Bimetallic Heterostructures as Effective Anode Materials for Sodium-Ion Capacitors.

Dr. Rahul R. Salunkhe
Department of Physics and Department of Interdisciplinary Programs, Indian Institute of Technology (IIT) Jammu, Jagti, NH-44, PO Nagrota, Jammu 181221, J&K, India.
Contact: rahul.salunkhe@iitjammu.ac.in

Abstract

The development of next-generation sodium storage systems critically demands anode materials with exceptional ion-storage capacity and structural robustness.[1] Strategic manipulation of the electronic structure and interfacial energy landscape of materials is the cornerstone for advancing the performance of anodes for sodium storage. Two-dimensionally (2D) confined SnS_2 materials possess lamellar channels that provide large active sites to facilitate the alloying reactions with sodium ions, thereby exhibiting high specific capacity.[2] However, alloying reactions often involve irreversible passivation reactions that result in large volumetric changes (~500%); therefore, SnS_2 materials are inefficient at delivering the desired properties for stable, rapid kinetics in sodium-ion capacitor operations.[3] We have designed a 2D-2D bimetallic heterostructure using 2D SnS_2 and MoS_2 entities using a two-step hydrothermal method (FESEM image in **Figure 1**). Such heterostructures with optimized structures offer distinct advantages, such as a built-in electric field (BIEF), a high diffusion coefficient, a low adsorption energy, and intermediate volume changes over the conventional SnS_2 monolayered structure, by synergistically stabilizing lattice frameworks through interfacial interactions.[4] Catalytic Mo converted from sodiated MoS_2, and BIEF at the SnS_2-MoS_2 heterointerfaces accelerates the migration of Na^+ ions to give a high rate reversible capacity of ~ 257 mAh g^{-1} at a high current of 1 A g^{-1}. This bonded configuration demonstrates superior structural stability for Na^+ ion storage, achieving ~90% retention after 200 cycles. When the presodiated SnS_2-MoS_2 heterostructure anode was paired with the commercial activated carbon cathode, the full cells delivered high gravimetric energy densities of 111 Wh kg^{-1} (**Figure 2**) and an excellent cycling stability, retaining 80% capacity after 10,000 cycles. Collectively, the strategy to design spatially confined 2D-2D heterostructures highlights the effectiveness of atomic-scale heterointerface engineering in mitigating irreversible structural changes associated with alloy-based anodes. The proposed 2D–2D confinement strategy provides a versatile platform for stabilizing high-capacity alloy-type materials in next-generation sodium-based energy storage systems.

References

[1] J. C. Hyun, H. M. Jin, J. H. Kwak, S. Ha, D. H. Kang, H. S. Kim, S. Kim, M. Park, C. Y. Kim, J. Yoon, J. S. Park, J.-Y. Kim, H.-D. Lim, S. Y. Cho, H.-J. Jin, Y. S. Yun, *Energy Environ. Sci. 17*, 2024, 2856.
[2] N. Bansal, N. Kumar, P. K. Pathak, H. Ahn, J. Tang, Y. Yamauchi, R. R. Salunkhe, *Adv. Mater. 37*, 2025, 2501490.
[3] Y. H. Kim, J. Y. Moon, Y. I. Yoon, J. C. Lee, Y. S. Choi, *ACS Nano 18*, 2024, 35595–35605.
[4] W. Yu, B. Cui, J. Han, S. Zhu, X. Xu, J. Tan, Q. Xu, Y. Min, Y. Peng, H. Liu, Y. Wang, *Adv. Sci.* 11, 2024, 2405135.

Figures

Figure 1: FESEM image of SnS_2-MoS_2 heterostructure.

Figure 2: Ragone plot comparing the specific energy and power of our cell with previously reported heterostructures.