Effect of PbS and polyaniline Film Thicknesses on Current Density (J) – Voltage (V) Characteristics of p-polyaniline/n-PbS heterojunction

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Abstract—In the present work, layer by layer depositions of p-polyaniline and n-PbS were carried out using electrodeposition and chemical bath deposition methods respectively to form a heterojunction and effect of variation of PbS and polyaniline thickness on the J-V characteristics were studied. Maximum forward bias current is observed for 0.55 µm thickness of the PbS thin films. Further keeping the constant thickness of 0.55 µm for PbS thin films polyniline thickness was optimized to get suitable forward bias current of the p-polyaniline/n-PbS heterojunction. The optimized heterojunction can be used for many applications like photocatalyst, Solar cells etc.

Indexed Terms—heterojunction, junction ideality factor, PbS, Polyaniline.

I. INTRODUCTION

Nowadays , the researchers are focused on deposition of multilayered materials for various applications such as photocatalyst, solar cells, gas sensors, bipolar transistors, ultraviolet photodetectors, photovoltaic diodes [1-6]. The electrical properties of heterojunction are influenced by its thickness, which is a crucial factor. Since the electrical properties determine the device's applicability, it is crucial to optimize the thickness of the films while fabricating heterojunction diodes. Feng et. al [7] reported Bismuth-Based Step-Scheme Heterojunction for photocatalyst application for pollution degradation. Another possible applications of these heterojunctions are ammonia and urea production.S. Rani et.al. [8] fabricated $SnSe_2$/SnOx/SnSe heterojunction thin films with different thicknesses via the thermal evaporation technique. The heterojunction showed the selectivity towards NO_2 gas with good response and recovery times. M. Yousefizadet. al. [9] studied flexible n-ZnO/p-CuO/n-ZnO heterojunction bipolar transistor and discussed simulation results.

In the present work, effect of thickness variation on the electrical properties of heterojunction were studied. The PbS thin film thickness was varied for constant polyaniline thickness. After optimizing the PbS thin film thickness, polyaniline thickness was varied to obtain best performance of forward bias characteristics of p-polyaniline/n-PbS heterojunction.

II. EXPERIMENTAL

A. Deposition of PbS thin film

PbS thin films are deposited on stainless steel that has been ultrasonically cleaned. Anions (S^{-2}) and cations (Pb^{+2}) are obtained from thiourea and lead acetate, respectively. Solution of lead acetate (0.05 M) and thiourea (0.1 M) were combined in a beaker at room temperature (300 K) to produce PbS thin films onto stainless steel substrate. Drop by drop, ammonia solution was added to the solution until the pH was 9 ±0.1. When the ionic product of Pb^{2+} and S^{2-} exceeds the solubility product of PbS, PbS deposits form. After varying deposition times, well adhering PbS thin films with varying thicknesses were produced. After being removed from the bath, the films were dried, cleaned in double-distilled water, and stored. The film has a grayish color.

B. Deposition of polyaniline thin film

Polyaniline thin films were deposited using electro-deposition technique. Three electrode system is used in which deposition of polyaniline thin films were obtained by applying a constant current density (4.5 mA/cm^2). Galvanostatic deposition controlled current reaction proceeds at a constant rate. Due to the activation of space charge region, potential was suddenly raised to +268 mV/SCE and then started to decrease and oxidation of aniline on substrate took place. Afterwards, a continuous growth of polyaniline is observed.

III. FORMATION OF HETEROJUNCTION

The p-polyaniline/n-PbS heterojunctions were created via chemical bath deposition and electrodeposition methods. Polyaniline was electrodeposited onto a stainless steel substrate on top of pre-deposited PbS thin films.Galvanostaticelectrodeposition was used to create the p-polyaniline/n-PbS heterojunction. Using a continuous current of 4.5 mA/cm^2, a polyaniline film was applied onto a PbS thin film that had already been chemically deposited. The figure below shows a schematic illustration of the n-PbS/p-polyaniline heterojunction.

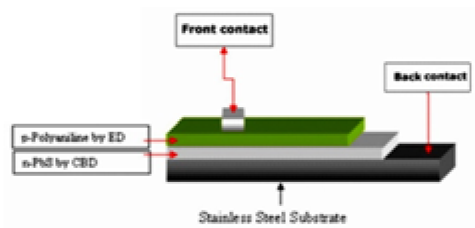

Fig.1. Schematic of n-PbS/p-polyaniline heterojunction

A p-polyaniline/n-PbS heterojunction, formed on a stainless steel substrate with an area of 1 x 1 cm^2, was put on a PCB board in order to examine the properties of current density (J) and voltage (V). Carefully fine connections are made, rear contact from the stainless steel substrate for the PbS thin film, and front contact from the top for polyaniline. Soldering metal and silver paste are used to make contacts.

IV. RESULT AND DISCUSSION

A. J-V characteristics and junction parameters of p-polyaniline/n-PbS heterojunction

A.1. Effect of PbS Film Thickness on Current Density (J) – Voltage (V) Characteristics

Figure 2 shows the J-V characteristics of a heterojunction using PbS thin films of varying thicknesses. At a biasing voltage of + 1.5 V, the greatest forward current of heterojunction is recorded in the range of 2 to 10 mA/cm^2 for PbS thicknesses ranging from 0.23 to 0.55 µm. The junction's rectifying behavior was evident in the J-V characteristics. PbS thickness and carrier diffusion length may be similar at 0.55 µm in terms of increasing device current.

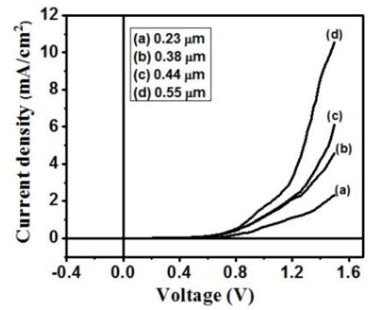

Fig. 2 The current density (J) – voltage (V) plots of p-polyaniline/n-PbS heterojunction at different thickness of PbS films a) 0.23, b) 0.38, c) 0.46 and d) 0.55 µm.

A.2.ln (J) - (V) Plots

Plots of ln (J) vs (V) of the p-polyaniline/n-PbS heterojunction at varied PbS film thickness in the range of 0.23 to 0.55 µm are shown in Fig. 3. Plots show that the evaluated junction ideality factors range from 2.47 to 3.2, with 2.47 serving as the lowest value for PbS thicknesses of 0.55 µm. Table 1 lists the variations in electrical parameters with PbS film thickness. Static resistance (Rs) and junction ideality factor (η) showed a declining trend while rectification ratio (RR) increased. At 0.55 µm of PbS film, the maximum rectification factor (1.23 x103) was measured, whereas the lowest ideality factor (2.47) was found.

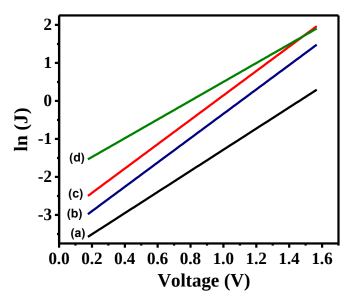

Fig 3 The plots of ln (J) - voltage (V) of p-polyaniline/n-PbS heterojunction at variable thicknesses of PbS films a) 0.23, b) 0.38, c) 0.46, and d) 0.55 µm.

Table 1 Thickness (PbS film) dependent electrical parameters of p-polyaniline/n-PbS heterojunction.

Thickness of PbS film, (µm)	Knee voltage V, (volts)	Saturation Current, Isc (mA)	Static Resistance, Rs (Ω)	Rectification Ratio, RR (102)	Junction Ideality Factor, N
0.23	0.7	0.0063	831	2.94	3.68
0.38	0.64	0.0072	567	5.29	3.25
0.46	0.54	0.0083	482	7.17	3.10
0.55	0.35	0.0089	271	1.23	2.47

From Table 1, it is seen that at a fixed polyaniline thickness of 0.84 µm, increase in PbS thickness decreased the knee voltage, rectification ratio and static resistance and increased the saturation current and ideality factor of the heterojunction

B.1 Effect of Polyaniline Film Thickness on Current Density (J) – Voltage (V) Characteristics

Variations in the thickness of polyaniline films were deposited over an optimum PbS film thickness of 0.55 µm. To create a heterojunction, polyaniline films with thicknesses of 0.44, 0.66, 0.75, and 0.84 µm were placed on a PbS substrate. The J-V properties of the heterojunction with varying polyaniline film thicknesses were investigated.

Figure 4 displays the J-V parameters for films with varying thicknesses of polyaniline. The features demonstrated the junction's rectifying behavior. Between 5.01 to 15.16 mA/cm2 was determined to be the peak forward current density for biasing voltage +1.5 V, whereas the range for polyaniline film thickness was 0.44 to 0.84 µm.

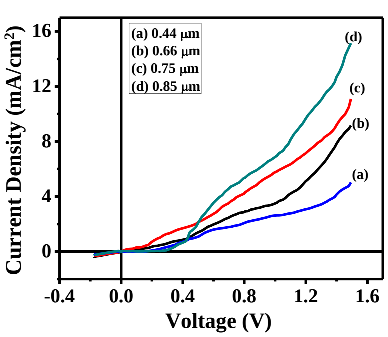

Fig. 4 The current density(J) – voltage(V) plots of p-polyaniline/n-PbS heterojunction at variable thickness of polyaniline films: a) 0.44, b) 0.66, c) 0.75 and d) 0.84 µm

B.2 ln (J) – (V) Plots

Fig. 5 shows the corresponding ln (J) – (V) plots corresponding to various thicknesses of polyanilinefilms. From the plots, the evaluated junction ideality factors are found to vary in the range 2.59 to 1.79, with minimum value of 1.79 for thickness of polyaniline equal to 0.84 µm.

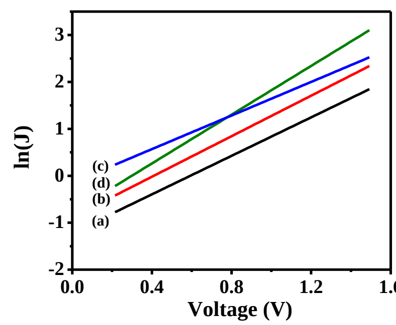

Fig. 5 The plots of ln (J) – voltage (V) of p-polyaniline/n-PbS heterojunctions at different thickness of polyaniline films a) 0.44, b), 0.66, c) 0.75 and d) 0.84 µm

Table 2 Thickness (Polyaniline film) dependent electrical parameters of p-polyaniline/n-PbS heterojunction

Thickness of Polyaniline film, (µm)	Knee voltage V, (volts)	Saturation Current, I_{sc} (mA/cm^2)	Static Resistance R_s(Ω)	Rectification Ratio, $R_R 10^2$	Junction on Ideality Factor, n
0.44	0.025	0.38	346	1.59	2.59
0.66	0.07	0.31	202	2.65	2.15
0.75	0.019	0.25	156	3.66	1.79
0.84	0.026	0.20	111	6.04	2.05

Table 2 shows the fluctuation in electrical characteristics of the p-polyaniline/n-PbS heterojunction with polyaniline film thickness. The saturation current (Isc), static resistance (Rs), and junction ideality factor (n) exhibit a declining trend as the thickness of the polyaniline film grows, whereas the rectification ratio (RR) rises. The decrease in reverse saturation current is the reason of the increase in rectification ratio. With a rectification ratio of 6.04 x 102 and a thickness of 0.75 µm, the polyaniline film exhibits the lowest value of the junction ideality factor (1.79).

CONCLUSION

Film thickness plays important role in the electrical properties of p-polyaniline/n-PbS heterojunction. The optimized films thickness of PbS thin film is 0.55 µm where as for polyaniline is 0.75 µm. The heterojunction fabricated with these values showed the good junction ideality factor of 1.79.

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