Study of the Effect of Irradiation on Structural and Electrical Properties of (Bi_2Te_3) Thin Films

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Abstract: The object of this paper was devoted to study the crystal structure of Bismuth Telluride thin films. The X-ray diffraction patterns of powder Bi_2Te_3 showed polycrystalline structure of Hexagonal phase with lattice constants of: a = 4.45 Å , c = 30.47 Å. The X-ray diffraction patterns on Bi_2Te_3 thin films shows that the crystal structure of Hexagonal system and they have prefer orientation (015) and (006). The annealing effect shows an increase in the degree of crystallinity. The effect of gamma irradiation on Bi_2Te_3 thin film was studied at doses of 50,200,500 kGy. The X-ray diffraction patterns of Bi_2Te_3 thin films shows that the degree of crystallization increases as the doses increase. The electrical transport properties such as electrical resistivity ρ was studied for films of different thickness as deposited and annealed samples.
[Fatmah Salem Bahabri and Shoroog Wasel Al-raddadi **Study of the Effect of Irradiation on Structural and Electrical Properties of (Bi_2Te_3) Thin Films**] Journal of American Science 2012; 8(2):175-179]. (ISSN: 1545-1003). http://www.americanscience.org. 27

Keywords: Bismuth Telluride, irradiation, gamma rays, electrical transport properties, energy gap.

Introduction

Bismuth chalcogenides have been of research interest for some time due to their thermoelectric properties. These semiconductor materials have narrow band-gaps, low thermal conductivity, and high thermoelectric figures of merit at room temperature.[1-4] The required carrier concentration is obtained by choosing a nonstoichiometric composition, which is achieved by introducing excess bismuth or tellurium atoms to primary melt or by dopant impurities. Some possible dopants are halogens and group IV and V atoms. Due to the small band gap 0.16 eV. Bi_2Te_3 is partially degenerate and the corresponding Fermi-level should be close to the conduction band minimum at room temperature. The size of the band-gap means that Bi_2Te_3 has high intrinsic carrier concentration. Therefore, minority carrier conduction cannot be neglected for small stoichiometric deviations. Use of telluride compounds is limited by the toxicity and rarity of Tellurium. [5]

Bismuth Telluride based material that are used for power generation or cooling applications must be polycrystalline.[6] Furthermore, the Seebeck coefficient of bulk Bi_2Te_3 becomes compensated around room temperature, forcing the materials used in power generation devices to be an alloy of Bismuth, Antimony, Tellurium, and Selenium.[7]

Recently, researchers have attempted to improve the efficiency of Bi_2Te_3 based materials by creating structures where one or more dimensions are reduced, such as nanowires or thin films[8] . However, one must realize that Seebeck Coefficient and electrical conductivity have a tradeoff; a higher Seebeck coefficient results in decreased carrier concentration and decreased electrical conductivity.[9]

In another case, researchers report that Bismuth Telluride has high electrical conductivity , similar to ordinary glass.[10]

The effects of irradiation with gamma rays, electrons, neutrons and protons on the electrical properties of the compound Bi_2Te_3 have been investigated. These investigations show that the transport properties of Bi_2Te_3 are sensitive to the defects generated during irradiation. It has also been found that some of the defects are mobile at or slightly above room temperature 50^{o}C changed the Hall coefficient and electrical resistivity of specimens of Bi_2Te_3, which had been exposed to gamma radiation; these changes were attributed to the dissociation of interstitial clusters.[11]

The observed grain sizes were approximately 900 nm and 1500 nm for Bi_2Te_3 film of 2.6 μm and 9.8 μm thicknesses, respectively. The X-ray diffraction analysis indicated the presence of rhombohedral (Bi_2Te_3) crystal structures.[12]

2. Sample preparation and measurements:

For this purpose, high purity Bi_2Te_3 is thermally evaporated from molybdenum boat in a vacuum of 10^{-5} Torr, at room temperature, on to glass substrates for structural and electrical transport measurements.

The X-ray diffraction patterns of powder Bi_2Te_3 and thin films samples, with thicknesses of 93nm and 241 nm, were calculated according Bragg`s equation[13], where $\lambda_{CuK\alpha}$=1.5405 nm, to obtained the lattice constants for both powder and thin films.

The effect of film thickness and heat treatment on structural were investigated, for the as-deposited or annealed samples at different temperature for 2h ,at room temperature R.T, 373K and 473K. The effect of gamma irradiation from ^{60}Co- using(GC-220Gamma Cell 220 Excel) from MDS Nordion company. The intensity rate is 11.18566 kGy/hr, on Bi_2Te_3 thin films were studied at doses 50, 200, 500 kGy. The X- ray diffraction patterns of Bi_2Te_3 thin films were studied.

The electrical transport properties such as electrical resistivity ρ was studied using Van der Peau method[13,14], for films of different thicknesses as deposited and with a heat treatment at the above temperatures.

The tow activation energies ΔE_1, ΔE_2 of the free charge carriers for Bi_2Te_3 samples was calculated using the electrical resistivity data at different temperatures from 300-480K, for different thicknesses 93 nm and 241 nm.

3. Results and Discussion:

The X-ray diffraction patterns Fig.1. of powder Bi_2Te_3 showed polycrystalline structural of Hexagonal phase with lattice constants of:

a = 4.45 Å , c = 30.47 Å. This value contrasts with data of other author(1-3).

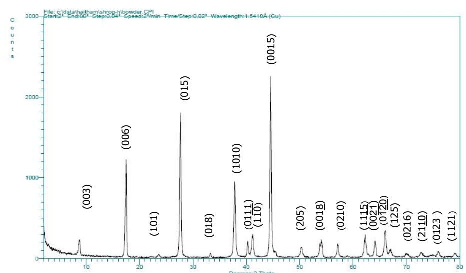


Fig. 1. X-ray diffraction of powder Bi_2Te_3

Hexagonal system and they have prefer orientation (015), (101) and (01<u>11</u>). the annealing effect is increase the degree of crystallinity.

The X- ray diffraction patterns Fig.2. of Bi_2Te_3 thin films of 93 nm and Fig.3. of Bi_2Te_3 thin films of 241 nm thickness, showed that the crystal structural of the effect of gamma irradiation on Bi_2Te_3 thin films showed in Fig.4. of 93nm and Fig.5. of 241 nm thickness were studied at doses 50, 200, 500 kGy, at room temperature and at 373K for 2h. The X- ray diffraction patterns Fig.4. and Fig.5. of Bi_2Te_3 thin films showed that the degree of crystallinity increase as the doses increase.

The electrical transport properties such as electrical resistivity ρ was studied for films of different thicknesses 93nm and 241nm as deposited films. Fig.6. shown the electrical resistivity log ρ of Bi_2Te_3 thin films as a function of temperature$10^3/T$. It was found that the electrical resistivity ρ of Bi_2Te_3 films with temperature from 300 – 480 K is strongly affected by the heat treatment of the samples and film thicknesses. Bi_2Te_3 films showed semiconducting behavior Fig.6. The dependence of electrical resistivity on film thicknesses showed that the electrical resistivity decrease as the film thickness increase.

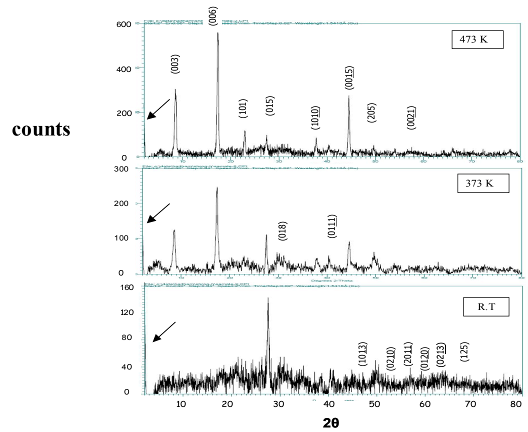


Fig. 2. X-ray diffractogram of Bi_2Te_3 films of 93 nm thickness at different temperature for 2h.

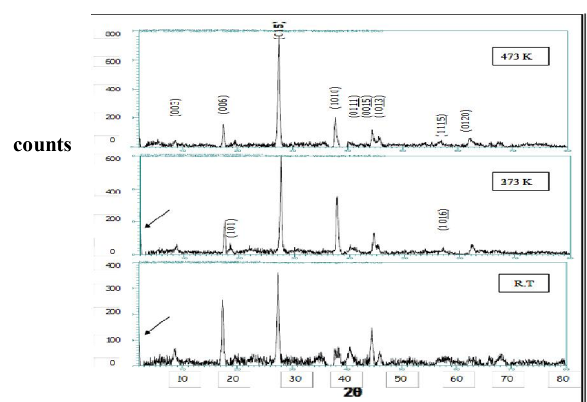


Fig.3. X-ray diffractogram of Bi_2Te_3 films of 241 nm thickness at different temperature for 2h.

The electrical transport properties such as electrical resistivity ρ, was obtained, as:

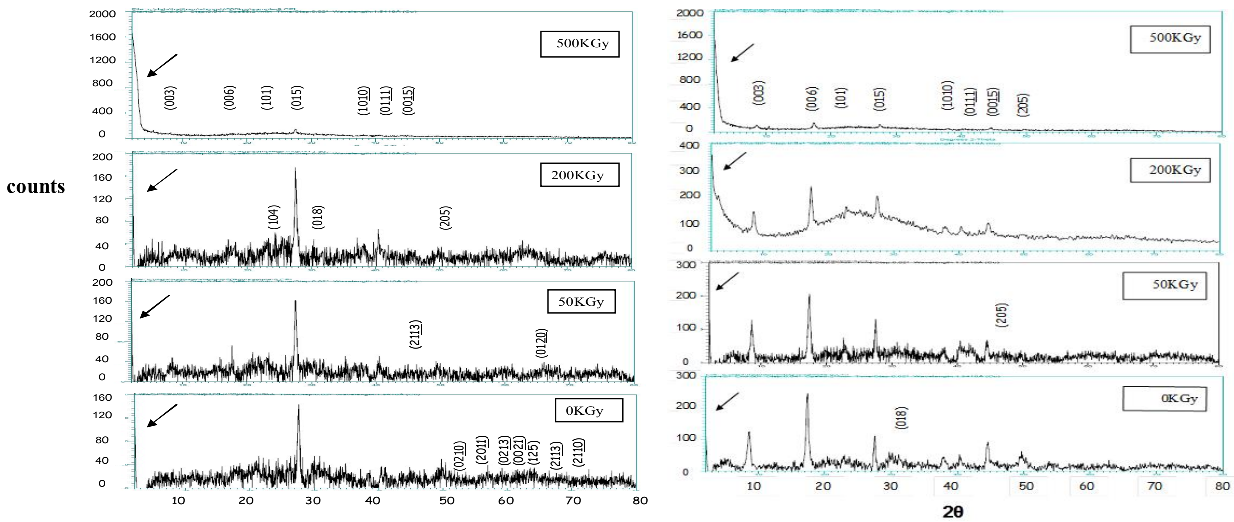
$$\rho_T = \rho_B \exp \{(\Delta E_1+\Delta E_2) / KT\} \quad (1)$$

Where: ρ_T is the electrical resistivity at T temperature, ρ_B is the balk electrical resistivity, K is Boltzmann constant and ΔE_1, ΔE_2 are the tow thermal activation energies of the free charge carriers for Bi_2Te_3 samples were calculated using the electrical resistivity data at different temperatures for different thicknesses.

At the low temperature regions the relation between the temperature and electrical resistivity ρ can be given as:

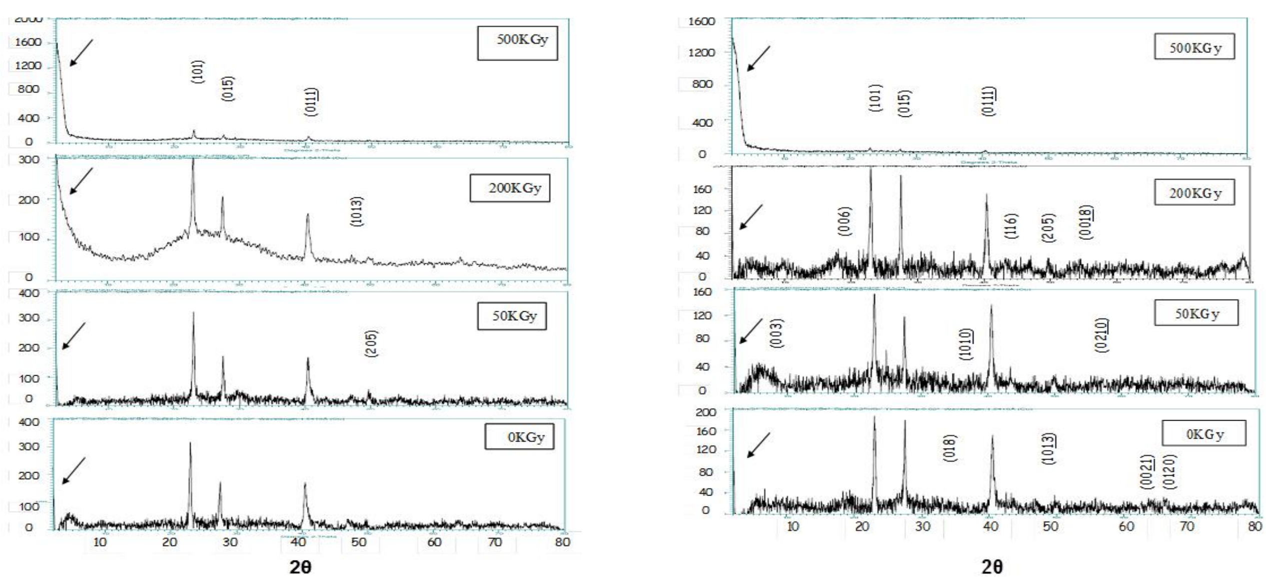
$$\rho = \rho_o \exp\left(E_g / 2KT\right) \quad (2)$$

Where ρ_o is the pre-exponential factor and E_g is the energy gap, $E_g = 2\Delta E_1$ of the ionization energy of donor atoms. This is observed in the temperature interval 300 - 416 K and E_g was found to be 0.3140 eV for 93 nm film thickness and 0.1994 eV for 241 nm film thickness .



At room temperature **at 373K**

Fig.4. X-ray diffractogram of Bi_2Te_3 film thickness 93 nm of various irradiation at different temperatures.



At room temperature **At 373K**

Fig.6. Electrical resistivity log ρ of Bi_2Te_3 thin films as a function of temperature$10^3/T$.

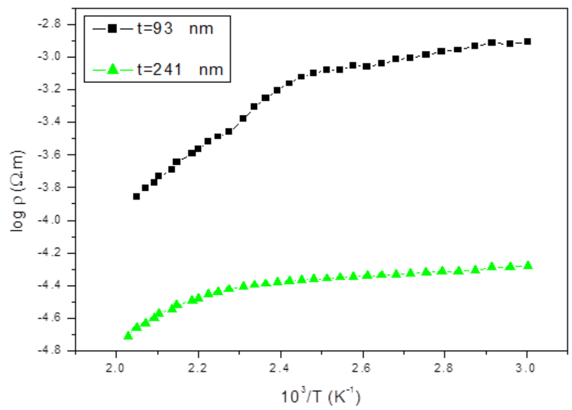


Fig.6. Electrical resistivity log ρ of Bi_2Te_3 thin films as a function of temperature$10^3/T$.

It is also seen from the curve that the resistivity ρ decrease rapidly as the temperature rises because of the decrease in the total current density (electrons plus holes). The calculated energy gap width in the present work is larger than that reported in the literature[1-3]. We may attribute the discrepancy between the values of E_g partially to the presence of the large number of intrinsic defects that affects strongly the motion of scattering of current carriers and phonons. The calculated energy gap width in the present work is larger than that reported in the literature.

Fig.7 represents the temperature dependence of the electrical resistivity ρ of Bi_2Te_3 samples. Measurement of the effect of temperature on electrical resistivity ρ was done from 333K to 440 K.

As shown in Fig.7. The dependence of electrical resistivity of the tow activation energies ΔE_1 at high temperature which express the mechanism of intrinsic electrical conductivity and ΔE_2 at low temperature which express the mechanism of extrinsic electrical resistivity.

From Fig.7. the free charge carriers for Bi_2Te_3 samples was calculated using the electrical resistivity data at different temperatures for 93 nm and 241nm thicknesses were found that the activation energies decreases as the film thicknesses increases.

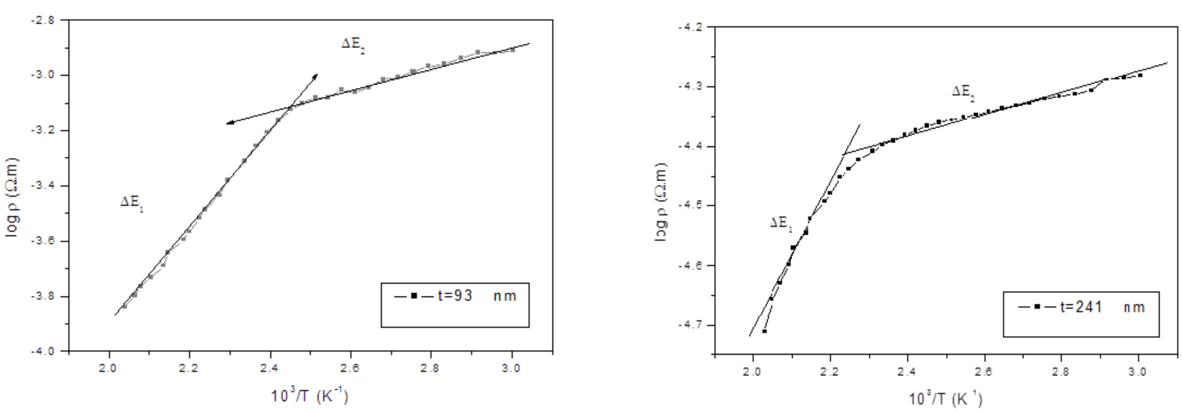


Fig.7. The tow activation energies $\Delta E_1$and ΔE_2 from the dependence of electrical resistivity .

The curve shows a typical semiconductor behavior. As illustrated in the figure.7 and Table.1. The activation energies calculated from these graphs decreases with increasing thickness in the range of 0.16 – 0.01 eV. This decrease in activation energy with film thickness may be due to the change in the barrier height, which is due to the change of crystallite size in the films a much rapid increase in resistivity is observed in the high temperature range with a linear relation between 415K to 490K. After this region the electrical resistivity exponentially increases with a relatively speed rate in the temperature range extending from 340K up to 415K, a rapid increase in the resistivity with linearity is observed in the low temperature range above 400K.

Table.1. The two activation energies and energy gap of Bi_2Te_3 samples

t(nm) Film thickness	ΔE_1(eV) Activation energy	E_g(eV) Energy gap	ΔE_2 (eV) Activation energy
93	0.1570	0.3140	0.0338
241	0.0997	0.1994	0.0125

It can be stated that the room temperature resistivity reaches a values of $\rho = 2.92$ Ω.m and 4.28 Ω.m. In the extrinsic region ρ decreases slowly as a result of liberation of the ionized donors and their transition from the impurity level.

4. Conclusion:

The work reported here is part of an investigation of the effects of irradiation with gamma on the compound Bi_2Te_3.The X- ray diffraction patterns of Bi_2Te_3 thin films of different thicknesses showed that the crystal structural of Hexagonal system and they have prefer orientation (015),(101) and (0111). The annealing out of defects during irradiation doses were considered to be one of the reasons for this difference. The structure of the compound Bi_2Te_3 is Hexagonal system . The annealing and irradiation doses effect are increases the degree of crystallinity of Bi_2Te_3 thin films as they increases.

Measurements of the electrical resistivity in a wide range of temperatures extending from 160 – 440 K was reported. The main conclusions were:-

1. Bi_2Te_3 thin films are a promising n-type semiconductor.
2. The two energy gap for the compound are 0.3140 eV and 0.1994 eV, while the activation energies of donors are 0.1570 eV and 0.0997 eV.

This study is a timely one in view of the recent interest in this compound. The important parameters deduced from this study leads to better applications in electronic devices and techniques.

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References

1. Chung Hogan. D.Y, Schindler T, Iordarridis. J, Brazis. L., Kannewurf. P, Baoxing Chen Uher. C.R and Kanatzidis. C., (1997), 16th International Conference on Thermoelectrics , pp. 459-462.
2. Dheepa. J, Sathyamoorthy. R and Velumani. S, (2007) "Characterization of Bismuth Telluride Thin Films – Flash Evaporation Method". J. Mate. Cha. Vol. 58, Issu 8-9, pp.782 – 785.
3. Santosh. G., Arora. M, Sharma. R. K., and Rastogi. A. C., (2003). J. current Applied Physics. Vol.3. Issu 2-3, pp.195 – 197.
4. Desalegne Teweldebrhan, Vivek Goyal, Muhammad Rahman, and Alexander A. Balandin, (2010). "Atomically-thin crystalline films and ribbons of bismuth telluride". J. Appl. Phys. Lett. 96, Issue 5-053107; doi:10.1063/1.3280078.
5. Venkatasubramanian. R., Silvoia. E., Colpitts. T, and O'Quinn. B., (2001), Nature pp.413, 597.
6. Saji. A, Ampili. S, Yang. S-H., Ju . K.J., and Elizabeth. M, (2005),. J. Phys. Condens. Matter 17, pp.2873.
7. Satterthwaite. C .B. and Ure. R, (1957) "Electrical and Thermal Properties of Bi_2Te_3". Phys. Rev. 108 (5): 1164. doi:10.1103/ Phys Rev , pp.108.1164.
8. Tan. J, (2005) "Thermoelectric properties of bismuth telluride thin films deposited by radio frequency magnetron sputtering". Proceedings of SPIE. 5836, pp. 711. doi:10.1117/12.609819.
9. Goldsmid. H. J., Sheard. A. R., and Wright. D.A (1958). "The performance of bismuth telluride thermojunctions". Br. J. Appl. Phys. 9 (9), pp. 365. doi:10.1088/0508-3443/9/9/306.
10. Takeiishi . M., (2006) "Thermal conductivity measurements of Bismuth Telluride thin films by using the 3 Omega method". The 27th Japan Symposium on Thermophysical Properties, Kyoto. Archived from the original on 2007-06-28. Retrieved 2009-06-06.
11. Tan.J, Kalantarzadeh. K, Wlodarski. W, Bhargava. S, Akolekar. D, Ho-lland. A and Rosengarten.G., (2005). Smart Sensors, Actuators, and MEMS II. Edited by Cane, Carles; Chiao, Jung-Chih; Vidal Verdu, Fernando. Proceedings of the SPIE, Volume 5836, pp. 711-718.
12. C. Julien, M. Eddrilf, M. Balkanski, E. Hatzikraniotis and K. Kambas, (1985) Phys. Stat. sol. 88, pp. 687.
13. Kireev. P., (1975) The Physics of Semiconductors, editions MIR, Moscow.
14. Satterthwaite. C.B., and Ure. R., (1957). "Electrical and Thermal Properties of Bi_2Te_3". Phys. Rev. **108** (5): 1164. doi:10.1103/PhysRev.108.1164

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