Chapter 10
Chalcogenide-Based Nanocomposites as Counter Electrodes for Quantum Dot-Sensitized Solar Cells

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ABSTRACT

This study explores a sustainable and cost-effective method to improve dye-sensitized solar cells (DSSCs) by developing nickel sulfide (NiS) nanoparticle composites combined with activated carbon (AC) derived from sugarcane waste. The NiS/AC nanocomposites were prepared through a facile hydrothermal process assisted by ultrasonication and characterized using XRD, TEM, UV-Vis, Raman spectroscopy, and XPS to analyze their structure and optical features. Notably, the composite with 20% AC showed enhanced optical transmittance and a lowered bandgap from 1.82 to 1.56 eV, facilitating better visible light absorption. Electrochemical tests revealed that NiS/AC-20 electrodes had improved triiodide reduction kinetics compared to those with lower AC content. The optimized NiS/AC counter electrode exhibited a power conversion efficiency of 8.54%, supported by a short-circuit current density of 19.5 mA cm^{-2} and an open-circuit voltage near 0.759 V.

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INTRODUCTION

Rising fossil fuel dependency has accelerated energy insecurity and climate change impacts, (Nabera et al., 2023). Photovoltaic (PV) systems offer direct solar-to-electric conversion; however, conventional silicon PV deployment is constrained by cost-intensive manufacturing and environmental drawbacks, restricting large-scale applications mainly to terrestrial platforms (Nie et al., 2023). According to (Tamilselvan et al., 2024), chlorophyll-rich CCE dye, extracted from plant biomaterials through ethanol-assisted solvent extraction, functions as a photosensitizer in DSSCs. The fabricated DSSC achieved 0.49% PCE, validated by JV analysis. UV–Vis, XRD, and FTIR confirmed dye–semiconductor interactions, while EIS revealed charge-transfer resistance correlating with the device's photovoltaic performance, while its measured photoelectric conversion efficiency is 0.146%. (Tamilselvan & Shanmugan, 2024) highlight the transition from fossil fuels to carbon-neutral energy, emphasizing DSSCs. Bio-nano dyes, TCO layers, and optimized metal oxide deposition advance efficiency, achieving ~11% light-to-power conversion. (Premkumar et al., 2024) investigated ethanol-extracted pineapple crown leaf dye, rich in cellulose-lignin fibrils, demonstrating visible absorption, FTIR/PL signatures, and DSSC performance with 1.0034% efficiency, supported by PC1D-based photovoltaic simulation.

To maintain high device performance, it is imperative to suppress charge recombination, wherein the counter electrode plays a pivotal catalytic role. The counter electrode, located at the electrolyte–electrode interface, catalyzes the redox reaction by reducing triiodide ions (I_3^-) to iodide ions (I^-). Platinum (Pt) has conventionally been employed in this role due to its superior electrocatalytic activity, (Althomali et al., 2023). Nevertheless, the high cost, limited abundance, and chemical instability of Pt in iodide-based electrolytes have prompted extensive research into alternative counter electrode materials. The development of cost-effective, Pt-free electrocatalysts with comparable or enhanced catalytic performance is thus essential for improving the commercial scalability and environmental sustainability of DSSC technology, (Alizadeh et al., 2023). Recent advancements in DSSCs have increasingly focused on the development of platinum-free (Pt-free) electrocatalysts, motivated by the high cost, scarcity, and corrosion issues associated with Pt (Akman et al., 2022). Alternative counter electrode materials include carbon frameworks, conductive polymers, transition-metal compounds, and hybrid composites (Gottipati et al., 2022), have shown considerable promise as efficient counter electrode (CE) materials. Transition metal chalcogenides (TMCs) exhibit excellent redox kinetics for triiodide (I_3^-) reduction and superior charge-transfer properties, establishing them as promising candidates for DSSC counter electrodes (Qian et al. 2019).

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