

Vol. 22 • No. 30 • May 27 • 2026

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NANO • MICRO small





REVIEW

Advances in Ta₃N₅-Based Photoanodes for Photoelectrochemical Hydrogen Production and Beyond

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Received: 24 February 2026 | **Revised:** 6 April 2026 | **Accepted:** 12 April 2026

Keywords: photoanodes | photoelectrochemical water splitting | solar fuels | Ta₃N₅ | tandem devices

ABSTRACT

Photoelectrochemical (PEC) water splitting has garnered significant attention as a highly promising and environmentally sustainable route for direct solar-to-hydrogen conversion. Nevertheless, its practical application hinges critically on highly efficient and stable photoanode materials. Tantalum nitride (Ta₃N₅), an n-type semiconductor featuring an ideal bandgap and suitable energy band edges for water splitting, has emerged as a prominent candidate for PEC hydrogen generation. In this review, recent progress in Ta₃N₅-based photoanodes for solar energy conversion is comprehensively summarized. It begins with an overview of basic properties of Ta₃N₅, with an emphasis on its advantages and key challenges for solar water splitting. Next, the main fabrication methods for Ta₃N₅ film photoanodes are introduced. Highlighted are the effective performance enhancement strategies via improving light absorption, charge separation, and surface reaction kinetics. Furthermore, the development of Ta₃N₅-based PEC tandem cells for unassisted overall water splitting is discussed. Beyond hydrogen production, their emerging applications for the coproduction of high-value-added chemicals and other hydrocarbon fuels are also presented. Finally, the ongoing challenges and future prospects of Ta₃N₅ photoanodes for solar fuel production are discussed. It is anticipated that this comprehensive review can provide an instructive guideline for the rational design of high-performance Ta₃N₅-based photoanodes toward efficient solar energy conversion and storage.

1 | Introduction

Energy constitutes a cornerstone of both human civilization and socioeconomic advancement, and the rapid global economic expansion and societal transition in the 21st century have precipitated a steep rise in worldwide energy consumption [1, 2]. The escalating reliance on non-renewable fossil fuels (e.g., coal, oil, and natural gas) has led to persistent environmental degradation and a deepening energy crisis, highlighting the urgent need

to transform the current energy landscape by accelerating the widespread adoption of clean and renewable energy sources [3, 4]. As an ideal energy carrier, hydrogen has garnered significant attention due to its environmental sustainability and broad applications across transportation, power generation, and industrial processes [5]. Compared with other energy sources, hydrogen offers several distinct advantages: (i) a high calorific value of approximately 142 MJ kg⁻¹, roughly 4.5 times that of coke; (ii) combustion yielding only water vapor, fully compatible