

Nanotechnologies / Materials



Beyond precious metals: Redefining catalysis with ubiquitous metals

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Abstract

The transition of chemical industries from reliance on precious and rare metals to technologies rooted in abundant and sustainable elements represents one of the major challenges in modern society. This study successfully addressed this issue by developing iron phosphide nanocrystals (Fe₂P NC) that overcome the inherent limitations of conventional iron catalysts, including low activity and oxidative deactivation. Fe₂P NC demonstrated high performance in nitrile hydrogenation, outperforming traditional iron catalysts and achieving remarkable durability under mild conditions. By simultaneously achieving high activity and stability, this research establishes a novel design paradigm for air-stable and highly active iron catalysts, broadening the scope of applications for iron-based catalysts and laying a strong foundation for sustainable chemical processes.

Background & Results

Iron, a ubiquitous and low-toxicity element, has long been considered a promising resource for catalysts. However, the inherent low activity and susceptibility to oxidative deactivation have limited its catalytic applications. This research overcomes these challenges by synthesizing iron phosphide nanocrystals (Fe₂P NC) using a liquid-phase thermal decomposition method. The Fe₂P NC catalysts achieved both air stability and high catalytic activity. In nitrile hydrogenation, Fe₂P NC outperformed conventional iron catalysts, demonstrating high activity and durability under mild conditions. Additionally, the remarkable air stability of Fe₂P NC enabled its integration with various metal oxides, resulting in further improvements in catalytic performance. Specifically, composites of Fe₂P NC with TiO₂ exhibited a significant enhancement in activity, maintaining high performance even after multiple reuse cycles. This stability also eliminated the need for oxygen-free environments or high-temperature pretreatment with H₂, simplifying and streamlining catalytic processes.

These results present a novel design principle for non-precious metal catalysts, greatly expanding the functional scope of iron catalysts. By harnessing the inherent potential of iron-based materials, this research is a robust foundation for advancing sustainable chemical processes.

Significance of the research and Future perspective

This research represents the transformative potential of iron, a ubiquitous element, as a sustainable alternative to precious metals. The developed catalysts offer significant advancements in energy efficiency, cost reduction, and environmental impact. Additionally, the simplification of catalytic processes enhances their industrial applicability. Future efforts will focus on expanding these catalysts' applications to pharmaceutical intermediate synthesis and environmentally friendly chemical processes, advancing the practical implementation of next-generation sustainable technologies.

Next-Generation Iron Catalysts for Sustainability

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Background: the abundant and cost-effective iron catalysts have faced significant limitations in activity and durability, restricting their application.

Main Achievement: The first successful development of iron catalysts demonstrating both high activity and exceptional durability.

HAADF-STEM images of Fe₂P NC Wide applicability D P 92% 85% 81% 89% 81% 81% 95% NH₂ Û H_aN. \triangleright 80% 89% 95% **Durability** Fe2P NC/TiO2 (7.6 mol%) NH₃ (0.2 MPa), H₂ (3.8 MPa), 180 °C, 3h 100 (%) 80 94 93 93 89 Yield of 2a 60 **High Activity** 40 20 Fe₂P NC/TiO₂ (Fe : 0.33 mol%) NH₂ TON 295 0 Fresh 1 2 3 5 H₂ (4.4 MPa), NH₃ (0.6 MPa) TOF 12.3 h⁻¹ 2-propanol, 180 °C, 24 h Recycling run 1.2 g Yield 96% Patent Application: WO2023-200015

Patent WO/2023/200015

e a tise Tsuda, Tomohiro; Mitsudome, Takato et al. Iron phosphide nanocrystals as an air-stable heterogeneous catalyst for liquid-phase nitrile hydrogenation. Nature Communications. 2023, 14, 5959. doi: 10.1038/s41467-023-41627-6

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Keyword catalyst, green chemistry, nanoparticles, non-precious metals



