Title : Enhancing Perovskite Solar Cell Efficiency with GQD-Modified Mesoporous TiO_2 Electron Transport Layers

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ABSTRACT

Titanium dioxide (TiO_2) is widely used as an electron transport layer (ETL) in perovskite solar cells (PSCs) due to its well-established semiconductor properties, including high chemical and optical stability, non-toxicity, low cost, and excellent corrosion resistance. However, PSCs employing TiO_2 as the ETL often suffer from intrinsic limitations such as oxygen vacancies, UV-induced degradation, and low electron mobility, which hinder device performance. Graphene quantum dots (GQDs), a novel class of nanomaterials, have attracted significant interest due to their unique properties, including excellent electrical conductivity, quantum confinement effects, edge effects, non-toxicity, facile synthesis, and cost-effectiveness. These characteristics make GQDs a promising candidate for modifying TiO_2-based ETLs to enhance charge transport and mitigate recombination losses in PSCs. In this study, we doped TiO_2 ETLs with electrochemically synthesized GQDs at varying concentrations, resulting in the formation of a GQDs/TTIP solution. The goal was to address the limitations associated with TiO_2, particularly low electron mobility and charge recombination. Under standard illumination conditions, our results demonstrated that the incorporation of an optimal concentration of GQD-doped TiO_2 significantly improved the open-circuit voltage (V_{OC}) and short-circuit current density (J_{SC}) compared to pristine TiO_2. The highest power conversion efficiency (PCE) of approximately 10% was achieved in the MAFAPbI$_2$-based PSCs with an optimized GQD/TiO_2 ratio. This enhancement correlated with a pronounced quenching of perovskite photoluminescence observed at approximately 780 nm, indicating improved charge extraction and reduced recombination. These findings substantiate the role of GQDs as an effective modifier for TiO_2 ETLs, acting as a conductive pathway for

electron transport and mitigating recombination losses. We conclude that GQD incorporation into TiO_2 ETLs enhances charge carrier dynamics and improves overall PSC performance, making it a viable strategy for next-generation perovskite solar cells.