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Synergistic optimization of CdS quantum dot-sensitized TiO_2 electron transport layer and annealing conditions for enhanced efficiency in perovskite solar cells

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Abstract

The electron transport layer (ETL) plays a critical role in facilitating charge transport and influencing the overall performance of perovskite solar cells (PSCs). Titanium dioxide (TiO_2), owing to its favorable band alignment and chemical stability, remains the most commonly employed ETL. However, it suffers from limitations such as low electron mobility, high charge recombination, and poor UV stability. In this study, we enhance the optoelectronic properties of mesoporous TiO_2 by surface modification with cadmium sulfide (CdS) quantum dots via the successive ionic layer adsorption and reaction (SILAR) method. Additionally, we investigate the impact of different annealing temperatures (200, 300, 400, 450, and 500 °C) on the morphology and photovoltaic performance of the fabricated PSCs. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses revealed that increasing CdS deposition cycles led to more compact perovskite layers with larger grain sizes and highly crystalline perovskite films. Optical absorption (UV–Vis) and photoluminescence (PL) spectra exhibited a redshift in the absorption edge and diminished emission intensity, indicating improved crystallinity and suppressed radiative recombination. The photovoltaic parameters measurements showed that after five cycles of CdS SILAR and annealing at 400 °C, the device achieved a power conversion efficiency (PCE) of 5.88%, significantly higher than the 4.43% obtained for the pristine TiO_2-based device annealed at 500 °C. This improvement is attributed to better charge extraction, reduced interfacial recombination, and enhanced light absorption. The study demonstrates that CdS sensitization effectively passivates surface defects in TiO_2 and enables efficient charge transport. Furthermore, annealing at a moderate temperature of 400 °C proved optimal for balancing morphology, and interfacial properties. These findings highlight the synergistic effect of CdS modification and thermal optimization, providing a promising strategy for improving the efficiency and stability of PSCs.

Keywords: Perovskite solar cells, TiO_2 electron transport layer, CdS quantum dots, Annealing, Surface morphology, Photovoltaic performance.

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