reported in research papers. The optical transmission spectra of BiI₃ films show a high transmission of about 80% in visible region with a sharp fall near the fundamental absorption at 650 nm. Resistivity of the as-grown film was found to be around 10¹² ohm-cm suitable value for X-ray detection application. Films were subjected to scanning electron microscopy to study the growth features of both as-grown and annealed films.

1. Introduction

Gamma ray detectors have become increasingly important for the application of medical imaging and environmental safety. Photographic films, Phosphor screens, and Silicon array have been used as imaging detectors for many years but all these devices are indirect detectors with low efficiency and poor spatial resolution. Compound semiconductors are the most promising radiation detector compared to high purity Ge and Si because of their moderate band gap and ability to operate at room temperature [1]. Bismuth iodide is one such compound semiconductor with potential for room temperature gamma and X-ray detection applications [2]. Bismuth Triiodide is having both high atomic number and high absorption coefficient, important parameters for material to detect X-rays and Gamma rays [3]. Bismuth

Triiodide is a layered compound having low melting point of 408°C. BiI₃ is stable within the range from melting point to room temperature [4]. BiI₃ is reported to have vapor pressure of around 90 mbar at temperatures 250°C to 300°C [5, 6]. Therefore, BiI₃ films can be grown from both liquid and vapour phases. BiI₃ has been reported with different band gap characteristics and values. Experimentally and computationally, band gap value is ranging from 1.5 eV to 2.2 eV [7]. It is reported that BiI₃ has both direct and indirect band gaps.

The aim of the present work is to prepare polycrystalline thin films of Bismuth Triiodide by thermal evaporation method and study the optical and structural properties of the material to present preliminary results which would be in future help in developing Bismuth iodide as room temperature radiation detector.

2. Experimental

Bismuth Triiodide films were grown on glass substrate (2 cm × 6 cm) at room temperature by conventional thermal evaporation technique using molybdenum boat at a pressure approximately 10^{-6} Torr. Starting material (99.99% purity) procured from Aldrich chemicals was used for growing films. Uniformity and thickness of the films were found out using DEKTAK 150 surface profiler. The deposition rate was maintained to be slow around 5-6 nm/s as the higher deposition rate led to nonuniform film growth and low sticking adherence to the glass substrate.

Structural analysis of the as-grown and annealed films was carried out using X-ray diffraction using Bruker D8 XRD. Optical transmission spectra of the annealed and as-grown Bismuth Triiodide films deposited on the glass substrate were recorded as a function of wavelength in the range (200–1100) nm at room temperature using Perkin Elmer, lamda 35 UV/VIS spectrometer. Surface morphology of the films has been studied through scanning electron microscope (SEM MIRA3TESCAN)) to ascertain the uniformity of as-grown and annealed films. The resistivity of films was measured using Keithley semiconductor analyser (SCS 4200).

3. Result and Discussion

The as deposited BiI_3 films were found to be smooth and strongly adhered to the substrate surface. The as-grown films were polycrystalline and stoichiometric (as per X-ray diffraction). Figure 1 shows the XRD pattern of as grown Bismuth Triiodide films. Sharp and well-defined reflections corresponding to (003), (006), (008), (009), (300), (0010), and (0012) planes of BiI_3 were observed at around $2\theta = 12.79^\circ$, 25.78° , 26.99° , 35.27° , 39.09° , 41.59° , 43° and 52.99° , respectively, which are in good agreement to the corresponding reflections reported in the PCPDF card number 76–1742. The XRD analysis shows a high degree of orientation with basal plane parallel to substrate and c -axis normal to the substrate. On annealing, the intensity of certain peaks are increasing along with appearance of planes. The crystalline size of the as-grown and annealed film was estimated by fitting the FWHM of dominant (003) plane using Scherrer's formula:

$$d = \frac{K\lambda}{\beta \cos \theta}, \quad (1)$$

where K is 0.94, λ is X-ray wavelength, β is FWHM, and θ is diffraction peak position. The estimated value of crystallite size is about 32 nm. On annealing the films, decrease in FWHM from approximately from 0.2470 to 0.2006 manifests an improvement in the crystalline quality and enlargement of grain size from around 32 nm to 40 nm.

Figure 2 shows the optical transmittance spectrum of the BiI_3 films deposited on the glass substrate. Films exhibit a high optical transmission (80%) in the visible range and show a sharp fundamental absorption edge at around 650 nm. The presence of well-defined interference pattern in the optical transmittance spectra indicates the growth of uniform good quality BiI_3 film free from any inhomogeneity which is also

FIGURE 1: XRD of as-grown and annealed films of Bismuth Triiodide.

FIGURE 2: Optical transmission spectra of as-grown BiI_3 thin film.

well explained by sharp reflections in the XRD pattern. The value of optical band gap (E_g) was estimated from the linear portion of the Tauc plot (Figure 3) between $(\alpha h\nu)^2$ with photon energy ($h\nu$), where α is the absorption coefficient and ν is the optical frequency. The value of E_g was found to be about 1.82 eV which is close to the corresponding reported value for BiI_3 thin film by other workers.

Scanning electron microscope (SEM) micrographs are shown in Figures 4 and 5. The surface morphology of BiI_3 is of uniform nature having nanocrystalline size grains whose sizes are close to the grain size reported from XRD. Films on annealing appear to be highly oriented suggesting micrograins aligned themselves to grow parallel to the substrate [8]. Also, it appears that film is grown by layer growth mechanism

FIGURE 3: Tauc plot of BiI₃ thin film.

FIGURE 4: SEM micrograph of as-grown film of Bismuth Triiodide.

which is a characteristic property of layered compounds like Bismuth Triiodide.

4. Conclusion

BiI₃ thin films were grown by thermal evaporation technique. Structural, morphological, and optical properties of thin films were studied by XRD, SEM, and UV-visible spectroscopy, respectively. It was observed that the films were polycrystalline with hexagonal nature and grain size increased upon annealing the films at 100°C. Also, on annealing microcrystalline grains arranged themselves periodically indicating improvement in the crystalline quality of the film.

FIGURE 5: SEM micrograph of annealed film of Bismuth Triiodide.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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