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Energy Band Outline of Thin Film CoO:Au/Si Solar Cells

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Abstract

In this work, thin film heterojunction solar cells were fabricated by the deposition of p-type gold-doped cobalt oxide layers on n-type silicon substrates using pulsed-laser deposition technique. The effects of the contact material on the photovoltaic characteristics of the fabricated solar cells. It was found that the conversion efficiency was higher than that of the p-CoO/n-Si thin film solar cells, which may attributed to the role of Au-doped CoO layer as a hole collector as well as a barrier for charge recombination.

Keywords: Solar cells, Band energy outline, CoO:Au thin films, Pulsed-laser deposition
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1. Introduction

Magnetic metal/metal oxide particles have various fundamental and industrial applications. Cobalt is a special element that changes between two phase structures of hcp and fcc at a transition temperature of 450°C [1]. It is a ferromagnetic material, and due to such interesting properties, as good mechanical hardness, chemical stability and high electrical resistance, it has been used in many applications, including magnetic photocatalysts [2], high frequency magnets [3], information storage systems [4], magnetic bulk cores [5], microwave absorbers [6] and in biological applications, such as drug delivery [7], magnetic resonance imaging [8] and bio-sensors [9].

Cobalt oxide (CoO) is one of the most intensively investigated transition metal oxides. It is an antiferromagnetic oxide semiconductor with cubic structure. It can be a promising candidate for many applications such as solar thermal absorber [10], catalyst for O evolution [11], photoelectrolysis [12] and electrochromic device [13]. Cobalt oxide is also studied as the positive electrode in batteries [14]. Pure stoichiometric CoO crystals are perfect insulators [15]. Several efforts have been made to explain the insulating behavior of CoO. Appreciable conductivity can be achieved by creating Co vacancies or substituting lithium (Li) for cobalt (Co) at Co sites [15]. Hydrogen gas sensors based on electrostatically spray deposited CoO thin film was recently studied [16,17]. High efficient electrical devices can be fabricated by doping cobalt oxide with gold.

Pulsed-laser deposition (PLD) is one of the most important and powerful techniques for thin film deposition of complex materials. It consists of three major parts, laser source, vacuum system and deposition chamber [18]. Electrical properties of pure CoO and CoO:Au thin films prepared by PLD has been intensively [19].

Solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect which is a physical and chemical phenomenon. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light [20]. They are used as a photodetector, detecting light or measuring light intensity [21]. Recent studies have been shown that CoO thin films can be used successfully as solar cell.

A photovoltaic (PV) cell may be represented by the equivalent circuit model 2420 [22]. The more important characteristic of PV are conversion efficiency (η) and fill-factor that defined as [22]:

$$\eta = \frac{maximum\ output\ power\ (P_m)}{input\ power\ (P_{in})} \quad (1)$$

and the fill-factor (FF) is define as:

$$FF = \frac{I_m V_m}{I_{SC} V_{OC}} \quad (2)$$

where P_{in} is the power input to the cell, V_{oc} open circuit voltage, I_{sc} is the short circuit current, and I_m and V_m are the maximum cell current and voltage respectively at the maximum power point, $P_m = I_m \cdot V_m$. Figure (1) illustrates the typical (I-V) characteristic of a Si PV cell, showing I_m and V_m at the maximum power point. Solar cell behavior can conveniently be examined through four main parameters as shown in Fig. (1).

2. Experimental Part

The PLD experiment was carried out inside a chamber initially evacuated to 10^{-3} Torr [23]. The main experimental parameters of laser source are 532 nm wavelength, 1000 mJ pulse energy, 10 ns pulse width, 5 Hz repetition frequency and 100 number of shots. The substrate (Si) is placed in front of the target (CoO with different doping ratio of Au) with its surface parallel to that of the target. Sufficient gap is kept between the target and the substrate so that the substrate holder does not obstruct the incident laser beam. The temperature of Si substrate was 100°C.

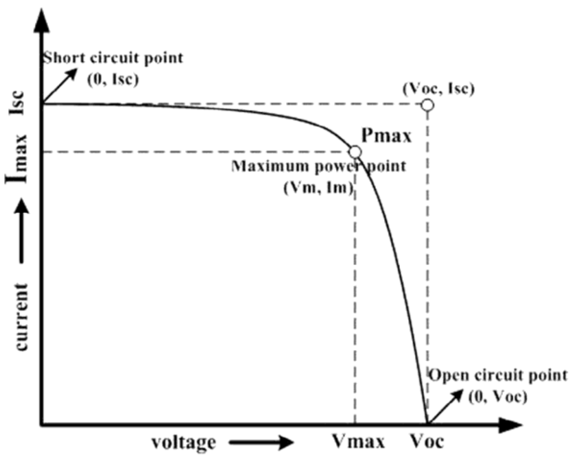

Fig. (1) Forward bias I-V characteristic of typical Si PV cell [11]

Different Au doping ratios (0,1, 2, and 4 wt. %) of CoO were used to prepare the CoO:Au/Si structure. The thicknesses of films were measured to be about 400 nm for all samples while the area (A) was about 1 cm^2. A typical scheme of the fabricated device is shown in Figure (2).

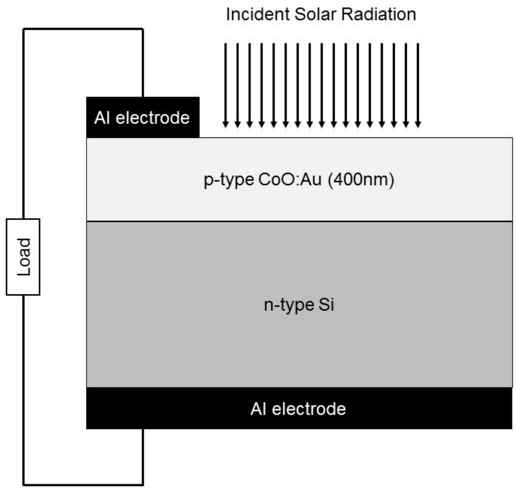

Fig. (2) Schematic diagram of the CoO:Au/Si solar cell fabricated in this work

A digital muitimeter victor VC97 was used to measure the current flow in a detector, manufactured from the prepared structure in dark condition. Voltage was applied from a KIETHLEY power supply at arrange of 0-5V in forward and reverse biasing conditions. This characterization was used to determine the conversion efficiency (η) and fill-factor (FF), where the power input (P_{in}) to the cell of 50 mW.

3. Result and Discussion

The morphology of thin films of pure and Au-doped CoO films deposited on Si substrates by PLD at 100°C temperature was examined using SEM. Figure (3) shows that all films are homogeneously distributed, very smooth and the crystallites are very fine.

Table (1) shows the effect of doping ratio on conductivity (σ) and energy band gap (E_g) of CoO. From the result, one may conclude that adding a small amount of Au in CoO material enhances the conductivity of the CoO because the conductivity of Au is higher than CoO, moreover the energy gap of CoO will be decrease.

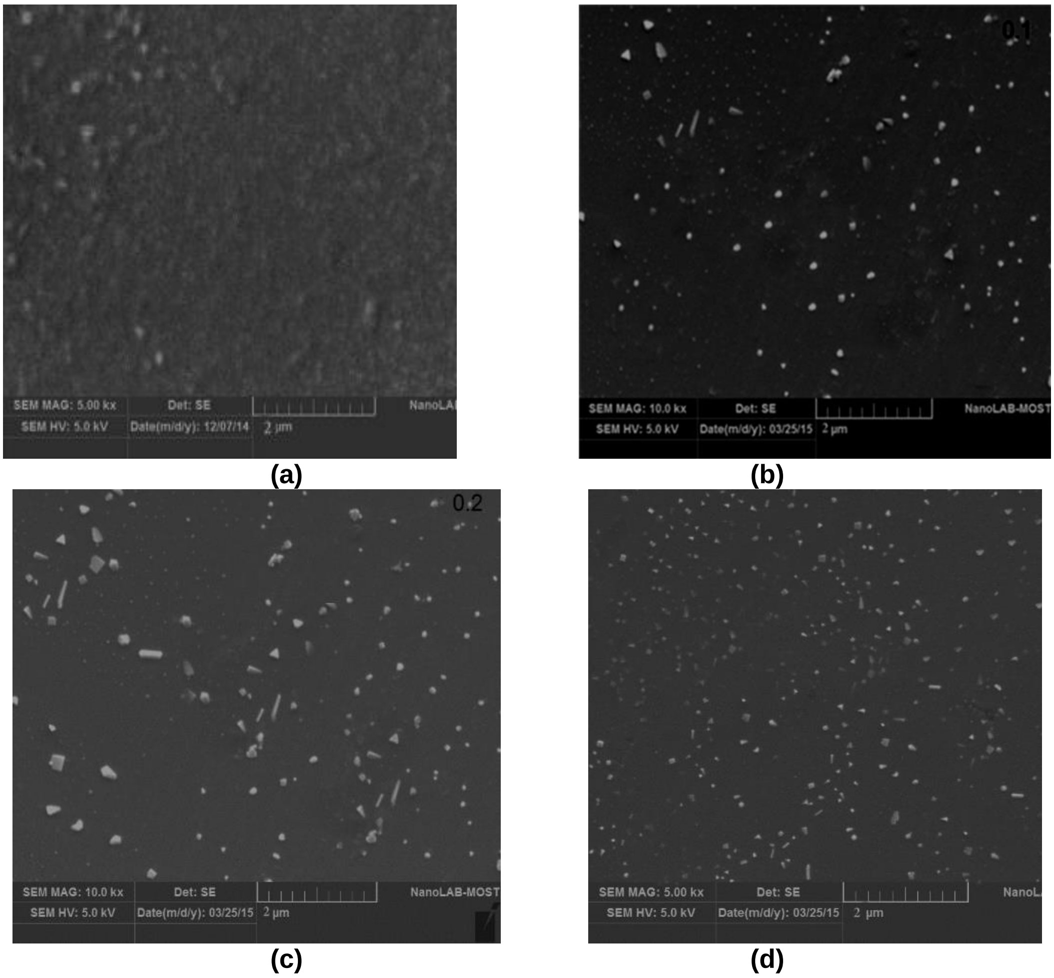

Fig. (3) SEM images for (a) pure CoO and (b and c) Au-doped CoO thin films at room temperature

Table (1) Effect of doping with gold on conductivity and energy band gap of CoO films

Sample	σ (Ω. cm^{-1})	E_g (eV)
Pure	4.17×10^{-6}	3.60
0.1	3.35×10^{-4}	3.50
0.2	2.34×10^{-3}	3.45
0.4	8.46×10^{-2}	3.4

Heterojunctions between p-type CoO with different doping ratios and n-type Si substrate is formed. The dark I-V curve in the forward and reverse bias for cell constructed with CoO:Au/Si as shown in figures (4), (5), (6) and (7). The doping ratio (wt.%), short-circuit current (I_{sc}), the open-circuit voltage (V_{oc}), maximum power points (V_m and I_m), fill-factor (FF) and conversion efficiency (η) were listed in Table (2). It is concluded from this table that the highest value of conversion efficiency was obtained at 0.4 wt.% doping ratio. The device had an open-circuit voltage of 0.21, short-circuit current of of 182 mA, and maximum power points (V_m and I_m) of 0.08 and 115, respectively. The conversation efficiency (η) derived from Fig. (7) is 18.4%.

The solar cell made without Au doping give lower values of conversion efficiency (η) (~0.84%) at the same illumination intensity. From the results presented above, it is clearly seen that the CoO:Au layer on Si substrate acts as a hole collector, so this kind of solar cells can be improved for a future work to give much higher efficiency. To illustrate the relationship between the conversion efficiency with doping ratio, figure (8) shows the gradual increase in conversion efficiency at 0.1 wt.% doping ratio. This increase becomes higher to reach 16.38%. Finally, a slight increase in the conversion efficiency is observed to reach a maximum value of 0.4%. The effect of doping on open-circuit (V_{oc}) and short-circuit current (I_{sc}) is shown in Fig. (9), where both increase with increasing the doping ratio.

Table (2) The cell parameters for CoO:Au/Si solar cells of 1 cm^2 area and incident power (P_{in}) of 50 mW

N	I_{sc} (mA)	V_{oc} (V)	I_m (mA)	V_m (V)	Fill factor (F.F)	Efficiency (η%)
Pure	10	0.16	7	0.06	0.262	0.84
0.1	30	0.14	14	0.08	0.266	2.24
0.2	180	0.178	105	0.078	0.255	16.38
0.4	185	0.21	115	0.8	0.252	18.4

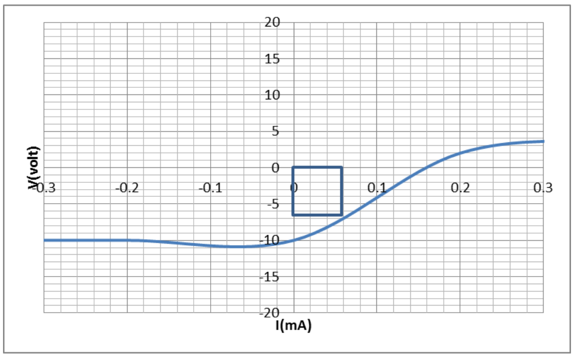

Fig. (4) I-V curve for pure CoO/Si solar cell

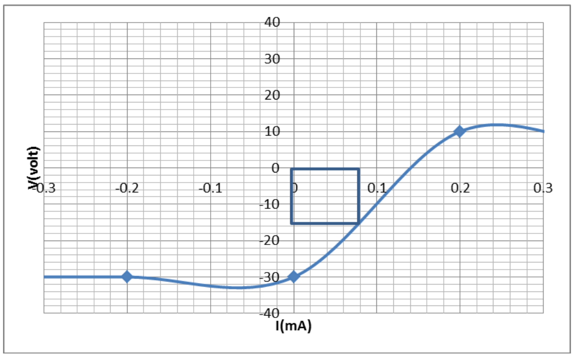

Fig. (5) I-V curve for CoO:Au/Si solar cell with Au doping ratio of 0.1 wt.%

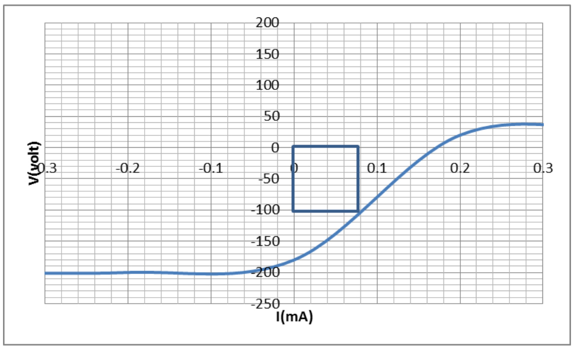

Fig. (6) I-V curve for CoO:Au/Si solar cell with Au doping ratio of 0.2 wt.%

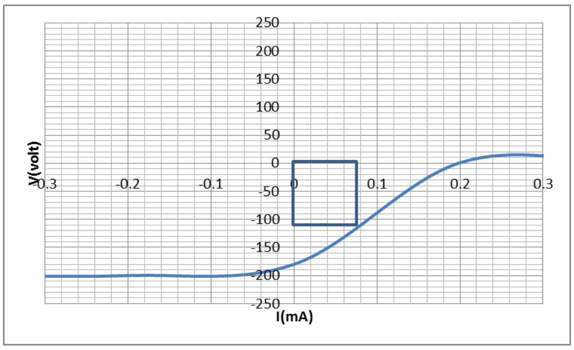

Fig. (7) I-V curve for CoO:Au/Si solar cell with Au doping ratio of 0.4 wt.%

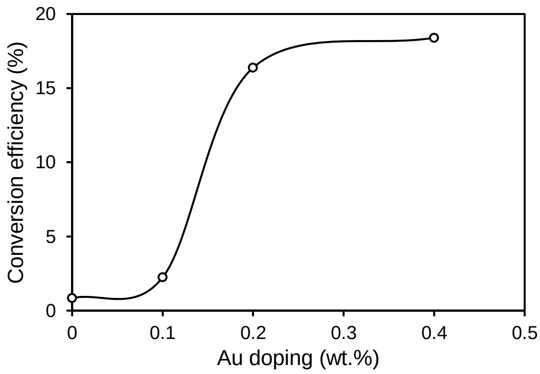

Fig. (8) Conversion efficiency (η) vs. Au doping ratio for the CoO:Au/Si solar cells fabricated in this work

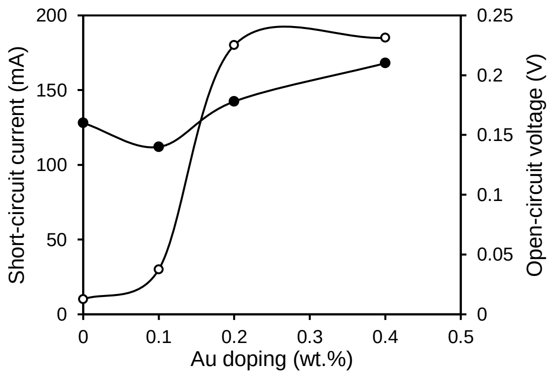

Fig. (9) Variation of V_{oc} (black circles) and I_{sc} (white circles) with Au doping ratio of CoO layer

4. Conclusion

According to results presented in this work, it can be concluded that the CoO:Au/Si thin film structures can be used as heterojunction solar cells, where the highest value of conversion efficiency can be obtained at doping ratio of 0.4 wt.%. The CoO:Au layer acts as a p-type layer on n-type Si substrate, so it can be used as a hole collector to improve the performance of the solar cells based on these structures.

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