



# Surfactant-assisted synthesis of Ni<sub>2</sub>P nanostructures: effect of surfactant concentration on photocatalytic activity

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Received: 11 October 2021 / Accepted: 30 March 2022

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**Abstract** Nickel phosphide nanostructures exhibit superior photocatalytic performance for dye removal and hydrogen evolution reaction. In this study, the preparation of Ni<sub>2</sub>P nanocatalysts with a simple and convenient hydrothermal method was studied. The effect of Hexamethylenetetramine (HMT) surfactant on the physical properties of the prepared samples was investigated through various characterization techniques, including XRD, FESEM, FTIR, BET, and DRS analysis. The results showed that the presence and concentration of HMT played a significant role in the variation of morphology and surface area of the samples. So that the shape of Ni<sub>2</sub>P nanostructures was adjusted, without using a template, by different amounts of HMT. In addition, XRD analysis coupled with Rietveld refinement, and FTIR spectroscopy confirmed the phase transition by adding a high amount of HMT surfactant. Due to higher specific surface area, Ni<sub>2</sub>P nanostructures synthesized in the presence of surfactant, showed higher photocatalytic activity for MB dye removal under UV lamp irradiation.

## 1 Introduction

Pollution caused by organic dyes in the industry has become a serious problem. Various chemical, physical, and biological methods have been investigated to overcome this issue [1–3]. Nanocatalyst-assisted advanced oxidation processes (AOP) are the best choice for wastewater treatment due to the cost-effectiveness, non-toxicity of the materials, no need to dispose of materials produced by the oxidation process, and recyclability. Over the last decade, the semiconductor nanostructures such as TiO<sub>2</sub>, ZnO, Fe<sub>2</sub>O<sub>3</sub>, CdS, GaP, and ZnS have been widely used in the AOPs [4–9]. So far, several nanoparticles based on phosphides, oxides, and nitrides of transition metals have been introduced. Phosphides are of special importance between the compounds mentioned above due to their interesting features such as morphology, size, various phases, low cost, abundance, corrosion resistance, and high thermal stability [1, 10–12].

Nickel phosphide-based materials are excellent photocatalysts among other transition metal phosphides. Many studies have indicated that the properties of nickel phosphide nanoparticles are highly dependent on their phase, size, and morphology. Among the various phases of nickel phosphides, the hexagonal structure of Ni<sub>2</sub>P has a better photocatalytic performance than other phases such as Ni<sub>12</sub>P<sub>5</sub> and Ni<sub>5</sub>P<sub>4</sub> [13, 14]. Hence, an appropriate method for synthesizing nickel phosphide nanostructures is chosen by their properties and applications.

The main methods for fabrication of nickel phosphide nanostructures are direct combination of metallic nickel and red phosphorus under high temperature [15], solid-phase reaction between nickel halogens and phosphorus [16, 17], phosphine and nickel salt reaction [18, 19], decomposition of organic nickel compounds [20, 21], electrolysis of nickel salt melt [22, 23], reduction of phosphate-containing nickel salt [24], hydrothermal [25, 26], etc. Among the various methods, the hydrothermal method has received special attention due to its easy preparation conditions, no environmental pollution, and ability to control the size and morphology of the products. In this method, mineral salts such as NiCl<sub>2</sub> [27], NiCl<sub>2</sub>·6H<sub>2</sub>O [28, 29], NiSO<sub>4</sub>·xH<sub>2</sub>O [30], Ni(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O [31], Ni(CH<sub>3</sub>COO)<sub>2</sub>·4H<sub>2</sub>O [32] are mostly used as a source of nickel and red phosphorus [31], white phosphorus [30], or yellow phosphorus [33] are used as phosphorus precursors. However, most phosphorus precursors (especially white phosphorus) are highly reactive and explosive [1, 34].

In addition to the synthesis method, the use of surfactants can affect the physical properties of Ni<sub>2</sub>P nanostructures. It can improve the photocatalytic activity of nanoparticles by affecting the morphology and increasing the specific surface area by preventing the agglomeration of nanoparticles [35–37]. Nanocatalysts represent a higher photocatalytic performance by increasing the active sites for redox reactions [38, 39]. Different surfactants such as oleylamine [40], oleic acid [41], SDBS, CTAB and PEG [42], PEG/HMT [43] TOPO/HAD [44], and so on have been applied to synthesize the nickel phosphide nanostructures. Among the various surfactants,

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