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Dual-functionality for solar hydrogen generation and high-performance energy storage

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ABSTRACT

Cadmium zinc telluride (CdZnTe) thin films were successfully synthesized via a cost-effective electrochemical deposition method and characterized for structural, optical, and electrochemical properties to assess their potential for multifunctional applications. X-ray diffraction confirmed the films' polycrystalline nature, and scanning electron microscopy revealed a porous nanorod morphology. Optical studies have shown strong absorption in the visible region and a bandgap of 1.95 eV, making it suitable for optoelectronic applications. Electrochemical analyses, including impedance spectroscopy, galvanostatic charge-discharge, and photoelectrochemical tests, demonstrated the dual functionality of the CdZnTe films in the PEC cell. The electrode exhibited a low charge-transfer resistance of 29.9 Ω, a high specific capacitance of 178 F g-1, an energy density of 15.48 Wh kg^{-1}, and a power density of 4.98×10^3 W kg^{-1}, indicating excellent energy storage capabilities. Furthermore, photoelectrochemical measurements revealed a photocurrent density of 3.50 mA cm^{-2} and an applied-bias photon-to-current efficiency (ABPE) of 1.8% under simulated solar light, highlighting its potential for solar hydrogen generation. The incorporation of Zn into the CdTe lattice enhanced the structural and functional properties of the films compared to pure CdTe films. These findings underscore the promise of electrochemically deposited CdZnTe thin films as efficient and cost-effective materials for integrated energy storage and solar energy conversion.

1. Introduction

II–VI semiconductor compounds, particularly those composed of cadmium (Cd), zinc (Zn), and tellurium (Te), have attracted significant attention owing to their direct bandgap and superior optoelectronic properties. Among them, cadmium zinc telluride (CdZnTe or CZT) stands out as a ternary semiconductor with a tunable bandgap of (1.7–1.92) eV at room temperature, depending on the zinc content [1,2]. CdZnTe exhibits several advantageous characteristics, including high radiation resistance, thermal stability, and excellent charge-carrier mobility, making it suitable for applications in radiation detection, infrared optics, and photodetection [3–5]. Moreover, incorporating Zn into CdTe enhances its structural stability and modifies its electronic structure, making CdZnTe a promising candidate for energy-related technologies.

In recent years, the growing demand for sustainable energy systems has intensified research into efficient energy storage technologies, particularly supercapacitors, due to their high power density, rapid charge-discharge capability, and long cycle life [6]. Supercapacitors store energy through two main mechanisms, namely electrical double-layer capacitance and pseudocapacitance, which strongly depend on the nature and surface properties of electrode materials. Carbon-based materials, especially those derived from biomass, have gained considerable attention as electrode materials owing to their high surface area, good electrical conductivity, low cost, and environmental friendliness [7,8].

Recent trends in renewable energy research have highlighted the potential of CdZnTe in two emerging areas: photoelectrochemical (PEC) water splitting for hydrogen generation and electrochemical energy storage in supercapacitors. The high absorption coefficient, favorable band alignment, and stability of materials in aqueous media are key attributes for PEC applications. Simultaneously, its nanostructured form

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