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Studies of Junction Parameters of Sn/(p)Bi_2S_3 Schottky Junction Prepared by Vacuum Evaporation Technique

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Abstract

The forward bias current-voltage (I-V) characteristics of vacuum deposited Sn/(p)Bi_2S_3 metal semiconductor (MS) Schottky diodes have been studied at room temperature and elevated temperatures. The junctions exhibited rectifying I-V characteristics and also photovoltaic effect. Different junction-parameters such as ideality factors, band gap, short-circuit current, open circuit voltage, fill factor, efficiency etc. have been determined from I-V characteristics of the junction. The ideality factor n and series resistance R_s was found to decrease and zero bias barrier height ϕ_b found to remain more or less constant with the increase of temperature in (308-328)K range. Proper doping, annealing and hydrogenation are necessary to reduce the series resistance so as to achieve high conversion efficiency of the junction. More works are being carried out in this direction.

Key words : photovoltaic effect, ideality factors, band gap, fill factor, Schottky diodes, series resistance.

1. Introduction

Among the non-conventional renuable energy resources, solar energy is a potential source of renewable energy which is easily available all over the world. There are various methods to convert solar energy into other form. Solar cell directly converts light into electrical energy. The exploration of low cost and echo-friendly materials to fabricate solar cell have been subject of both experimental and theoretical studies in the present time. The Bi_2S_3 thin film with reported band gap (1.2-1.7) eV [1, 2, 3] and high absorption coefficient (10^4 to 10^5 cm^{-1}) has been creating interest to the scientist for its possible use as solar cell. The optical band gap of our sample was found to be 1.45eV. Up to our knowledge no data have been reported on Schottky barrier junction of Bi_2S_3 thin films prepared by thermal evaporation method except our report [4]. However, there are few reports of junctions on Bi_2S_3 thin films prepared by chemical methods [5, 6, 7, 8, 9,10]. The Bi_2S_3 thin films prepared by chemical method reported to be n-type in nature [11, 12, 13, 14]. The Bi_2S_3 thin films used in polymer solar cell shows acceptor type nature [5, 6]. The Cu_3BiS_3 thin films have been reported to behave as p-type semiconductor [15]. In the present work, electrical and optical properties have been studied on Sn/(p)Bi_2S_3 Schottky barrier diode prepared by evaporation method.

2. Experimental Procedure

Three thick films of Nickel (Ni), each of width 1mm and a length 25 mm were first deposited by vacuum evaporation on a chemically cleaned glass substrate ($3\times3cm^2$ size). Above these Ni films, Bi_2S_3 (SIGMA ALDRICH) powder and 7.21% Indium (In) was simultaneously deposited from two different sources by thermal evaporation technique covering an area (1.5×1.5 cm^2). It has been observed that Bi_2S_3 highly decomposes during vacuum evaporation [16] and also found to react with some base materials. Therefore, special care is taken in depositing Bi_2S_3

thin films. The films then annealed in air inside an oven for five hours at temperature 438K. The type of carriers of these films were examined by hot probe method and found to behave as p-type. Over the composite film three tin (Sn) films each of width 1mm and length 25mm were vacuum deposited horizontally making crossed with the Nickel films. Thus 9 Sn/(p)Bi_2S_3 Schottky junction, each of equal area (1mm^2) were obtained on the same substrate. The Ni (work function = 5.01eV) films connected to (p)Bi_2S_3 (work function= 4.93eV) [17] film were used as the lower electrode and Sn (work function = 4.08eV) films deposited over the (p) Bi_2S_3 was used as the upper electrode. They form Schottky contact with the (p) Bi_2S_3 films. During all depositions, substrates were kept more or less at room temperature (308 K) and pressure was maintained at 10^{-5} Torr.

For measuring *I-V* of the junctions, the sample was mounted on a specially designed sample holder fitted inside a vacuum chamber. Electrical and optical measurements were performed at room temperature as well as at elevated temperatures using a specially designed electronic temperature controller. To measure *I-V* under illumination, the junction inside the chamber was illuminated using white light from a tungsten halogen lamp (500 W) through a glass window. The light was incident from the "Sn" side. The input intensity of the light was measured with a Lux meter (Luxmat-300ED; Research Ins ND-110028, India). The type of carrier concentration was determined by hot probe method. The capacitance of the junction was measured by 4-digit auto compute LCR-Q meter (Aplab-4910). The monochromator (Oriel 77022) fitted with a grating 1200 per cm, blazed at 35nm (Oriel 77233) was used to study the spectral response of the junctions. The input and output slits were set at 3mm. A tungsten halogen lamp was used to illuminate the entrance slit of the monochromator. Output of the monochromator was carefully allowed to fall on the junction for spectral response measurement. Thickness of all films was measured using interference technique. All electrical measurements were performed at pressure 10^{-2} Torr.

2. Results and Discussion

2.1. Study of I-V Characteristic

Nine Schottky barrier diodes (Sn/(p)Bi_2S_3) of equal area (.01cm^2) was fabricated on a micro slide glass substrate. All junctions show more or less same *I-V* characteristics. The curves show rectifying [Fig.1(a)]. nature with very low photovoltaic effect. The current density *J* was calculated from the well known expression [18],

$$J = J_0 \exp(qV/nkT)\{1-\exp(-qV/kT)\}] \quad (1)$$

where J_o is reverse saturation current density and is equal to

$$J_o = A^* T^2 \exp\left(\frac{-q\phi_b}{kT}\right) \quad (2)$$

The J_o values were found out by extrapolating the linear portion of ln[J/{1-exp(-qV/kT)}] vs *V* plots (plots are not shown) to the intercept on the current axis at zero bias (*V*=0) and the ideality factor n was calculated from the slope of the plot(not shown) using ,

$$n = \frac{q}{kT}\frac{dV}{dJ} \quad (3)$$

The J_o values of the junctions at room temperature (308K) in dark and under illumination (2000Lux) were found to vary within (3-3.3) x10^{-7} Acm^{-2} and (6-7) x10-7Acm^{-2} respectively. The ideality factor of the junctions studied in the present case at room temperature (308K) was found to vary within (5.2- 5.7) in dark and (4-4.4) under illumination (2000Lux). The *I-V* characteristic of the Sn/(p)Bi_2S_3 Schottky junction have been studied in (308-328)K [Fig. 1(b)] range to understand the detail information about conduction mechanisms or the nature of barrier formation at the MS diodes. The rectification has been observed to increase with the increase in temperature. The values n and J_o at different temperatures were found out from ln[J/{1-exp(-qV/kT)}] vs V plots [Fig. 2(a)] using Eq. (1) as discussed above. The value of Richardson's constant (*A**) of a typical junction was found out

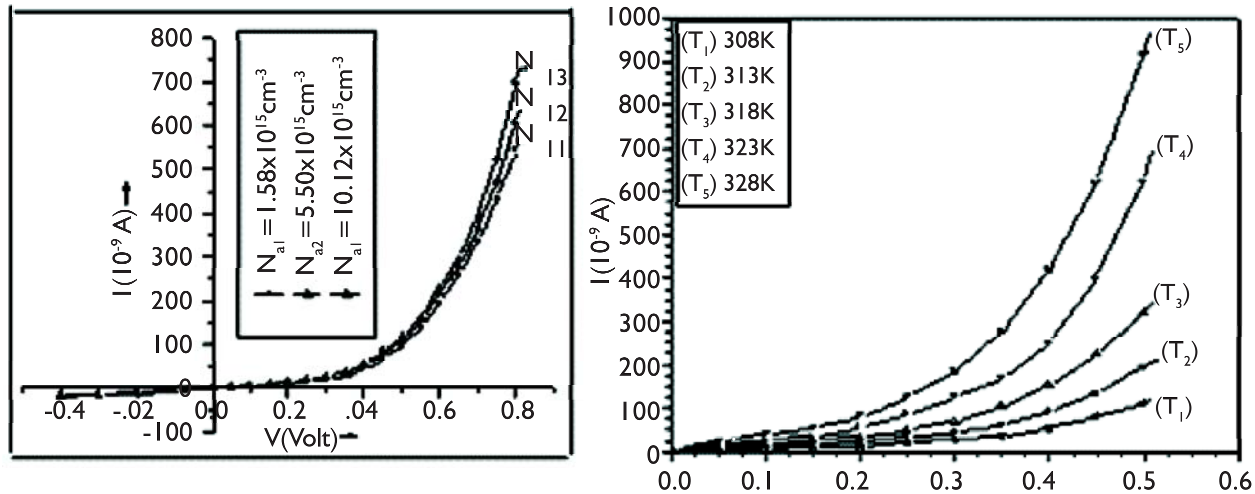


Fig.1 (a) *I=V* characteristics of three typical Sn/(p) Bi_2S_3 Schottky barrier junction with different carrier concentrations in Dark; (b) I=V characteristics of a typical Sn/(p) Bi_2S_3 Schottky barrier junction for different temperature in dark

from the intercept of ln[J_o/T^2] vs 1/T plots [Fig.2 (b)] on ln[J_o/T^2] axis for 1/T=0. The value was found to be 87.35Acm^{-2} K^{-2}. Using A* value the zero bias barrier height (ϕ_b) values of the Schottky junction for different temperature have been calculated by using Eq. (2). The J_o, n and ϕ_b values found out at different temperatures are shown in Table 1. It is apparent from Table 1, that, J_o and n values of the junction are strongly temperature dependent. The ϕ_b values found to remain more or less constant within (308-328)K. The value of n has been observed to decrease from 5.7 to 4.3 and J_o has been found to increase from1.31$0^{-9}$A to16.6$\times$1$0^{-9}$A with the increase of temperature in (308-328)K .

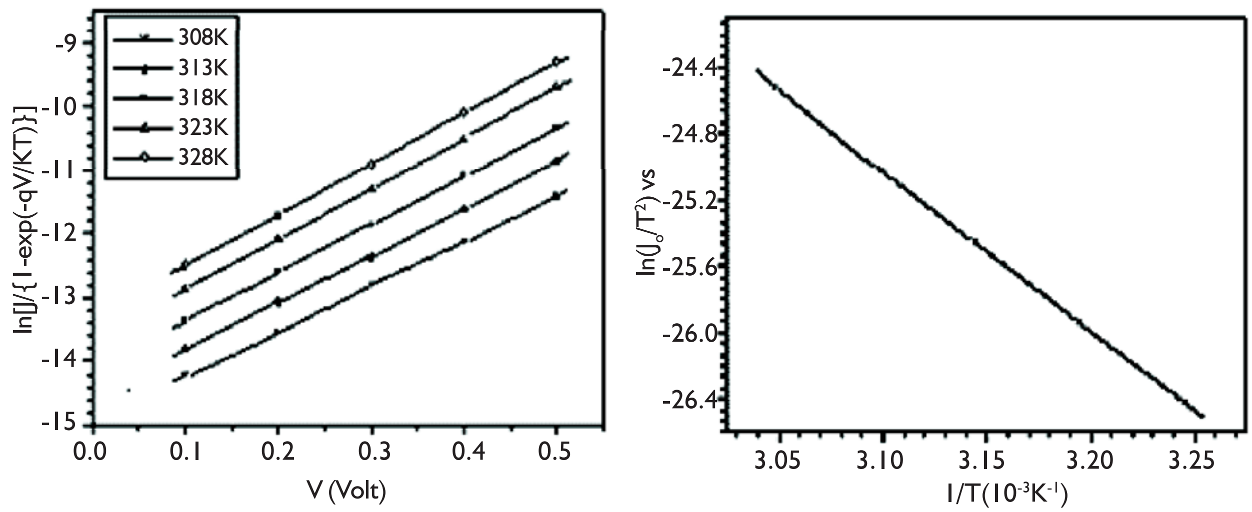
Table 1
Variation of some parameters of a typical Sn/(p)Bi_2S_3 junction with temperatures in dark

Temperature (K)	Saturation current density J_O(10^{-7}A cm^{-2})	Ideality factor (n)	Barrier height ϕ_b (eV)
308	03.17	5.3	0.82
313	05.30	5.0	0.82
318	08.80	4.8	0.82
323	12.10	4.6	0.82
328	24.21	4.3	0.82

The presence of interfacial layer, image force lowering of barrier height, recombination of electron and hole in the depletion region and tunnelling effect are the main regions for ideality factor greater than unity. The high values of the ideality factor show that there is a deviation from TE theory in the current conduction mechanism. Moreover, the ideality factor varies almost linearly with T^{-1} [Fig. 3(a)]. The temperature dependence of n suggests that the current conduction mechanism is controlled by the thermionic field emission theory . The barrier height does not change significantly with the change of temperature from 303K to 328K.

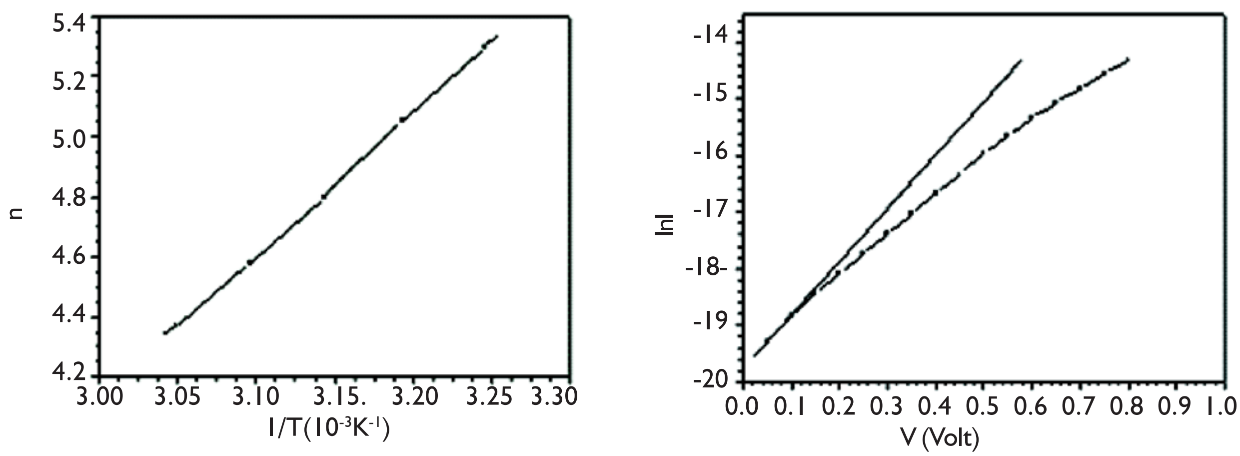
2.2 Effect of Series Resistance

The presence of series resistance in the Sn/(p)Bi_2S_3 Schottky junction was also investigated. The series resistance was calculated for forward bias condition using *lnI* vs *V* plot [Fig. 3(b)] and *ΔV* vs *I* plot [Fig. 4(a)]. The result shows that the device possesses high series resistance both in dark and under illumination, the same was found to decrease with the increase of temperature. The series resistance of a typical junction under study was found to be 416 kΩ (in dark), 344 kΩ (2000 Lux) both calculated at 308 K same was found to decrease to 250 kΩ , when temperature was raised up to 328 K in dark.



(a) (b)

Fig.2 (a) *ln[J/{1-exp(-qV/KT)}]* vs *V* plots of a typical $Sn/(p)Bi_2S_3$ Schottky barrier junction
(b) $\ln(J_o/T^2)$ vs 1/T plot of a typical $Sn/(p)Bi_2S_3$ Schottky barrier junction



(a) (b)

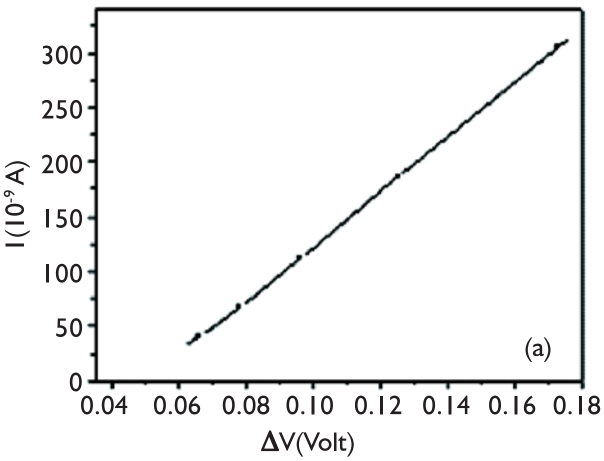
Fig. 3 (a) *n* vs *1/T* plot of a typical $Sn/(p)Bi_2S_3$ Schottky barrier junction. (b) *lnI* vs *V* plot of a typical $Sn/(p)Bi_2S_3$ Schottky barrier junction

2.3 Capacitance-Voltage Measurment

The capacitance of the junction was measured at room temperature and under reverse bias condition. The acceptor concentration (N_a) was calculated from the slop of C^{-2} vs V_r plot using the relation

$$C = \left(\frac{q\varepsilon_s N_a}{2}\right)^{1/2}\left(V_{do} + V_r - \frac{kT}{q}\right)^{-1/2}$$

A typical C^{-2} vs *V* plot at 1 kHz is shown in Fig. 4(b). Here V_{do} is the diffusion voltage at zero bias which is equal to $V_I + kT/q$, where V_I is the negative intercept on the V_r axis and ε_s is the permittivity of $(p)Bi_2S_3$. The value of N_a for a typical junction was found to be $5.253\times10^{15}/cm^3$. Barrier height obtained from the relation $\phi_b = V_{do} + \xi$ (ξ is the energy difference between the Fermi level and the top of the valence band) was about 0.82 eV in dark. This value is also in good agreement with the value obtained from I-V characteristic in dark.



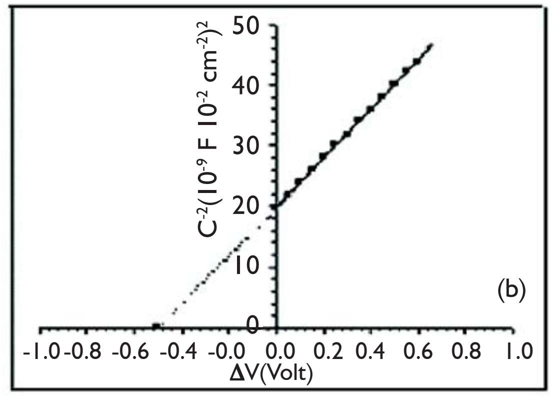


Fig.4 (a)) *I* vs *ΔV* of a typical Sn/(p)Bi_2S_3 Schottky barrier junction. (b) C^{-2} vs V_r plot of a typical Sn/(p)Bi_2S_3 Schottky barrier junction

2.4 Photovoltaic effect

The junctions under study show photovoltaic effect (Fig. 5). The open circuit voltage and short circuit current of a typical junction was found to be 215mV and 10×10^{-9}A respectively. Different parameters of a typical Sn/(p)Bi_2S_3 junction illuminated have been calculated and showed in Table 2. Investigation was also carried out on spectral response of the junctions (plot not shown here).

3. Conclusion

Thin films Sn/(p)Bi_2S_3 Schottky barrier junction prepared by vacuum evaporation exhibits rectifying I-V characteristic and photovoltaic effect. Junction

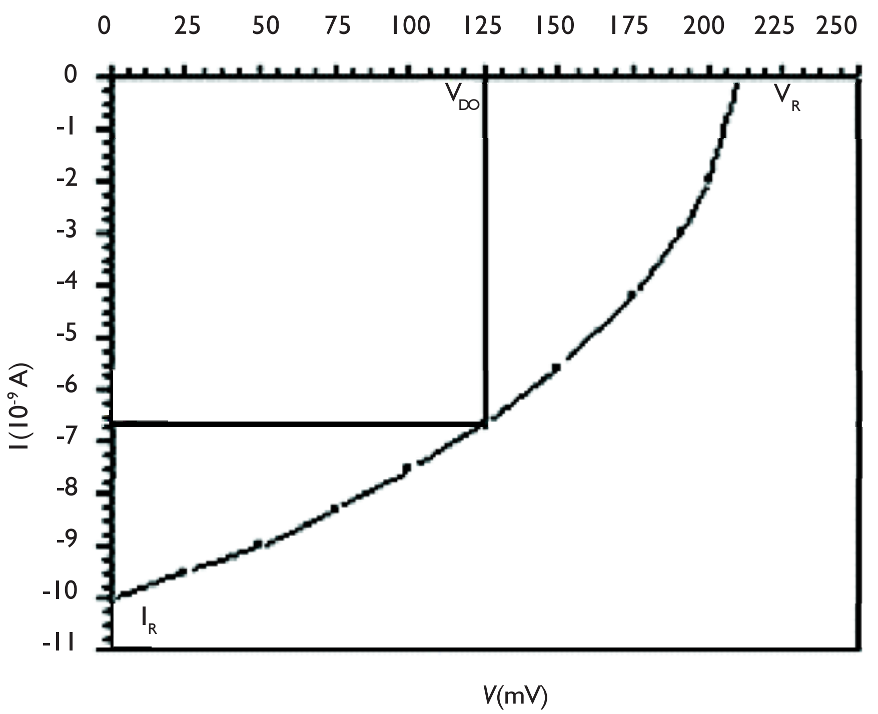


Fig. 5. Photovoltaic effect of a typical Sn/(p)Bi_2S_3 Schottky barrier junction at 2000Lux

Table 2
Some photovoltaic parameters of a typical Sn/(p)Bi_2S_3 Schottky barrier junction at room temperature. (Illumination intensity 2000Lux)

Open circuit voltage (mV)	Short-circuit current density $J(10^{-7}A/cm^2)$	Maximum power output (μWcm^{-2})	Fill factor (%)	Efficiency (%)	Ideality factor *n*	Saturation current density $J_s(10^{-7}Acm^{-2})$
215	10	0.0832	38.70	0.231	8.74	4

parameters such as the barrier height, the diode ideality factor, saturation current density and the Richardson's constant of a vacuum deposited Sn/(p)Bi_2S_3 structure were determined from its I-V characteristics. The ideality factor greater than unity is attributed to the interfacial layers and series resistance associated with MS junction and within the semiconductor. They are found to change under illumination and with change in temperature. It has been observed that Bi_2S_3 compound highly decomposes into Bismuth and Sulphur and S/Bi ratio of the source was found to decreases with passes of time during evaporation, which hinders in preparing Bi_2S_3 thin film stoichiometric in composition. To overcome this difficulty special care is taken in evaporating Bi_2S_3 compound. Sulphur is highly reactive to any base material and sulphur produced during evaporation due to decomposition of Bi_2S_3, reacts with most of the base metals (counter electrode) forming sulphide compound which is one of the main regions of ideality factor greater than unity. However, this can be reduced by increasing the carrier concentration and also improving preparation technique. More works is progress in this direction.

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