Chapter 9

Advancements in Chalcogenide Nanocomposites of Next-Generation Materials for Dye-Sensitized Solar Cells:

Emerging Trends and Future Solar Innovations

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DOI: 10.4018/979-8-3373-3962-7.ch009

ABSTRACT

Dye-sensitized solar cells (DSSCs) are a promising photovoltaic technology known for low cost, flexibility, and eco-friendliness. Chalcogenide-based nanocomposites, with their unique electronic, optical, and catalytic features, have attracted significant interest for boosting DSSC efficiency. This review explores next-generation chalcogenide nanocomposites—sulfides, selenides, tellurides, and hybrids—used in key DSSC components like photoanodes, counter electrodes, and electrolytes. It highlights synthesis methods, structural traits, and the functional improvements these nanomaterials offer. Challenges, recent progress, and future perspectives for integrating chalcogenide nanocomposites into commercially viable DSSCs are also discussed.

INTRODUCTION

Dye-sensitized solar cells (DSSCs), first introduced by O'Regan and Grätzel in the early 1990s, have sparked significant interest in the scientific community due to their relatively simple construction, ease of fabrication, and potential for cost-effective energy conversion, (Kannan & Tari, 2025; Regan & Grätzel 1990; Srivastava et al., 2025). These devices mimic natural photosynthesis by using a dye molecule to harvest sunlight and generate electricity through electron transfer processes, (Shahid et al., 2025). The core components of a DSSC include a photoanode, a sensitizing dye, an electrolyte, and a counter electrode, (Agrawal et al., 2022). Over the decades, DSSCs have evolved from lab-scale prototypes to semi-commercial devices with improved efficiencies and durability. However, to surpass their limitations and compete with other photovoltaic technologies, innovations in material science, especially at the nanoscale, have become imperative.

Nanomaterials have revolutionized the field of DSSCs by offering a higher surface area, improved charge transport, and enhanced light-scattering properties, which collectively contribute to improved photovoltaic performance (Figure 1), (Korir et al., 2024). Incorporating nanostructures such as nanoparticles, nanorods, nanotubes, and quantum dots, (Tari et al., 2022) into the photoanode or counter electrode can significantly influence the efficiency and functionality of DSSCs, (Zheng et al., 2024). These materials can be tailored to control the morphology, surface chemistry, and electronic properties of each DSSC component. As a result, the utilization of nanomaterials represents a major paradigm shift, opening avenues for designing next-generation solar cells with superior energy conversion capabilities.