Behaviour of Switching Phenomena in Single Crystals of $TlInTe_2$ Compound

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The p–type $TlInTe_2$ single crystals were grown by a directional freezing method based on the Bridgman – Stockbarger technique for crystal growth. The electrical switching effect, in the crystals under work, was investigated at various temperatures (183 to 233 K). The current–voltage characteristics of the above – mentioned compound showed two different regions. An Ohmic region was observed at low current densities and a negative deferential resistance region (NDR) at the moderate and high current densities. In this investigation, the switching parameters (I_{th}, V_{th}, P_{th}, E_{th} and R_{Off}/R_{On}) were determined and it was noticed that they are very sensitive to temperature, light intensity and change in the sample thickness. The electrical switching effect was observed in the low temperature region for the $TlInTe_2$ single crystals, whereas the I–V measurements exhibit no switching phenomenon at room temperature and in the high temperature region. It was also remarked that if the current slowly decreases to its zero value, the memory state persists. However if the current was forced to suddenly decrease, the specimen returns to its high resistance state. In addition, the samples under investigation showed that a holding current (I_{th}) was found to be independent of temperature and the holding voltage (V_{th}) was observed to be decreased with the increase in temperature.

1. Introduction:

Basically, switching consists in a transition form a state of high–resistance (OFF) to one of low–resistance (ON), the transition being generated by the application of a specific voltage known as the threshold voltage V_{th} [1]. If the OFF–state can be recovered by removing the voltage, the electrical event is referred to as threshold switching. Whereas if the ON–state persists when the applied voltage is turn off, the material is said to have a memory switching [2]. Switching phenomenon, from the beginning, attracted considerable interest [3]. All experiments leading to that the switching phenomenon is still a controversial subject; therefore, its clarification is beneficial [4]. According to the electro-thermal mechanism, for interpreting the switching phenomenon in semi-conducting glasses [5, 6], small local deviations from the homogeneous distribution of imperfections lead a higher current density in negative deferential (NDR) regions. These current densities are usually accompanied by the formation of high–current density filament between the two electrodes. The formation of a current filament (channel) is among the principal consideration for the interpretation of the NDR. Since this filament has a high conductivity, the high–current density results in increased power dissipation, leading to a Joule–heating. As the temperature increases, the conductivity also increases, and increase in temperature permits a higher current to pass through the filaments. But when the heat dissipation equals to the heat loss, the steady–state of this high conductivity filament is reached [2, 7].

Recently, there is grown interest in the utilization of a similar switching effect in crystalline substances. The switching effect of the chalcogenide semiconductors, in their single crystal form, is principally electro-thermal [4, 8]. On other hand, these references show that the switching effect, in the crystal form of the chalcogenide semiconductors, is due to the formation of a high–current density filament in which the elevated current density results in an increased power dissipation leading to Joule–heating.

The aim of the present work is to elucidate the electrical and optical switching in the p–type $TlInTe_2$ single crystals. The basic measurements needed for the above – mentioned investigation, is to find the voltage – current characteristics (VAC). In line with the VAC curves, all switching parameters such as I_{th}, V_{th}, P_{th}, E_{th} and R_{Off}/R_{On} are easily to be estimated. As the main objectives of the present investigation-, the temperature-, light intensity- and thickness-dependences of switching phenomena has to be elucidated.

2. Experimental Setup:

A local technique related to the basic Bridgman method was used for growing the $TlInTe_2$ single crystals. For investigating the switching phenomenon of the $TlInTe_2$ single crystals, a point contact holder was constructed by two flat copper sheets mounted on a rectangular block of insulating material. A brass screws were fixed at the midpoint of each copper sheet face to act as point electrodes. The sample, used in the current–voltage measurements, was treated to be with a typical dimensions 6.2 x 3.1 x 2 mm^3. The thickness of the sample under work was successively reduced by polishing followed by washing for obtaining the influences of the thickness on the I–V characteristic curves, where the thickness of the used sample was varied from 2.0 to 1.4 mm. The mentioned measurements were carried out by using a simple circuit containing a dc power supply, current meter (Keithly electrometer of 610-type), and series load resistance. The arrangements make it possible to vary the applied voltage steadily up to the point where the crystal switching, thereafter the series resistor limited the applied voltage to prevent the crystal destruction.

The treated sample was mounted on the cold finger inside a cryostat (Oxford DN1704-type), which was evacuated to about 10^{-4} Torr. The temperature inside the cryostat was controlled by a digital temperature controller (Oxford ITC601-type). Illumination was carried out by a tungsten lamp of 1000 Watt. The incident light was focused by using an optical system consisting of two convex lenses, which enables a homogeneous illumination to be obtained. Influence of light intensity on the switching phenomenon of the $TlInTe_2$ single crystals was studied by varying the intensity of radiation from 150 to 1200 Lux.

3. Results and Discussion:

In this investigation, the switching behavior of the $TlInTe_2$ single crystals was found to be very sensitive to temperature, light intensity and sample thickness. The voltage – current characteristics (VAC), of the above – mentioned crystals, were measured in the temperature range 183 to 233 K. The VAC curves were investigated in the existence of different values of the light intensity through the range 150 to 1200 Lux. In addition, the mentioned phenomenon was investigated for the $TlInTe_2$ single crystals with the thickness variation form 2 to 1.4 mm. The temperature impact on the VAC curves of the specimen under work is depicted in Fig.(1). The VAC measurements were carried out for a thickness of 2 mm. In line with this figure, it is obvious that the VAC curves have the characteristic-shape, as in the whole temperature range of investigation. However, two sections were observed for such a VAC curve: a pre–switching portion (Off–state) and a sharp current growth portion with sequent switching to the low–resistance state (On–state). Experimental measurements showed that after several repetitions, the form of the VAC for the specimen under work was stabilized. In the switching branch with which the current follows essentially the load line, a fast switching of the sample was observed with the increase in temperature. It was also noted that the VAC curves are shifted toward low values of potential with the increase in temperature. After switching to the low–resistance state, the specimen under work was found to be in this mentioned state for some hours although zero value of the bias voltage was reached, this effect is known as switching with memory. It is clear from Fig. (1) that the VAC curves are symmetrically shaped with respect to the bias applied voltage. The impact of the ambient temperature on the threshold switching voltage (V_{th}) is illustrated in Fig.(2). It is obvious from this figure that the threshold voltage decreases with the increase in temperature.

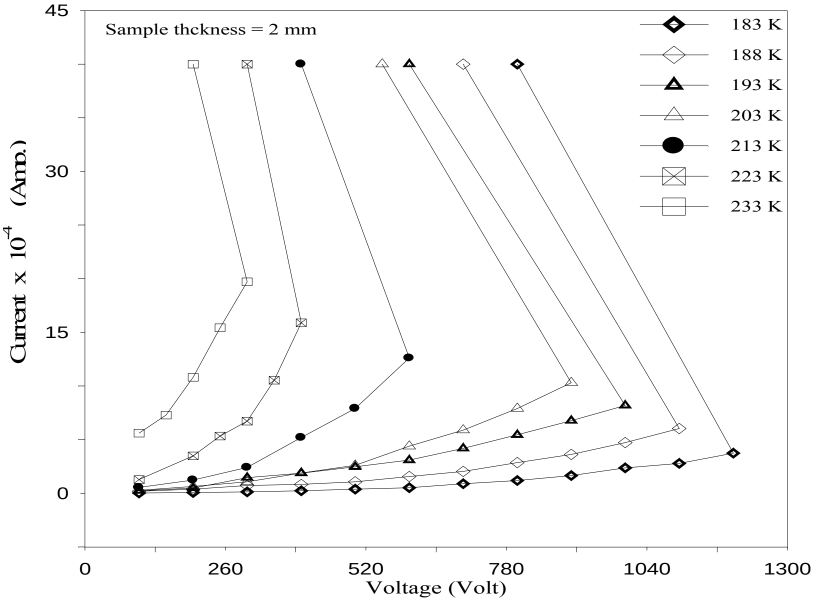

Fig. (1): Shows temperature impact on the VAC curves of the $TlInTe_2$ single crystals.

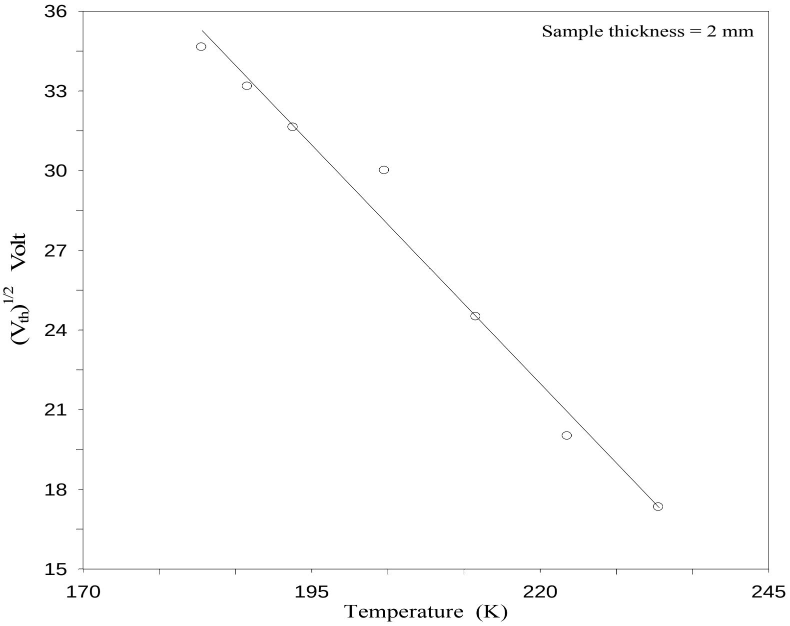

Fig. (2): Shows temperature effect on the threshold voltage for the $TlInTe_2$ single crystals.

The temperature dependence of the threshold voltage was investigated and analyzed on the base of the thermal–field Frenkel effect. The allowance for this effect [9] yielded the following expression relating the threshold voltage and temperature:

$$V_{th} = \left(\frac{(\pi)\,(\varepsilon_0 \varepsilon_\infty)\,(d)}{e} \right) (\varphi - CT)^2$$

where ε_0 is the permittivity of vacuum, ε_∞ is the electron component of the permittivity, d is the distance between the two electrodes, C is a constant, e is the electronic charge, φ is the depth of the potential well and T is the absolute temperature. Depending on this equation, the temperature impacts on the threshold voltage (V_{th}) were measured, plotted and depicted in Fig. (2). The temperature dependence of the threshold voltage may be interpreted as that the switching in the M–InTe–M structures from the high– to low–resistivity states occurs under the simulation action of an electric field and temperature [10]. This behavior is confirmed by the thickness dependence of the threshold voltage in $TlInTe_2$ single crystals. The switching process is due to the crystalline conducting channels formed between the electrodes at the threshold voltage [11], giving rise to the low resistance state. The decrease in the threshold voltage with the increase in temperature supports the idea that thermally generated conducting channels are responsible for switching. The irreversible phenomenon has been attributed to the formation of conducting channels in the switching region, which is understandably facilitated at higher temperature [12].

The temperature dependence of the threshold power (P_{th}) in the $TlInTe_2$ single crystals is depicted in Fig. (3). In accordance with this figure, there are two behaviors of the temperature dependence of the threshold power in the investigated range of temperature. In the first one (observed in the temperature region 183 to 203 K), it is noticed that the threshold power, for the mentioned crystals, increases with the increase in temperature. While the P_{th} – T relation for the second behavior, observed in the temperature range 203 to 233 K, exhibits a decrease in the threshold power with the increase in temperature. The influence of temperature on the ratio R_{Off} / R_{On} is illustrated in Fig. (4). It is observed that this ratio decreases with the increase in temperature over the whole investigated range of temperature. The memory switching effect in such crystals is an effect, which appears after the negative – resistance process. It is evident that the thermal effect plays a role whatever the basic nature of the switching process. Even if an electronic switching mechanism is assumed it is probable that the switching parameters will vary with temperature. Therefore, changes in the temperature of a material caused by Joule heating and due to the leakage current during the pre–switching time, are expected to affect the measured switching parameters.

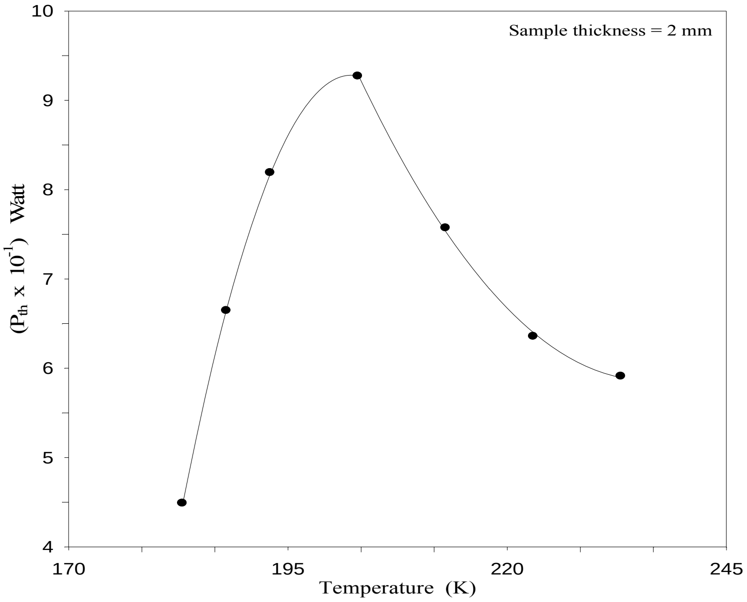

Fig. (3): Shows temperature effect on the threshold power for $TlInTe_2$ single crystals.

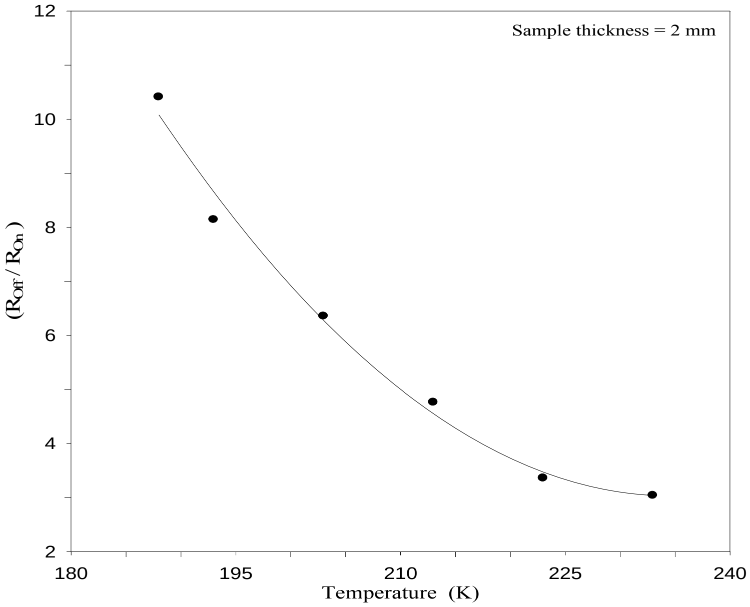

Fig. (4): Shows temperature effect on the R_{Off} / R_{On} ratio for the $TlInTe_2$ single crystals.

The light intensity impact on the switching behaviour of the $TlInTe_2$ single crystals is shown inFig. (5). In line with this figure, it is obvious that the switching behavior in the mentioned crystals is very sensitive to illumination. The switching behaviour was investigated in the light intensity range of 150 - 1200 Lux, where the VAC measurements were carried out with a fixed value of temperature (~ 203 K) and thickness (~ 2 mm). Figure (5) shows that the VAC curves have the same behavior of the switching phenomena observed in the crystals under work. But it is clear form this figure that the sharp rise in light intensity leads to a quick transition from the high – resistance to the low – resistance states, since the field necessary for switching to be performed is reached quickly as light intensity increases. Figure (6) shows the light intensity dependence of the threshold switching power (P_{th}). It is obvious from this figure that two behaviours are exhibited. The first behaviour was found to be over the light intensity region from dark to 300 Lux in which the threshold power increases with the increase in the intensity of illumination. While the second one was noticed to be over the light intensity region of 300 - 1200 Lux in which the threshold power decreases with increasing intensity of illumination.

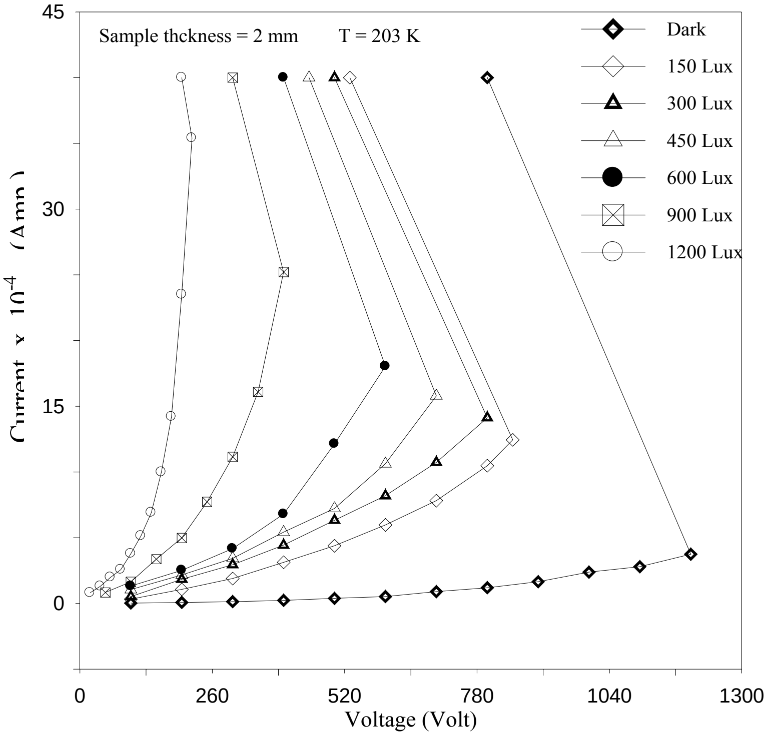

Fig. (5): Shows the light intensity impact on the VAC curves of $TlInTe_2$ single crystals.

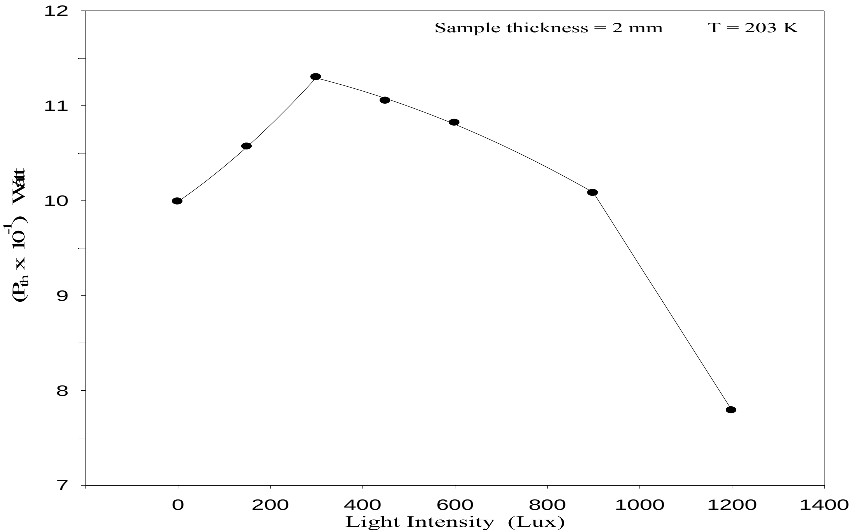

Fig. (6): Shows light intensity effect on the threshold power for $TlInTe_2$ single crystals.

The above–mentioned behavior of the threshold power with the variation in light intensity may be attributed to the trapping centers in the forbidden gap extensive changes in the switching power. The above mentioned figure was used for estimating the R_{Off} / R_{On} values for the investigated range of light intensity. The influence of light intensity on the ratio R_{Off} / R_{On} is illustrated in Fig. (7). It is observed that this ratio decreases with the increase in temperature over the whole investigated range of temperature.

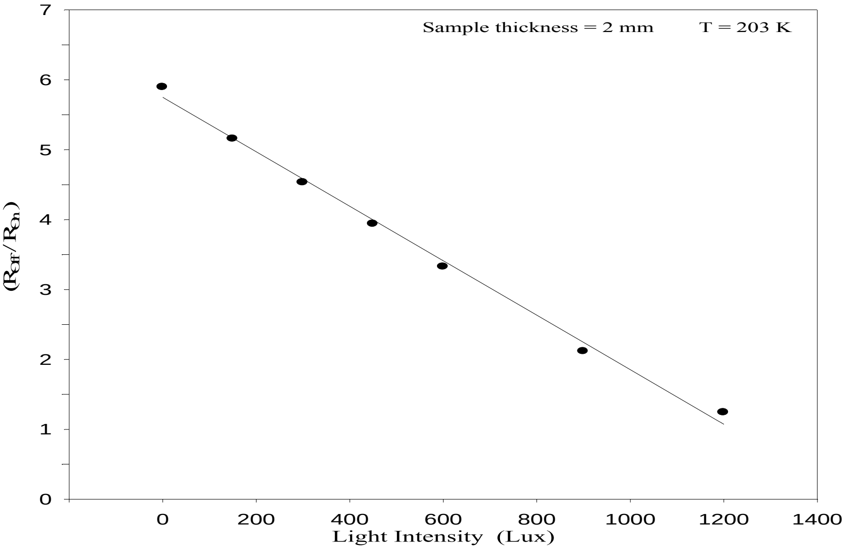

Fig. (7): Shows light intensity effect on the R_{Off} / R_{On} ratio for $TlInTe_2$ single crystals.

In line with the thickness dependence of the switching behavior in the $TlInTe_2$ single crystals, the VAC measurements were carried out for the specimen thickness range of 2-1.4 mm at a fixed value of temperature (203 K). The thickness influence on the VAC curves is illustrated in Fig. (8). It is observed from this figure that a choice of the specimen, whose resistance is changed from a high value (Off–state) to a low value (On–state) by the lowest switching power, can be obtained through the study of the impact of the specimen thickness on switching phenomena. The variation of the threshold power with the change in the specimen thickness is plotted in Fig. (9) that lead to a minimum switching power is observed at small thickness. According to Nagat [8], the decrease in the specimen thickness lowers the potential for the switching process.

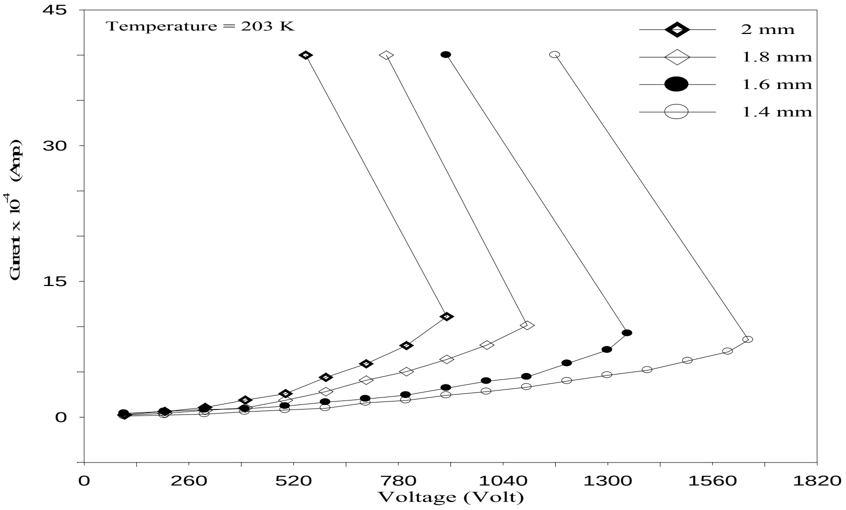

Fig. (8): Shows the thickness impact on the VAC curves of $TlInTe_2$ single crystals.

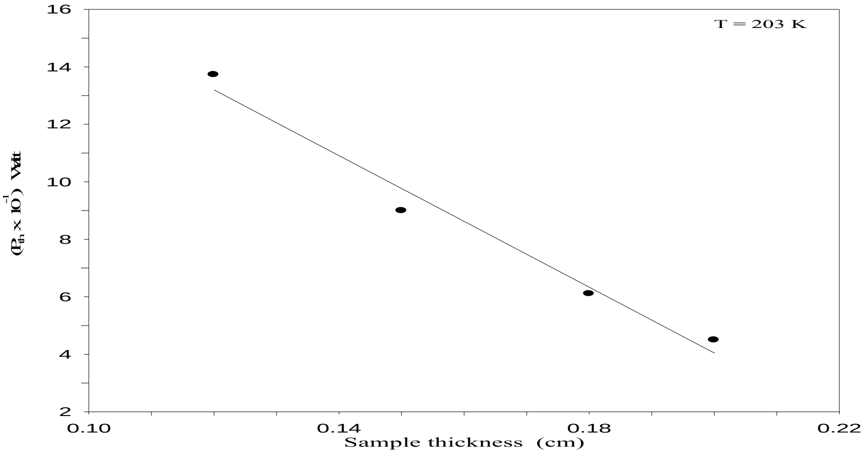

Fig. (9): Shows thickness effect on the threshold power for $TlInTe_2$ single crystals.

4. Conclusions:

The VAC curves have the characteristic-shape in the whole temperature range of investigation (183-233 K). After several repetitions, the form of the VAC for the specimen under work was stabilized. There are two behaviours of the temperature dependence of the threshold power in the investigated range of temperature. In the first one (temperature range 183 to 203 K), it is noticed that the threshold power, for the mentioned crystals, increases with the increase in temperature. While the P_{th}–T relation for the second behaviour (temperature range 203 to 233 K) exhibits a decrease in the threshold power with the increase in temperature. The sharp rise in light intensity leads to a quick transition from the high–resistance to the low–resistance states, since the field necessary for switching to be performed is reached quickly as light intensity increases. A choice of the specimen, whose resistance is changed from a high value (Off–state) to a low value (On–state) by the lowest switching power, can be obtained through the study of the impact of the specimen thickness on switching phenomena.

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