EXPERIMENTAL INVESTIGATION OF ELECTRICAL PROPERTIES OF BISMUTH SELENIDE THIN FILMS

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Developing high efficient energy materials with low toxicity is present need of research. Today bismuth selenide, a topological insulator has attracted great attention due to its electrical properties. Solid samples of bismuth selenide of different elemental ratio of Bi/Se have been prepared by solid state reaction and thin films of these solid sample have been deposited on glass substrate using thermal evaporation technique. Transport properties of bismuth selenide thin films were investigated. Electric properties of these films were studied by Hall measurements. A comparative study among different thin films along with annealing effect has been reported.

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Keywords: Bismuth selenide, Thin films, Thermal evaporation, Hall measurements

1. Introduction

In present time energy production is the biggest challenge day by day to satisfy the basic need of society. The lack of energy resources such as oil, coal, natural gas etc. there is need of development of technology based on use of alternative energy resources like solar energy, wind energy, bioenergy energy, geothermal energy etc. Thermoelectric materials have significant properties to generate electricity from waste heat so it has a huge area of applications (1,2). Thermoelectric materials are environment friendly and has energy conversion technology with small size, high reliability, no pollutants which can be use through wide temperature range. Semiconductors which have narrow band gap and high mobility carriers are best suitable as thermoelectric materials (3,4). Group V-VI binary compounds are in interest from the point of view of the preparation and characterization in order to test their suitability as desired application (5,6). Bismuth selenide belongs to group V-VI and is a topological insulator which has exciting unique conductive properties on its surface. So in present work bismuth selenide solid samples with different elemental ratio of Bi/Se have been prepared by solid state reaction. Thin films of these solid samples have been prepared by thermal evaporation technique (7-9). Study of bismuth selenide thin film is useful because of its suitable optical and electrical properties for construction of Hall effect magnetometer, high frequency power sensor thermopliers wide band radiation detector and humidity sensors (10-12). Hall measurements, I-V measurements were performed on these films and have been reported.

2. Experimental details

Bismuth selenide solid samples have been synthesized using solid state reaction process. In this process bismuth and selenium have been taken in four quartz ampoules in different stoichiometry ratio. These ampoules were sealed properly after creating vacuum of 10^{-6} torr . These were then placed in muffle furnace for heating. The temperature was gradually increased up to 850°C and kept for 1 hour. Then ampoules were slowly cooled down to room temperature. Thin films of these different solid samples have been prepared by thermal evaporation process on glass

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substrate. So four different types of thin films having different elemental ratio (0.123 to 0.309) have been prepared. These films were annealed at 200°C. Characterization of these thin films using of Hall measurements and I-V measurements were performed.

3. Results and discussion

3.1 EDAX (ENERGY DISPERSIVE X-RAY SPECTROSCOPY)

The elemental compositions of these films were analyzed by elemental energy X-ray spectroscopy (EDAX). Table-1 represents the results of elemental composition of bismuth and selenium present in as-deposited thin films (TF) (13).

Table -1.Elemental composition of Bi/Se in bismuth selenide thin films

Thin Films (TF)	Bi/Se (at%)
TF-1	0.123
TF-2	0.176
TF-3	0.182
TF-4	0.309

3.2. I-V Characteristics

The variation between current and voltage were taken for room temperature thin films and annealed thin films. I-V characteristics of as-deposited and annealed thin films are shown in Fig.-1 as below.

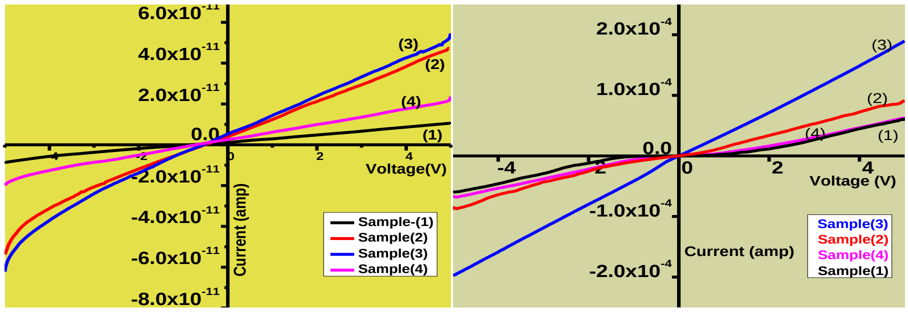

Fig. 1 I-V curve of as deposited and annealed thin films

Current is increasing with voltage in both curves. In fig-1 upper I-V curve indicates that current is varying from 0 to 0.06 nA for room temperature thin films. That shows that bismuth selenide thin films of thickness 100 nm deposited at room temperature have low conductivity. Fig-1 upper curve represent that films at room temperature did not shows ohmic nature because curves are not passing through origin. But lower curve indicates ohmic conduction from low voltage to higher voltage (-5V to 5V) for annealed thin films. In lower curve current is of order of micro ampere (mA). This indicates that conductivity increases by annealing treatment.

It is observed that conductivity of films affected by compositional variation. It means that as composition ratio increases in films conductivity also increases. Conductivity of films increases from TF-1 to TF-3, but for TF-4 conductivity becomes down. This is due to higher composition ratio of Bi/Se present in TF-4, which composition ratio is much higher than other thin films composition. In thin films both the elements bismuth and selenium have their unique properties. Selenium has semiconducting nature. So low value of selenium present in TF-4 is the reason of low conductivity.

3.2. Hall measurements

Electrical properties of thin films of bismuth selenide were investigated at room temperature. 0.1mA current was applied for the measurement. Bulk concentration, sheet resistance, mobility, resistivity and conductivity were measured for as-deposited and annealed thin films. The quantitative results of different electric parameters are presented in table-2 for room temperature thin films and table-4 represents electric parameter of annealed thin films.

Table -2.Electrical parameter of as-deposited thin films.

Thin films	**Bulk concentration ($\times 10^{19}cm^3$)**	**Mobility (cm^2/Vs)**	**Resistivity $\times 10^{-2}$ (Ω-cm)**
TF-1	-10.368	6.4	1.04
TF-2	- 5.33	20.6	.83
TF-3	- 3.98	22	.82
TF-4	-6.40	14.1	.95

In Table 2 the negative sign of bulk concentration indicates that bismuth selenide thin films belongs to the n-type. Table -3 results indicates that TF- 3 shows low bulk concentration, low sheet resistance and low resistivity but high mobility among all sample thin films. TF-1 which has lowest composition ratio of Bi/Se has higher bulk concentration, high sheet resistance, high resistivity but low mobility. Bulk concentration of films decreases from TF-1 to TF-3 and becomes down for TF-4. Mobility of films also increases from TF-1 to TF-3 and becomes down for TF-4. Different electric parameters for TF-1 to TF-3 has comes in a manner but becomes change for TF-4. So composition of thin films changes the different electric parameters. Highest mobility is obtained for TF-3 which has 0.182 composition ratio. So among all films TF-3 found best results.

Table 3.Electric parameters of annealed bismuth selenide thin films

Thin film	**Bulk concentration ($\times 10^{19}cm^3$)**	**Mobility (cm^2/Vs)**	**Resistivity ($\times 10^{-2}$ Ω-cm)**
TF-1	-24.8	8.3	0.89
TF-2	-4.44	28.6	0.67
TF-3	-3.06	32.8	0.22
TF+-4	-7.07	19.2	0.45

In Table3 negative sign of bulk concentration is obtained for annealed thin films that revealed that films are n-type semiconductor. Mobility increases fromTF-1 to TF-3 and become down fro TF-4. TF-3 has highest mobility among all. Results of annealed thin films are comes in same manner as they have been achieved in table-2 for as-deposited thin films. Conductivity of different thin films have been show in Fig. 2.

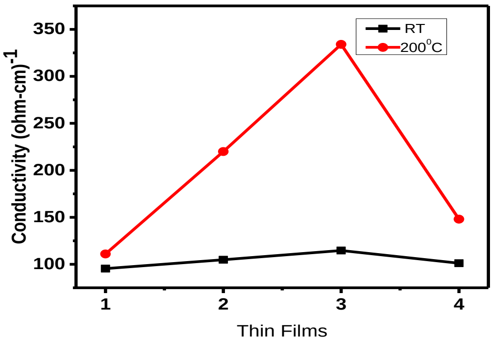

Fig. 2.Conductivity of as-deposited and annealed thin films

As fig-2 indicates that annealed thin films are more conductive than as-deposited thin films. Conductivity increases from TF-1 to TF3 and becomes down for TF-4. Mobility of thin films has been shown in fig-3. As fig-3 indicates that mobility of thin films increases by annealing treatment.

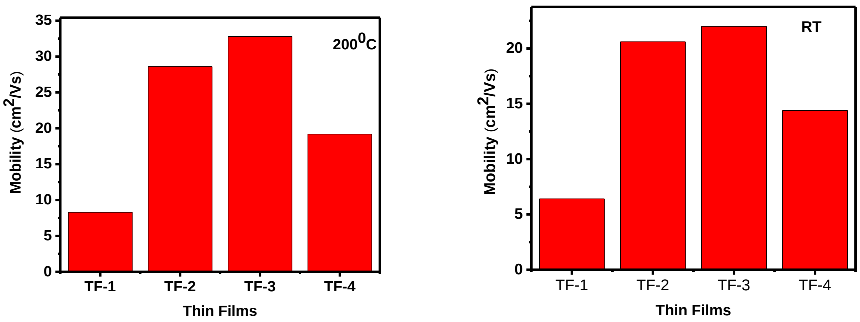

Fig. 3.Bar graphs of as-deposited and annealed thin films

By observing all electric parameters it found that composition of Bi/Se in films change the electric properties. TF-3 has found highest electrical conductivity among all films. So TF-3 which has composition ratio of 0.182 can be used in electric devices and many other electronic applications.

4. Conclusions

In previous research work synthesized Bi_2Se_3 thin films having elemental ratio of 0.66 discussed by researchers but in present work different thin films with different compositional ratios (0.123 to 0.309) of Bi/Se have been prepared on glass substrate by thermal evaporation method. Electric properties of these thin films have been investigated. The main aim of the preparation of four different films is to investigate the effect of compositional variation on the electrical properties and to find out the best stoichimetry out of four different thin films, which could be more applicable in field of electronics. From TF-1 to TF-3 bulk concentration, resistivity decreases but mobility increases. But for TF-4 mobility becomes down. The bulk concentration of thin films are achieved negative in sign, that conclude that thin films are n-type in nature. Moreover electrical conductivity also increases from TF-1 to TF-3. . But TF-4 which has high value of elemental ratio (0.309) of Bi/Se showed low conductivity because of very low concentration of selenium. Out of four thin films, TF-3 which has elemental ratio 0.182 showed good electric results and achieved results indicate that these thin films can be used in electric devices.

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