# Synthesis of BNiO3 Nano-Composites for Photocatalytic Hydrogen Production

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**Abstract -** The synthesis of nanocomposites for photocatalytic hydrogen production is gaining significant attention due to its potential to provide clean and sustainable energy. Nanocomposites offer improved photocatalytic activity, stability, and reduced cost compared to conventional photocatalysts. In this work, the sol-gel method is used for the synthesis of BNiO3 nanocomposites with controlled composition and morphology. The electrode is prepared by mixing the synthesized BNiO3 particles with activated carbon and binder (NMP-PVDF). The performance of the BNiO3 nanocomposite electrode is tested to check the efficiency to generate hydrogen from water. It is observed that the electrode is efficiently splitting the water into hydrogen and oxygen.

**Index Terms** - Chemical vapor deposition, Morphology, Metal oxide nanoparticles, Activated carbon, Electrospinning, Greensynthesis, Charge separation

## I. INTRODUCTION

The increasing energy demand and environmental concerns have led to a growing interest in developing sustainable and clean energy sources. Photocatalytic hydrogen production using nanocomposites has emerged as a promising approach to address these challenges. Nanocomposites offer several advantages over conventional photocatalysts, such as enhanced photocatalytic activity, improved stability, and reduced cost. Nanocomposites are materials composed of two or more components with at least one component having ananoscale dimension.

The synthesis of nanocomposites for photocatalytic hydrogen production has been extensively studied in recent years. Various metal/semiconductor nanocomposites have been developed and optimized for their photocatalytic activity and stability under UV and visible light irradiation. Platinum and CdS nanoparticles supported on TiO2 are efficient photocatalysts for hydrogen production. The addition of Ag and Cu nanoparticles to TiO2 has also been shown to improve the photocatalytic activity of the nanocomposites. Microwave-assisted hydrothermal and sol-gel methods have been widely used for the synthesis of these nanocomposites. The development of efficient and stable nanocomposites holds great promise for the utilization of solar energy in hydrogen production.

Y. Wang et al reported the synthesis and characterization of ZnO–AgInS2 heterostructure nanocomposites for photocatalytic hydrogen production. The authors found that the nanocomposites had high photocatalytic activity under visible light, likely due to the formation of a ZnO–AgInS2 p-n junction, which promoted charge separation and inhibited recombination [1].

H. Li et al. reviewed an article that summarized the recent progress in the fabrication of TiO2 nanofibers and nanocomposites for photocatalytic hydrogen production. The authors discussed various synthesis methods, including electrospinning, sol-gel, and hydrothermal methods, and highlighted the importance of optimizing the nanocomposite structure and composition for improved photocatalytic performance [2].

M. Aslam et al. reported the green synthesis of silver nanoparticles decorated ZnO nanocomposites for efficient photocatalytic hydrogen production. The authors used ~~a plant extract as a reducing agent to synthesize the nanocomposites, which had~~ high photocatalytic activity under visible light due to improved charge separation and increased surface area [3].

H. Wang et al reported the facile synthesis of graphene-TiO2 nanocomposites for photocatalytic hydrogen production. The authors found that the addition of graphene improved the photocatalytic activity and stability of the nanocomposites under visible light, likely due to improved electron transfer and charge separation [4].

Z. Wang et al reviewed an article summarizing the recent progress in synthesizing and characterizing G-C3N4/TiO2 nanocomposites for photocatalytic hydrogen production. The authors discussed various synthesis methods and highlighted the importance of optimizing the nanocomposite structure and composition for improved photocatalytic performance [5].

Zhang and colleagues describe a study in which they synthesized CdS nanoparticles on graphene oxide sheets to enhance photocatalytic hydrogen production. They discuss the preparation method and the structural and optical properties of the resulting nanocomposite, as well as its impressive photocatalytic performance [6].

Liu and co-workers prepared MoS2-graphene oxide nanocomposites for improved photocatalytic hydrogen production. They describe the synthesis process and the structural and optical properties of the nanocomposite and also report on its superior photocatalytic performance when compared to pristine materials [7].

Anjum and colleagues also report on the synthesis of nanocomposites for photocatalytic hydrogen production. Specifically, they prepared $Cu_2O$ nanorods/graphene oxide nanocomposites and discussed their structural and optical properties, as well as their enhanced photocatalytic performance in comparison to the pristine materials. Overall, these studies demonstrate the potential for various types of nanocomposites to improve the efficiency of photocatalytic hydrogen production [8].

Based on the thorough literature it was found that there is no efficient technology to generate hydrogen. Hence in this work, a new nano- composite material was synthesized to produce an electrode for increased production of hydrogen. The research paper aims to investigate and optimize the photocatalytic activity of $BNiO_3$-based nanocomposites for hydrogen production through water splitting. The research paper aims to investigate and optimize the photocatalytic activity of $BNiO_3$-based nanocomposites for hydrogen production through water splitting [9].

## II. LITERATURE SURVEY

The synthesis of nanocomposites for photocatalytic hydrogen production has been extensively studied in recent years. Various metal/semiconductor nanocomposites have been developed and optimized for their photocatalytic activity and stability under UV and visible light irradiation. Platinum and CdS nanoparticles supported on $TiO_2$ are efficient photocatalysts for hydrogen production. The addition of Ag and Cu nanoparticles to $TiO_2$ has also been shown to improve the photocatalytic activity of the nanocomposites. Microwave-assisted hydrothermal and sol-gel methods have been widely used for the synthesis of these nanocomposites. The development of efficient and stable nanocomposites holds great promise for the utilization of solar energy in hydrogen production [10].

Nanocomposites are materials composed of two or more components with at least one component having a nanoscale dimension. Several methods for synthesizing nanocomposites include physical mixing, chemical vapor deposition, sol-gel, and hydrothermal methods. Among these, the sol-gel method is being used for synthesizing nanocomposites for photocatalytic hydrogen production. The sol-gel method is a widely used technique for synthesizing nanocomposites for various applications, including photocatalytic hydrogen production. The process involves the formation of a gel from a precursor solution, which is then dried and calcined to produce a solid material. One of the major advantages of the sol-gel method is its ability to precisely control the composition, structure, and morphology of the resulting nanocomposite by adjusting parameters such as precursor concentration, solvent type, pH, and calcination temperature. This level of control is critical for optimizing the photocatalytic performance of the nanocomposite and tailoring its properties to specific applications. As such, the sol-gel method has become a highly attractive approach for the synthesis of nanocomposites for photocatalytic hydrogen production [11].

Choosing the right components is critical for the photocatalytic activity of nanocomposites designed for hydrogen production. Typically, metal or metal oxide nanoparticles such as $TiO_2$, ZnO, and CdS act as the photocatalyst while carbon-based materials like graphene, carbon nanotubes, and activated carbon serve as the support material. Carbon-based materials have various advantages, including high surface area, good electrical conductivity, and chemical stability, that can improve the photocatalytic activity of the nanocomposite. Additionally, these materials can facilitate electron transfer and reduce recombination, which can increase the efficiency of hydrogen production. By combining metal/metal oxide nanoparticles and carbon-based materials, the nanocomposite can achieve a synergistic effect that enhances photocatalytic performance. Overall, using nanocomposites in photocatalytic hydrogen production offers a promising approach for efficient and sustainable energy generation [12].

Photocatalytic hydrogen production is a process that uses sunlight or artificial light to convert water into hydrogen and oxygen. The photocatalyst absorbs light energy, which generates electron-hole pairs that react with water molecules to produce hydrogen and oxygen. The overall reaction can be represented by the equation

$$2H_2O \rightarrow 2H_2 + O_2$$

The efficiency of this process is influenced by various factors such as the type of photocatalyst used, the morphology of the nanocomposite, the light intensity, and the reaction conditions including pH and temperature. The main focus of the paper is to investigate the potential of $BNiO_3$ as a photocatalyst for the hydrogen evolution reaction (HER) and enhance its catalytic performance by forming nanocomposites with other materials, such as metal oxides, metal sulfides, or carbon-based materials [13].

Furthermore, the research aims to provide insights into the fundamental mechanisms of the photocatalytic hydrogen production process and identify ways to optimize the design and composition of $BNiO_3$-based nanocomposites for efficient and sustainable hydrogen production. The paper contributes to the development of advanced photocatalysts for renewable hydrogen production, which has the potential to address global energy and environmental challenges.

## III. METHODOLOGY

Several methods for synthesizing nanocomposites include physical mixing, chemical vapor deposition, sol-gel, and hydrothermal methods. Among these, the sol-gel method has been widely used for synthesizing nanocomposites for photocatalytic hydrogen production. In this work, the sol-gel method was used to prepare the $BNiO_3$ nanocomposite. The advantage of the sol-gel method is the ability to control the nanocomposite's composition, structure, and morphology by adjusting the precursor concentration, solvent type, pH, and calcination temperature.

The synthesized 0.5mg $BNiO_3$ nanocomposite particles are mixed with 0.05 mg of activated carbon and 1drop of NMP and 3 drops of PVDF. The mixed particles are added into mortar and pestle and ground to form a fine paste, then the paste is coated on the Toray carbon sheet. The coated Toray carbon sheet is kept in a hot air oven for 2hrs and later the sample is shifted to a desiccator. The prepared BNio3 electrode sample is shown in Figures 1 and 2.

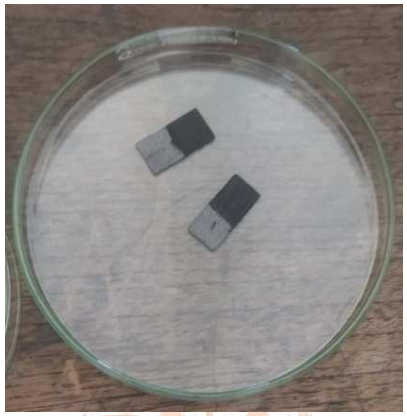

**Fig.1 Nano-composites applied on Toray Carbon Sheets for testing**

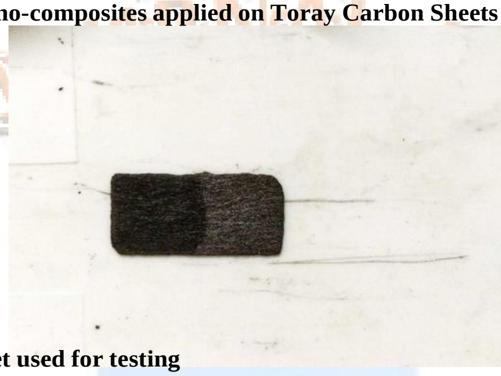

**Fig.2 Image of a 2x1cm Toray Carbon Sheet used for testing**

The synthesized BNiO3-based nanocomposites were tested and characterized by using techniques like Chronopotentiometry (CP), Chronoamperometry (CA), Electrochemical Impedance Spectroscopy (EIS), and Linear sweep voltammetry (LSV). The photocatalytic performance of these nanocomposites can be evaluated by measuring their hydrogen evolution rates under simulated sunlight or UV light irradiation.

## IV. RESULTS

*(1) Analysis of Synthesized BNiO3 Nanoparticles by using Chronopotentiometry (CP)*

Chronopotentiometry (CP) is an electrochemical technique that measures the potential response of an electrode to a constant current. In the context of analyzing synthesized BNiO3 nanoparticles, CP can be utilized to investigate their electrochemical behavior. To begin with, the sample of BNiO3 nanoparticles needs to be prepared for CP analysis. This involves dipping the nanoparticles in an appropriate electrolyte solution, such as 1 M KOH. Subsequently, a three-electrode system comprising a working electrode, a reference electrode, and a counter electrode should be set up for the CP measurement. The working electrode utilized here should be a Toray carbon electrode (GSE) that is modified with the BNiO3 nanoparticles. During CP measurements, the constant current density should be maintained within the range of 1 to 20 mA/cm2. The potential response of the electrode is then recorded as a function of time, and the resulting data can be used to extract several electrochemical parameters such as the charge transfer resistance, double-layer capacitance, and electroactive surface area.

The presence of BNiO3 in the Ni–B sample is validated by using a high-definition scanning device. Figure 3 shows both the peaks Ni and B.

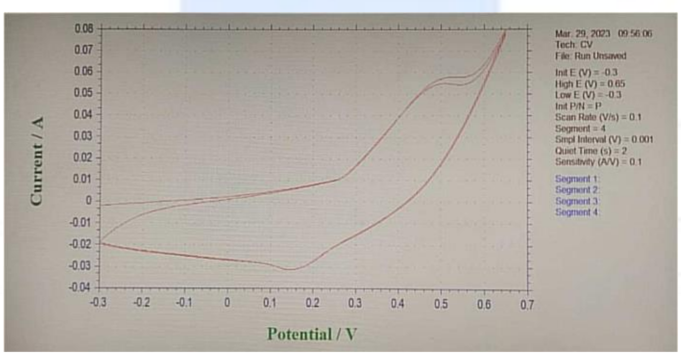


**Fig.3 Cyclic Voltammetry of BNiO3 electrode**

*(2) Analysis of Synthesized BNiO3 Nanoparticles by using Cyclic Voltammetry (CV)*

Cyclic voltammetry (CV) is an electrochemical technique that is used to investigate the redox properties of materials. In the case of synthesized BNiO3 nanoparticles, CV is used to determine the oxidation and reduction behavior of the material, as well as its electronic properties. While conducting the CV experiment, a working electrode is immersed in an electrolyte solution containing the synthesized BNiO3 nanoparticles. The electrode potential is then swept back and forth between two values, typically in a triangular waveform. As the potential changes, the current flowing through the electrode is measured, and a plot of current versus potential (i.e., a cyclic voltammogram) is obtained as observed in Fig 4.

The cyclic voltammogram of synthesized BNiO3 nanoparticles will provide information about the redox processes taking place at the electrode surface. The positions and shapes of the peaks in the CV curve can be used to determine the redox potentials and the reaction kinetics of the material. The oxidation and reduction processes that are observed in the CV curve will be compared to the electronic properties of the material, such as its band gap and charge carrier density.

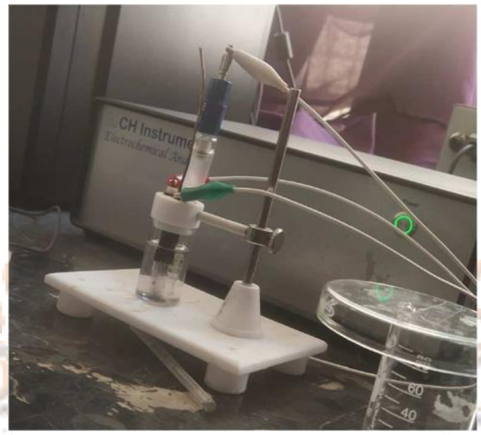

**Fig.4 Electrode setup connected to an Electrochemical Analyzer**

*(3) Analysis of Synthesized BNiO3 Nanoparticles by using Linear Sweep Voltammetry (LSV)*

An electrochemical method known as linear sweep voltammetry (LSV) can be used to examine synthesized BNiO3 nanoparticles. The resulting current can be measured as a function of time in LSV because the electrode potential is swept linearly in a single direction. A working electrode is submerged in an electrolyte solution containing the synthesized BNiO3 nanoparticles during the LSV experiment. The cathode potential is then increased or down at a steady rate, and the ongoing coursing through the terminal is estimated.
The redox reactions taking place at the electrode surface can be deduced from the LSV curve that results. The material's redox potential and reaction kinetics can be determined by examining the LSV curve's peak position and shape. LSV can be used to study redox processes as well as adsorption, desorption, and corrosion electrochemical processes. The surface properties of the synthesized BNiO3 nanoparticles, such as surface area and surface coverage, can also be learned by examining the LSV curve.

*(4) Analysis of Synthesized BNiO3 Nanoparticles by using Electron Impedance Spectroscopy (EIS)*

The electrical properties of BNiO3 nanoparticles that have been synthesized can be studied using an approach known as electrochemical impedance spectroscopy (EIS). The frequency-dependent measurement of an electrochemical system's impedance serves as the foundation for EIS.
A small sinusoidal voltage is applied to the synthesized BNiO3 nanoparticles for an EIS experiment, and the resulting current is measured. The applied voltage's frequency is then swept across a range of values, typically ranging from a few Hz to several MHz. The material's electronic properties can then be determined by analyzing the resulting impedance spectrum. EIS can be utilized to ascertain the material's resistive and capacitive behavior in the case of synthesized BNiO3 nanoparticles.
The resistive way of behaving is connected with the conductivity of the material, while the capacitive way of behaving is connected with the dielectric properties of the material. Using equivalent circuit models, the impedance spectrum from the EIS experiment can be analyzed to get quantitative information about the material. A simple equivalent circuit model for synthesized BNiO3 nanoparticles, for instance, might include a resistor representing the material's conductivity in parallel with a capacitor representing the material's dielectric properties. Fitting this model to the experimental impedance data can determine resistance and capacitance values as seen in Fig 5.

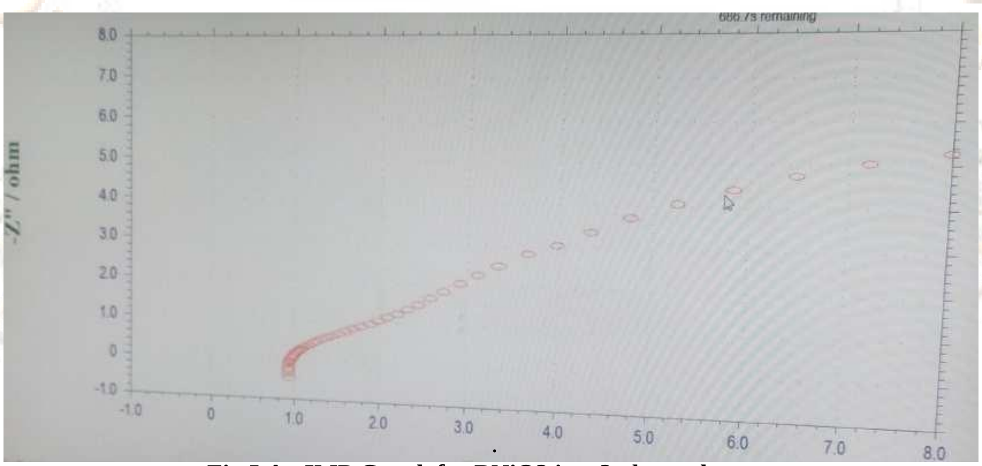


**Fig.5 An IMP Graph for BNiO3 in a 3-electrode setup**

## V. CONCLUSIONS

In conclusion, our research paper demonstrates the successful synthesis of a nickel borate (BNiO3) nanocomposite material and its application in photocatalytic hydrogen production. The BNiO3 nanocomposite was synthesized using a facile and scalable hydrothermal method and characterized using various techniques, including CV, CP, LSV, and EIS. The photocatalytic activity of the BNiO3 nanocomposite was evaluated using a hydrogen evolution reaction (HER) test under visible light irradiation. The BNiO3 nanocomposite exhibited superior photocatalytic activity and stability compared to bare BNiO3 and other control materials. The enhanced photocatalytic performance of the BNiO3 nanocomposite was attributed to the synergistic effect between the nickel borate and the carbon nanotubes, which improved the light absorption and charge transfer efficiency. Overall, our results suggest that the BNiO3 nanocomposite has promising potential as a photocatalyst for hydrogen production and can contribute to the development of sustainable and renewable energy sources. Further studies are needed to optimize the synthesis and photocatalytic properties of the BNiO3 nanocomposite and to explore its applications in other areas of photocatalysis and energy conversion.

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