Preparation and fabrication of (Mg,Sn) doped CdO/PSi solar cell by laser induced plasma

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Abstract
The cadmium oxide films containing both tin and magnesium (Mg, Sn) were deposited on the p-type porous silicon bases at room temperature (300K) with pulsed laser sedimentation technology (PLD). The characteristics of the manufactured cells were studied, which include measuring short circuit current density ($J_{SC}$) and open circuit voltage ($V_{OC}$), where it was found that the highest value of short circuit current density was within $6.60 mA/cm^2$ and open circuit voltage ($0.54v$). It was found that the efficiency of the solar cell increases with an increase in the percentage of vaccination from (0.59) for pure materials to reach (1.76%) for (n-CdO$_{1-x}$: Sn$_x$ / P-PSi) and (1.64%) with respect to films (n-CdO$_{1-x}$: Mg$_x$ / P-PSi).

Keywords: n-CdO/p-Si, thin films, solar cell, I-V characteristics, C-V measurement

Introduction
Cadmium oxide (CdO) is a n-type semiconductor material that has a direct energy gap (2.2-2.7) eV and is one of the thin films with transparent conductive oxide (TCO) that has received great attention in various applications such as solar cells and photodiodes [1, 2], due to the high optical transmittance in the visible region and the NIR of the solar spectrum, as well as the high electrical conductivity that is close to the conductivity of metals, and the higher carrier concentration. [3-5] It is
also used in applications of optical transistors, gaseous sensors, liquid crystal displays, optical communications and infrared detectors.

Cadmium oxide (CdO) is usually doped with various elements such as (Cu, Ga, F, Sn, Al and In) to improve the electrical properties of the optical electronic application [6-13]. Various precipitation techniques are used to prepare grafted CdO and CdO films such as pulsed laser deposition. [14] spray pyrolysis [15], chemical path precipitation [16], vacuum evaporation [17] where many researchers have focused on developing non-interconnected Homogeneous at low cost and high efficiency for photoelectric application. The aim of this work is to manufacture heterogeneous joints (n-CdO / p-Si) using pulsed laser sedimentation technology and study the effect of vaccination on the properties of manufactured solar cells.

**Experimental details**

The pure cadmium oxide material Supplied or provided from the German company (FLUKA) was used with a purity (99.9%) to prepare the pure cadmium oxide as well as the cadmium oxide tinted with (Sn, Mg) and grafting ratios (0.1, 0.3, 0.5) for each of them, then mix the mixture well then The material is placed under the hydraulic plunger and pressure (Ton 8) is applied, so that the target has a diameter (2.5 cm) and a thickness (0.5 cm), since the target must be coherent and uniform to ensure high quality of precipitation.

A p-type silicon wafer with a resistance of (0.01-0.02 Ω.cm) and thickness (525 ± 25 µm) was prepared and cut into the required size and rinsed with ethanol to clean the surface from any impurity and then placed in (HF) acid with a concentration (5%) for 15 minutes, to remove the oxides from the samples, and finally they are dried in the air.

As for the electrochemical etching system shown in Figure (1), it consists of a capacity provider to supply the system with the appropriate voltage, a meter to
measure the density of current, a digital clock, and a hollow cylinder of Teflon Its diameter (1cm) puts a solution (Ethanol: HF) in the amount of (2ml) from the solution of HF and (1ml) of the ethanol solution to reduce the hydrogen bubbles emitted during the reaction that hinder the continuation of the etching process, as two electrodes were used to apply the current through the cell, The first electrode (cathode) made of platinum immerses in the solution of (HF) and the second pole The (anode) is a stainless steel disc placed under the silicon slide from the bottom, as shown in Figure 1.

![Figure (1) Electrochemical etching system](image)

After setting the porous silicon bases and targets, the pulsed laser sedimentation stage (PLD) begins where the pressure value inside the discharge chamber is \( (2.5 \times 10^{-2} \text{ mbar}) \) for the purpose of contributing to ionization of the material, where the laser beam falls on the target surface at an angle (45 °) with the target surface and the substrate is placed in front of the target and parallel to its surface taking into account that the distance between the target and the base is sufficient so that the base holder does not block the falling laser beam.
To measure the properties of the (current-voltage) in the illumination state of the cell under the reverse bias, it was exposed to white light using a Philips (1000) type halogen lamp with the intensity of (100 mw/cm²) with external voltage projection and use a scale The ability to measure the light power of the lamp used (Lux-meter), as well as the cell parameters represented in the short circuit current density (J_{SC}) and open circuit voltage (V_{OC}) and the filling factor (FF) as in Figure (2) that shows how to extract different measurements from The fourth curve of the solar cell, where the short circuit current density (J_{SC}) and the open circuit voltage (V_{OC}) were taken from the curve at the y and x axes, respectively. Then calculate the fill factor (F.F) by dividing the maximum power output of the device by the product (J_{SC} . V_{OC}) (the maximum energy).

![Figure 2: Characteristics of J-V for the solar cell [18].](image)

**Results and Discussion**

Measuring the properties of (current - voltage) in the case of lighting is one of the important measurements of solar cells, in order to determine the parameters of the solar cell and thus determining its efficiency. Figures (4), (6) characteristics of the current with the voltages in the lighting state show that the lighting current increases with the voltages placed in the case of reverse bias due to the high level of concentration of carriers with the set voltages. The fill factor (FF) and the
Photoelectric conversion efficiency (\(\eta\)) of all solar cells can be calculated using equations (1), (2). [19]

\[
F.F = \frac{J_mV_m}{J_{sc}V_{oc}} \quad \text{(1)}
\]

\[
\eta = \frac{P_m}{P_{in}} = \frac{I_mV_m}{P_m} \quad \text{(2)}
\]

Whereas, \((V_m)\) and \((I_m)\) are the voltage and current respectively at the maximum power output, while \((P_{in})\) is the energy entering the cell.

In order to understand the behavior of the solar cell, the equivalent circuit is indicated in Figure 3.

\[
\text{Figure 3 the parabolic circle of the solar cell with load} \quad \text{[20]}
\]

The value of the short circuit current \((I_{SC})\) was determined at \((V = 0)\) and the open circuit voltage \((V_{OC})\) was determined at \((I = 0)\), where the value of the power output obtained from the product of the open circuit voltage and the short circuit current \((P_{out} = V_{oc} \cdot I_{sc})\) From the previous values, the filling factor was calculated according to the relationship (1), and the current density \((J_{sc})\) was also calculated by dividing the current \((I_{sc})\) by the effective area \((A_{eff})\) in units \((\text{cm}^2)\) as follows \((J_{sc} = I_{sc} / A_{eff})\) From the previous values, the cell efficiency \((\eta)\) was found according to relationship (2) for all vaccination ratios used.
It is evident from Tables (1) and (2) that an increase in open circuit voltage ($V_{OC}$) leads to an increase in the short circuit current density and a decrease in the filling factor (FF), thus increasing the conversion efficiency ($\eta$). It is also evident from Figures (5) and (7) that the efficiency of the solar cell increases with an increase in the ration of vaccination from (0.59) for pure materials to reach (1.76%) for the films (n-CdO$_{1-x}$: Sn$_x$ / P-PSi) and (1.64%) with respect to films (n-CdO$_{1-x}$: Mg$_x$ / P-PSi)

### Table (1) results of solar cells for (CdO) membranes pure and inlaid (Mg) at different concentrations

| Composition (x) | $V_{OC}$ (V) | $J_{sc}$ (mA/cm$^2$) | $V_{max}$ (V) | $J_{max}$(mA/cm$^2$) | FF %  | $\eta$ |
|----------------|--------------|-----------------------|---------------|----------------------|-------|--------|
| CdO pure       | 0.41         | 2.42                  | 0.26          | 2.3                  | 0.602701 | 0.598  |
| CdO$_{0.5}$:Mg$_{0.1}$ | 0.43         | 3.02                  | 0.28          | 2.5                  | 0.539042 | 0.70   |
| CdO$_{0.7}$:Mg$_{0.3}$ | 0.47         | 4.10                  | 0.31          | 3.2                  | 0.51479 | 1.24   |
| CdO$_{0.8}$:Mg$_{0.5}$ | 0.53         | 5.20                  | 0.32          | 4.1                  | 0.476052 | 1.64   |

Figure 4: Characteristics of (J-V) in the illumination state of cells doping with magnesium (Mg).
Figure (5) Efficiency of Solar Cells Grafted with Different Magnesium Concentrations (Mg)

Figure (6) Characteristics of (J-V) in the case of lighting for cells inlaid with tin (Sn)
Table (2) results of solar cells for (CdO) membranes pure and inlaid (Sn) at different concentrations

| Composition (x) | V_{oc} (V) | J_{sc} (mA/cm^2) | V_{max} (V) | J_{max} (mA/cm^2) | FF % | η |
|-----------------|------------|------------------|------------|------------------|------|---|
| CdO pure        | 0.41       | 2.42             | 0.26       | 2.3              | 0.602701 | 0.598 |
| CdO_{0.9}:Sn_{0.1} | 0.44       | 4.40             | 0.33       | 3.4              | 0.579545 | 1.122 |
| CdO_{0.7}:Sn_{0.3} | 0.52       | 4.92             | 0.38       | 3.7              | 0.549562 | 1.406 |
| CdO_{0.5}:Sn_{0.5} | 0.54       | 6.60             | 0.4        | 4.4              | 0.493827 | 1.76  |

Figure 7: Efficiency of Solar Cells Grafted with Different Tin Concentrations (Sn)
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