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Review Article

MXene mastery: Transforming supercapacitors through solid-solution innovations

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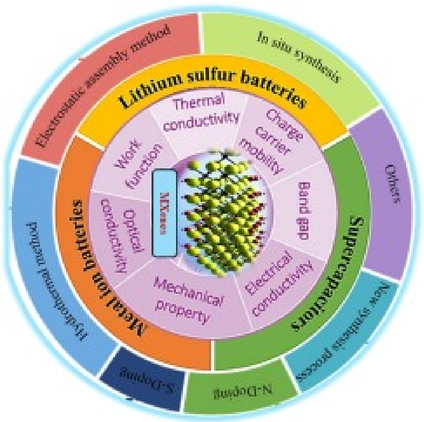
Highlights

- Solid-solution MXenes show promise for supercapacitors with unique energy storage properties.
- Etching and intercalation enhance MXene electrochemical performance in supercapacitors.
- Crystallographic, chemical, and morphological design optimizes solid-solution MXenes for energy storage.
- Solid-solution MXenes are pivotal in advancing renewable energy storage technologies.

Abstract

Exploring innovative materials for supercapacitors has been a focus to broaden energy storage alternatives. The distinctive properties and applications of solid-solution MXenes have garnered significant attention in this regard. This research delves into the application of solid-solution MXene materials in supercapacitor energy storage, examining aspects such as manufacturing, electrochemical behaviour, and structural characteristics. The article begins with an overview of the MXene family, highlighting its potential for energy storage, a highly sought-after quality. The solid-solution approach is particularly favoured for its ability to enhance MXenes electrochemical properties by introducing additional components. This study explores how etching, and intercalation impact the material's structure and energy storage capabilities. Detailed analyses of the crystallographic, surface chemical, and morphological properties of solid-solution MXenes are conducted. The study emphasizes the influence of these factors on the electrochemical performance of MXene supercapacitors, stressing the importance of tailored design. The research extensively investigates the durability, electrical storage capacity, and charge retention mechanisms of these materials. Understanding the effects of dopants and intercalants on charge storage dynamics could lead to improvements in MXene electrode energy storage. The paper reviews the current advancements, challenges, and the potential of solid-solution MXenes in supercapacitors. With a careful examination of existing research and strategic selection of constituents, solid-solution MXene materials could play a crucial role in future energy storage systems, providing a valuable tool for engineers and scientists exploring renewable energy storage technologies.

Graphical abstract



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Introduction

Supercapacitors, referred to as electrochemical capacitors or ultracapacitors, possess an extended lifespan, a high energy output per unit volume, and rapid charging and discharging abilities [1], [2], [3]. These attributes render them a potential technology for energy storage. MXenes have undergone rapid development since their discovery in 2011, especially in the area of supercapacitors. Initially, their high electrical conductivity, large surface area, and tunable surface terminations made them attractive for energy storage applications [4], [5], [6], [7]. These properties, combined with their excellent metallic conductivity and hydrophilic nature, allow MXenes to offer rapid electron transport and efficient ion diffusion, which are crucial for improving energy storage devices [8], [9]. Early efforts focused on exploiting their pseudocapacitive behaviour, with MXene-based supercapacitors demonstrating significantly higher capacitance than traditional carbon materials [10], [11]. However, early challenges included material restacking, limited ion diffusion, and environmental concerns due to the hazardous hydrofluoric acid (HF) used in synthesis. To address these issues, researchers explored various approaches to optimize electrolyte compatibility and surface functionalization, leading to enhanced electrochemical performance. During this period, MXenes were combined with other nanomaterials