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Effect of Li_2O Molar Concentration on Current–Voltage Characteristics and Photovoltaic Performance of Solar Cells

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تأثير التركيز المولاري لأكسيد الليثيوم (Li_2O) على خصائص التيار– الجهد والأداء الكهروضوئي للخلايا الشمسية

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Abstract

This study investigates the effect of Li_2O molar concentration on the photovoltaic performance of solar cells. Thin films were prepared at molar concentrations of 0.3, 0.5, 0.7, 0.9, and 1.0 M, and their photovoltaic performance was evaluated by current–voltage (I–V) measurements under illumination. The results show that increasing the Li_2O concentration enhances light absorption and charge-carrier generation. Consequently, the short-circuit current density (Jsc) increased from 0.9266 to 0.9586 mA cm^{-2}. The highest photovoltaic performance was achieved at 1.0 M, with a short-circuit current (Isc) of 5.991 mA, an open-circuit voltage (Voc) of 0.582 V, a fill factor (FF) of 0.89, and a power conversion efficiency (η) of 0.903%. The improvement in device performance is attributed to enhanced optoelectronic properties and reduced internal losses at higher concentrations. The findings demonstrate that Li_2O molar concentration plays a significant role in determining the photovoltaic characteristics of solar cells and can be optimized to improve device performance.

Keywords: Li_2O thin films; Solar cells; Molar concentration; Current–voltage characteristics; Power conversion efficiency; Fill factor.

الملخص

تدرس هذه الدراسة تأثير التركيز المولي لأكسيد الليثيوم (Li_2O) على الأداء الكهروضوئي للخلايا الشمسية. تم تحضير أغشية رقيقة بتراكيز مولية مختلفة (0.3، 0.5، 0.7، 0.9، و1.0 مولارية)، وقُيّم أداؤها الكهروضوئي من خلال قياسات التيار-الجهد (I-V) تحت الإضاءة. أظهرت النتائج أن زيادة تركيز Li_2O تُحسّن امتصاص الضوء وتوليد حاملات الشحنة. ونتيجةً لذلك، زادت كثافة تيار الدائرة

القصيرة (Jsc) من 0.9266 إلى 0.9586 مللي أمبير/سم². وقد تحقق أعلى أداء كهروضوئي عند تركيز 1.0 مولار، حيث بلغ تيار الدائرة القصيرة 5.991 (Isc) مللي أمبير، وجهد الدائرة المفتوحة 0.582 (Voc) فولت، وعامل الملء 0.89 (FF)، وكفاءة تحويل الطاقة 0.903% (η). يُعزى تحسّن أداء الجهاز إلى تعزيز الخصائص الكهروضوئية وتقليل الفاقد الداخلي عند التركيزات العالية. وتُظهر النتائج أن التركيز المولي لأكسيد الليثيوم (Li_2O) يلعب دورًا هامًا في تحديد خصائص الخلايا الشمسية الكهروضوئية، ويمكن تحسينه لرفع أداء الجهاز.

الكلمات المفتاحية: أغشية رقيقة من أكسيد الليثيوم (Li_2O)، خلايا شمسية؛ التركيز المولي، خصائص التيار-الجهد، كفاءة تحويل الطاقة، عامل الملء.

1. Introduction

1.1. Lithium oxide

Lithium oxide (Li_2O) is an important alkali metal oxide that has attracted considerable attention because of its unique optical, electrical, and chemical properties. It is widely utilized in glass and ceramic manufacturing, lithium-based energy storage systems, solid-state electrolytes, and optoelectronic applications. Due to its wide band gap, good thermal stability, and favorable electronic characteristics, Li_2O has emerged as a promising material for advanced semiconductor and photovoltaic devices [1,2].

In recent years, Li_2O thin films have been investigated extensively for their potential use in solar cells and other optoelectronic applications. The optical and electrical properties of these films are strongly dependent on preparation conditions such as deposition technique, annealing temperature, film thickness, and precursor concentration. Variations in these parameters can significantly influence the crystal structure, surface morphology, charge transport behavior, and optical absorption characteristics of the resulting films [3,4].

Among the various preparation parameters, precursor molar concentration plays a crucial role in controlling the microstructure and optoelectronic properties of Li_2O thin films. Changes in concentration affect grain growth, defect density, crystallinity, and band-gap energy, thereby influencing the photovoltaic performance of fabricated solar cells. Optimizing the precursor concentration can improve light absorption, facilitate charge-carrier transport, and reduce recombination losses, leading to enhanced device efficiency [4].

Furthermore, the optical band gap of Li_2O-based materials can be tailored through processing conditions and compositional modifications. A reduction in the band gap generally enhances photon absorption and increases charge-carrier generation, thereby improving photocurrent density and overall solar-cell performance [4,5].

"Solar cell efficiency is one of the most important indicators used to evaluate photovoltaic performance, as it reflects the cell's ability to convert incident light energy into usable electrical energy. Efficiency is influenced by several factors, including material properties, fabrication quality, and operating conditions."[21].

1.2. Theoretical background:

Solar energy is considered one of the most promising renewable energy sources due to its abundance, sustainability, and environmental compatibility. Continuous efforts have been directed toward developing efficient photovoltaic materials capable of converting solar radiation into electrical energy with improved performance and lower production costs [6,7]. Among the various semiconductor materials investigated for solar-cell applications, metal oxide thin films have attracted significant interest because of their excellent optical transparency, chemical stability, low toxicity, and ease of fabrication [8,9].

Lithium oxide (Li_2O) is an important alkali-metal oxide that exhibits attractive optical and electronic properties. The material possesses good transparency in the visible region, high thermal stability, and favorable charge-transport characteristics, making it suitable for several optoelectronic applications. In addition, Li_2O-based materials have shown potential for use in photovoltaic devices, transparent conducting layers, and photoactive thin films [10,11].

The optical behavior of semiconductor thin films is largely determined by their electronic band structure. The optical band gap (Eg) represents the minimum energy required to excite an electron from the valence band to the conduction band. This parameter plays a fundamental role in determining the spectral absorption range of a semiconductor. Materials with lower band-gap energies are capable of absorbing a larger fraction of the solar spectrum, resulting in enhanced generation of electron–hole pairs and improved photovoltaic performance [12,13]. "The transparency and absorption behavior of materials are key factors that influence their performance in optical devices" [24]. "The optical properties of semiconductors depend significantly on their energy gap. The values of these optical properties (such as absorbance, transmittance, and reflection) are directly affected when the thickness of the material layers changes" [25]. "The absorbance curves show approximately the same behavior for all samples, with a rapid increase in absorbance at wavelength 304 nm. The absorbance values increase with the increase of the thickness of the sample."[26].

Thin-film solar cells operate based on the photovoltaic effect, where incident photons generate charge carriers within the semiconductor material. The generated electrons and holes are separated by an internal electric field and collected by electrodes, producing electrical power. The effectiveness of this process depends on photon absorption, carrier mobility, recombination rate, and interface quality within the device structure [7,9,14].

The photovoltaic performance of a solar cell is commonly evaluated using current–voltage (I–V) measurements. Important parameters extracted from the I–V curve include the short-circuit current (Isc), open-circuit voltage (Voc), maximum power point (MPP), fill factor (FF), current density (Jsc), and power conversion efficiency (η). These parameters provide quantitative information regarding charge generation, carrier transport, and overall device quality [8,15].

Among the factors affecting thin-film properties, precursor molar concentration is considered one of the most influential processing parameters. Changes in concentration can significantly affect nucleation and growth mechanisms during film formation, leading to variations in grain size, crystallinity, thickness, surface morphology, and defect density. Consequently, the optical and electrical properties of the resulting films are altered [16,17].

Several studies have reported that increasing precursor concentration may improve film uniformity and enhance light absorption through modifications in the electronic structure. Improved crystallinity generally reduces carrier trapping and recombination losses, thereby increasing current density and fill factor. However, excessive defect formation may have the opposite effect, emphasizing the importance of concentration optimization [15,18].

Recent investigations on Li_2O thin films have demonstrated that their optical and photovoltaic properties are highly dependent on preparation conditions. Variations in Li_2O concentration have been shown to influence optical absorption, band-gap energy, and photovoltaic efficiency. These findings suggest that controlling the precursor concentration is a practical approach for enhancing the performance of Li_2O-based solar cells [10,19,20].

"The efficiency of optical materials is strongly influenced by their structural and optical properties, which determine their performance in electronic and optical devices"[22]. "The optical properties of Li_2O are significantly influenced by molar concentration, making it a promising material for optical applications, especially in systems requiring high transparency in the visible region" [23].

2. Problem Statement

Although lithium oxide (Li_2O) has attracted considerable attention for photovoltaic and optoelectronic applications, the influence of molar concentration and photovoltaic properties is not yet fully understood. In particular, the relationship between Li_2O molar concentration, optical band gap, and solar-cell performance requires further investigation. Therefore, it is important to study the effect of different Li_2O concentrations in order to determine the optimum concentration that provides enhanced photovoltaic performance and improved energy conversion efficiency.

3. Research Objectives

3.1. General Objective

To investigate the effect of Li_2O molar concentration on the photovoltaic properties of thin-film solar cells.

3.2. Specific Objectives

1-To prepare Li_2O thin films with different molar concentrations.

2-To evaluate the photovoltaic characteristics of the fabricated solar cells.

3-To investigate the relationship between optical band gap and photovoltaic performance parameters.Significance of the Study

This study contributes to the development of low-cost and efficient photovoltaic materials for renewable energy applications. Understanding the influence of Li_2O molar concentration electrical properties of thin films can help improve solar-cell performance and provide valuable information for optimizing thin-film fabrication processes. The results may also support future research aimed at enhancing the efficiency of Li_2O-based photovoltaic devices.

4. Materials

1-Lithium Oxide (Li_2O) precursor.
2-Distilled water.
3-Glass substrates.
4-Conductive electrodes.
5-Cleaning chemicals and laboratory reagents.

5. Instruments and Equipment

1-Magnetic Stirrer.
2-Hot Plate.
3-Spin Coater (if used).
4-Drying Oven.
5-Solar Simulator.
6-Digital Multimeter.
7-Source Meter / I–V Measurement System.
8-Film Thickness Measurement Device (if available).

6. Experimental Methodology

Li_2O solutions with different molar concentrations (0.3, 0.5, 0.7, 0.9, and 1.0 M) were prepared. The glass substrates were thoroughly cleaned before film deposition. Thin films were then deposited using the selected preparation technique and subsequently dried and thermally treated to improve film quality. The fabricated solar cells were characterized through current–voltage (I–V) measurements under illumination to obtain the photovoltaic parameters, including short-circuit current (Isc), open-circuit voltage (Voc), current density (Jsc), fill factor (FF), and power conversion efficiency (η).

7. Results and Discussion

Introduction

The effect of Li_2O molar concentration on the photovoltaic properties of thin films and solar cells was investigated. Consequently, improvements were observed in the short-circuit current density (Jsc), fill factor (FF), and power conversion efficiency (η), while the open-circuit voltage (Voc) remained nearly constant. The following sections discuss the relationship between Li_2O concentration and photovoltaic performance in detail.

Table (1) shows current and voltage for Li_2O sample with a concentration of 1.0 molarity.

No	Current (mA)	Voltage (V)
1	0.02263	6.04411
2	0.11069	6.03782
3	0.21768	6.00708
4	0.32598	6.02594
5	0.40275	5.98262
6	0.49571	5.87151
7	0.53593	5.20069
8	0.56399	4.56691
9	0.57431	3.91634
10	0.57836	1.61216
11	0.5824	0.0182

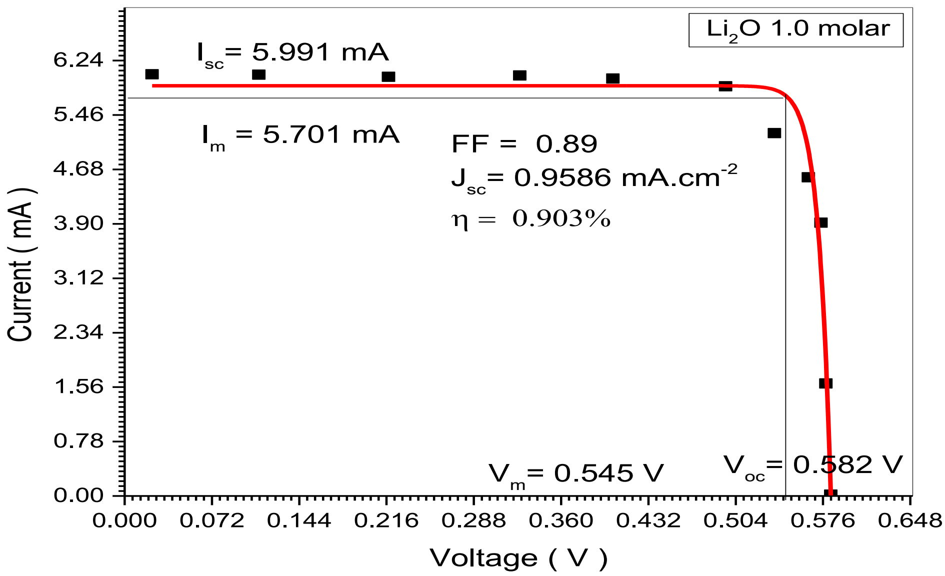

Figure (1) shows the current-voltage (I–V) curve for a solar cell made of Li_2O with a concentration of 1.0 molar.

The I–V curve of the Li_2O solar cell at 1.0 molar shows typical photovoltaic behavior. The short-circuit current (Isc) and open-circuit voltage (Voc) were found to be **5.991 mA** and **0.582 V**, respectively. The maximum power point occurred at (Vm=0.545V) and (Im=5.701mA), with a high fill factor of **0.89**, indicating low internal losses.
The current density (Jsc) was **0.9586 mA/cm²**, while the efficiency reached **0.903%**. Despite the relatively low efficiency, the high fill factor suggests good device quality and potential for improvement.

Table (2) shows the current and voltage for Li_2O sample with a concentration of 0.9 molarity.

No	Current (mA)	Voltage (V)
1	0.02263	5.95345
2	0.11069	5.94726
3	0.21768	5.91697
4	0.32598	5.93555
5	0.40275	5.89288
6	0.49571	5.78344
7	0.53593	5.12268
8	0.56399	4.49841
9	0.57431	3.85759
10	0.57836	1.58798
11	0.5824	0.01793

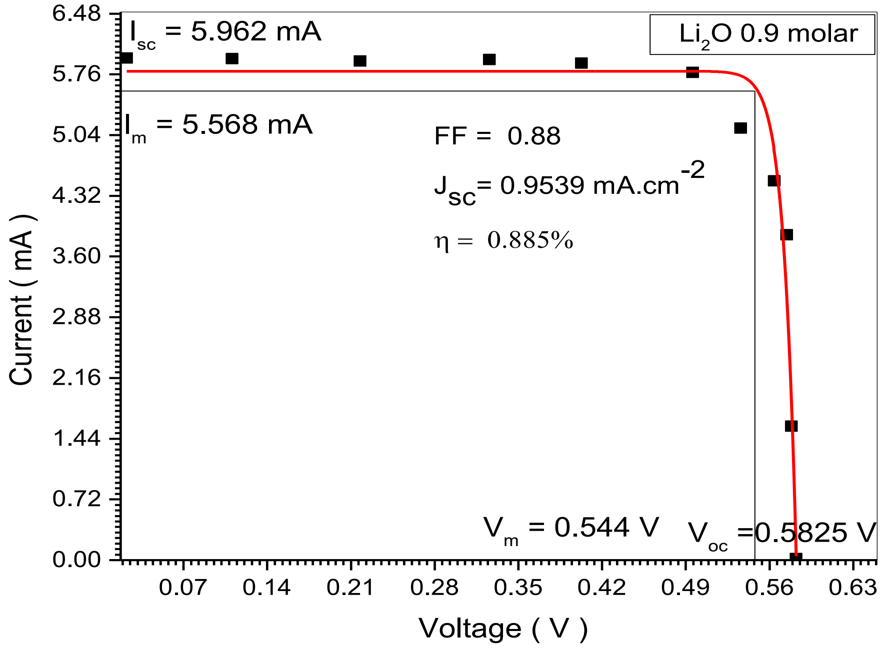

Figure (2) shows the current-voltage (I–V) curve for a solar cell made of Li_2O with a concentration of 0.9 molar.

The I–V curve shows typical photovoltaic behavior with Isc=5.962mA and Voc=0.5825V. The maximum power point occurs at Vm=0.544V and Im=5.568mA, with a high fill factor of **0.88**.
The current density (Jsc) is **0.9539 mA/cm²**, and the efficiency reaches **0.885%**, indicating good performance with a slight reduction compared to a higher concentration.

Table (3) shows the current and voltage for the Li_2O sample with a concentration of 0.7 molarity.

No	Current (mA)	Voltage (V)
1	0.02263	5.74553
2	0.11069	5.73955
3	0.21768	5.71033
4	0.32598	5.72826
5	0.40275	5.68708
6	0.49571	5.58146
7	0.53593	4.94378
8	0.56399	4.3413
9	0.57431	3.72287
10	0.57836	1.53252
11	0.5824	0.0173

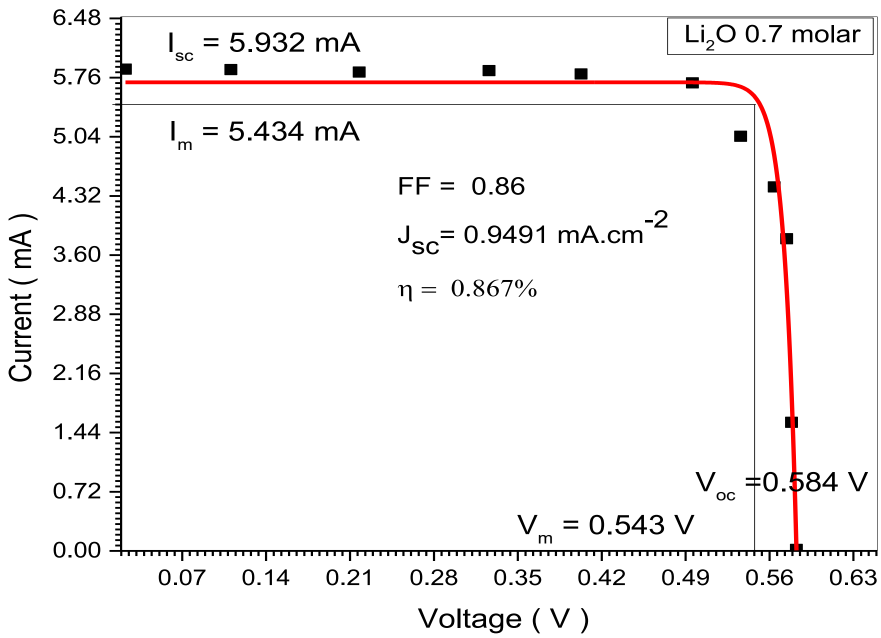

Figure (3) shows the current-voltage (I–V) curve for a solar cell made of Li_2O with a concentration of 0.7 molar.

The current–voltage (I–V) characteristics of the solar cell based on Li_2O with a molar concentration of 0.7 are shown in Fig. (X). The curve demonstrates a typical photovoltaic behavior under illumination. The short-circuit current (Isc) was found to be **5.932 mA**, indicating the maximum current generated when the applied voltage is zero. The open-circuit voltage (Voc) reached **0.584 V**, which represents the maximum voltage under zero current conditions.

The maximum power point (MPP) was obtained at a voltage (Vm) of **0.543 V** and a current (Im) of **5.434 mA**, where the solar cell delivers its highest output power. The fill factor (FF) was calculated to be **0.86**, suggesting a relatively good quality of the device with low internal resistive losses.

Furthermore, the short-circuit current density (Jsc) was **0.9491 mA/cm²**, while the overall power conversion efficiency (η) was determined to be **0.867%**. Although the efficiency is relatively low, this may be attributed to recombination losses, limited light absorption, or structural imperfections in the thin film.

The deviation between the experimental data points and the ideal curve near the open-circuit voltage region indicates the presence of series resistance and recombination effects, which negatively impact the device performance.

Table (4) shows the current and voltage for Li_2O sample with a concentration of 0.5 molarity.

No	Current (mA)	Voltage (V)
1	0.02263	5.80416
2	0.11069	5.79812
3	0.21768	5.76859
4	0.32598	5.78671
5	0.40275	5.74511
6	0.49571	5.63842
7	0.53593	4.99423
8	0.56399	4.3856
9	0.57431	3.76086
10	0.57836	1.54816
11	0.5824	0.01748

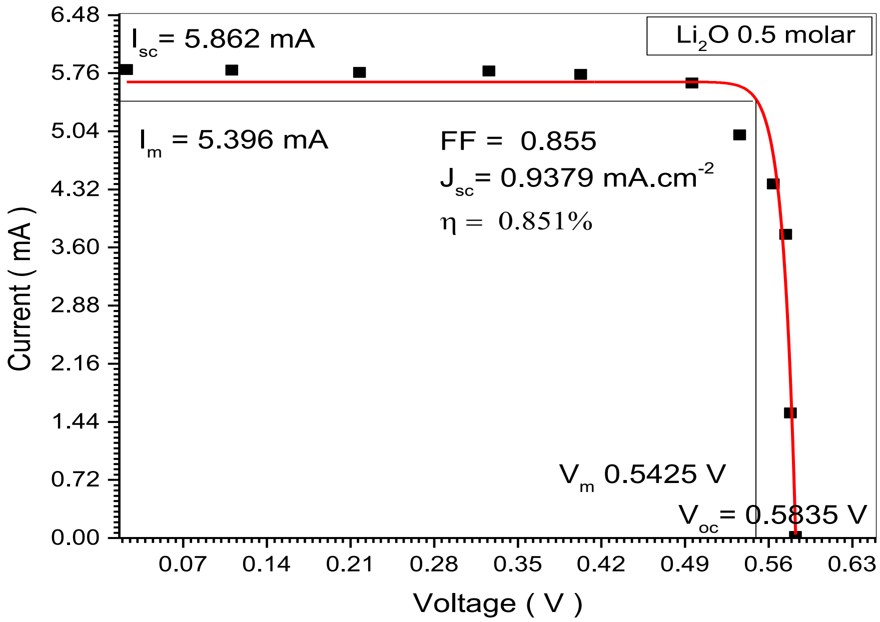

Figure (4) shows the current-voltage (I–V) curve for a solar cell made of Li_2O with a concentration of 0.5 molar.

The current–voltage (I–V) characteristics of the Li_2O-based solar cell with a molar concentration of 0.5 are illustrated in Fig. (X). The curve exhibits a typical photovoltaic response under illumination conditions.

The short-circuit current (Isc) was measured to be **5.862 mA**, indicating the maximum generated current at zero applied voltage. The open-circuit voltage (Voc) reached **0.5835 V**, representing the maximum voltage when the current is zero.

The maximum power point (MPP) was observed at a voltage (Vm) of **0.5425 V** and a current (Im) of **5.396 mA**, where the device produces its highest output power. The fill factor (FF) was calculated to be **0.855**, which reflects a good device quality with relatively low resistive losses.

Additionally, the short-circuit current density (Jsc) was found to be **0.9379 mA/cm²**, while the overall power conversion efficiency (η) was determined to be **0.851%**. The relatively low efficiency may be attributed to recombination losses, limited photon absorption, or structural defects within the thin film. The deviation between the experimental data points and the ideal curve near the open-circuit voltage region suggests the influence of series resistance and carrier recombination, which reduce the overall performance of the solar cell.

Table (5) shows the current and voltage for Li_2O sample with a concentration of 0.3 molarity.

No	Current (mA)	Voltage (V)
1	0.02263	5.74553
2	0.11069	5.73955
3	0.21768	5.71033
4	0.32598	5.72826
5	0.40275	5.68708
6	0.49571	5.58146
7	0.53593	4.94378
8	0.56399	4.3413
9	0.57431	3.72287
10	0.57836	1.53252
11	0.5824	0.0173

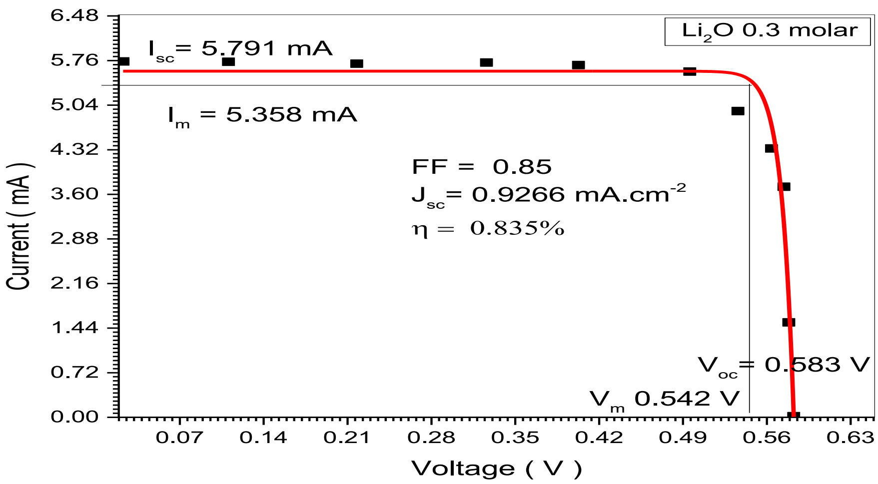

Figure (5) shows the current-voltage (I–V) curve for a solar cell made of Li_2O with a concentration of 0.3 molar.

The current–voltage (I–V) characteristics of the Li_2O-based solar cell with a molar concentration of 0.3 are presented in Fig. (X). The curve shows a typical photovoltaic behavior under illumination.

The short-circuit current (Isc) was measured to be **5.791 mA**, representing the maximum current at zero applied voltage. The open-circuit voltage (Voc) was found to be **0.583 V**, indicating the maximum voltage at zero current condition.

The maximum power point (MPP) occurred at a voltage (Vm) of **0.542 V** and a current (Im) of **5.358 mA**, where the solar cell achieves its highest power output. The fill factor (FF) was calculated to be **0.85**, suggesting good device performance with moderate internal losses.

The short-circuit current density (Jsc) was **0.9266 mA/cm²**, while the overall conversion efficiency (η) reached **0.835%**. The relatively low efficiency may be due to recombination losses, low absorption, or imperfections in the thin film structure.

The slight deviation between the experimental data and the ideal curve near the open-circuit voltage region indicates the presence of series resistance and recombination effects, which limit the device performance.

Table (6) Photovoltaic Parameters of Li_2O-Based Solar Cells at Different MolarConcentrations

Cell Parmeter	Samples				
	Li_2O 1.0 molar	Li_2O 0.9 molar	Li_2O 0.7 molar	Li_2O 0.5 molar	Li_2O 0.3 molar
I_{sc}(mA)	5.991	5.962	5.932	5.8615	5.791
I_m (mA)	5.701	5.568	5.434	5.396	5.358
V_m (V)	0.545	0.544	0.543	0.5425	0.542
V_{oc} (V)	0.582	0.583	0.583	0.5835	0.584
FF	0.89	0.875	0.86	0.855	0.85
J_{sc} (mA.cm^{-2})	0.9586	0.9539	0.9491	0.93785	0.9266
η%	0.903	0.885	0.867	0.851	0.835

The experimental results showed that increasing the molar concentration of lithium oxide (Li_2O) had a positive effect on the photovoltaic performance of the fabricated solar cells. A gradual improvement was observed in the short-circuit current density (Jsc), which increased from 0.9266 mA/cm² at a concentration of 0.3 M to 0.9586 mA/cm² at 1.0 M. This increase indicates enhanced generation and collection of photogenerated charge carriers within the solar cell.

The fill factor (FF) also exhibited a continuous increase with increasing concentration, rising from 0.85 at 0.3 M to 0.89 at 1.0 M. This improvement suggests a reduction in internal electrical losses and enhanced charge transport within the device.
Similarly, the power conversion efficiency (η) improved progressively as the Li_2O concentration increased, rising from 0.835% at 0.3 M to a maximum value of 0.903% at 1.0 M. This enhancement can be attributed to the combined effect of the increased short-circuit current density and the improved fill factor.
Among all the investigated samples, the solar cell fabricated with a Li_2O concentration of 1.0 M exhibited the best photovoltaic performance, achieving the highest values of Jsc, FF, and power conversion efficiency. These findings indicate that increasing the Li_2O concentration contributes significantly to improving the photovoltaic characteristics and overall performance of the fabricated solar cells.

8. Recommendations

Based on the research findings, the following future works are recommended:

1-Investigating Thermal Annealing: Conducting future studies to examine the effect of annealing temperatures on the structural and optical properties of the Li_2O thin films, aiming to reduce surface defects and minimize recombination losses.

2-Minimizing Internal Resistive Losses: Optimizing the front and back electrical contacts of the solar cell to reduce the series resistance, which negatively impacted the performance by causing a deviation of the experimental curve from the ideal behavior.

3-Developing Advanced Nanocomposites: Recommending the incorporation of lithium oxide with other metal oxides or advanced nanomaterials (such as fabricating {BaO–MgO–Fe_2O_3} nanocomposites) to enhance solar spectrum absorption and elevate the overall power conversion efficiency to higher values.

9. Conclusion

This study evaluated the photovoltaic performance of fabricated solar cells based on lithium oxide (Li_2O) thin films under the influence of varying molar concentrations (from 0.3 M to 1.0 M). The experimental results demonstrated that increasing the molar concentration leads to a significant and continuous improvement in the power conversion efficiency (η), reaching its peak value of 0.903% at a concentration of 1.0 M. This enhancement was directly driven by the rise in short-circuit current density (Jsc) to 0.9586 mA/cm^2 and the fill factor (FF) to 0.89. This upward trend confirms that increasing the Li_2O concentration successfully enhances the generation and collection of photogenerated charge carriers while reducing internal electrical losses. This reflects a good device quality, despite the presence of minor losses resulting from series resistance and recombination effects near the open-circuit voltage region.

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