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RESEARCH ARTICLE

# INFLUENCE OF DEPOSITION TIME AND TEMPERATURE ON THE FORWARD BIAS CURRENT-VOLTAGE (I-V) CHARACTERISTICS OF $BI_2S_3$ THIN FILMS

[1*]Balasubramanian, V., [2]Chandrasekaran, J. and [3]Prabahar, S.

[1]Department of Physics, SNS College of Technology, Saravanampatti, Coimbatore-641-035, Tamilnadu, India
[2]Department of Physics, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, Tamilnadu, India
[3]Department of Physics, Tamilnadu College of Engineering Karumathampatti, Coimbatore, Tamilnadu, India

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## ABSTRACT

$Bi_2S_3$ thin films have been prepared with different deposition time and temperature by chemical bath deposition method. The influence of deposition time and temperature of $Bi_2S_3$ films on I-V characteristics are investigated. The current increase with increase of the film thickness and current is directly proportional to the applied voltage. The decrease in resistivity is due to the improvement in the crystallinity of films, which increases the conductivity. It exhibits semiconducting nature of the films.



## INTRODUCTION

Semiconductor compounds have attracted considerable interest of the international physical community due to their potential for solving number of problems in semiconductor electronics and opto electronics and thus remain in the focus of considerable intellectual and funding effort in the world's leading industrial countries (Farag *et al.,* 2009). In recent years, Bismuth trisulphide ($Bi_2S_3$) has been the focus of great interest due to its low cost and high absorption coefficients for applications in photovoltaic, photoelectro chemical cells, optoelectronic devices, solar cells and solar absorbers. The material is widely used in photoelectro chemical cell (Ali *et al.,* 1998) and has been prepared with various techniques. Chemical bath deposition technique offers the advantage of cost effectiveness, simplicity of the equipment, deposition of films of uniform thickness over large areas and the possibility of adapting the process to mass production. CBD method also produces films in the correct stoichiometric ratios of the constituent elements (Saeed Salem Babkair *et al.,* 2007). This study presents results on I-V measurement performed on chemically deposited $Bi_2S_3$ film with a view to ascertain the nature of the mechanisms responsible for current transport.

***Corresponding author: Balasubramanian, V.***
*Department of Physics, SNS College of Technology, Saravanampatti, Coimbatore- 641 035, Tamilnadu, India.*

### Experimental details

$Bi_2S_3$ thin films were deposited on glass substrates employing the chemical bath deposition technique, the details of which have been reported elsewhere (Balasubramanian *et al.,* 2012). The $Bi_2S_3$ thin films were prepared at different deposition time periods (4 hrs, 8 hrs and 12 hrs) and different deposition temperatures (40°C, 50°C, 60°C, 70°C). Current-Voltage characteristics were carried out by Electrometer (Keithley) system. This is complete system for measuring the current and voltage of semiconducting films by two point probe. Resistivity and conductivity is calculated from the relations,

$\rho = 2\pi s\,(V/I)$ …………………..(1)

$\sigma = 1/\rho$ ………………………..(2)

Where $\rho$ is the surface resistivity of a material, I is the current in the probe, V is the applied voltage and s is the distance between the voltage measurement and the current probe. $\sigma$ is the conductivity of material.

## RESULTS AND DISCUSSION

### I-V characteristics of $Bi_2S_3$ films for different deposition time period

Current-Voltage characteristics measurements were performed on Keithley High resistance meter/Electrometer. Electrometer was used to apply the voltage across the films and to measure the current through the films as it has an in-built capability of output independent voltage source. The indigenously designed sample holder with electrode was used in the circuitry for the thin films. Thin film samples of area one square cm are used to carry out the I-V measurements. Figures 1-3 shows the dependence of electrical parameters of $Bi_2S_3$ films prepared at different deposition time periods (4 hrs, 8 hrs and 12 hrs). The resistivity and conductivity of films are calculated from I-V measurements. The applied voltage was changed from 1V to 10V. Fig.1. shows that the current is directly proportional to the applied voltage. The current increases with increases of the films thickness and deposition time periods (Lokhande *et al.,* 1997). As the thickness is increased, the number of injected carriers increases so that space charge accumulates limiting the current. The resistivity decreases with increasing conductivity with applied voltage in Fig.2 and 3. The decrease in resistivity is due to the improvement in the crystallinity of films, which increases the conductivity. This behavior indicates that the semiconducting nature of films (Mane *et al.,* 2000). Several others have reported similar behavior by nano crystalline materials prepared by different methods (Kale *et al.,* 1996; Wang *et al.,* 1993). Table 1. shows the electrical parameters of $Bi_2S_3$ films prepared with different deposition time periods.

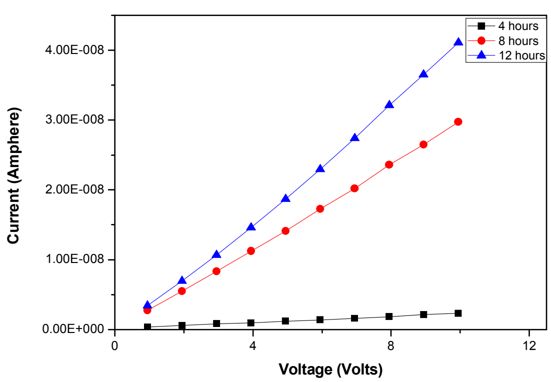


**Fig.1. Current-Voltage plot of $Bi_2S_3$ films for different deposition time periods**

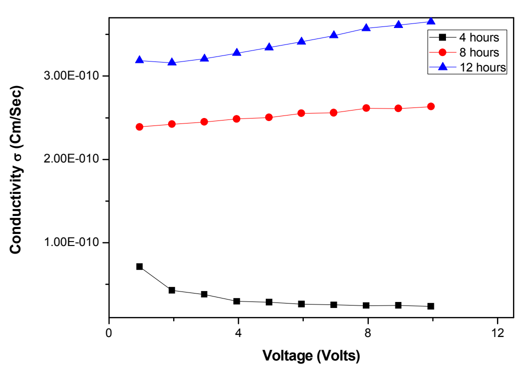


**Fig.2. Voltage-Conductivity plot of $Bi_2S_3$ films for different deposition time periods**

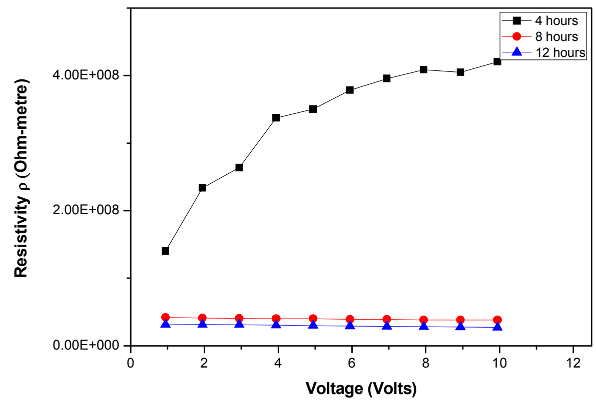


**Fig.3. Voltage-Resistivity plot of $Bi_2S_3$ films for different deposition time periods**

## I-V characteristics of $Bi_2S_3$ films at different deposition temperatures

Fig. 4 to 6 shows the variation of current, conductivity and resistivity as a function of voltage for $Bi_2S_3$ films prepared at different deposition temperatures ($40^0$C, $50^0$C, $60^0$C and $70^0$C). The current (I) exhibits the dependence of applied voltage (V) in the form of I α $V^n$, where n depends on the field and temperature in Fig.4. The value of 'n' is around 1 at low fields, where as it is near about 2 at high fields. The transport mechanism of DC field may be ohmic conduction at lower fields and non-ohmic conduction at higher fields (Nataraj *et al.,* 1999). The increase in current with the applied voltage for all temperatures studied indicates that the thermally generated carriers control the current at lower field (Mageshwari *et al.,* 2011). Fig. 5. shows that the conductivity increases with temperature.

The resistivity decreases linearly with increase in the deposition temperature (Patil *et al.,* 2009). It is confirming the semiconducting nature of $Bi_2S_3$ films. But above $60^0$C, resistivity increases due to reducing the thickness of film. It is observed that there is a maximum decrease in resistance at $60^0$C. Any increase in temperature of film (maximum thickness of films obtained at $60^0$C) causes the electrons to acquire enough energy and cross the barrier at grain boundaries (Borse and Garde 2008). There can be decrease in potential barrier at grain boundaries, since at higher temperatures the oxygen adsorbates are desorbed from the surface of the films (Borse and Garde 2008; Henry Windischmann and Peter Mark 1979). Also at higher temperatures the carrier concentration increases due to intrinsic thermal excitation and electron emission process improves with increase in temperature. The maximum thickness film shows decrease in resistance with increase in temperature is due to increasing drift mobility of the charge carriers or due to lattice vibrations associated with increasing temperature, where the atoms occasionally come close enough for the transfer of the charge carriers and the conduction is induced by lattice vibration (Borse and Garde 2008; Shubra Singh *et al.,* 2007). Electrical parameters of $Bi_2S_3$ thin films at different deposition temperature are shown in Table 2.

**Table 1. Electrical parameters of $Bi_2S_3$ thin films for different deposition time periods**

| Deposition time periods (hours) | Thickness (nm) | Applied Voltage (V) | Current (A) | Resistance (Ohms) | Resistivity (ρ) | Conductivity σ(S/m) | Conductivity σ(S/cm) |
|---|---|---|---|---|---|---|---|
| 4 | 210 | 0.457913 | 3.69E-10 | 1.24E+09 | 1.40E+08 | 7.13E-09 | 7.13E-11 |
| | | 1.173589 | 5.68E-10 | 2.07E+09 | 2.34E+08 | 4.28E-09 | 4.28E-11 |
| | | 1.944172 | 8.34E-10 | 2.33E+09 | 2.64E+08 | 3.79E-09 | 3.79E-11 |
| | | 2.808341 | 9.41E-10 | 2.98E+09 | 3.37E+08 | 2.97E-09 | 2.97E-11 |
| | | 3.72147 | 1.20E-09 | 3.10E+09 | 3.50E+08 | 2.85E-09 | 2.85E-11 |
| | | 4.665654 | 1.39E-09 | 3.35E+09 | 3.78E+08 | 2.64E-09 | 2.64E-11 |
| | | 5.641633 | 1.61E-09 | 3.50E+09 | 3.95E+08 | 2.53E-09 | 2.53E-11 |
| | | 6.672209 | 1.84E-09 | 3.62E+09 | 4.09E+08 | 2.45E-09 | 2.45E-11 |
| | | 7.61845 | 2.13E-09 | 3.58E+09 | 4.05E+08 | 2.47E-09 | 2.47E-11 |
| | | 8.578468 | 2.31E-09 | 3.72E+09 | 4.21E+08 | 2.38E-09 | 2.38E-11 |
| 8 | 437 | 1.021177 | 2.76E-09 | 3.70E+08 | 4.18E+07 | 2.39E-08 | 2.39E-10 |
| | | 2.007394 | 5.50E-09 | 3.65E+08 | 4.13E+07 | 2.42E-08 | 2.42E-10 |
| | | 3.002534 | 8.32E-09 | 3.61E+08 | 4.08E+07 | 2.45E-08 | 2.45E-10 |
| | | 3.99747 | 1.12E-08 | 3.56E+08 | 4.02E+07 | 2.49E-08 | 2.49E-10 |
| | | 4.990102 | 1.41E-08 | 3.53E+08 | 3.99E+07 | 2.50E-08 | 2.50E-10 |
| | | 5.988822 | 1.73E-08 | 3.46E+08 | 3.92E+07 | 2.55E-08 | 2.55E-10 |
| | | 6.984071 | 2.02E-08 | 3.46E+08 | 3.91E+07 | 2.56E-08 | 2.56E-10 |
| | | 7.98065 | 2.36E-08 | 3.38E+08 | 3.82E+07 | 2.62E-08 | 2.62E-10 |
| | | 8.977178 | 2.65E-08 | 3.39E+08 | 3.83E+07 | 2.61E-08 | 2.61E-10 |
| | | 9.977457 | 2.97E-08 | 3.36E+08 | 3.79E+07 | 2.64E-08 | 2.64E-10 |
| 12 | 860 | 1.113993 | 2.35E-09 | 4.73E+08 | 5.35E+07 | 1.87E-08 | 1.87E-10 |
| | | 2.100959 | 5.08E-09 | 4.13E+08 | 4.67E+07 | 2.14E-08 | 2.14E-10 |
| | | 3.092709 | 8.45E-09 | 3.66E+08 | 4.14E+07 | 2.42E-08 | 2.42E-10 |
| | | 4.079901 | 1.23E-08 | 3.31E+08 | 3.75E+07 | 2.67E-08 | 2.67E-10 |
| | | 5.066788 | 1.57E-08 | 3.24E+08 | 3.66E+07 | 2.73E-08 | 2.73E-10 |
| | | 6.056662 | 1.95E-08 | 3.11E+08 | 3.51E+07 | 2.85E-08 | 2.85E-10 |
| | | 7.045559 | 2.30E-08 | 3.07E+08 | 3.47E+07 | 2.88E-08 | 2.88E-10 |
| | | 8.032639 | 2.69E-08 | 2.98E+08 | 3.37E+07 | 2.97E-08 | 2.97E-10 |
| | | 9.0168 | 3.07E-08 | 2.94E+08 | 3.32E+07 | 3.01E-08 | 3.01E-10 |
| | | 10.00635 | 3.40E-08 | 2.94E+08 | 3.33E+07 | 3.01E-08 | 3.01E-10 |

**Table 2. Electrical parameters of $Bi_2S_3$ thin films at different temperatures**

| Deposition temperatures(degree) | Thickness (nm) | Applied Voltage (V) | Current (A) | Resistance (Ohms) | Resistivity (ρ) | Conductivity σ(S/m) | Conductivity σ(S/cm) |
|---|---|---|---|---|---|---|---|
| 40 | 191 | 1.079419 | 2.69E-09 | 4.02E+08 | 4.54E+07 | 2.20E-08 | 2.20E-10 |
| | | 2.075394 | 5.26E-09 | 3.95E+08 | 4.46E+07 | 2.24E-08 | 2.24E-10 |
| | | 3.063351 | 8.08E-09 | 3.79E+08 | 4.29E+07 | 2.33E-08 | 2.33E-10 |
| | | 4.062348 | 1.08E-08 | 3.77E+08 | 4.26E+07 | 2.35E-08 | 2.35E-10 |
| | | 5.045306 | 1.36E-08 | 3.71E+08 | 4.20E+07 | 2.38E-08 | 2.38E-10 |
| | | 6.052585 | 1.66E-08 | 3.64E+08 | 4.12E+07 | 2.43E-08 | 2.43E-10 |
| | | 7.044558 | 1.95E-08 | 3.61E+08 | 4.08E+07 | 2.45E-08 | 2.45E-10 |
| | | 8.03662 | 2.25E-08 | 3.57E+08 | 4.04E+07 | 2.48E-08 | 2.48E-10 |
| | | 9.032507 | 2.56E-08 | 3.53E+08 | 3.99E+07 | 2.51E-08 | 2.51E-10 |
| | | 10.026424 | 2.86E-08 | 3.51E+08 | 3.96E+07 | 2.52E-08 | 2.52E-10 |
| 50 | 590 | 0.948758 | 3.42E-09 | 2.78E+08 | 3.14E+07 | 3.19E-08 | 3.19E-10 |
| | | 1.946616 | 6.95E-09 | 2.80E+08 | 3.16E+07 | 3.16E-08 | 3.16E-10 |
| | | 2.947028 | 1.07E-08 | 2.76E+08 | 3.12E+07 | 3.21E-08 | 3.21E-10 |
| | | 3.946568 | 1.46E-08 | 2.70E+08 | 3.05E+07 | 3.28E-08 | 3.28E-10 |
| | | 4.947146 | 1.87E-08 | 2.65E+08 | 2.99E+07 | 3.34E-08 | 3.34E-10 |
| | | 5.947917 | 2.30E-08 | 2.59E+08 | 2.93E+07 | 3.41E-08 | 3.41E-10 |
| | | 6.947086 | 2.74E-08 | 2.54E+08 | 2.87E+07 | 3.49E-08 | 3.49E-10 |
| | | 7.946674 | 3.21E-08 | 2.48E+08 | 2.80E+07 | 3.57E-08 | 3.57E-10 |
| | | 8.944352 | 3.65E-08 | 2.45E+08 | 2.77E+07 | 3.61E-08 | 3.61E-10 |
| | | 9.947053 | 4.11E-08 | 2.42E+08 | 2.74E+07 | 3.66E-08 | 3.66E-10 |
| 60 | 860 | 1.113993 | 2.35E-09 | 4.73E+08 | 5.35E+07 | 1.87E-08 | 1.87E-10 |
| | | 2.100959 | 5.08E-09 | 4.13E+08 | 4.67E+07 | 2.14E-08 | 2.14E-10 |
| | | 3.092709 | 8.45E-09 | 3.66E+08 | 4.14E+07 | 2.42E-08 | 2.42E-10 |
| | | 4.079901 | 1.23E-08 | 3.31E+08 | 3.75E+07 | 2.67E-08 | 2.67E-10 |
| | | 5.066788 | 1.57E-08 | 3.24E+08 | 3.66E+07 | 2.73E-08 | 2.73E-10 |
| | | 6.056662 | 1.95E-08 | 3.11E+08 | 3.51E+07 | 2.85E-08 | 2.85E-10 |
| | | 7.045559 | 2.30E-08 | 3.07E+08 | 3.47E+07 | 2.88E-08 | 2.88E-10 |
| | | 8.032639 | 2.69E-08 | 2.98E+08 | 3.37E+07 | 2.97E-08 | 2.97E-10 |
| | | 9.0168 | 3.07E-08 | 2.94E+08 | 3.32E+07 | 3.01E-08 | 3.01E-10 |
| | | 10.00635 | 3.40E-08 | 2.94E+08 | 3.33E+07 | 3.01E-08 | 3.01E-10 |

**Table 2. (Continued)**

| Deposition temperatures(degree) | Thickness (nm) | Applied Voltage (V) | Current (A) | Resistance (Ohms) | Resistivity (ρ) | Conductivity σ(S/m) | Conductivity σ(S/cm) |
|---|---|---|---|---|---|---|---|
| 70 | 500 | 1.074367 | 2.58E-09 | 4.16E+08 | 4.70E+07 | 2.13E-08 | 2.13E-10 |
| | | 2.067719 | 5.10E-09 | 4.05E+08 | 4.58E+07 | 2.18E-08 | 2.18E-10 |
| | | 3.067302 | 7.82E-09 | 3.92E+08 | 4.44E+07 | 2.25E-08 | 2.25E-10 |
| | | 4.062828 | 1.07E-08 | 3.78E+08 | 4.28E+07 | 2.34E-08 | 2.34E-10 |
| | | 5.060053 | 1.35E-08 | 3.75E+08 | 4.23E+07 | 2.36E-08 | 2.36E-10 |
| | | 6.060379 | 1.65E-08 | 3.67E+08 | 4.15E+07 | 2.41E-08 | 2.41E-10 |
| | | 7.057393 | 1.95E-08 | 3.61E+08 | 4.08E+07 | 2.45E-08 | 2.45E-10 |
| | | 8.053359 | 2.27E-08 | 3.55E+08 | 4.01E+07 | 2.49E-08 | 2.49E-10 |
| | | 9.052162 | 2.56E-08 | 3.54E+08 | 4.00E+07 | 2.50E-08 | 2.50E-10 |
| | | 10.053868 | 2.88E-08 | 3.49E+08 | 3.94E+07 | 2.54E-08 | 2.54E-10 |

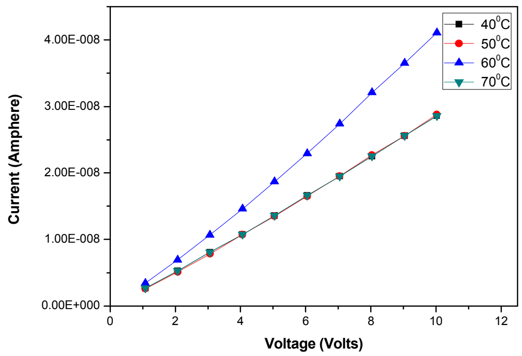


**Fig.4. Current-Voltage plot of $Bi_2S_3$ films for different deposition temperatures**

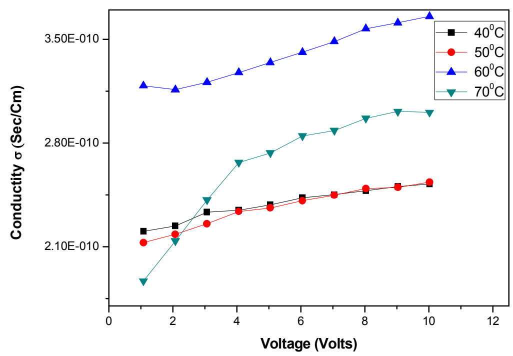


**Fig.5. Conductivity -Voltage plot of $Bi_2S_3$ films for different deposition temperatures**

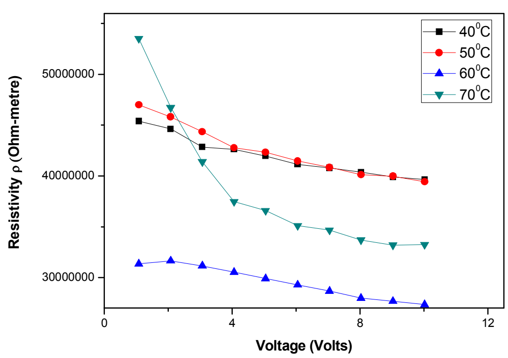


**Fig.6. Resistivity -Voltage plot of $Bi_2S_3$ films for different deposition temperatures**

## Conclusion

The current conduction mechanism across $Bi_2S_3$ films was carried out using I-V measurements. It is observed that the current is directly proportional to the applied voltage for all films in forward bias. The current increases with increase of the film thickness. The decrease in resistivity is due to the improvement in the crystallinity of films, which increases the conductivity. This behaviour indicates that the semiconducting nature of films.

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