

Facile Co-precipitation Synthesis and Characterization of Bismuth Phosphate for Enhanced Photocatalytic Applications

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ABSTRACT

Bismuth phosphate (BiPO_4) photocatalysis has been under a lot of research regarding environmental applications in previous years. Studies have further revealed that it is effective in the oxidization of lasting organic pollutants, including industrial dyes, and pharmaceutical residues. In this research work, BiPO_4 nanoparticles were synthesized for efficient photocatalyst. Pure doped BiPO_4 nanoparticles were successfully prepared by coprecipitation method. FTIR spectroscopic analysis, from the spectrum of pure BiPO_4 exhibiting characteristic P-O vibrational bands at 1052 cm^{-1} and 982 cm^{-1} , revealed the formation of phosphate network.

Keywords: Bismuth phosphate, coprecipitation, photocatalysis

Introduction

The field of nanotechnology is concerned with creating and using nanomaterials, or materials smaller than 100 nm. The scale of nanoparticles is the only factor that sets them apart from other materials. Furthermore, it has been shown that nanoparticles have a greater adsorption capability in both liquid and gaseous phases. Nanomaterials have several uses because of their huge surface area, quantum effects, and small size. conductivity, chemical, mechanical, and physical. Material composition, doping, and selection can be used to customize conductivity, optical, thermal, magnetic, and morphological features. In many scientific, technical, and technological domains, scientists and researchers have employed intrinsic nanomaterials with altered and enhanced capabilities. Key industries that are anticipated to gain greatly from nanoparticles' profound impact include medical, IT, transportation, food safety and homeland security (1).

Nanotechnology can be used to manufacture, process, photograph, measure, and apply materials as small as 100 nm. Their small size or nanoscale impact results in a considerable shift in chemical and physical properties including thermal, magnetic, catalytic, unique optical and electrical properties as compared to bulk materials. The mechanical, electrical, chemical, biological, and physical properties of nanomaterials can all be dramatically altered by these extraordinary features. Nanotechnology has provided a wide range of interdisciplinary research, development, innovation, and industrial activity, and it has been rapidly growing in recent years. Economically speaking, the growing integration of nanotechnology into several industrial sectors, including the food industry, should result in a significant increase in the worldwide market for nanomaterials between 2021 and 2027 (2)

Photocatalysis is a process where a semiconductor material (photocatalyst) absorbs light energy to drive chemical reactions, such as pollutant degradation, water splitting, or CO₂ reduction, without being consumed in the process (3). Bismuth phosphate compound (BiPO₄), consisting of phosphate (PO₄³⁻) and bismuth (Bi³⁺). It occurs largely in two crystallographic forms namely, hexagonal and monoclinic monazite type. Its bandgap of 3.8 4.5 eV is wide and thus makes it particularly versatile to UV-powered applications (4). The outstanding chemical stability of the material exhibits resistance to both basic and acidic environments and can be photocorrosion proof, and the bandgap can be designed to the visible spectrum with many different modification approaches. Also, it is relatively eco-friendlier than traditional heavy metal-based materials such as lead containing or cadmium containing ones because of its low toxicity (5).

BiPO₄ has proven to be very effective in treating the environment especially in the elimination of heavy metals and in processing the polluting elements. It, along with g-C₃N₄ forms heterojunctions under visible light, which can degrade up to 95 percent of tetracycline antibiotics by acting as oxidation/reduction sites to produce reactive oxygen species (6). Its ability to reduce antibiotic agents in waste has particularly been outstanding, since it addresses the forbidding issue of development of antibiotic resistance in water sources. Moreover, BiPO₄ has already proved to be useful in remediating heavy metals, specifically, in the decontamination of toxic forms of chromium to non-toxic ones (7).

It is particularly more appropriate to be used in water treatment processes because of

its stability in a wide range of pH values and its ability not to be corrosively photo corrosive. Biomedical industry has applied the photocatalytic properties of BiPO_4 in the antimicrobial applications. The research has also revealed that BiPO_4 nanoparticles may effectively kill the drug-resistant gram-positive and gram-negative bacterial strains when triggered by appropriate light sources (8). BiPO_4 photocatalysis has been under a lot of research regarding environmental applications in the previous years. Studies have further revealed that it is effective in the oxidization of long-lasting organic pollutants, including industrial dyes, and pharmaceutical residues (Patel and Joshi, et al.,2023) (9).

Its ability to reduce antibiotic agents in waste has particularly been outstanding, since it addresses the forbidding issue of development of antibiotic resistance in water sources. Moreover, BiPO_4 has already proved to be useful in remediating heavy metals, specifically, in the decontamination of toxic forms of chromium to non-toxic ones (10). Research in BiPO_4 photocatalysis in recent times has been aimed at enhancing performance and overcoming the shortcomings. As it is shown, the reduction of band gap and improved absorption of visible light can be achieved due to doping with transition metals or non-metallic elements (11)(12)(13).

Material and Method

Co-Precipitation Method: Wet-chemical Co-precipitation One of the most common methods of the synthetic process of homogeneous multi-component materials is the method of co-precipitation, wherein the examples of such materials are given by metal oxides, phosphates and doped nanomaterials. It can especially be used to produce photocatalysts in forms like BiPO_4 , as well as Ag_3PO_4 which work exemplarily around wastewater treatments processes. The approach means that there is combined precipitation of two or more metallic ions in a solution resulting in the generation of controlled composition and shape materials (10).

Stages in the Coprecipitation:

Solution Preparation: In aqueous or organic solvent, metal precursors (e.g. nitrates, or chlorides) solution is prepared. To illustrate, NiCl_2 and $\text{Bi}(\text{NO}_3)_3$ can be mixed to constitute Ni-doped BiPO_4 (14).

Precipitation: Precipitation of metal species is simultaneously caused by adding a base (NaOH , NH_4OH) or precipitating reagent ($6\text{H}_3\text{PO}_4$).

Aging and Washing: The reasons are that it is through continuous shaking of the mixture to facilitate the development of colloidal particles followed by thorough washing to remove the impurities (14).

Calcination and Drying: The precipitates are dried and can be calcinated to add more crystallinity. According to, there have been repeated attempts to manipulate the COVID-19 pandemic via its nomenclature and other aspects (15).

Co-Precipitation Advantages: Among its strengths, it is possible to indicate that this procedure is inexpensive, scalable, and makes it possible to obtain materials with high

purity and homogeneous particle size distribution. It enables to regulate doping, namely such addition of Ni^{2+} into BiPO_4 to enhance photocatalytic activity that could be performed at room temperature to conserve energy(16).

Apply to Environmental Remediation Use: The use of core synthesized materials in photocatalysts is very common in treating dyes and BiPO_4 is particularly effective when supplied with UV (10). During the process, battery materials are also produced such as LiFePO_4 and magnetic nanoparticle applied in biomedical applications (17).

SYNTHESIS OF BiPO_4 (BISMUTH PHOSPHATE) USING CO-PRECIPITATION METHOD: A simple and practicable approach of fabricating the BiPO_4 (bismuth phosphate) is through the co-precipitation technique that has been applied to synthesize such a material which is also antibacterial in nature and is greatly explored since it can be used as a photocatalyst and is adequate as a luminescent material. The outline of synthesis method of BiPO_4 through this method is as follows:

Materials Required

Bismuth source: Bismuth nitrate pentahydrate ($\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$).

Source of phosphorus: Dipotassium Hydrogen phosphate K_2HPO_4 .

Solvent: De-ionized water

Optional nitric acid: (HNO_3 (to balance the pH and prevent hydrolyzing of Bi^{3+}))

Experimental Procedure

Step 1: Precursors Solutions Preparation

Solution of bismuth nitrate:

To prevent hydrolysis, the $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ was dissolved in 100 mL of 1 M HNO_3 . The 0.25 M solution of bismuth nitrate was obtained through the dissolution of 6.06 g of $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ in 100 mL of deionized water. This blend was agitated, and it turned out to be clear.

Phosphate solution:

2.85 g of K_2HPO_4 was dissolved in 100 mL deionized water to form 0.125 M solution. (H_3PO_4 (0.5 mL 85%) dilutions was replaced with water.)

Step 2: Reaction of Co-Precipitation

To solution of $\text{Bi}(\text{NO}_3)_3$, a drop-by-dropper was added to solution of phosphate under a strong agitation (Bi:P molar ratio = 1:1). Immediately at the beginning a white precipitate (BiPO_4) was found. The entire reaction was created by stirring this at a room temperature more than 1-2 hours with magnetic stirrer.

Step 3: Aging / Washing

The suspension was aged at 12-24 h (longer to attain a better crystallinity).

Separation of the precipitate was obtained through the process of centrifugation which was carried out thrice at the speed of 5000rpm over a duration of 5minutes.

Precipitation was washed 3-4 times (with a deionized water each time) after each centrifugation to remove the resin impurities.

Step 4: Drying Calcination

The resultant BiPO_4 was dried in a temperature range of 80-100° C degrees, and a period of 6-12 hours.

Finally, the dried material (BiPO_4) is transferred to a Gooch crucible. After grinding, the prepared nanomaterials are stored as 'appen drops' for further characterization.

Results and Discussion

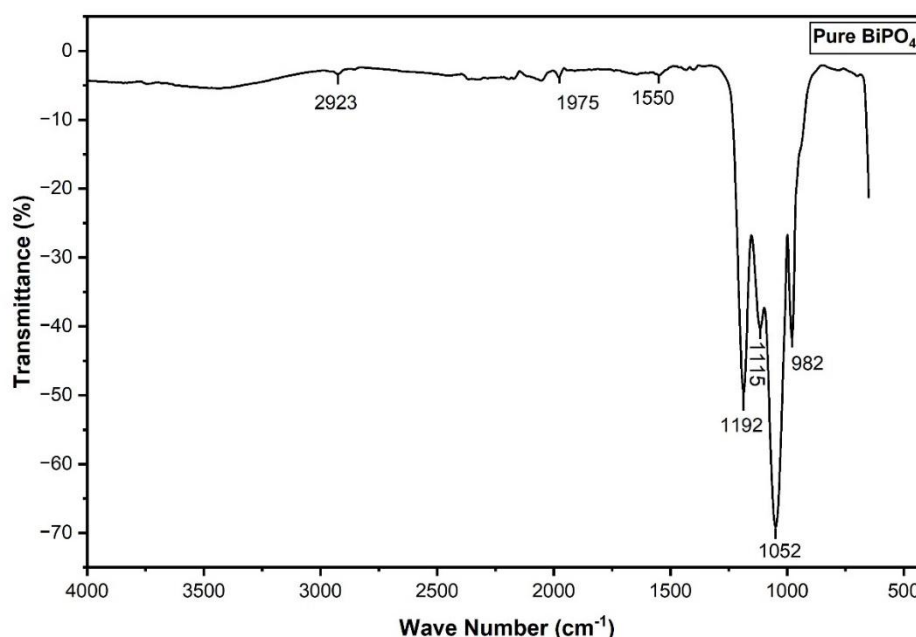


Fig. 1 FTIR spectrum of pure BiPO_4

The FTIR spectrum of pure BiPO_4 shows characteristic vibrational bands which confirm its chemical composition and crystallinity. The most intense band is a strong broad absorption band found at $\sim 1052 \text{ cm}^{-1}$, assigned to the asymmetric stretching vibration (ν_3) of the P-O bonds around the phosphate (PO_4)₃- tetrahedron. This is followed by sharper bands at 1192 cm^{-1} and 982 cm^{-1} , assigned to the symmetric stretching vibrations (ν_1) of the P-O bonds, and the sharpness of which shows a well-crystallized material. Furthermore, the bending vibrations of the O-P-O bonds (ν_4) are predicted in the lower wavenumber region below 650 cm^{-1} . A broad absorption band at $3000\text{-}3500 \text{ cm}^{-1}$ also exists but is not characteristic of BiPO_4 , but a common artifact that arises from O-H stretching vibrations associated with moisture absorbed at the surface of the sample or from the KBr pellet used during measurement. Overall,

the compound was successfully formed as confirmed by the intensive fingerprints of the phosphate anion dominating the spectrum.

Conclusions

The FTIR spectrum proves that pure crystalline BiPO₄ has been successfully synthesized, which is a prerequisite for the application of BiPO₄ as a photocatalyst. The strong bands at about 1052 cm⁻¹ and 982 cm⁻¹ correspond to the dominant P-O stretching vibrations confirming the integrity of the phosphate (PO₄)-tetrahedra. This crystalline order is of utmost importance for ensuring an efficient separation and migration of photogenerated charge carriers (electrons and holes), which will reduce recombination losses. Due to the lack of significant impurities-related peaks, the observed photocatalytic activity in the degradation reactions can be directly ascribed to the intrinsic nature of the BiPO₄ material. Therefore, this spectrum has confirmed the formation of a promising candidate for photocatalytic applications.

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