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PHOTOELECTROCHEMICAL SOLAR CELL CHARACTERIZATION OF CHEMICALLY DEPOSITED Cd1-xZnxSe THIN FILMS

Physics

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ABSTRACT

Chemically deposited II–VI semiconductor thin films have attracted significant attention for low-cost and scalable photoelectrochemical (PEC) solar energy conversion. In the present work, Cd1-xZnxSe thin films with varying Zn composition (x = 0–1) were successfully synthesized on glass substrates by the chemical bath deposition (CBD) technique to investigate their suitability as photoelectrodes for photoelectrochemical solar cells. PEC measurements performed in suitable electrolyte under simulated solar illumination exhibited enhanced photocurrent density, open-circuit voltage, and conversion efficiency for optimized Zn concentration. The photoelectrochemical (PEC) cell of the configuration Cd1-xZnxSe / 1M (NaOH +Na2S + S) / C is fabricated to study the current-voltage (I-V) characteristics in dark and under illumination. The photovoltaic power output curves have been obtained under 25 mW/ cm2 light intensity. The power conversion efficiency (η) and fill factor (ff) are obtained.

KEYWORDS

Cd1-xZnxSe thin films; Chemical bath deposition; Photoelectrochemical cell, Cd_1-Zn_a Se electrode, efficiency, fill factor.

INTRODUCTION

Ternary semiconductors belonging to II-VI and IV-VI group are gaining much importance due to their wide spectrum utility in various optoelectronic devices such as IR detectors, photoconductive, photovoltaic cells, light amplification, LED's, lasers, PEC cells [1-3] and is an efficient absorbers in visible region of the solar spectrum [4]. Among these groups, the semiconductors CdSe and ZnSe are highly sensitive to light radiations, so due to the practical applications, the study of the photoelectrochemical properties of their mixed thin structures has technical as well as scientific importance. Band gap engineering through alloying offers an effective strategy to enhance the optoelectronic performance of CdSe-based materials. Incorporation of Zn into CdSe to form $Cd_{1-x}Zn_xSe$ enables systematic tuning of structural, optical, and electronic properties, including improved crystallinity, increased band gap, and reduced defect density. These modifications facilitate better charge separation and enhance photogenerated carrier transport, which are essential for high PEC efficiency [5-6].

Among various deposition techniques, chemical bath deposition (CBD) is particularly attractive due to its simplicity, low temperature processing, cost-effectiveness, and ability to produce uniform and large-area coatings without sophisticated instrumentation. This technique also allows easy control over composition and thickness by adjusting bath parameters [7-8].

In this work, $Cd_{1-x}Zn_xSe$ thin films with different Zn concentrations were synthesized via CBD and systematically characterized to understand their structural, morphological, optical, and photoelectrochemical properties. The objective is to correlate composition-dependent material characteristics with PEC performance and to identify optimized conditions for efficient solar energy conversion.

Experimental details

Preparation of photoelectrodes

The photoelectrodes of $Cd_{1-x}Zn_xSe$ thin films were deposited on FTO coated glass substrates procured from Sigma-Aldrich (Mumbai).

Construction of photoelectrochemical (PEC) solar cell

The photoelectrochemical (PEC) solar cells were prepared using the $Cd_{1-x}Zn_xSe$ thin films of various thicknesses deposited on FTO glass substrates as photoelectrodes, polysulphide as an electrolyte and graphite as the counter electrode. The configuration of the PEC cell is as below:

n- $Cd_{1-x}Zn_xSe$ | 1M (Na_2S + S + NaOH) | C

RESULTS AND DISCUSSION

Current-voltage (I-V) characteristics

The current density–voltage curves of $Cd_{1-x}Zn_xSe$ photoelectrodes recorded versus the saturated calomel electrode (SCE) exhibit typical photoelectrochemical behavior under illumination as shown in Fig. 1. The plots show both cathodic and anodic photocurrent responses over the applied potential window (−800 to +800 mV), confirming the semiconducting and photoactive nature of all deposited films.

At negative potentials, all samples display cathodic photocurrent, indicating reduction reactions at the semiconductor–electrolyte interface due to photogenerated electrons. As the applied potential shifts toward positive values, the current gradually increases and crosses zero near the flat-band region, followed by a sharp rise in anodic photocurrent, characteristic of efficient hole-driven oxidation processes. This behavior confirms the formation of a depletion layer and effective charge separation within the photoelectrode [9-12].

A clear composition-dependent trend is observed with Zn incorporation. The photocurrent density initially increases with Zn addition, reaching a maximum for the x = 0.2 composition. This sample exhibits the highest anodic photocurrent density indicating superior charge transport and interfacial kinetics. The enhancement can be attributed to improved crystallinity and reduced defect density [13-15].

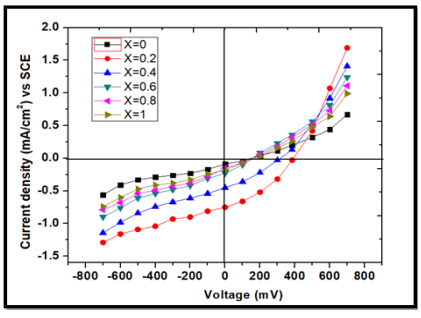

Fig. 1: Current-voltage characteristics of n-Cd1-xZnxSe (0.0<x<1.0) thin films/1M polysulphide/C photoelectrochemical cells.

Power output characteristics

The illuminated current density–voltage curves of Cd1-xZnxSe thin film photoelectrodes exhibit typical photovoltaic behavior with composition-dependent power generation capability. The photocurrent density decreases monotonically in magnitude with increasing applied forward bias and approaches zero near the open-circuit potential (Voc), confirming photovoltage development across the semiconductor–electrolyte junction. This behavior arises from light-induced charge separation within the space charge region formed due to band bending at the interface [16].

At zero bias, all compositions show significant short-circuit photocurrent density, indicating efficient photon absorption and carrier generation. The magnitude of photocurrent density is highest for the x

= 0.2 film (= −391 μA cm⁻²), followed by x = 0, 0.4, 0.6, 0.8, and 1.0. The enhanced current for x = 0.2 suggests improved crystallinity, reduced defect density, and enhanced carrier mobility due to optimal Zn incorporation. Moderate alloying reduces recombination centers and improves interfacial charge transfer kinetics, leading to superior photocurrent collection [17].

The maximum power output point (MPP), obtained from the product P=JV, occurs in the intermediate voltage region where both current and voltage are appreciable. The x = 0.2 composition exhibits the largest rectangular area under the J–V curve, corresponding to the highest power density and fill factor. In contrast, higher Zn concentrations show reduced slope and curvature, indicating increased recombination and resistive losses that lower the fill factor.

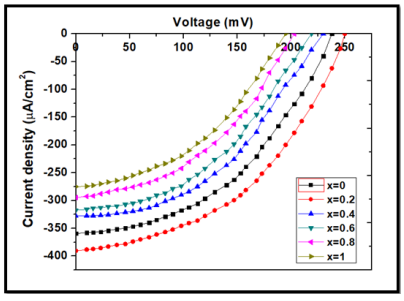

Fig. 2: Photovoltaic power output characteristics for chemically deposited n-Cd1-xZnxSe thin films.

Table 1. Estimated photoelectrochemical parameters of Cd1-xZnxSe PEC cells.

Composition	Isc (uA)	V_{oc} (mV)	FF (%)	Rs (Ω)	Rsh (kΩ)	n (%)	E_g (eV)
CdSe	360	238	45.17	238	2.67	1.54	1.78
Cd0.8Zn0.2Se	391	253	46.62	195	3.02	1.82	1.95
Cd0.6Zn0.4Se	328	230	43.97	286	2.91	1.48	2.16
Cd0.4Zn0.6Se	317	219	42.77	340	2.81	1.19	2.38
Cd0.2Zn0.8Se	295	203	42.35	357	2.76	1.01	2.53
ZnSe	275	195	41.95	375	2.58	0.90	2.68

CONCLUSION

The n- Cd1-xZnxSe thin films can be deposited on to conducting FTO-coated glass substrates using simple chemical bath deposition technique. As-deposited Cd1-xZnxSe thin films are n-type polycrystalline and photoactive. The results demonstrate that controlled Zn incorporation effectively tunes the optoelectronic and PEC properties of CdSe, with $Cd_{0\cdot8}Zn_{0\cdot2}Se$ showing the best performance among the investigated compositions. The enhanced photocurrent response confirms its suitability as an efficient photoelectrode material for low-cost photoelectrochemical solar cell applications. Thus, controlled Zn incorporation effectively tunes the trade-off between photocurrent and photovoltage, with moderate alloying (x = 0.2) delivering the best power conversion performance. These results demonstrate that chemically deposited Cd1-xZnxSe thin films are promising low-cost photoelectrodes for PEC solar energy applications.

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