INTERFACE ENGINEERING OF CARBON-BASED PHOTOELECTRODES FOR SOLAR-POWERED BATTERIES

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Abstract

Integrating solar energy harvesting and storage into a single battery remains challenging due to limited charge transport in photoactive materials. This study develops an NVO-rGO photocathode through a one-step hydrothermal method to enhance photoelectrochemical performance in zinc-ion batteries. Under illumination, the capacity increases from 310 to 348 mAh g^{-1}, the CV curve area improves by 61%, and charge-transfer resistance decreases from 115 to 53 Ω. The photoelectrode also enables direct photocharging with a photoconversion efficiency of 0.62%, demonstrating the potential of interface engineering for solar-powered energy storage.

Keyword: Photoelectrode, carbon-based materials, interface engineering, solar-powered batteries, NVO-rGO, photoelectrochemical energy storage.

Introduction

Solar energy utilization remains challenging due to its intermittent nature, highlighting the need for efficient and sustainable energy storage technologies. Solar-powered batteries offer an integrated approach by combining light harvesting and energy storage in a single device. However, their performance is limited by the low electrical conductivity of photoactive materials and charge carrier recombination.

Interface engineering between semiconductor materials and conductive carbon networks offers a promising strategy to enhance electron transport and photogenerated charge carrier utilization. This study investigates this approach through the development of an NVO-rGO photocathode for solar-powered batteries.

Research Methodology

1. Material Synthesis and Characterization
NVO-rGO composites were synthesized via a one-step hydrothermal method at 180 °C for 12 hours using ammonium metavanadate and graphene oxide as precursors. Unmodified NVO was prepared as a reference. Material properties were characterized using XRD, Raman, SEM/TEM, XPS, UV-Vis, photoluminescence (PL), and BET analysis.

2. Battery Fabrication and Evaluation
NVO-rGO photoelectrodes were employed as cathodes in zinc-ion batteries with Zn anodes and $Zn(CF_3SO_3)_2$ electrolytes. Electrochemical performance was evaluated using CV, GCD, and EIS under dark and illuminated conditions. Direct photocharging capability was assessed by monitoring voltage changes during illumination, followed by dark discharge to determine photoconversion efficiency.

Result & Discussion

1. Enhanced Energy Storage Performance
At a current density of 0.2 A g^{-1}, NVO-rGO delivers a capacity of 310 mAh g^{-1}, compared with 237 mAh g^{-1} for unmodified NVO, representing an approximately 31% improvement in capacity.

The NVO-rGO composite also exhibits improved rate capability and capacity retention compared with NVO during 300-cycle testing at a current density of 0.2 A g^{-1}.

2.Enhanced Photoelectrochemical Response
Under illumination, the capacity of NVO-rGO increases from 310 to 348 mAh g^{-1}. The CV curve area increases by 61%, compared with 21% for unmodified NVO.

The charge-transfer resistance of NVO-rGO decreases from 115 Ω under dark conditions to 53 Ω under illumination, indicating improved charge-transfer kinetics.

3. Role of NVO-rGO Interface Engineering
The rGO network provides electron transport pathways that facilitate the electrochemical processes of NVO. The lower PL intensity observed in NVO-rGO is consistent with reduced radiative recombination.

Material characterization and electrochemical testing support the proposed role of the NVO-rGO interface in facilitating the transport and utilization of photogenerated charge carriers.

4. Direct Photocharging Capability
The NVO-rGO photoelectrode enables direct charging using light without an external charging current, reaching a voltage of 0.81 V after approximately 3 hours of illumination.

Subsequent discharge testing after illumination yields a photoconversion efficiency of 0.62%, demonstrating the integration of light harvesting and energy storage within a single battery system.

Conclusion

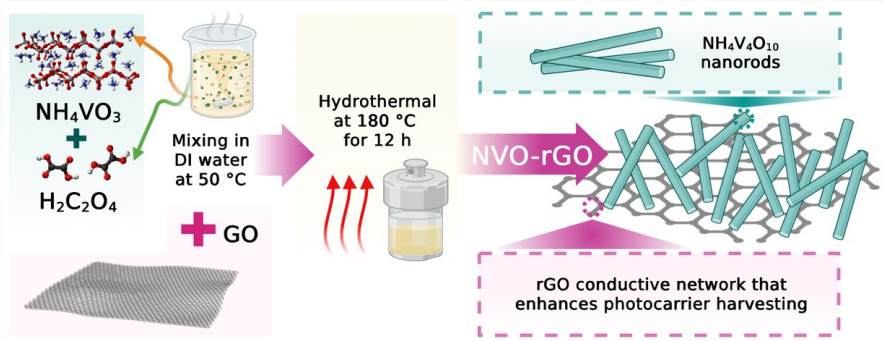
Interface engineering of NVO-rGO through the integration of photoactive materials with conductive carbon networks successfully enhances ion-storage capacity and electrochemical responses under illumination.

NVO-rGO achieves a capacity of 348 mAh g^{-1} under illumination and enables direct photocharging using light with a photoconversion efficiency of 0.62%.

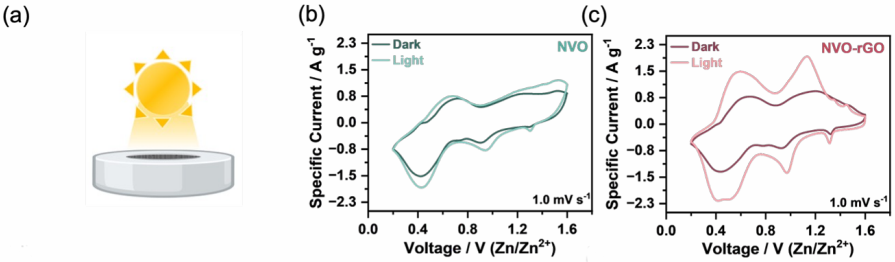
These findings demonstrate that interface engineering between photoactive materials and conductive carbon networks is a promising strategy for developing batteries that integrate solar energy harvesting and energy storage.

Expected Output

One scientific publication in a Q1-ranked international journal (Under Review).



Picture 1. Fabrication procedure of NVO-rGO



Picture 2. (a) Schematic of a photo-rechargeable zinc-ion battery under light condition test. CV curves of (b) NVO and (c) NVO-rGO under dark/light conditions at 1.0 mV s^{-1} .