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Optoelectronic Properties of ppn-Heterojunction Photovoltaic Devices using n-CdSe and p-CuS Thin Films via Dual Deposition Methods

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ABSTRACT
This study focuses on the fabrication and performance analysis of a heterojunction device utilizing n-CdSe and p-CuS semiconductor films. These films were deposited using two different techniques: spray pyrolysis for the n-CdSe and chemical bath deposition for the p-CuS. The (p-Si/p-CuS/n-CdSe) structure was prepared under the conditions approved above for the 100°C and 400nm films. The optoelectrical properties of the device were tested under both illuminated (light) and dark conditions. The device exhibited a conversion efficiency of 1.05% and an ideality factor n≥1.

Keywords: photovoltaic, CdSe, CuS, optoelectronic

I. INTRODUCTION

Cadmium Selenide is a semiconductor material from the II-VI group. It typically crystallizes in a cubic or hexagonal structure and has a direct band gap of about 1.75 eV at room temperature, making it ideal for applications in visible light emission and absorption. In thin film, the exciton binding energy is about 20 meV[1]. Strong photoluminescence is observed, making CdSe suitable for light-emitting devices and display technologies[2]. The electron mobility ranges from 10 to 100cm²/Vs, depending on the quality and fabrication method of the film[3].

CuS is a valuable material with semiconductor characteristics that show potential in various industries, including thermoelectric power, optoelectronics, and catalysis. Ongoing research aims to investigate and enhance its properties for different applications. Typically, CuS has an orthorhombic crystal structure with layered arrangements of copper and sulfur ions. It has an electrical conductivity that falls between semiconductor[4]. The band gap of CuS is approximately 1.2 to 1.5 eV. CuS has garnered attention for its potential use in optoelectronic devices due to its suitable band gap and high light absorption qualities. It can be utilized as a light-absorbing material in photodetectors, sensors, IR detectors, and thin film solar cells[4].

This work aims to prepare two types of thin film semiconductors (n-CdSe) and (p-CuS) using two deposition techniques and prepare the PPN heterojunction photovoltaic device based on these films.

II. EXPERIMENTAL PROCEDURE

1.1. CdSe and CuSThin films preparing:

CdSe solution was prepared by mixing (0.8) gm of selenium (Se) powder with (1.2) gm sodium sulfite (Na_2SO_3) powder in 40 ml of de-ionized water in a reflux system, then stirring the solution with a magnet in the hotplate heater CdSe precursor heater solution vapor substrate for two hours at 60°C. A magnetic stirrer is placed to accelerate the solution's dissolution and prevent it from sticking to the walls of the beaker[2]. Then the solution was filtered to remove the sediments[3,4]. Cadmium chloride was used as a precursor of the Cd+ source, it was prepared from the dissolving of 1gm of $CdCl_2$ in 20 ml of deionized water and 1 ml of ammonia NH_3 as a complex agent was added to reach pH=11. Finally, both solutions were mixed and stirred at 70°C for 15 min. The precursor was sprayed with pressurized atmospheric air into substrates with a spray pyrolysis system. On the other hand, the distance between the nozzle and substrate is fixed at 25 cm, and the flow rate is 4 ml/m.

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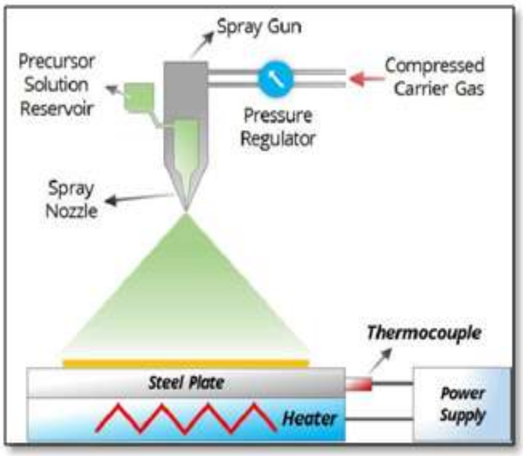

Figure 1:Schematic diagram of spray pyrolysis method

CuS film was prepared using a bath deposition technique as follows; 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[5,6]. 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 70°C. After mixing the two solutions, it is filtered with filter paper, and the solution is ready for sedimentation to be placed in the chemical bath. In our work, (ph=9) was taken[9,10]. The solution was placed in the bath and deposited according to the time (3hr) 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.

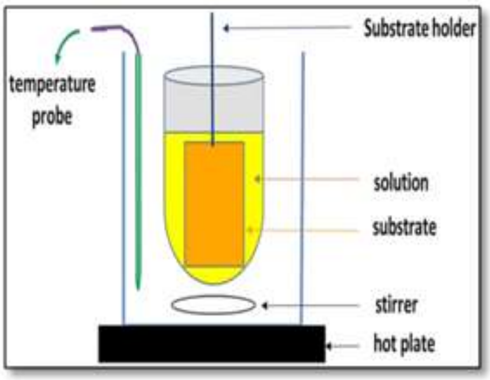

Figure 2:Schematic diagram of chemical bath deposition

1.2. The p-Si/p-CuS/n-CdSeFabrication:

Via above techniques (Figure 1. and Figure 2.) the (p-Si/p-CuS/n-CdSe) as shown in Figure 3, was fabricated using a single-crystal p-type Silicon wafer Si(100) orientation as the substrates, with an area of 1.0 cm^2 and resistivity 5^{-10} Ω.cm. Silicon wafers ultrasonically were cleaned with Acetone, 2-propanol, and DI water under ultrasonication for 10 minutes each to remove contamination from the substrate[7,8].The film thickness was measured by the gravimetric method. The nozzle-to-substrate distance was maintained at 25 cm. For ohmic contact, (Au) was used as a metal contact on the Si by a DC sputtering device. DC 150R E/ES model with 10^{-5} vacuum.

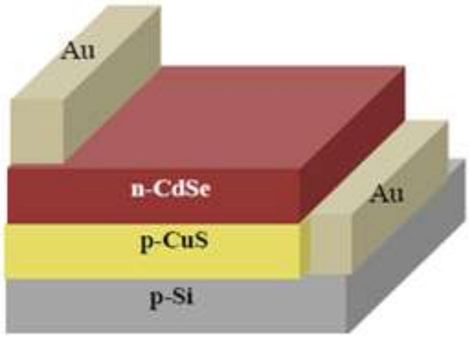

Figure 3: Schematic diagram PPN heterostructure

III. RESULTS:

The (p-Si/p-CuS/n-CdSe) heterostructure, is composed of three layers. Firstly, the solar cell properties of the resulting device were examined. Then, diode I-V properties were examined. Figure (4) Solar cell I-V curve and output power of the solar cell. The parameters of the obtained solar cell are; (η = 1.051, FF = 0.708, I_{SC} = 2.183 $mW/cm^2$and V_{OC} = 0.680 V).On the other hand, the I-V characteristic of the related device in dark and illumination conditions is shown in Figure (5). The ideality factor, barrier height, saturation current and series resistance were calculated by the thermionic emission and Cheung function models. The related parameters are tabulated in Table 1.

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

Samples	ideality factor n Dark	Light	Barrier height (eV) Dark	light	Current Saturation (μA) Dark	light	Series Resistance (Ω) Dark	
I-V	1.37	2.58	0.85	0.64	$1.7x\ 10^{-8}$	$2.73x10^{-7}$	-------	-------
Cheung	2.51	2.12	0.43	0.52	-----------	----------	407	1609

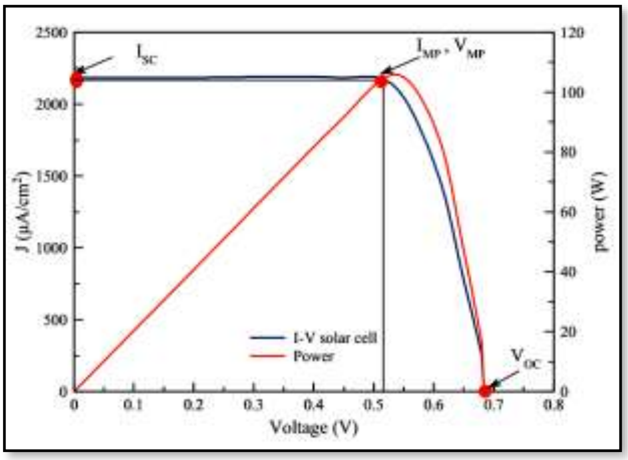

Figure (4) I-V and P-V characteristic of p-Si/p-CuS/n-CdSe photovoltaic

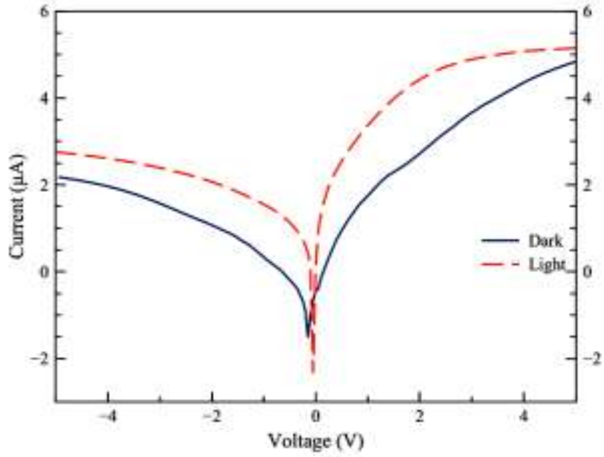

Figure 5: I-V of p-Si/p-CuS/n-CdSeheterojunction device in dark and light

IV. DISCUSSION

The p-Si/p-CuS/n-CdSe structure of the ppn device were fabricated. The current voltage (I-V) measurements of the diodes were taken in the dark and under (100 mW/cm^2) illumination. Using these measurements, current density-Voltage graphs were drawn. Photovoltaic parameters such as short circuit current, open circuit voltage, fill factor and efficiency were determined from the I-V graph. At the same time, diode properties such as ideality factor, barrier height and series resistance of this structure in dark and light conditions were revealed by (current-voltage) and Cheung methods. According to the result obtained, the efficiency of the solar cell is 1.05%.

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