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An analysis study for the effect of annealing temperatures on (I-V) characteristics of PbS photodetector

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ABSTRACT

This study was carried out by the preparing PbS thin films and studying the effect of annealing temperatures on electrical properties. The PbS thin films have been prepared by thermal evaporation in a vacuum of (10^{-5}-10^{-6}) Torr with thickness 500°A at room temperature and annealed at different annealing temperatures of (200, 300, 400, and 500) °C for 30 min. From the electrical measurement show that the (I-V) characteristic behavior linear and best with increase in temperature. For importance of the effect of temperature on the electrical properties, the theoretical model was estimated by using (table curve 2D) program. An estimated theoretical equation was power equation.

INTRODUCTION

Thin films are extensively used in wafer fabrication, and they can be a resistor, a conductor, an insulator, or even a semiconductor. Thin films behave differently from bulk materials of same chemical composition in several ways. For instance, thin films are sensitive to surface properties while bulk materials generally aren't[1]. In one way or another most physical properties of films (optical, chemical, magnetic, electrical, etc.) are of importance in an ever widening sphere of industrial, scientific and technical application[2]. Lead chalcogenide, a compound of lead with elements of group VI (sulfur, selenium and tellurium) belongs to a class of semiconducting compounds described by the general formula $A^{IV}B^{VI}$ [3,4]. Lead chalcogenides have many special characteristics in comparison with other semiconductors:

1- The band gaps are smaller at lower temperatures, i.e. the temperature coefficients of Eg are positive while they are negative in all other elementals or compounds[5].
2- The lattice structure may be very unstoichiometric. The vacancies and interstitials control the conductivity type, an excess of Pb causes n – type conductivity and excess of chalcogenide causes p–type conductivity[5].
3- The band gap of PbS is smaller than the band gap of PbTe, although commonly the band gap in the metal chalcogenide semiconductors diminishes as the chalcogenide increases[5].
4- Large carrier mobilities may be unique among polar compounds and make these semiconductors a very interesting branch of basic physical research[6].
5- Lead chalcogenides are ones of the best thermoelectric materials for working temperature range of 500 –900K[7].

Some researchers studied different properties of PbS photodetector such as; Gelmont et al[8] have obtained the absorption spectrum near and above the fundamental edge of PbTe films on BaF_2 substrate at 313

K between 2 and 8μm. The thickness of film was (0.61μm) from parallel measurements of transmission and reflection. They found that the direct energy gap at L is 0.321eV.

Saloniemi[5] has studied the physical, chemical and electrical properties of PbS thin films prepared by electro-deposition method. After annealing; the conductivity of films will be p-type, and the annealing at 373K does not much affect on the resistivity of PbS which remained between 0.5 – 10 Ω cm.

Khairnar et al.[9] have prepared PbTe thin films with thickness ranging from (1000– 2500)°A by evaporation technique onto glass substrates at various temperatures. They found the activation energies of films are evaluated as (0.099, 0.109, 0.102) eV for substrates temperatures (323, 373, 423) K, respectively.

This research considers studying PbS thin film because it is one of the important lead chalcogenide compounds, and has many practical applications in the fields of detectors, semiconductors' laser and diodes. Therefore the goal of this research is to prepare of PbS thin films by using thermal evaporation method, and study the effect of annealing temperatures on electrical properties of films. Also, estimate theoretical model for this effect.

THEORETICAL PART

A semiconductor is a material whose conductivity lies between that of conductors and of insulators[3], the conductivity of semiconductor is generally sensitive to temperature, illumination, magnetic field. This sensitivity in conductivity makes the semiconductor one of the most important materials for electronic application[10]. Semiconductors consist of two bands namely valence and conduction bands which are separated by a forbidden gap[11]. This gap is usually quite narrow in semiconductors[12]. So that, as the temperature of the semiconductor is increased, some electrons receive energy greater than the energy gap and get transferred to the upper energy band. These electrons now contribute to the conduction[13]. PbS is used for the fabrication of IR detectors. They have found wide spread application for detection of IR radiation[14]. For pure PbS; the forbidden energy gap decreases as the temperature is lowered[3]. The density of PbS is (7.5) g.cm^{-3}[15]. The use of PbS as the laser material has made it possible to extend spectral range of laser radiation in the direction of wavelength longer than those emitted by InSb laser[4].

EXPERIMENTAL PART

The preparation of pbs thin films

A molybdenum boat is used in evaporation process because it will not react with the evaporated material and it has a melting point greater than that of PbS (1114 C). The appropriate amount of PbS powder is selected and measured by using sensitive electrical balance. During the deposition some of the material will be lost by volatilization or expansion from the substrate surface, therefore we should add ~20% in excess of material to be sure that the wanted thickness will be achieved. The (glass) substrates are fixed on the substrate's holder at a distance about 16cm above the source of evaporation (boat). When the vacuum in chamber reaches(10^{-3}-10^{-6}) Torr, an electrical current is applied from the power supply passing through the boat. We used annealing process to change the structure properties of materials[17] such as thin films like (CdS, PbS, PbO, MnS,…), so this method affects on electrical properties because the heat help electron to move from valance band to conductive band so that the electrical conductivity increased[10].

The annealing process was performed in an electrical furnace of the type (Heraeus), and at different temperatures of (200, 300, 400, 500) C for 30 min. period.

The weight method

Weight method is used in measuring prepared PbS film thickness. This method is one of the classic approximate methods in measuring. The material is weighted using sensitive electrical balance (mentioned in previous paragraph); if the weight of the material is equal to the mass of film and (R) is the distance between the boat and the substrates over which the film will be deposited, the thin film thickness will be according to the relation:

$$t = m / 2\pi R^2 \rho \qquad (1)$$

Where m : is the mass of the evaporated material (gm)·
ρ :density of alloy (gm/cm^3).

This method is one of the oldest, simplest and least accurate methods, but it has the advantage that it gives average values for film thickness[18].

Electrical properties (I-V) characteristics

In order to measure the electrical properties we need Ohmic contacts. It was obtain by under vacuum of Aluminum wire of high purity on the surface of film, as mentioned by Al-Nuaimy[19].

RESULTS AND DISCUSSIONS

The study of (I-V) characteristic of thin films in the presence of luminance determines the quality of the detector. Figure (1) illustrates the (I-V) curves for PbS thin film with thickness 500 A for different annealing temperature (200, 300, 400, 500 and 600) C and the time 30 min. The film has linear relation between current and voltage so when voltage increased the current that cross in the film increased too.

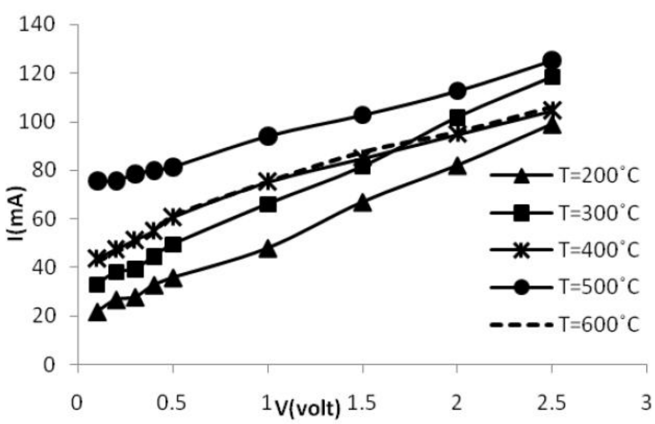

Figure 1 : The (I-V) curves for PbS thin films for different annealing temperatures.

The photocurrent increased with increasing voltage. The effect of increasing temperature led to increase photocurrent until reach T=500C^{O},then the photocurrent will decreased.

We developed a theoretical model for these experimental data by fitting all of the (I-V) curves using the (table curve, 2D, version5.01) software. These fitting curves are plotted in Figures (2-6) for all temperatures (200, 300, 400, 500 and 600) C, respectively.

An estimated theoretical fitting equation was power (a, b, c) equation.

$$y = a + b\,x^{c} \qquad (2)$$

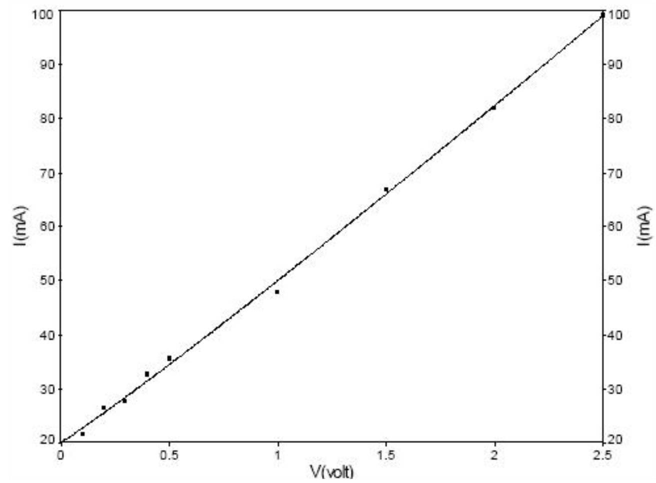

Figure 2 : Fitting curve (I-V) at annealing temperature 200 °C

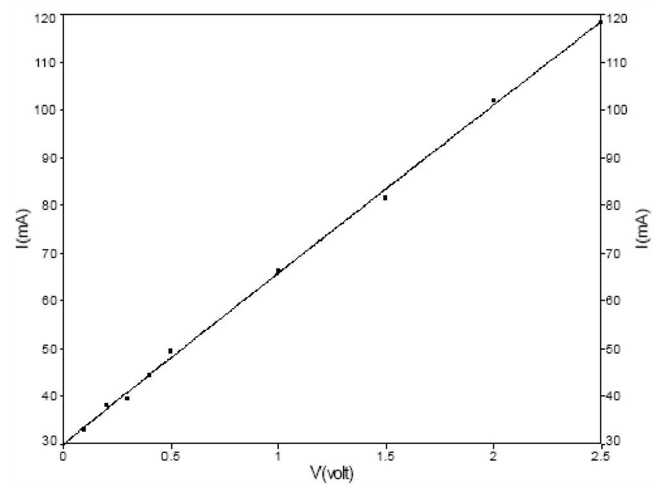

Figure 3 : Fitting curve (I-V) at annealing temperature 300 °C

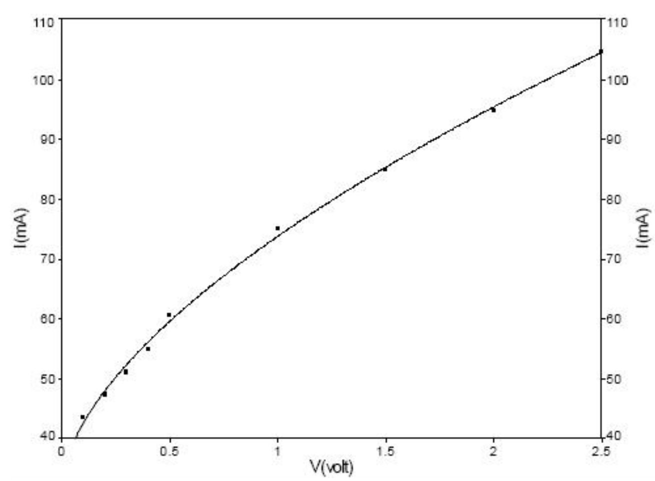

Figure 4 : Fitting curve (I-V) at annealing temperature 400 °C

where x and y represent photocurrent and voltage, respectively. The values of the parameters a, b and c are presented in TABLE (1), r^2 represents the correlation factor between practical and theoretical data. From this

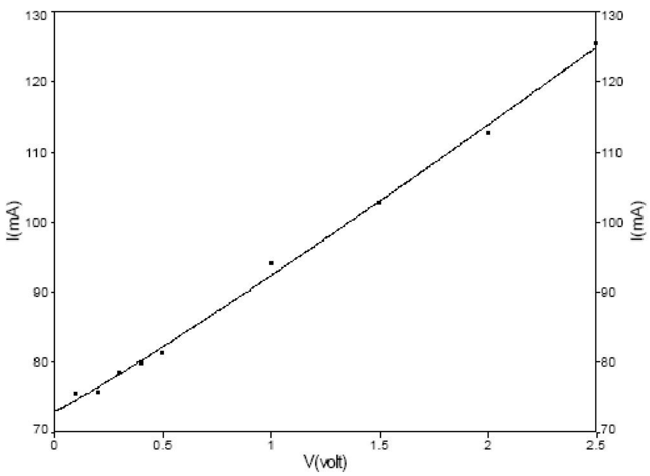

Figure 5 : Fitting curve (I-V) at annealing temperature 500 °C

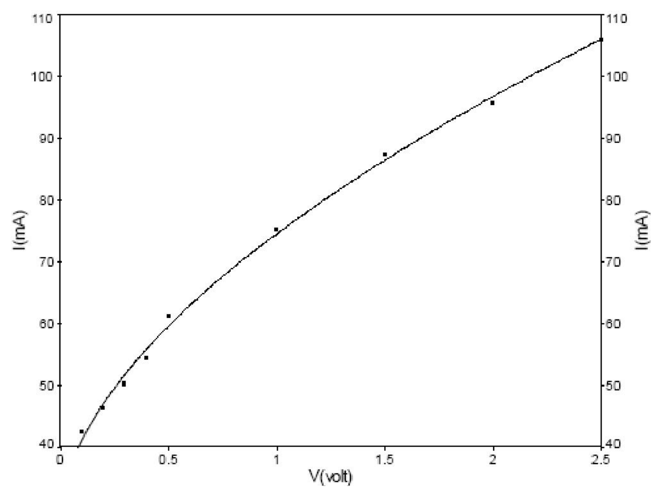

Figure 6 : Fitting curve (I-V) at annealing temperature 600 °C

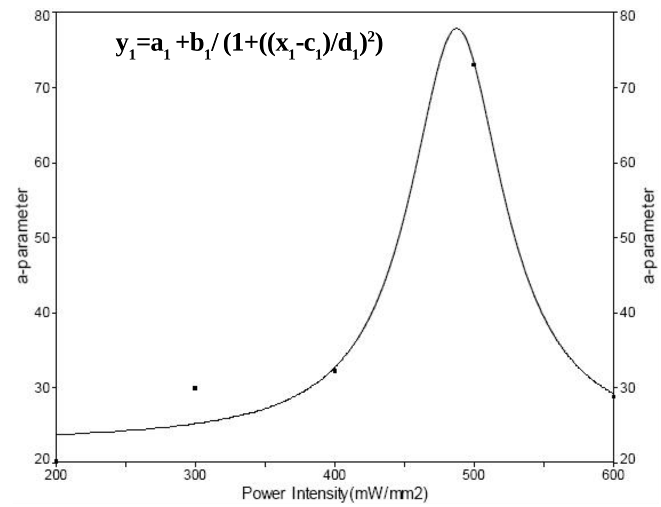

Figure 7 : The relation between a-parameter and annealing temperature

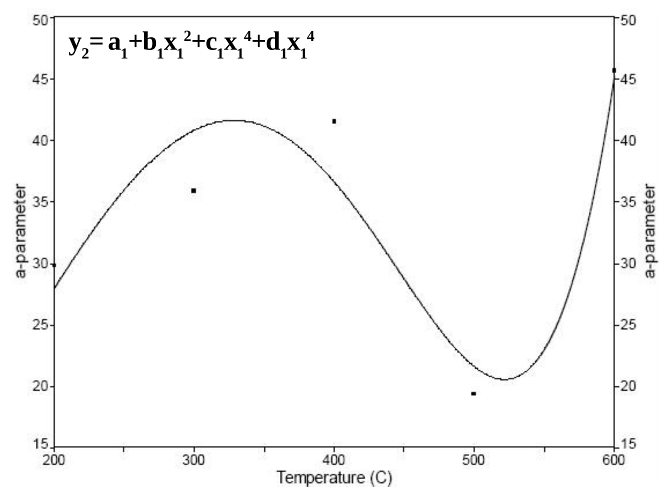

Figure 8 : The relation between b-parameter and annealing temperature

equation, we can show that the increased photocurrent with increasing voltage.

Each parameter was plotted against the temperature as shown in Figures (7-9). The best fit equations are demonstrated above each curve.

Where the values of parameters of these equations are illustrated in TABLE (2). x_1 represents the temperature in °C and y_1,y_2, and y_3 represent a-,b-,and c- parameters.

The estimated theoretical (I-V) curves are plotted for two test temperatures (250, and 450) C with experimental data is shown in Figure (10).

For test temperature 250 C, the estimated theoretical equation is :

$$y = 24.306014 + 35.98024\, x^{(0.93991045)}$$

and for test temperature 450 C, the estimated theoretical equation is :

TABLE 1 : The parameters of theoretical model

Temperature (^{o}C)	a-parameter	b-parameter	c-parameter	r^2
200	20.155631	29.813166	1.0603794	0.99815273
300	29.889456	35.895787	0.98543866	0.99872968
400	32.179019	41.555742	0.60403744	0.99814266
500	73.061565	19.340531	1.0760659	0.99755768
600	28.803509	45.691064	0.57198385	0.99722813

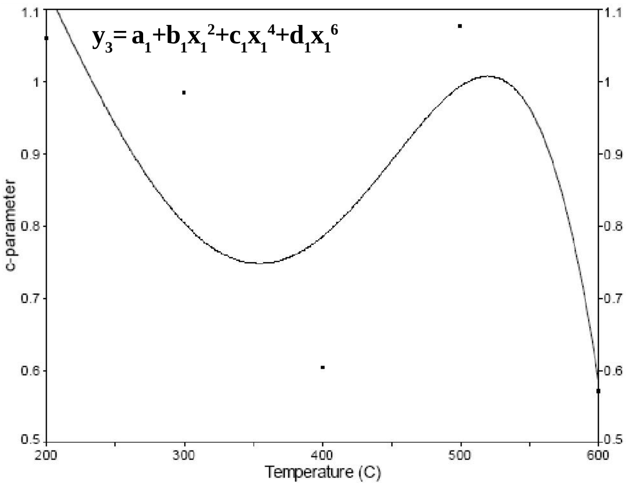

Figure 9 : The relation between c-parameter and annealing temperature

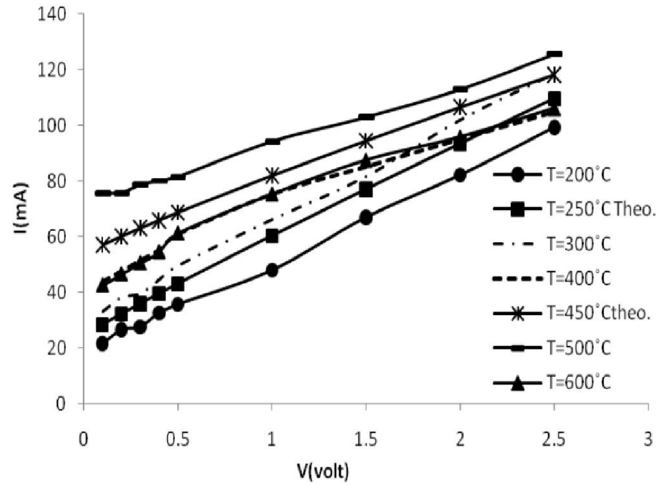

Figure 10 : Effect of temperature on (I-V) curves (theoretically and experimentally) for PbS thin film.

TABLE 2 : The values of the parameters of the best fit equation for the parameters of the theoretical equations.

parameter	a-parameter	b-parameter	c-parameter
a_1	22.681454	2.5671898	1.674118
b_1	55.24424	0.00083619422	-1.7427258e^{-5}
c_1	487.14271	-5.4203886e^{-9}	1.0156424e^{-10}
d_1	41.277705	9.5203499e^{-15}	-1.70964e^{-16}

$y = 53.208443 + 28.681465\ x^{(0.89016338)}$

This model allows us to plot the (I-V) curve for any temperature for PbS photo detector that has not been experimentally taken.

CONCLUSION

From our studying for the effect of annealing temperatures on the (I-V) characteristics of PbS thin films experimentally and theoretically, we concluded that increase temperature led to increase photocurrent. The estimated theoretical model is power (a, b, c) equation. This modeling enables to plot (I–V) curve for any annealing temperatures for PbS thin films that cannot take experimentally.

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