International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

PNPN- Heterojunction Photovoltaic Devices Based on p-Si Via Two Deposit Techniques and Studying the Optoelectronic Properties

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***Abstract*—*In this work, a (pnpn) multilayer was fabricated and the performance was analyzed as a heterojunction photovoltaic device utilizing n-CdSe and p-CuS semiconductor films. These films were deposited using two different techniques: chemical bath deposition for the p-CuS and spray pyrolysis for the n-CdSe based on the p-Si wafer. The (p-Si/p-CuS/n-CdSe) structure was prepared under the conditions approved above for the 100°C and 400nm films. The optelectrical properties of the device were tested under both illuminated (light) and (dark) conditions. The results parameters of the optoelectrical properties are: η=1.03, FF=0.795, ISC=1.907 mW/cm2, and VOC =0.680 V.*

***Keywords*— *Heterojunction device, optoelectrical, solar cell, CdSe, CuS.*

I. Introduction

Semiconductor devices are electronic components that utilize the properties of semiconductors, materials with intermediate electrical conductivity between conductors (such as metals) and insulators (nonmetals). Modern electronics are built on semiconductors, and semiconductor devices are essential to many different electronic systems. A p-n heterojunction refers to a junction formed between two different semiconductor materials with distinct doping types, namely p-type and n-type. In a p-type semiconductor, the majority of charge carriers (electrons) are holes, while in an n-type semiconductor, the majority of charge carriers are electrons. Here, if the n-type and p-type material consists of the same type of semiconductors, it is called homojunction, and if it consists of different types of semiconductors, it is called heterojunction. Forbidden energy gaps, work functions, and electron affinities are different in heterojunctions. Heterojunctions are widely used in solar cells. The work function of a p-type semiconductor is larger than that of an n-type semiconductor. At the same time, when these two materials, which have different electron and hole densities, are brought into contact, an electron transition from the n-type semiconductor to the p-type semiconductor occurs, and a hole transition occurs in the opposite direction, through the internal electric field formed in the junction region. This charge transition continues until the Fermi levels of the materials reach equilibrium [1]. A solar cell is an electronic device that converts solar energy directly into electrical energy through the photovoltaic effect. These devices are called photovoltaics (PV) because they provide this conversion with the photovoltaic effect of semiconductors. Photovoltaic conversion is based on the generation of electron-hole pairs in the transition region and the separation of both types of carriers by the junction electric field.

This work aims to prepare two types of thin film semiconductors (n-CdSe) and (p- CuS) by chemical bath deposition [2], as well the spray pyrolysis techniques [3]. And to fabricate a PNPN multilayer junction (p-Si/n-CdSe/p-CuS/n-CdSe) as a photovoltaic devices based on these films and study the optoelectronic performance of it.

II. Methods and Materials

The silicon wafers were cleaned in several steps. To remove the oxidation layer from the silicon wafer we used Hydrofluoric acid %10 HF. During the cleaning process, we kept wafers in 10% HF solution diluted in volume for 2 minutes, and then the samples were put in de-ionized water to remove from the HF solution.

A (0.8)gm of selenium (Se) powder was mixed with 1.2 gm of sodium sulfite (Na_2SO_3) powder in 40 ml of deionized water in a reflux system. The solution was stirred with a magnet on a hotplate heater at 60°C for two hours. To aid the dissolution and prevent sticking, a magnetic stirrer was used, and the solution was later filtered to remove sediments [4]. Cadmium chloride was used as a precursor of the Cd^+ source. In order to get pH=11, 1 milliliter of ammonia (NH_3) was added as a complex agent after 1 gram of $CdCl_2$ was dissolved in 20 milliliters of deionized water. After that, for fifteen minutes, both solutions were combined and agitated at 70°C. The precursor was sprayed with pressurized atmospheric air onto substrates using a spray pyrolysis system [5-6]. The distance between the nozzle and substrate was fixed at 25 cm, and the flow rate was 4 ml/min.

The CuS films were prepared using a bath deposition technique: Dissolve copper chloride $CuCl_2$ in 40 ml of distilled water using a hot stir plate for 30 min at 70°C and 0.1 M, in the Reflux system. Dissolve the Na_2S sodium sulfide compound in 40 ml of distilled water using a hot plate stirrer for 30 minutes at a concentration of 0.1 M in the Reflux system [7]. Copper chloride ($CuCl_2$) is mixed with sodium sulfide (Na_2S) in 80 ml, mixed and heated in the same apparatus for 30 minutes at 70ºC. After mixing the two solutions, are filtered with filter paper, and the solution is

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ready for sedimentation to be placed in the chemical bath. In our work, (pH=9) was taken [8]. The solution was placed in the bath and deposited according to the times (3hr) on the glass substrate to complete the deposition process at a temperature of 70°C. After deposition, the samples are removed from the chemical bath and left to dry at room temperature [9].

For ohmic contact, (Au) was used as a metal contact on the p-Si/CdSe/CuS/CdSe heterostructures. Besides, the glass is coated with pure gold and silver by a DC sputtering device in the Department of Physics at the College. DC 150R E/ES model with 10-5 vacuum sputtering devices.

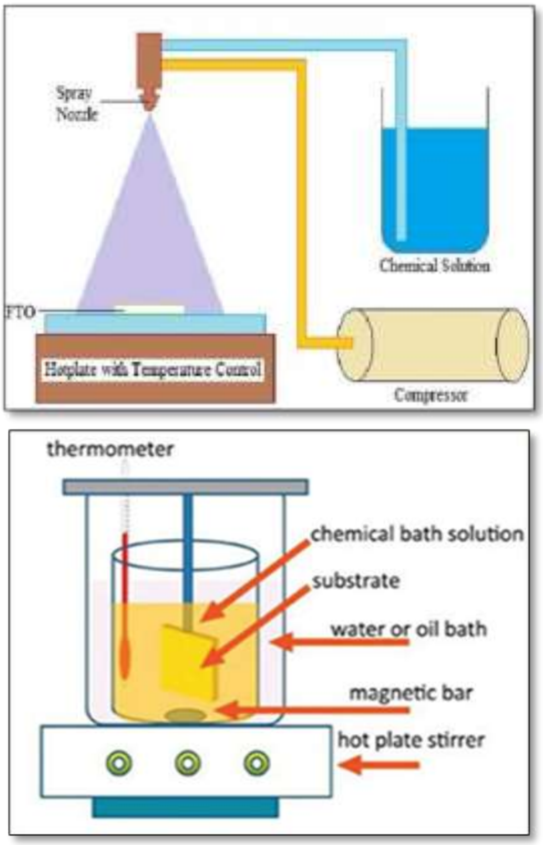

Fig. 1: Schematic diagram of: (a) the spray pyrolysis technique. (b) the chemical bath

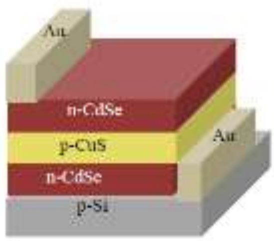

Fig. 2: PNPN multilayer solar cell.

III. Results and Discussion

The fabricated heterostructure (p-Si/n-CdSe/p-CuS/n-CdSe) consists of four layers as shown in the figure (2). The solar cell properties of the resulting device were examined. Then, the I-V properties were analyzed. Figure (3) shows the solar cell I-V curve and the output power of the solar cell. The parameters of the obtained solar cell are as follows: η = 1.03, FF= 0.795, I_{SC} = 1.907 mW/cm^2, and V_{OC} = 0.680 V.

On the other hand, the I-V characteristic of the related device under dark and illumination conditions is depicted in Figure (4). The ideality factor, barrier height, saturation current, and series resistance were calculated using the thermionic emission and Cheung function models [10]. The related parameters are tabulated in Table (1).

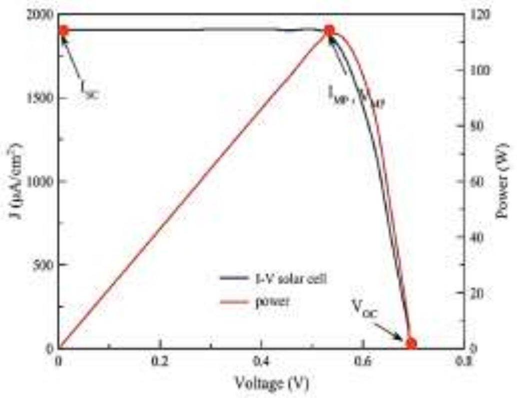

Fig. 3: The I-V and P-V of p-Si/n-CdSe/p-CuS/n-CdSe photovoltaic's

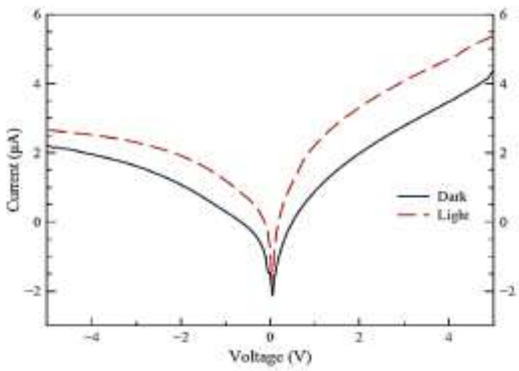

Fig. 4: I-V of p-Si/n-CdSe/p-CuS/n-CdSe heterojunction device in dark and light

This structure, (PNPN) photocell gives an efficiency about 1.03%. The related parameters are calculated and tabulated in Table (1).

TABLE 1: The I-V parameters of p-Si/n-CdSe/p-CuS/n-CdSe heterostructure

Samples	ideality factor n		Barrier height (eV)		Current saturation (µA)		Series resistance (Ω)	
	Dark	Light	Dark	Light	Dark	Light	Dark	Light
IV	2.54	3.6	0.71	0.65	$1.16x10^{-10}$	$2.77x10^{-7}$	-----	-----
Cheung	2.61	3.81	0.41	0.56	--------		4193	7821

IV. Conclusion

In this work, the p-Si/n-CdSe/p-CuS/n-CdSe heterostructure performance was investigated via the I-V parameters in the dark and under illumination for optoelectrical properties were: FF=0.795, I_{SC}=1.907mW/cm^2, and V_{OC}=0.680 V. where the photocell efficiency was 1.03%. This paper recommends developing this (pnpn) structure by adding a layer of graphene in the middle to increase conversion efficiency.

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