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A STUDY OF ELECTRICAL PROPERTIES OF Bi_2Te_3 THIN FILMS

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ABSTRACT

The films of Bi_2Te_3 are prepared by thermal evaporation technique on glass substrate. The study of thermoelectric and electrical properties of Bi_2Te_3 thin films have been carried out in the thickness range 50 – 360 nm and temperature 295 – 373^0 K. The dc activation energy for the planar and sandwich devices lie in the range of 0.04 – 0.17 eV. The dc high field results have been interpreted in the light of Poole – Frenkel emission model. The Hall co-efficient and thermoelectric power results suggest p-type nature of Bi_2Te_3 thin films.

Keywords: Thin films, thermal evaporation, vacuum deposition.

1. INTRODUCTION

The contributions of thin films technology [1-3] make the present world a global village. Thin films technology is an important special branch of physics in which the characteristics of different metals, semiconductors and insulators are investigated in thin films form. The investigation of the characteristics of metals, semiconductors and insulators in thin films form is very important because the characteristics of the films are quite different from their bulk values. Most of the electronics equipments in the modern world are the contribution of thin films technology. The technological importance of thin films is reflected in the fundamental study of their physical properties. Thin films are widely used in today's technology and their applications are expected to be even more wide spread in the near future. Thin films exhibit different electrical, optical, mechanical, structural and magnetic properties than their corresponding bulk bodies. These different characteristics of thin solid films from bulk materials are very important for applications of thin films and hence their properties must be studied before their applications. If we know the properties of thin films, then we can choose the field of its applications.

2. EXPERIMENTAL

The films of Bi_2Te_3 were prepared by thermal evaporation technique [4-5] using Edwards E-306A high vacuum coating unit. Resistively heated Molybdenum (Mo) source in the form of boat was used for evaporation of Bi_2Te_3. Well shaped mask was placed on the substrate of which films was grown and the substrate-mask couple was clamped with the holder about 7 cm apart from the source. When the required vacuum was obtained ($\sim10^{-6}$ Torr), then the source was heated by passing current of about 18 ampere through the source. The evaporation of Bi_2Te_3 was started after a certain period of time. A shutter was placed between the source and the substrate and it was removed when the evaporation of Bi_2Te_3 seemed to be uniform. Varying the deposition time, chamber pressure, source to substrate distance and source temperature, different thickness of films were prepared. The electrical properties of thin solid films depend on films thickness [6] and care was taken during films thickness measurement. In the present work, optical interference fringe method was used for films thickness measurement. To make ohmic contact, lead was attached with the films by using silver paint (Leading silver D 2000). Here one end of a fine copper whisker was placed on the films and a small drop of silver paste was fell onto fine wire and after a period of time the fine wire was attached with films and make electrical contact.

3. RESULTS AND DISCUSSION

The I-V characteristics for as-deposited and annealed films of Bi_2Te_3 in planer form for different thickness are shown in Fig 1(a) & 1(b). The pattern of I-V graphs for both as-deposited and annealed films are almost similar. It is seen from the graph, smaller the Bi_2Te_3 film thickness, lower the current flowing through the films. After annealing, the current flowing through these device has decreased in a greater extent. The decrement of the current in the annealed devices due to the minimization of the structural defects of these devices. The temperature dependence of I-V characteristics for both as-deposited and annealed films also investigated. It is evident that electrical conductivity increases with temperature. The temperature variation of electrical conductivity is less in annealed devices. The increase of electrical conductivity with temperature indicates the nonmetallic character [7] of these Bi_2Te_3 thin film devices.

The I-V characteristics of as-deposited and annealed Cu - Bi_2Te_3 - Cu sandwitch devices for different Bi_2Te_3 film thickness are shown in Fig 2(a) & 2(b). The pattern of the I-V graphs for both as-deposited and annealed devices are almost similar. It is observed from the graphs that the device current increase with Bi_2Te_3 film thickness. The I-V graphs show that the resistivity of the annealed devices have increased. The interesting feature of the I-V characteristics is that they are non-ohmic under high electric field conditions. The effect of temperature on the I-V characteristics of Cu - Bi_2Te_3 - Cu sandwitch devices of different thickness for both as-deposited and annealed films are observed. It is seen that the device currents are strongly dependent on temperature. It is also observed that the temperature did not affect the non-linearity of the I-V characteristics in the high electric field region.

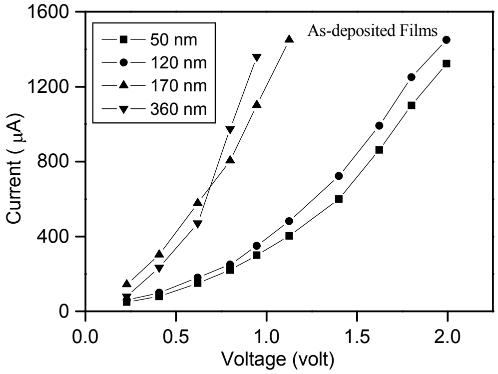

Fig 1(a): I-V characteristics of as-deposited Bi_2Te_3 thin films for different thickness at room temperature.

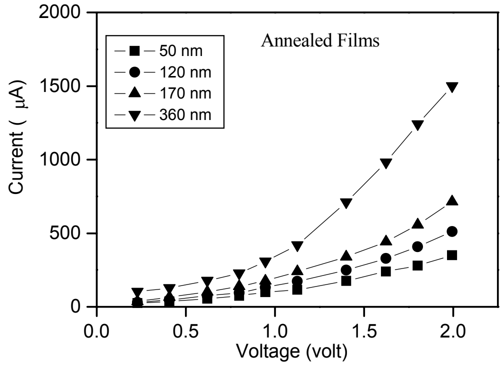

Fig 1(b): I-V characteristics of annealed Bi_2Te_3 thin films for different thickness at room temperature of annealing temperature 373^0K and annealing period 1 hour.

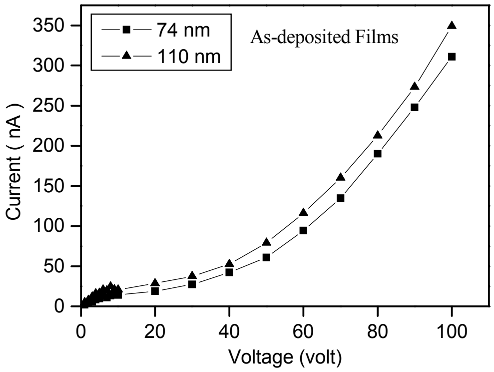

Fig 2(a): I-V characteristics of as-deposited Cu-Bi_2Te_3-Cu sandwich device for different Bi_2Te_3 film thickness at room temperature

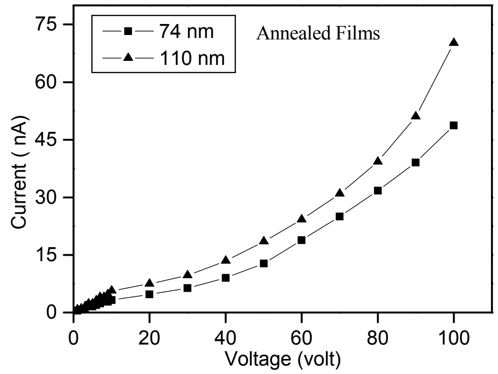

Fig 2(b): I-V characteristics of as-deposited Cu-Bi_2Te_3-Cu sandwich device for different Bi_2Te_3 film thickness at room temperature of annealing temperature 373^0K and annealing period 1 hour

The non-ohmic behavior of Metal-semiconductor-metal devices under high electric field condition may be explained generally by Schottky emission or Poole Frenkel emission model. Firstly the I-V characteristics are tested by Schottkey emission model. The main features of this model are : (i) The activation energy for Schottky emission should normally be greater than 0.8 eV. But in our experiment, the dc activation energy for the planer and sandwitch devices lie in the range of 0.04 to 0.17 eV which are far below from 0.8 eV. (ii) The Shottkey emission theory requires that the extrapolation of I versus $E^{1/2}$ graph for same cathode materials and for various thickness should pass through a single point at V equal to zero. This is not observed in the present case Fig 3(a) & (b). (iii) IT^{-2} versus T^{-1} graph for different fixed biases are expected to be linear for Shottky emission model. This has not been seen in the present investigation Fig 3(c) & (d).

In the light of these strong reasoning, it may be concluded that Shottkey emission model is inapplicable to explain the dc high field results. The experimental data are then tested by Poole-Frenkel emission model. According to this model the plot of IE^{-1}versus $E^{1/2}$ at particular device temperature should be straight line. It is seen from the graph depicted in Fig. 3 (e) & (f) that this relation is satisfied.

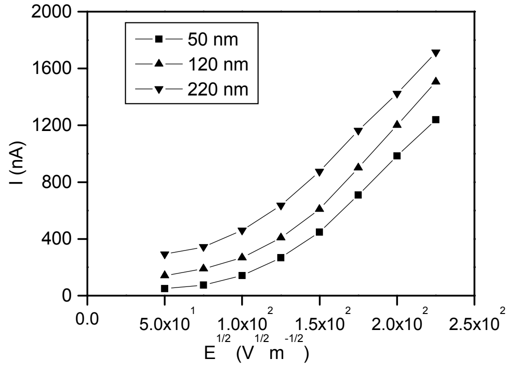

Fig 3(a): I vs $E^{1/2}$ graph for Bi_2Te_3 planar device at room temperature.

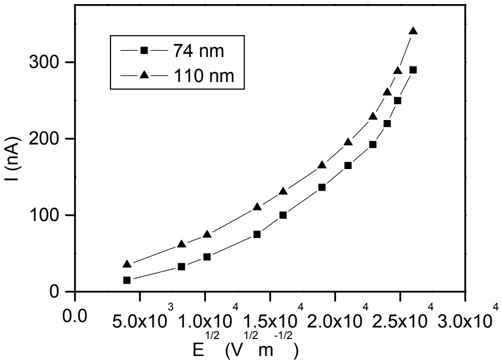

Fig 3(b): I vs E1/2 graph of Cu-Bi2Te3-Cu sandwich device at room temperature.

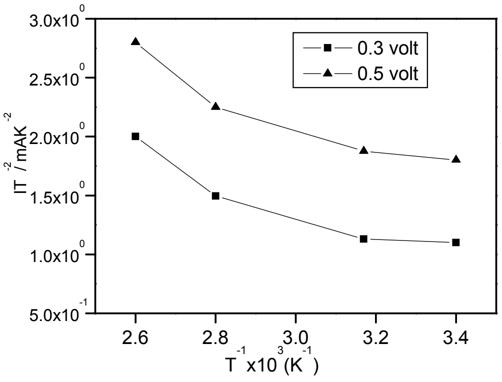

Fig 3(c): IT $^{-2}$ vs T $^{-1}$ graph for Bi_2Te_3 planar device at two fixed biases.

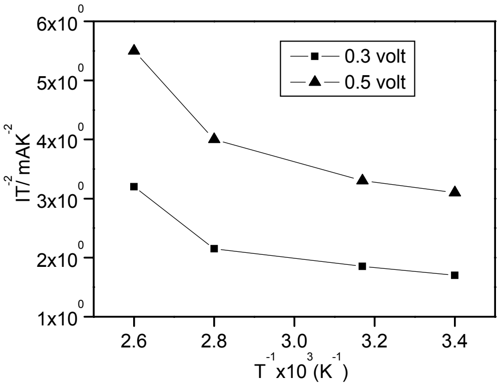

Fig 3(d): IT $^{-2}$ vs T $^{-1}$ graph of Cu-Bi_2Te_3-Cu sandwich device at two fixed biases

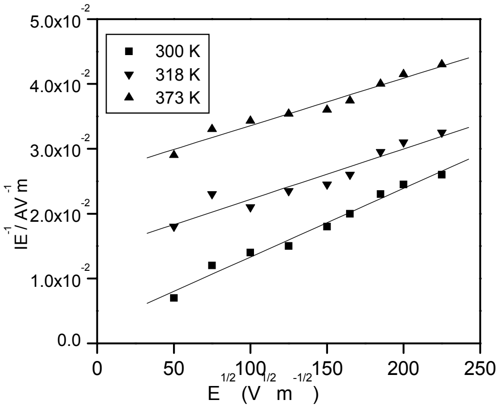

Fig 3(e): IE $^{-1}$ vs $E^{1/2}$ graph for Bi_2Te_3 planar device at various temperatures.

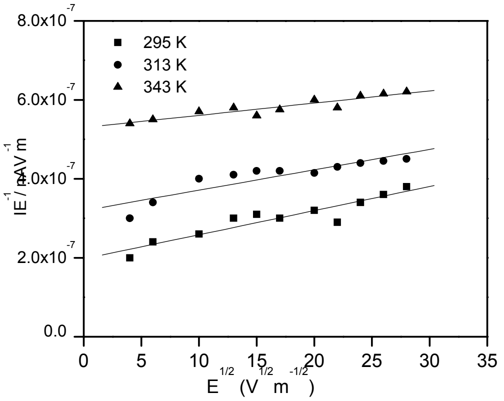

Fig 3(f): IE $^{-1}$ vs $E^{1/2}$ graph for Cu-Bi_2Te_3-Cu sandwich device at various temperatures

In AC measurements, the variation of capacitance with frequency was investigated in the frequency range 0 to 100 KHz. Capacitance versus frequency for as-deposited and annealed Cu - Bi_2Te_3 - Cu devices at room temperature are shown in Fig. 4(a) & (b). It is seen that all the curves follow the similar pattern. Capacitance is found to decrease with increasing frequency of the applied ac signal. But the values of capacitance are higher for the annealed device. It is also seen from the graph that the device capacitance decrease with the increase of thickness of Bi_2Te_3 films for both as-deposited and annealed devices. The decrease of capacitance with frequency can be explained in the following manner. In the lower frequencies all the polarizing mechanisms such as atomic dipolar and electronic respond to the applied ac field as a result the capacitance of the device will be higher but at a higher frequencies some of the mechanisms such as atomic and dipolar are incapable of responding the applied ac field. As a result there appears a phase difference between the applied field and the polarization, which in turn decreases the capacitance of the devices. This increase of capacitance in annealed devices is due to the heat treatment

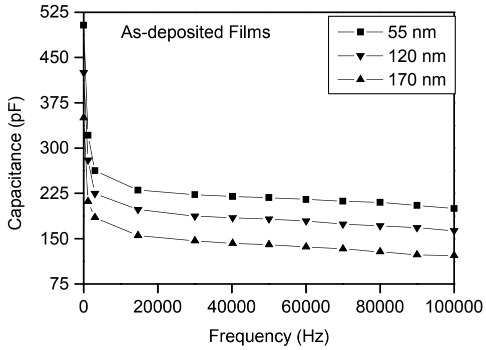

Fig 4(a): Capacitance vs frequency graph for as-deposited Cu-Bi_2Te_3-Cu device at 300^0K.

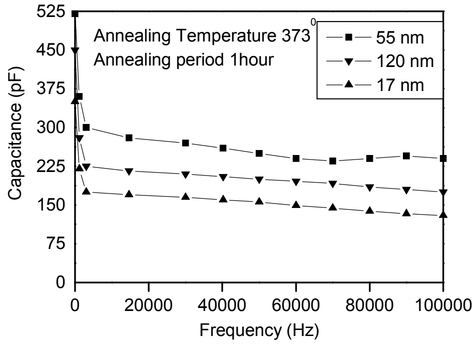

Fig 4(b): Capacitance vs frequency graph for annealed Cu-Bi_2Te_3-Cu device at 300^0K.

The TCR measurement were carried out by measuring the resistivity of the asdeposited and annealed devices with reference to the room temperature resistivity. The estimated TCR were all negative which indicate that the Bi_2Te_3 devices are all nonmetallic.

The thermal activation energy for as-deposited and annealed films was measured. It is found that this value lie in the range 0.04 to 0.10 eV for as-deposited films and 0.08 to 0.17eV for annealed films. Lower is the film thickness, higher is the activation energy.

The Hall effect measurement was carried out in both as-deposited and annealed Bi_2Te_3 thin films. The variation of the Hall coefficient, carrier mobility and carrier concentration are shown in Fig. 5(a), 5(b) & 5(c) respectively.

It is seen from the Fig. 5(a) that the Hall coefficients vary with thickness of the Bi_2Te_3 thin films. In as-deposited case, the Hall coefficient is found to decrease with film thickness. The measured values of the Hall coefficients lie in the range $9x10^{-3}$ to $1.5x10^{-2}$ cm^3/coul for as-deposited films and $2.4x10^{-2}$ to $3.7x10^{-3}$ cm^3/coul for annealed films. In the case of as-deposited films, the Hall coefficients decrease with increase of thickness but in the case of annealed films the Hall coefficients first decrease with the increase of film thickness but after a certain thickness of the film, becomes almost constant. This variation is consistent with the theoretical model for Hall effect. According to the model, the value of Hall coefficient decrease with the increase of the carrier mobility and carrier concentration.

It is seen from the Fig. 5(b) that the carrier mobility increase with the film thickness. This increase may be partly due to size effect as well as effect of structural defects. The measured carrier concentration is holes as confirmed by the hall coefficient measurements Fig.5(c) gives the variation of these carrier concentration with thickness. The carrier concentration is seen to increase with thickness. Dug [8] reported that trapping of holes occurs near the edge of dislocations. The vacuum deposited films are always associated with structural defects. The thickness dependence of carrier concentration may be due to the fact that this trapping of holes is dominant in thinner films than that of thicker films.

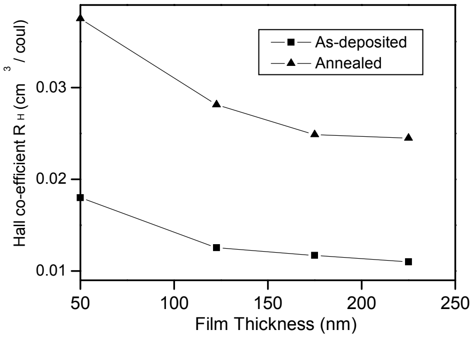

Fig 5(a): Hall co-efficient vs film thickness at room temperatures.

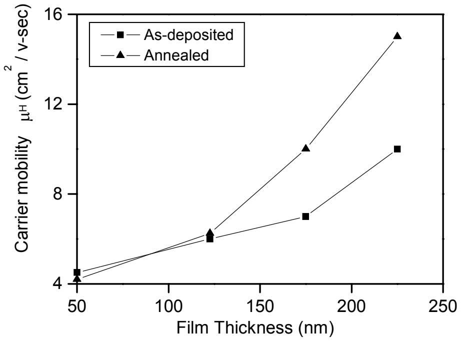

Fig 5(b): Carrier mobility vs film thickness at room temperatures.

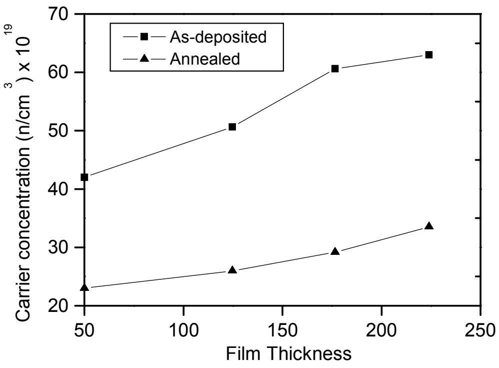

Fig 5(c): Carrier concentration vs film thickness at room temperatures

4. CONCLUSIONS

All the planer and sandwich device exhibit non-ohmic behavior under high field conditions which is satisfactorily explained Poole Frenkel emission model. The TCR for both as-deposited and annealed Bi_2Te_3 films found to be negative and this result indicates that Bi_2Te_3 is a non-metal. Annealing effect has profound influence on electrical properties of Bi_2Te_3 thin films. It is observed that both for planer and sandwich devices the resistivity increases after annealing. This is due to the minimization of structural defects. The activation energy of as-deposited Bi_2Te_3 thin films is found to lie in the range 0.04 to 0.1eV and for annealed films, it varies from 0.08 to 0.17 eV. The variation of capacitance is consistent with the theoretical model. The Hall effect measurement on these films show a positive hall coefficient. This indicates that the samples are P-type in nature.

5. ACKNOWLEDGEMENT

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6. REFERENCES

1. L.I.Maissel & R.Glang (1970), "*Handbook of thin film technology*", p1-38.
2. K.L.Chopra (1969), "*Thin Film Phenomena*", Mc Graw-Hill Book Company, NewYork.
3. K.L.Chopra (1966), *J.Appl.Phys*., **37** p2249.
4. W.H.Kohl (1967), *"Handbook of Materials and Techniques for vacuum devices*", Reinhold Publishing Corporation , New York.
5. J.L.Vossen & W.Kern (1978), "*Thin Film Process*" Academic Press, Orlando.
6. L.Holland (1956), "*Vacuum Deposition of thin films*", John Wiley & Sons, Inc., New York.
7. C.Kittel (1988), "*Introduction to solid state physics*", 5th edition.
8. J.J. Duga, *J.Appl.Phys*., **33** p169