Journal of Ovonic Research Vol. 12, No. 3, May - June 2016, p. 129 - 136

NEGATIVE RESISTANCE CHARACTERIZATION AND MEMORY PHENOMENA OF THE BINARY CHALCOGENIDE INDIUM POLYTELLURIDE CRYSTAL

K. A. QUHIM[a], A. T. NAGAT[b], S. A. HUSSEIN[c], S. E. ALGARNI[b], S. R. AL – HARBI[b], A. A. EBNALWALED[d*]

[a]*Physics Department, College of Education for Girls in Namas, King Khaled University – KSA*

[b]*Physics Department, Sciences of Faculty for Girls, King Abdulaziz University – KSA*

[c]*Physics Department, Faculty of Sciences, South Valley University, Qena 83523, Egypt*

[d]*Electronics & Nano Devices lab, Physics Department, Faculty of Sciences, South Valley University, Qena, 83523 Egypt*

Indium polytelluride crystals were used in the present work. Samples were prepared by a special modified Bridgman technique with high quality. The observation of switching and memory phenomenon in this compound and the present study is the first for In_2Te_5. In this investigation we study Ag - In_2Te_5 – Ag structure in sandwich form. The current - voltage characteristics (CVC) of this compound exhibit two distinct regions high resistance OFF state and low resistance ON state having negative differential resistance (NDR) with S – type characteristics. The experimental results indicate that the phenomenon in our sample is very sensitive to temperature, light illumination and sample thickness. The switching parameters were cheeked under the influence of different factors of the ambient conditions. Possible explanations are mentioned.

(Received January 4, 2016; Accepted May 24, 2016)

Keywords: Switching and memory effect, S – type, CCNR, Binary chalcogenide In_2Te_5.

1. Introduction

In recent years, chalcogenide materials have received a lot of attention because of their potential and current use in various solid-state optical and electrical devices. Both selenium and tellurium are expected to be the important semiconductor elements, because of their possible application in the fabrication of semiconductor devices. There is a rapidly growing interest in the electrical properties of crystalline semiconductor due to their unusual properties which makes them promising materials for future device. Single crystal semiconductors have important practical applications in technology. Creation of more effective and different solid-electronic devices is limited by our knowledge of physical properties of different mono-binary and polyatomic semiconductors in mono crystalline states. Research on binary semiconducting compounds formed by elements from group (III) and (VI) of the periodic table ($A^{III}B^{VI}$) compounds as a collective group of materials have been and are still the subject of much intensive investigations. In the last few years widespread attention has been paid to the semiconductors of the $A^{III}B^{VI}$ group. This is connected with the use of these semiconductors as the basis materials for developing heterojunction, Schottky barriers and metal dielectric semiconductor structure represent a growing interest for electronic engineering. Indium telluride is useful as material for electronics and optical recording.

The phase diagrams of the In-Te system were studied by many authors [1, 2] and InTe, In_2Te_3, In_2Te_5 and In_4Te_7 compounds were claimed to be formed in the In-Te system under

[*]Corresponding author: kh_ebnalwaled@yahoo.com

standard conditions. In_2Te_5 is a member of this family, has interesting properties. There are some works devoted to In_2Te_5 [3, 4]. However, up to author's knowledge no systematic investigation has been carried out on the switching properties of the In_2Te_5 semiconductor compounds. Binary $A^{III}B^{VI}$ and ternary $A^{III}B^{VI}C^{VI}$ compounds exhibit many nonlinear effects in electrical behavior, such as S-shaped characteristic in negative differential resistance region (NDR), switching and memory effects, polarization and depolarization effects [5, 6]. The knowledge of the nature of the switching effect in materials of different kinds is important for the determination of the actual mechanism controlling this effect. However, the published mechanism is insufficient. In view of the absence of published observations of these phenomena in this compound, the authors under took such work and report here the results of switching effect and some factors affecting it for the first time. This lead to estimate potential applications of these materials in electronic device technology.

2. Experimental details

2.1 Apparatus and method of crystal growth.

The compound In_2Te_5 was prepared by direct melting of the elements taken in stoichiometric ratio and placed in a sealed quartz ampoules evacuated to about 10^{-6} Tor. The silica tube has a constricted shape end at bottom to facilitate seeding in the growth process. The quartz ampoule was washed with pure alcohol and hot distilled water, then coated with a thin layer of graphite to prevent contamination of the charge on the internal surface of the ampoule. Individual components were weighed to a within 10^{-4}gm using electric balance (Sartorius mark). The furnace has three section permitting creating of the desired temperature along the charged cell, which is a quartz ampoule 20 cm long filled with the substance in question. For In_2Te_5 the ampoule is charged with the required amount of material 13.2336 gm of pure indium (Aldrich Mark 99.999%) representing 26.4672% and 36.7664 gm of pure tellurium (Aldrich Mark 99.999%) representing 73.5328%. At the beginning of the growth run, the ampoule was held in the hot zone of the furnace at 510^{o}C to about 24 h for melt homogenization. Then the melt was shaken during heating several times to accelerate the diffusion of the constituents through each other. The mechanical system is always used to draw the charged ampoule from zone to another with the required rate. The rate of propagation of the crystallization front was 0.2 cm/h. The temperature of the middle zone is 467^{o}C corresponding to the crystallization temperature of In_2Te_5 according to the phase diagram [2]. The duration time for producing In_2Te_5 single crystal is about 20 days. With the design described previously [7]. A crystal with 1.49 cm diameter and 8 cm length with a high degree of perfection was produced. Ingot had a plate-like habit with metallic bright color in good agreement with the published description of the ingot [8]. X-ray analysis was used to identify the crystalline ingot. The results indicates that the compound is In_2Te_5 and the compound consist of single phase with tetragonal lattice, has lattice parameters a=13.57 Å and c=4.39 Å. The results were in good agreement with published values

2.2 Experimental arrangement for switching effect measurements

To study the switching phenomena of bulk specimen, the sample was prepared in a rectangular shape and placed in point contact flat copper sheets fixed on a rectangular block of insulting material (perspex).

A bras screw fixed in midpoint of the copper sheet faces, acts as point electrodes. The bras screw can be moved gently to make light pressure contact on the specimen, more details of the sample holders were described early [9]. The sample with its holder was positioned in a special evacuated system to control the temperature in the investigated range. Silver paste was applied in the opposite parallel surface of the sample. The investigation was carried out in wide range of temperature in order to show the influence of an ambient temperature in switching behavior. In order to investigate the effect of light intensity in the switching phenomena at room temperature, sample with appropriate thickness are mounted in a cryostat equipped made of quartz glass with suitable flat portion and clamped in its holder provided with apertures to allow the passage of radiation. Details of the apparatus and cryostat described elsewhere [10]. We used a simple circuit consisted of a digital DC stabilizer programmable power supply. Thermo EC type with accuracy better than 1% of set value, digital keithley electrometer 617, sample and load resistance were connected in series. The sample was connected in parallel into a sensitive voltmeter for measuring the potential difference across its ends. The values of the current and potential across the sample were recorded when the bias was increased until the threshold value of the electric field was reached. Switching from the high to the low resistivity state took place in the crystal. After which the series resistor limited the applied voltage for preventing crystal destruction. Samples with thickness varying from (3.75 mm - 1.5 mm) were used to investigate the influence of sample thickness on switching characteristics, details of the experimental procedures and apparatus were published earlier [11].

3. Results and discussion

In the present study, we investigate the switching phenomena of the binary chalcogenide in a sandwich type Ag- In_2Te_5- Ag structure.

Fig. 1 shows the I-V characteristic of In_2Te_5 crystal under static DC condition. The figure representatives the general behavior of the current controlled negative resistance (CCNR).

The figure shows an illustrative example for state I-V curve for In_2Te_5 which represents a typical memory switch like GaSe [10], $TlGaS_2$ [12] and $Tl_2GaInTe_4$ [13]. From this figure the first branch is called OFF state (with high resistance) of the switch.

It's observed that with increasing the applied voltage the current increases slowly from the first branch of the I-V curves called the off-state with high resistance at a certain value of applied voltage, called threshold switching voltage V_{th}, a sudden increase in the current and consequent decrease in voltage take place in a very short time = 10^{-9} sec, i.e. switching occurs through the load line, along which current and voltage readings cannot be recorded, this part of the curve representing the ON state with low resistance. The parts of I-V characteristic exhibiting negative slope is NDR and usually it's width ,shape, threshold voltage ,threshold current values, holding voltage and current are the main characteristic features of this region.

As we seen that initially in the high resistance (OFF state), the voltage across the sample varies ohmically with current, but near a critical voltage V_{th} (corresponding to critical current I_{th}) the characteristic becomes nonlinear.

Afterword the sample goes into a state of lower resistance. This state is maintained even without any energy being applied to the sample. A current pulse of about 2.1 mA amplitude can bring the sample to its original state of high resistance. At V_{th} the sample exhibit a negative resistance behavior which leads to a low resistance (ON state) region. In ON state the I-V characteristic is nearly linear and the dynamic resistance is almost zero. The general behavior of the CVC for virgin sample of In_2Te_5 single crystal has the S-type I-V characteristics as given schematically in Fig. 1, where it can be seen that the process take place with both polarities on the crystal and has symmetrical shape with respect to the reversal of the applied voltage and current. When the applied voltage exceeds some critical voltages of potential V_{th} the unit switches along the load line to the conduction state. As the crystal goes into the conduction state, it remains there even if it taken away from the circuit. A highly conduction state is retained in the absence of voltage for an indefinite time, which is important in data storage. The process can be repeated several times. The memory switching phenomenon is an effect which follows a negative resistance process. The form of the I-V characteristic suggests that the memory effect is composed of two processes:

(1) An electronic process which brings the sample into an s-type negative resistance zero. This process seems to be due to a double injection phenomenon [14].

(2) A thermal effect which is caused by the current previously canalized in the filament. There will be a Joul heating effect in the filament due to the high current in the device and the temperature rise so produced is sufficient to form the mono state ON state. The ON state switching can be included by (a) a sharp increase in carriers' concentration (b) a sharp increase in mobility

(c) sharp increase in both. It was found that the reversing of the voltage applied on the sample resulted to the same behavior indicating that the silver paste formed an ohmic contact with the investigated sample.

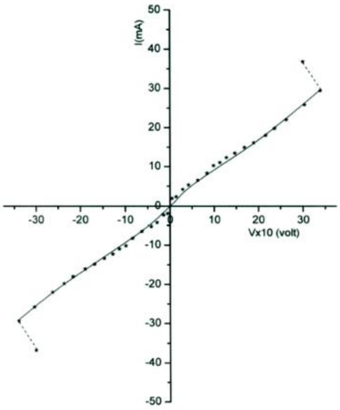

Fig. 1 Current-Voltage characteristic (CVC) of In_2Te_5 in case of forward and reverse biased

3.1 Temperature dependence of switching properties

The temperature dependence of the current - voltage characteristics (CVC) in the temperature range of 173-353 k for p-type In_2Te_5 was investigated. Fig. 2 depicts the temperature dependence I-V characteristic curves for In_2Te_5 crystals. As seen from these curves, there are two distinct regions in the I-V characteristics one is the off-state region and the other is NDR region. As it is evident from Fig. 1 and as predicted by the electrothermal model [12], the ambient temperature greatly influences both the form of the I-V curves and the threshold voltage V_{th}, that is, there is a weaker appearance of the NDR region of I-V characteristics at the higher ambient temperature. The observed strong temperature dependence of V_{th} can be understood in terms of an electrothermal process due to the Joul-heating effect accordingly the temperature rise in the heated region will be sufficient to initiate switching process. A stationary state is reached when the heat lost by conduction from the current filament becomes equal to the Joul heat generated in that region.

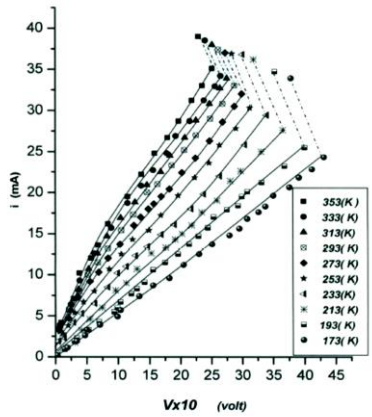

Fig. 2 The temperature dependence of switching effect for In_2Te_5 crystal

Several runs were made on each specimen in order to check the reproducibility of the results. Some fluctuations in the value of V_{th} (within 10%) were observed when the first three or four switching cycles were measured. After three or four sets of measurements were taken, the devices become more stable and V_{th} become constant to better than 1%. The measurements was repeated on the several samples which are taken from different regions of the ingots in the temperature range of investigation , the characteristics shape is the same as in Fig. 1. With increasing the temperature the current-voltage characteristic as a whole is shifted toward the lower potentials. The temperature dependence of the I-V characteristic is an important for information storage applications. Usually, in memory switching materials different samples of the same thickness are used to study the effect of temperature on the switching behavior. The ambient temperature greatly influences both the form of the CVC curves and the threshold voltage $V_{th,}$ the holding voltage V_h as well as the threshold current I_{th} and the holding current I_h. The NDR region of the curves is more pronounced at lower ambient temperature the transition from the low to the high conductivity state of the curves is almost abrupt at lower temperature. The threshold voltage V_{th} after which the NDR region set in, become higher with decreasing the temperature. Also we observe from the curves in Fig. 2, that the conduction state can be kept at a certain holding current I_h and holding voltage V_h, the holding voltage V_h increases with decreasing the temperature, while the holding current I_h increases gradually with increasing the temperature in the whole investigated temperature range. In the same curve the variation of threshold current and threshold voltage with temperature is illustrated. It is prove that the temperature has a significant effect on the threshold potential and threshold current, from this relation, one can notice that while I_{th} increases continuously with increasing the ambient temperature, continuous decrease in V_{th} can be observed. This shows that the switching in Ag-In_2Te_5-Ag structure from a high to a low resistivity state occurs under the simultaneous action of an electric field and temperature. This is supported by the linear dependence of the threshold voltage on the thickness of the active region. The dependence of V_{th} on T was analyzed on the basis of the thermal field Frenkel effect. Allowance for this effect in reference [16], the relation between V_{th} and T is described by expression

$$V_{th}=\left(\frac{\pi\epsilon_0\epsilon_\infty d}{e}\right)(\emptyset - cT)^2$$

Where ε_o is the permittivity of vacuum, ε_∞ is the electronic component of permittivity, d is the distance between the electrodes, c is the constant, e is the electron charge, φ is the depth of potential well, and T is the absolute temperature. The variation of V_{th} with temperature is plotted in Fig. 3, on the basis of the above equation. It is seen that in the whole temperature range of investigation, the threshold voltage decreases with increasing the temperature as expectant from the above equation.

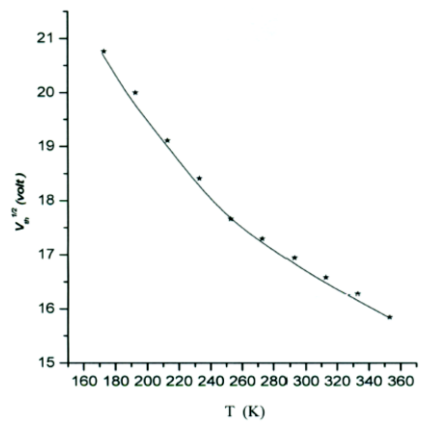

Fig. 3 The dependence of V_{th} on temperature for In_2Te_5 compound

The power necessary to change the material from high resistance state to low resistance state is called threshold power (P_{th}). Calculations showed that the magnitude of (P_{th}) sharply and linearly decreases with temperature. This explains why, at low temperature, large switching power is required. The ratio R_{off}/R_{on} was found to be temperature dependent, where it decreases with the temperature. The resistance ratio R_{off} / R_{on} for our samples at room temperature is of the order of 1.25.

3.2 Effect of illumination intensity on switching effect

Current-voltage curves obtained under illumination with 20, 200, 400, 600, 800, 1000, 1200 lux at room temperature is plotted in fig 4.

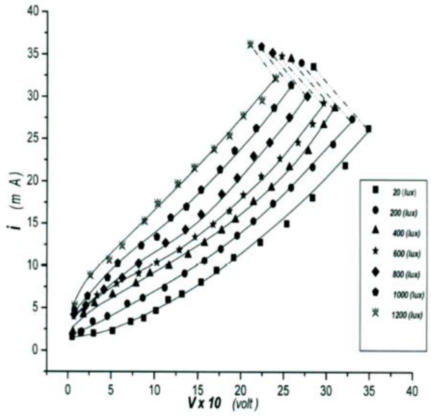

Fig. 4 Influence of light intensity on the I-V characteristic of In_2Te_5 single crystal

It was found that switching behavior in our In_2Te_5 sample was sensitive to the light intensity. The following observation can be noticed:-

1. Values of high resistance state decreases by increasing light intensity.
2. Value of V_{th} decreases by increasing light intensity, while I_{th} increases with light intensity.
3. The holding current I_h increases with light intensity whereas the holding voltage v_{th} decreases with increasing light intensity.
4. As it is seen the threshold voltage decreases with light illumination increases, whereas threshold current increases with light intensity. The main contribution comes from photo carries generation through excitation states.
5. As it is evident from Fig. 4, the form of the VAC and the magnitude of the photocurrent depend strongly on the intensity of the incident light.
6. With decreasing the intensity of the incident light, the VAC as a whole is shifted towards higher potentials. This mean that in the case of weak illumination, the threshold voltage is larger and the current threshold value is smaller than the value obtained in case of intense light.
7. All the curves have the same behavior of the switching phenomena, with S-shape.
8. Strong rise in illumination intensity makes the transition from the high resistivity state to the low resistivity state takes place early, since the field necessary for switching to be performed is reached quickly as light intensity increases.
9. The dependence of threshold voltage and current on light intensity indicate that as the light intensity increases the charge carriers generated by photons increases, which lead to increase the current.

Variations of threshold power P_{th} with light intensity is checked where we find that P_{th} decreases with increasing the light intensity. This indicates that, as the light intensity increases the photo generation processes take place under illumination of the sample, this lead to a low power for switching at higher intensities.

The dependence of the ratio R_{OFF} / R_{ON} illumination intensity is expected. This ratio decreases as the light intensity increases. This indicates that at higher intensity, the rate of recombination is larger than the rate of generation. This explanation is quite good for switching power, since the power required for switching at high intensity is greater than at lower intensity.

3.3 Dependence of switching effect on the sample thickness

Investigation of the effect of the sample thickness on switching phenomena is useful for choosing of a specimen whose resistance is changed from high value (OFF state) to a very low value (ON state) by lowest switching power. Fig. 5 shows the effect of the sample thickness on switching phenomena of In_2Te_5 crystal at room temperature. The specimen thickness varies from 0.15 to 0.375 cm. The figure indicates that the threshold potential and current changes with thickness of the active region and the width of the dashed line which represent the variation from OFF to ON state decreasing with thickness, but gradually and slowly. The holding current and voltage are also affected with the thickness of the sample. The variation of the threshold voltage and current with the thickness of the sample can be observed from the same figure, where it is evident that the threshold potential required for switching increases with the decrease of the thickness.

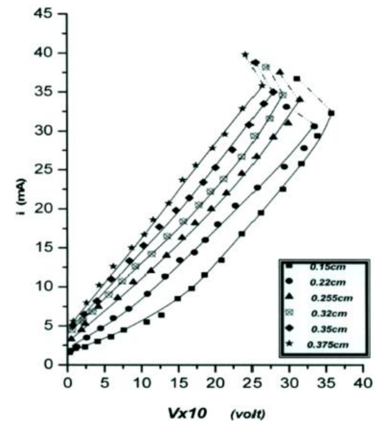

Fig. 5 I-V characteristic for In_2Te_5 with various thicknesses

One can say that increasing of the specimen thickness lowers the potential for the switching process in a certain specimen. This result indicates that the switching can be easily controlled with the sample thickness.

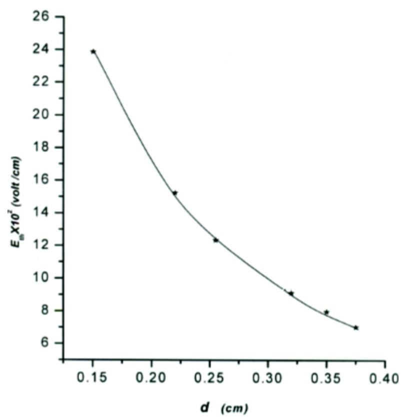

Fig. 6 Dependence of the threshold field (E_{th}) on the thickness of the active region for In_2Te_5 single crystal

Investigation of the threshold field (E_{th}) with respect to switching phenomena was carried out on In_2Te_5 crystal for various thicknesses. The general behavior of thickness dependence of threshold field is plotted in Fig. 6. This dependence shows that the threshold field decreases exponentially with the increase of the sample thickness; this supports the suggestion that the mechanism of the switching in In_2Te_5 samples may involve both electronics and thermal processes

[16]. The power required for switching is inversely proportional to the sample thickness, but with exponential relation. As the thickness of the device increased, small power for switching is required. As expected, the threshold power decreases with the active distance between the electrodes. At room Temperature, the ratio between R_{OFF} and R_{ON} for this compound is of the order of 1.2 to 1.31 in the investigated range of thickness.

4. Conclusion

By investigation of the D.C current voltage characteristics of In_2Te_5 crystal it had been found that:

The switching effect observed in such crystal shows memory effect.

The critical field of the switching being 7.97 x10^2 V/cm at room temperature.

Memory state persists if the current is decreased slowly to its zero value, however if the current is forced to decay suddenly, the specimen returned to the high resistance state.

The CVC is symmetrical with respect to the reverse of the applied voltage and current.

It is found that the I-V behavior indicates two region: the OFF state with a very high resistance and negative differential resistance state (NDR) region.

The phenomenon in pure sample is very resistive to the temperature, high intensity and sample thickness.

The VAC has S-shape type from the common form of the switching phenomena.

The switching parameters (I_{th}, V_{th}, I_h, V_h, P_{th}, E_{th}, R_{OFF}, R_{ON}) are checked under the influence of different factors of the ambient conditions, as well as the sample thickness.

The In_2Te_5 with such properties can be used as switching elements and memory elements in electronic devices in the field of modern electronic devices.

References

[1] Y. Feutelais, B. Legendza, Thermochemical Acta **314,** 35 (1998).

[2] V. P.Zlomanov, M. S. Sheiman, V. N. Demin, B. Legendze, J. Phase Equilibria **22**, 1 (2001).

[3] M. M. Nassary, M. Dongol, M.K. Gerges, M. A.Sebag, Phys .Stat. Sol. (a) **199**, 464 (2003).

[4] A. T Nagat, S. A. Al-gahtani, F.S. Shok, S. E Al Garni, S. R. Al-Harbi, K. A. Quhim Life Science J. **9** (4), 1495 (2013).

[5] S. Aydogan, T. Karacah, Y.K. Yoguiteu, Journal of crystal growth **279,** 110 (2005).

[6] M .P. Hanias, A.N. Anagnostopoulos, Phys. Review B **47**, 4261 (1993).

[7] S.A Hussein, A.T, Nagat, Crystal Res. tech.**24**, 283 (1989).

[8] J.J. Verkeline, Mat. Res .Bull **9**, 1063 (1974).

[9] A.T. Nagat, S.A. Hussein, Y. H. Gameel, G. A. Gamal, Phys .Stat. Sol. (a) **121**, 201 (1990).

[10] A.A. AL-Ghamdi, S.A. Hussein, M.M. Nassary, Mat .sci. Res .India **2**, 107 (2004).

[11] S.A. Hussein, Crystal Res. Tech. **24**, 467 (1989).

[12] A.A. Al Ghamdi, A.T. Nagat, F.S. Bahabri, R.H. Alorany, S.E. Al Garni, Applied surface Science **257,** 3205 (2011).

[13] Jazi Abdullah Mohammed Abdulwahed, International Journal of scientific and Engineering Research, **5**, 1258 (2014).

[14] S. Balevicues, A. Cevays, A. Deksnys, Phys .Stat. Sol. (a) **35,** 41 (1970).

[15] B. Abay, B. Gurbulak, M. Yildirim, H Efeoglu. Tuzemens, Y.k Yogurtcu, J. Electronics Materials **75,** 25 (1996).

[16] S. I. Alive, G. M. Niftiv, F.I Pliev, B. G Tagiev, Sov. Phys. Semiconductor. **12,** 340 (1979).

[17] S. Prakash, S. Asokan, D.B Ghane, J. Phy.**29**, 2002 (1996).