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Fabrication of Bismuth Telluride Thin Films using Thermal Evaporation Technique and its Electrical Properties

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Thin films have received great attention in recent years because of their extensive applications in various fields of science and technology. The studies of the electrical properties of semiconducting thin films have been primarily provoked by attractive micro-electronic device applications. Bismuth Telluride (Bi_2Te_3) is the most widely used material among the various V- VI compounds. In this study, thin films of Bi_2Te_3 were fabricated onto different substrates (*i.e.*, glass and silica) by using thermal evaporation technique. Their structural, morphological, optical, and electrical properties were investigated using X-ray diffraction (XRD), Field Emission-Scanning Electron Microscopy (FE-SEM), Photoluminescence (PL) spectroscopy, and Source meter instrument, respectively. XRD analysis showed that the films were crystalline in nature. FE-SEM images showed that the films have a homogenous and compact grain surface. The optical band gap was about 2 eV for both types of film. The I-V characteristics of thin films were analysed at temperatures ranging from 30 °C to 100 °C. It was found that the film fabricated onto silica substrates showed large electrical conductivity as compared to the others. Also, the increment in electrical conductivity was observed with the temperature indicating that the prepared films have a negative temperature coefficient of resistance.

Keywords: Thin film; Bismuth telluride; Photoluminescence; Optical properties; Electrical properties

1 Introduction

Bismuth Telluride is an indirect band-gap semiconductor having an energy bandgap of 0.165 eV. It has a high melting point (585 °C) and a density of 7.7 g cm^{-3}[1]. Bi_2Te_3 is the heaviest stable binary compound. Even though Bismuth Telluride is not hazardous, it can be fatal if inhaled in huge amounts[2]. It shows various properties like light absorption, low optical intensity, and a single Dirac cone at the surface. These properties make it more suitable for optoelectronic applications. All properties like mechanical, transport, and optical properties exhibited the highest anisotropy in Bi_2Te_3 crystal. The electrical conductivity, thermal conductivity, and other properties of Bismuth Telluride show dependency on temperature. It offers very high resistance to electric and heat shocks[3]. Bi_2Te_3 thin films are very suitable for low-temperature applications. These can be used for low-value large-scale power generation. Various studies have been carried out for the best utilisation of the properties of Bi_2Te_3 material[4].

Arora *et al*. studied the I-V characteristics for both as-deposited and annealed films fabricated on silicon substrate[1]. The effect of thickness and temperature on the electrical properties of thermally evaporated Bismuth Telluride thin films was investigated[5]. Elyamny *et al*. prepared Bismuth Telluride thin film using zone melting and thermal evaporation techniques and investigated its thermoelectric properties[6].

In this study, we fabricated Bi_2Te_3 thin films using thermal evaporation technique and investigated the effect of substrate and temperature on the electrical properties of the prepared films.

2 Materials and Methods

Bismuth Telluride powder procured from Sigma-Aldrich (purity 99.99%) was used for film fabrication. The material was weighed by using a digital weighing balance. Bi_2Te_3 films were fabricated on to cleaned glass and silica substrates using thermal evaporation technique[7]. The vacuum pressure was maintained at about 10^{-5} mbar. The substrate holder was rotated to obtain uniformity of film layers during the deposition process. Film thickness was controlled by using a digital thickness monitor provided on the front panel of the thermal evaporation system.

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The films were analysed by an X-ray diffractometer (Rigaku, Hisar) from 2θ values ranging from 20° to 70°. Field Emission-Scanning Electron Microscopy (JSM 7610F Plus) examined the surface morphology. Optical investigations were performed using a Spectro Fluorometer. The I-V measurements of Bi_2Te_3 films fabricated on different substrates were performed in the range of 30-100 °C as a function of temperature by using a Source meter SMU Instrument (Model 2450).

3 Results and Discussion

Fig. 1(a,b) represent the XRD pattern of Bi_2Te_3thin film deposited onto glass and silica substrate.

As illustrated in Fig. 1, the diffraction peaks of XRD corresponding to (015), (01 10), (10 11), (00 15), (205), (10 16), (02 10) and (11 15) were observed at 27.85°, 38.65°, 40.6°, 45.3°, 49.85°, 52.45°, 57.3° and 63.15°, respectively, for both the samples. The sharp and most intense peak was obtained for the plane (015) corresponding to the angle of 27.85°. The XRD patterns indicate the crystalline nature of the films. Fig. 1(a) shows that the film on a glass substrate is more intense than on a silica substrate. Hence, the XRD study of the film reveals more crystallinity of the film with the glass substrate, which is in agreement with the previous studies[8].

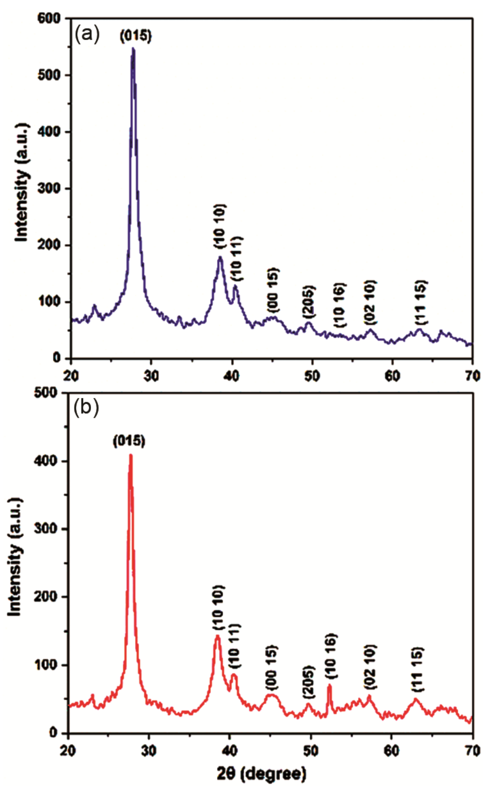

Fig. 1 — XRD spectra of Bi_2Te_3 film deposited onto (a) glass (b) silica substrates.

Figure 2 represents the FE-SEM images of the Bi_2Te_3 films at magnification 60 K. Fig. 2(a) refers to the images of film with a glass substrate, and (b) refers to the images of film onto a silica substrate.

The FE-SEM images show that the surface of the film on the silica substrate is smooth (Fig. 2(b)) as compared to the film deposited onto the glass substrate (Fig. 2(a)). The grain distribution on the surface of the film is homogeneous and compact. This distribution is largely observed on film with silica substrate, while in the case of glass substrate, grains with large sizes are observed. Since glass has a rough surface compared to silica, the film fabricated onto glass may lead to more structural disorder due to the rough interface between film and substrate. The results obtained by FE-SEM analysis are in agreement with the earlier studies[8].

The PL analysis was performed with the excitation wavelength of 375 nm. The strong red emission at wavelength 618 nm is observed for the film deposited on a glass substrate, and a similar peak is observed in the case of silica substrate at wavelength 616 nm. However, a highly intense peak is observed for the film deposited onto the silica substrate. The calculated optical band gap was about 2 eV for both types of film[9].

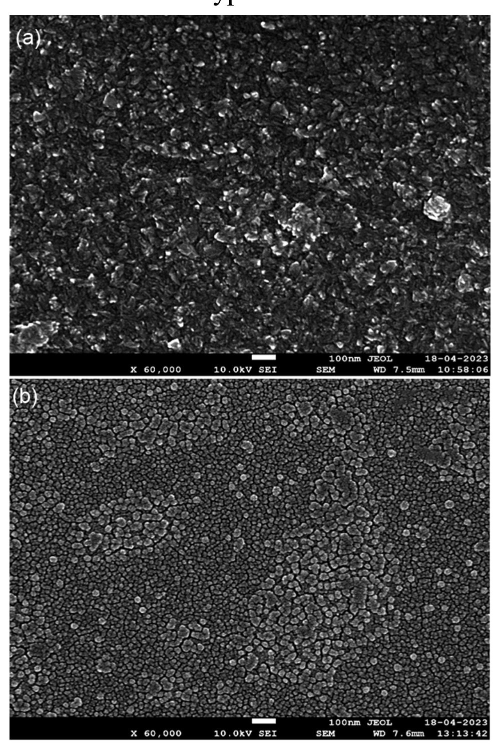

Fig. 2 — FE-SEM images of Bi_2Te_3 film deposited onto (a) glass (b) silica substrates.

The effect of thickness and temperature on the I-V characteristics of films are shown in Fig. 3 and Fig. 4, respectively. Fig. 3 (a,b) show the effect of thickness, and Fig. 4 (a,b) show the effect of temperature on the I-V characteristics of Bi_2Te_3 films deposited on both glass and silica substrates.

From Fig. 3, it is clearly observed that electrical conductivity increases with increasing film thickness on both glass and silica substrates. For instance, at an applied voltage of 0.1V, the current has increased from 0.52 μA to 2.14 μA when the thickness of the film on a glass substrate is increased from 200 nm to 600 nm (Fig. 3(a)). The current has become almost four times when the thickness is tripled. There is the same pattern in variation at other values of applied voltage. While in the case of film on silica substrate (Fig. 3(b)) at an applied voltage of 0.1V, the current has increased from 1.49 μA to 3.39 μA when the thickness of the film is increased from 200 nm to 600 nm. Almost double current on tripling the thickness. The defects *i.e.*, any impurities added at the time of film deposition or voids present in the film, may lead to a decrease in electrical conductivity value. With the increase in film thickness, these defects get reduced, and consequently, the electrical conductivity increases.

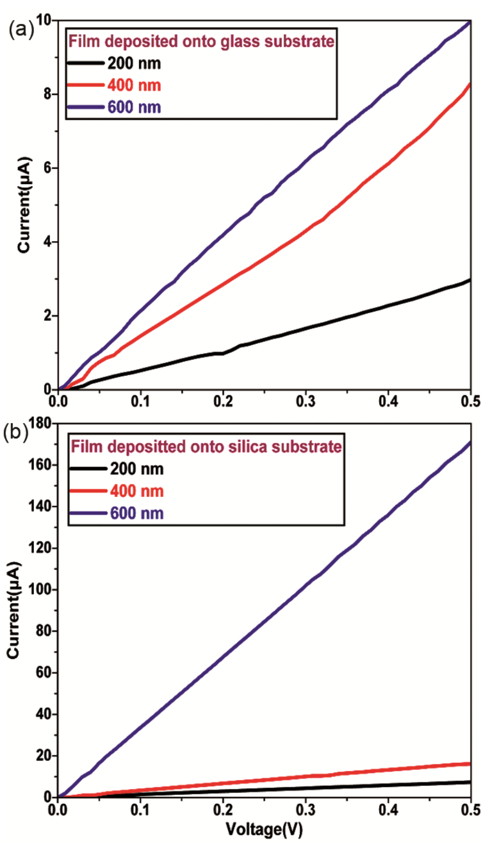

Fig. 3 — Effect of thickness on I-V characteristics of Bi_2Te_3 film deposited onto (a) glass (b) silica substrates.

The effect of temperature on the I-V characteristics of films was observed for the temperature range varied from 30 °C to 100 °C. The experimental result reveals the increment in the electrical conductivity of the film with the increase in temperature (Fig. 4). For instance, at an applied voltage of 0.1V, the current increased from 0.94μA to 1.82μA when the temperature of film on a glass substrate is increased from 30 ℃ to 100 ℃ (Fig. 4(a)). The current has become double with the rise in temperature from 30 ℃ to 100 ℃. While in the case of film on silica substrate at an applied voltage of 0.1V, the current has increased from 2.17μA to 3.72μA when the temperature of film on silica substrate is increased from 30 ℃ to 100 ℃ (Fig.4 (b)). Almost double current with rise in temperature from 30 ℃ to 100 ℃. There is the same pattern in variation at other values of applied voltage. The increased electrical conductivity observed in this study indicates the semiconducting behaviour of the prepared Bi_2Te_3 film.

The film prepared onto silica substrate has higher electrical conductivity at all temperatures than the film prepared onto a glass substrate. In reference to

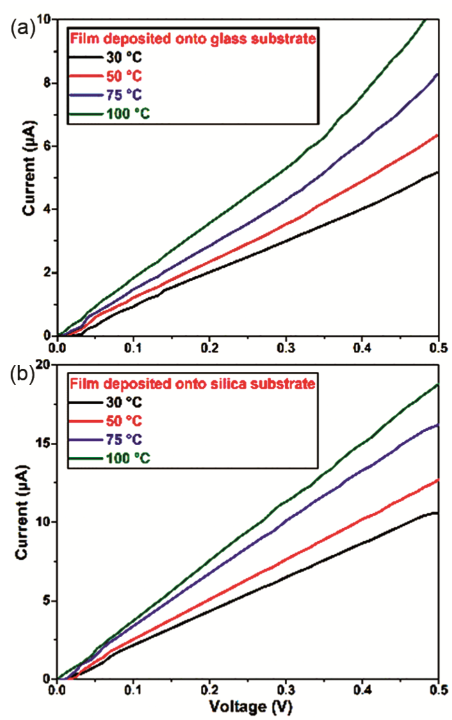

Fig. 4 — Effect of temperature on I-V characteristics of Bi_2Te_3 film deposited onto (a) glass (b) silica substrates.

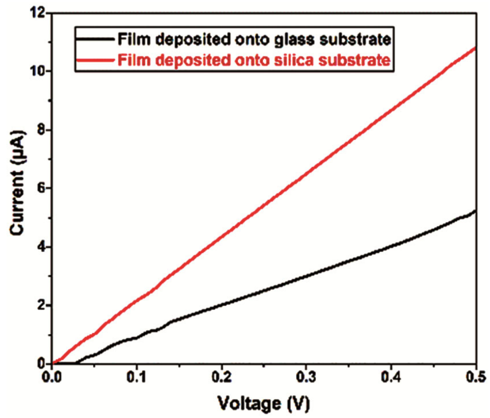

Fig. 5 — Comparison of I-V characteristics of Bi_2Te_3 films deposited onto different substrates for temperature 30 °C.

Fig. 5, at the temperature of 30 ℃ for both the substrates, it is evident that the current in film on silica substrate is almost double at all voltages compared to that of film on glass substrate. This may be due to the rough surface of the glass as the increase in roughness of the surface, the structural disorders get increase, resulting in the turbulent interface between the film and substrate. Because of this increment in structural disorder, the number of defects increases, resulting in decreased electrical conductivity. Hence, it was concluded that the film fabricated onto a silica substrate has high electrical conductivity. These results on electrical conductivity are in good agreement with the previous works[5].

4 Conclusion

Electrical properties of Bi_2Te_3 thin films deposited onto glass and silica substrates have been studied in the thickness range 200 - 600 nm and temperature range 30 °C - 100 °C. It was found that electrical conductivity increased with the thickness of the films, and this increment in electrical conductivity was also observed with the temperature indicating the semiconducting behaviour of the prepared films.

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