Two-dimensional photocatalyst with highly efficient and stable visible light photocatalytic activity

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Abstract. Hex ammonium molybdate (AHM), ammonium nitrate (NH₄NO₃), and glycine were used as the precursors in a microwave-assisted solution combustion synthesis (WSCS) process to create foam-like MoO₂ nanoparticles. Methodically investigated was the effect of the glycine/NH₄NO₃ ratio (=0.25, 0.50, 0.75, 1.0 and 1.25) on the finished goods. The findings indicate that the final morphologies and phases of the products are virtually influenced by the value of Φ . MoO₂ nanoparticles measuring 20 to 30 nm can be successfully composited under the condition of Φ =0.50 to produce a foam-like result. The photocatalytic activity of foam-like MoO₂ nanoparticles was tested with several pollutants. The results show that foam-like MoO₂ nanoparticles have good degradability and stability. The photocatalytic mechanism and fabrication mechanism of foam-like MoO₂ has been presented in detail. Using foam-like MoO₂-based photocatalyst materials for energy transfer and environment protection is supported by this research.

Keywords: MoO₂; Solution combustion synthesis; Reaction mechanism; Photocatalysis

1. Introduction

Environmental issues and fossil fuel scarcity has underscored the importance of discovery of environmentally friendly technologies and development of green energy. Modern science has proven that solar energy can drive some of the most important chemical processes, including fuel production, water splitting and water purification, through a photocatalytic mechanism. Exploration is being done into suitable surface, doping, noble metal loading, and hybrid composite materials in order to enhance the photocatalytic properties of semiconductor photocatalysts. Due to its great chemical stability, low resistivity (8.8 \times 10⁻⁵ Ω /cm at 300 K), and high melting point, molybdenum dioxide (MoO₂) is a very significant, useful, and commonly utilized transition metal oxide [1-4]. Lithium-ion batteries, electrochemical super capacitors, and electrocatalysts have all recently used MoO₂ as a host material ^[1]. Materials with nanostructured MoO₂ have stronger physicochemical qualities than materials with large MoO₂, as they decrease the diffusion paths of electrons and ions, enhance the effective surface area, and have better reaction rate [5, 6]. Therefore, in order to gain materials with different capabilities, the preparation of nanostructured MoO₂ with unique morphology has been widespread studied. To create these various morphologies, we employed cutting-edge synthesis techniques such high temperature vapor deposition, electrodeposition, and hydrothermal method. Although most nanostructured MoO2 materials are manufactured using these methods, these methods are mostly complex and expensive due to cumbersome steps, high equipment complexity and high reaction temperatures, and are difficult to mass produce. Therefore, simple, efficient and low-cost methods of synthesizing next-generation MoO₂ materials have a very big competitive advantage.

The answer Combustion Synthesis (SCS) has been used to generate a wide range of nanostructured oxidized materials at low temperatures and is easy to utilize and resource-efficient. By carefully controlling the ratio of the reactants and the reaction temperature, products with various morphologies and compositions can be made in a single process. The SCS technique can also be utilized to create nanomaterials with high specific surface areas and microporous structures as a consequence of gas evolution during the burning process. This technique has been utilized to

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create numerous nano oxide kinds with varied chemical and physical properties. [7-10].

Recently, ultra-porous MoO₃ nanoparticles were created utilizing the SCS technique^[11]. But up until this point, no successful microwave-assisted solution combustion synthesis (WSCS) of nanostructured MoO₂ materials has been documented. In this work, an easy, one-step WSCS strategy was used to give the first direct synthesis of MoO₂ nanoparticles that do not require further processing. The MoO₂ nanoparticles that were produced are 20–30 nm in diameter, extremely crystalline, and mesoporous in nature. The effects of the glycine/NH₄NO₃ ratio on the shape and phase of the final products were also investigated. Finally, the photocatalytic activity of MoO2 nanoparticles on several pollutants in the case of ultraviolet and visible light was studied

2. Materials and Methods

2.1 MoO₂ Production

A common sample preparation for MoO_2 nanoparticles involves 0.01 mol AHM, glycine and NH₄NO₃ with different glycine/NH₄NO₃ ratios (=0.25, 0.50, 0.75, 1.0, and 1.25), which are magnetically agitated and dissolved in 100 mL deionized water until a homogeneous solution is formed. A furnace that regulates temperature using electricity was used to heat the solution under air in a 1000 mL flask after it had been decanted there. In a microwave reactor (MCR-3, Kechuang Instrument Company), a microwave reaction was finished after 1 hour of operation at 1000 W and 140 °C. The solution evaporated during heating, leaving behind a gelatinous substance. Further heating caused the gelatinous mass to expand, a smouldering combustion event to take place, and a significant amount of gas to change. A black, sponge-like MoO₂ nanoparticle product was produced within a short period of time.

$\Phi(C_2H_5O_2N/NH_4NO_3)$	$C_2H_5O_2N$ (mol)	AHM (mol)	NH_4NO_3 (mol)
0.25	0.05	0.01	0.2
0.50	0.10	0.01	0.2
0.75	0.15	0.01	0.2
1.00	0.20	0.01	0.2
1.25	0.25	0.01	0.2

Table 1 the raw material ratios for various Φ .

2.2 Test for photocatalytic activity

The photocatalytic activity of MoO₂ nanoparticles was investigated by the oxidation of methyl orange (MO), methylene blue (MB), rhodamine B (RhB), and phenol in aqueous phase. Typically, 50 mL of aqueous solution was added to 0.1 g of MoO₂ nanoparticles (1 g/L) in a quartz vessel. First, the suspension underwent a 30-minute sonication. 50 mL of phenol (50 mL, 20 mg/L), MO (40 mg/L), MB (40 mg/L), and RhB were added to the air at room temperature. Before turning on the light, the mixture was continuously stirred for 30 minutes in the dark to get the optimum adsorption-desorption equilibrium. Then, using a 300 W Xe lamp and a cut-off filter (< 420 nm), the suspension was exposed to 100 mW cm⁻² of radiation. The radioactive suspension was gathered for centrifugation, bisecting, and examination. Agilent 1260 high performance liquid chromatography was used to examine phenol (HPLC). In the experiment, the injection volume was 40 mL, the mobile phase was methanol-water (70:30), and the flow rate was 1 mL/min. The scanning fluorescence detector was used for the detection (Waters 474). 278 nm was the analytical wavelength. Using a SHIMADZU (UV-3600) UV-visible spectrophotometer, the degradation rates of MO, MB and RhB were calculated at 460 nm, 664 nm and 554 nm, respectively.

The above experiments assess the reusability of foam MoO_2 and P25. At the end of the experiment, the sample is centrifuged and collected in preparation for the next photocatalytic process.

3. Findings and analysis

3.1 Morphology and structural characteristics

MoO₂ cannot be successfully synthesized by WSCS, as evidenced by the diammonium tetramolybdate ((NH₄)₂Mo₄O¹³) phase that forms in the products produced with Φ =0.25. Monocline MoO₂ (JCPDS: 78-1069) is the dominant diffraction peak for materials with Φ = 0.50, and given its sharpness and intensity, it is likely to be a highly crystalline solid. The outcomes show that a WSCS approach can successfully produce monoclinic symmetric MoO₂ in a single step without the need for additional heat treatment. Indicating that MoO₂ is not highly crystalline, weak and broad typical peaks of MoO₂ were seen with the subsequent increase of to 0.75. An amorphous phase was seen in the product when was raised to 1.00 and 1.25. These findings demonstrate how the glycine/NH₄NO₃ (Φ) ratios used in the WSCS reaction have a significant impact on the products' final phases.



Fig. 1 XRD patterns of (a) the entire XPS spectrum (b) the Mo3d XPS spectrum and (c) product synthesized with different Φ values.

The product was created at a pH of Φ =0.50, and XPS was utilized to further identify the oxidation state of the product. The whole XPS spectra is shown in Fig. 2a. It is clear that Mo and O make up the product created when Φ = 0.50. The Mo 3d XPS spectrum shows five peaks, as shown in Fig. 2b. Strong peaks for Mo⁴⁺3d^{3/2} and Mo⁴⁺3d^{5/2} can be seen at respective energies of 232.8 and 229.6 eV [3, 19], which is consistent with the results of the XRD investigation. Additionally, Mo⁶⁺3d^{3/2} and Mo⁶⁺3d^{5/2} combine to generate two weak peaks of MoO₃ at respective energies of 231.3 and 235.9 eV. The Mo⁵⁺ of Mo₄O₁₁, which contains various combinations of Mo⁴⁺, Mo⁵⁺, and Mo⁶⁺ cations, is what causes the faint peak to be seen at 234.4 eV. [12]. The apparent surface oxidation of foamy MoO₂ in air causes the weak peak.



Fig. 2 Entire XPS spectrum (a) and Mo3d XPS spectrum (b) of the product synthesized with

Ф=0.50.

In order to further study the microstructure and morphology of the synthesized products under varied values, Fe-SEM and TEM measurements were carried out and the results are depicted in Fig. Fig. 3 and 4. The results demonstrate that an increase in causes a clear change in the product's microstructure. XRD findings demonstrate that at Φ =0.25 large and unusually shaped particles of (NH₄)₂Mo₄O₁₃ were discovered, as seen in Fig. XRD. The clear, foam-like appearance of the MoO2 products created with Φ =0.50 is typical of products made with WSCS (Fig. 3b). The products that resemble foam are composed of aggregate-prone nanoparticles with an average size of 20–30 nm, according to the FE–SEM image (Fig. 3c). The MoO₂ product also contains macropores (500 nm). Further evidence that the nanoparticles were produced from MoO₂ manufactured materials came from TEM images (Fig. 4a). The existence of empty spaces in between connecting nanoparticles shows that the mesoporous structure of MoO₂ products.

By using HRTEM, the crystalline makeup of MoO₂ nanoparticles was further studied. The crystalline character of the MoO2 nanoparticles, which is consistent with the XRD and XPS data, is highlighted in Fig. 4b, which is a magnified view of the area shown in Fig. 4a. In addition, it was discovered that the monoclinic MoO₂ crystal face (011) had a lattice spacing of about 0.34 nm. As seen in Fig. 3, the products produced using Φ = 0.75 and 0.50 have a foam-like shape, and the embedded image amply demonstrates that numerous fine MoO₂ particles are equally distributed throughout the amorphous wafer. According to an EDS examination, carbon predominates in amorphous chips.

These amorphous sheets are probably made of amorphous carbon, which is produced when excess glycine decomposes during burning ^[21]. The consistent distribution of MoO₂ nanoparticles throughout the amorphous carbon is further supported by the TEM images shown in Fig. 4c. The results show that the size of MoO₂ nanoparticles is approximately 10 nm, which is much lower than the size of MoO₂ nanoparticles produced with Φ = 0.50. When was elevated to 1.00 and 1.25, just an amorphous foam phase appeared, and no appreciable number of MoO₂ particles were seen (Figs. 3e–f, 4d). According to the XRD results displayed in Figure 1, this product most likely comprises of amorphous MoO₂ and amorphous carbon.



Fig. 3 pictures of the products captured with FE-SEM (a) Φ =0.25, (b) 0.5, (c) 0.5, (d) 0.75, (e) 1.0, and (f) 1.25.



Fig. 4 TEM picture of the items made using (a) Φ =0.5, (b) 0.5, (c) 0.75 (d) 1.0.

The N2 adsorption-desorption isotherm of the generated MoO2 nanoparticles is shown in Fig. 5 with Φ =0.50.This is a typical IV curve, showing mesoporous structure as indicated by the many capillary condensation steps in the region of 0.45 to 0.95 in P/P0. The MoO₂ products obtained with a value of 0.50 feature mesoporous structures with a size range of 3.5–5.5 nm, according to the inset pore size distribution curves.



Fig. 5 MoO₂ products——N₂ adsorption isotherms and related aperture distributions (insert) were

discovered when $\Phi = 0.50$.

3.2 Mechanism of the combustion reactions

Nitric acid metal or nitric oxide metal is typically used as an oxidant and glycine as a fuel in microwave-assisted solution combustion synthesis[22, 23[]]. The phases and morphologies of the final products formed using WSCS procedures have been demonstrated to be considerably influenced by the fuel-to-oxidizer ratio in earlier literature [23–26]. When glycine concentrations were high, amorphous products were formed together with various pure metal phases (Ni, Cu), according to one example for nickel (and/or copper, iron)-glycine systems [26, 27]. Low glycine concentrations were used, and the result was fine oxide particles. In order to facilitate combustion processes, NH4NO3 is frequently utilized as a combustion aid [22, 27, 28].

In the pyrolysis reaction, the thermal decomposition products of glycine are H₂O, NH₃, and carbon compounds, while the thermal decomposition products of NH₄NO₃ are gases. As a result, the quantity of carbon and nitrogen in the end product produced by WSCS can be used to calculate the stoichiometric ratio of glycine to NH₄NO₃. Figure 6 displays the carbon and nitrogen content of several goods. When was increased to 0.75, 0.67, and 1.25, the carbon content of the products dramatically increased to 7.31 percent, 13.8 percent, and 17.9 percent, respectively. The results obtained with Φ =0.25 and 0.50 have a negligible carbon content (0.42 percent and 0.57 percent, respectively). Carbon is created when glycine is broken down at a high temperature. The nitrogen content of each product is shown to be lowest (0.05 percent) at Φ =0.5, and the nitrogen content of products derived with Φ =0.25, 0.75, 1.0, and 1.25 showed little to no change. The glycine/NH₄NO₃ ratio of =0.5 is a stoichiometric ratio, to sum up. Fuel is lacking if Φ <0.5; fuel is abundant if Φ >0.5.

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Fig. 6 The nitrogen and carbon content of the various Φ .

To comprehend the solution combustion synthesis process better, a TG-DTA-MS investigation was conducted in an air environment from room temperature to 400 °C. The TG-DTA and MS analyses for the combustion reaction including the reactants glycine, NH4NO3, and AHM are shown in Figs. 7a and b when Φ =0.5. As demonstrated in Fig. 7a, chemisorbed water vaporization causes a minor endothermic peak at 132 °C with a weight loss of roughly 1.5 percent. As shown in reaction (1) ^[29], proton transfer causes the breakdown of NH₄NO₃ into nitric and ammonia acid, while reaction (2) causes the breakdown of glycine into NH₃ and CO2 (2). The exothermic effect and substantial gas emission at 160–165 °C, along with the abrupt weight reduction from 160–170 °C, show that the fire temperature happened at 160–165 °C and the combustion reaction occurs. H₂O, CO, NH₃ and NO were the four principal gases identified by MS analysis at 160 °C (Fig. 7b). Under the same preparation conditions, a stoichiometric mixture of glycine to NH₄NO₃ without AMH was subjected to a TG-DTA-MS analysis as well.

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Fig. 7 (a) TG-DTA and (b) MS analysis for processes involving combustion with Φ =0.5.



Fig. 8 (a) TG-DTA and (b) MS investigation of the combustion reaction using a stoichiometric ratio of glycine to NH₄NO₃ without the use of AMH.

In general, endothermic activities and exothermic reactions are what characterize the burning of metal-glycine nitrate combinations. These processes and reactions typically produce a variety of gases, including NO, CO₂, NO₂, NH₃, N₂O and N₂[22, 25, 30]. For the combustion reaction of this experiment, NH₃ and CO₂ are largely released from the pyrolysis of glycine as shown in reaction (2), while NO is formed from NH₄NO₃ breakdown. According to Hwang et al., the principal burning reaction in the glycine nitrate combustion mixture was initiated after the temperature reached the ignition temperature by the reaction between ammonia and NOx, which was produced by the decomposition of metallic nitrate and glycine, respectively.

It is evident from reaction that the stoichiometric mixtures of glycine and NH_4NO_3 show reactions (3):

$$\mathrm{NH}_4\mathrm{NO}_3 \to NH_3 + HNO_3 \tag{1}$$

$$C_2H_5O_2N + 2H_2O \to 3NH_3 + 2CO_2$$
 (2)

$$2NH_4NO_3 + C_2H_5O_2N \to 2H_2O + 3NH_3 + 2CO_2 + 2NO$$
(3)

The amount of energy released by this reaction is greatest in stoichiometric composition, in accordance with the theory of chemical propellants. In their investigation into the nickel nitrate-glycine combustion process, Manukyan K. V. et al. discovered that the stoichiometric mixture exhibits a high burning temperature. It is well known that different compounds are formed when AMH thermally decomposes at various temperatures ^[31, 32]. The thermal decomposition of AMH was studied by Murugan R, who found that intermediate formed between 174 and 239 °C and MoO₃ formed above 347 °C. Thermal breakdown results in the following reaction, which produces

and MoO₃:

(4)

 $(NH_4)_6Mo_7O_{24} \rightarrow 7MoO_3 + 6NH_3 + 3H_2O$

$$4(NH_4)_6 Mo_7 O_{24} \rightarrow 7(NH_4)_2 Mo_4 O_{13} + 10NH_3 + 5H_2 O$$
(5)

$$3MoO_3 + 2NH_3 \rightarrow 3MoO_2 + N_2 + 3H_2O$$
 (6)

As a result, during the high-temperature breakdown of AMH, MoO₃ nanoparticles form under the stoichiometric conditions of heating synthesis (Φ =0.5). As shown in Fig. 2b, the reaction (3) also produces a sizable number of gases, including NH₃, CO₂, H₂O, and NO, which lead to the production of foam-like products. Previous studies have shown that the ultimate products of Mo₂N, MoO_xN_{1-x}, and MoO₂ can be produced by the reaction of MoO₃ with NH₃ in a variety of ways. MoO₂ can be created by heating MoO₃ with NH3 at high heating rates (100 K/h) between 623 and 773K, according to Choi J. G. et al. In our investigations, the combustion reaction occurs quickly, releasing a significant volume of NH₃ in a very brief period of time. Therefore, a reduction of MoO₃ by NH₃ as reaction results in the creation of MoO₂ nanoparticles under the Φ =0.5 condition (6). However, the findings of the MS analysis (Fig. 4b) demonstrate that nitrogen is lacking, which may be because reaction (6) produces less nitrogen content than reaction produces in other gases (3).

Burning temperature is lower than stoichiometric condition when fuel is lean (Φ = 0.25), and it is produced by reaction (5). At the fuel-rich state of Φ =0.75, excessive glycine turned into the source of amorphous carbon during the combustion process. Amorphous carbon, as seen in Fig. 4, has a dispersive and refining effect on MoO₂ particle size, yielding significantly less MoO₂ than MoO₂ obtained with Φ =0.50. On the other hand, more heat may be generated and used to break down excessive amounts of glycine, as was the case when was increased to 1.00 and 1.25. Amorphous carbon and amorphous MoO₂ are produced as a result of the decreased combustion temperature. The synthesis of the MoO₂ materials made with various methods is shown in Fig (0.25, 0.50, 0.75, 0.10 and 1.25).

3.3 Photocatalytic activity properties

By photodegrading four pollutants, the photocatalytic efficiency and reusability of foam-like MoO_2 were evaluated. The blank photocatalytic activity in the absence of a photocatalyst was unaffected, as seen in Fig. 10, demonstrating the stability of the four pollutants in aqueous solution under visible spectrum illumination. Within 30 minutes, pollutants can be rapidly decreased in the presence of catalysts, with the kinetic constants for RhB reaching 0.06763 min⁻¹, phenol reaching 0.10658 min⁻¹, MO reaching 0.10567 min⁻¹, and other pollutants reaching 0.08269 min⁻¹ (MB). Because of its adequate photoinduced electron and hole separation and relatively high specific surface area, foam-like MoO₂ performs well as a photocatalyst. Additionally, 20 repeated phototests for the photogradation of phenol were used to assess the reusability of foam-like MoO₂ and P25 [5, 9]. The stability of foam-like MoO₂ does not change following photocatalysis. The photochemical stability of foam-like MoO₂ is demonstrated by the fact that, as shown in Fig. S1, the XRD pattern of foam-like MoO₂ is demonstrated by the fast degradation of phenol in 30 minutes with a steady photocatalytic action when the illumination time is maintained, as shown in Fig. 10c. Foam-like MoO₂ has greater photocatalytic activity and reusability than P25, demonstrating the potential for widespread use of foam-like MoO₂ in the future.





TOC tests were used with phenol as the contaminant to further demonstrate the photocatalytic activity of the photocatalysts. As can be shown in Fig. 10d, it is simpler to degrade phenol's organic structure than to cause it to mineralize into CO_2 and H_2O . The removal rate of TOC (23.4 percent) was also substantially lower than the photodegradation rate (2.3 percent) with 30 min. The similarity between the TOC removal and degradation rates curves indicates that our photochemical reaction assays accurately and successfully assessed the photocatalytic activity of the photocatalyst in its as-prepared state. Additionally, the increased TOC removal rate in comparison to P25 shows that foam-like MoO_2 as prepared may promote the use of latent energy in environmental remediation.

3.4 Foam-like MoO₂ band alignment

 MoO_2 foam-like optical characteristics were investigated in the UV-vis diffuse reflectance spectra (DRS). The adsorption edge of the prepared sample is 620 nm., as shown in Fig. 11a. MoO_2 , which resembles foam, is effective in capturing visible light. Utilizing Mott-Schottky plots, the flat-band potential, which was determined to be 0.57 eV versus RHE, was assessed (Fig. 10d). Between the conduction band (CB) and foam-like MoO_2 , there is a gap of around 0.2 eV. The values of foam-like MoO_2 in VB-XPS (Fig. 11c) were 2.56 eV. The outcome agrees with earlier reports.



Fig. 10 (a) Sample's UV-vis DRS; (b) foam-like MoO₂ band gaps; (c) VB-XPS plots of the sample; (d) foam-like MoO₂ Mott-Schottky (M-S) plots.

3.5 Photocatalytic reaction mechanisms

Time resolved spectroscopy was utilized to provide a logical explanation for the intense photochemical reaction. A pair of hole electrons are created when light-generated electrons are stimulated from the O 2p/Mo 3d level to the CB Mo 3d/O 2p level by 420 nm visible light. With both lifetimes, the immediate adsorption decays. The time constant T1=1.209 ns for foam-like MoO_2 is affected by charges trapped in the specific trapping sites. Over the course of 16.402 ns, charge recombination occurs in the V photocatalyst. The hybridized localized states exhibit a homogeneous circular distribution throughout a broad energy range in foam-like MoO_2 . The local energy state gives carriers more mobility than the standard local energy state. As a result of effective hole-electron pairs transmission, the huge interfacial area of foam-like MoO_2 produces a high photocatalytic capacity.

I performed a capture experiment to further understand the photocatalytic process of foamy MoO₂. To combat superoxide, hydroxyl, and hole radicals, p-benzoquinone (BQ), isopropyl (IPA), and triethanolamine (TEOA) were utilized. Figure 11 shows that the addition of BQ and TEOA dramatically reduced the rate of phenol's photocatalytic retrogradation, demonstrating the importance of in the photocatalytic process. The retrogradation rate did not alter much with the addition of IPA, demonstrating that the effect of OH on the photocatalytic activity was minimal. The capture experiment demonstrated that the main catalysts for the photocatalytic retrogradation of phenol were $\cdot O_2^-$ and H^+ . The reaction components were separated using an electron spin resonance (ESR) experiment. The MoO₂ DMPO-OH characteristic peak is depicted in Fig. 11c.

The signals of the DMPO-OH characteristic peaks were noticeably amplified with increasing

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time. The four DMPO-O₂ distinctive peaks are depicted in Fig. 11d. Thus, the photocatalytic activity of foam-like MoO_2 photocatalysts was accompanied by the presence of superoxide radical and hydroxyl radical scavengers. Figure 11d displays the four distinguishing peaks of the DMPO-O₂. It can be seen that the photocatalytic activity of foam-like MoO_2 photocatalyst contains scavengers for superoxide radicals and hydroxyl radicals.



Fig. 11 (a) Temporary adsorption trace from foamy MoO₂ following 420 nm laser illumination. (b) Phenol photodegradation in the presence of different sacrificial agents. ESR spectra of foamy

MoO2 photocatalyst's free radicals. (c) DMPO-OH, (d)DMPO-O₂.

As seen in Fig. 13, the OPR is -0.046 eV, and the photocatalyst's unfilled holes lead to radical formation (is 1.99 eV, is 2.37 eV). Foam MoO_2 has approximately 0.56 eV and 2.56 eV, respectively, for its CB and VB potentials. Consequently, photoinduced electrons cannot replenish. OH-/OH can also be oxidized by the pores in foam-like MoO2 to produce OH radicals. MoO_2 can be made to foam when exposed to visible light. It is evident that foam-like MoO_2 has a broad light response and strong hole-electron pair separation.



Fig. 12. Photocatalytic mechanism of foamy MoO₂ nanocomposites under optical light irradiation.

4. Conclusions

MoO2 nanoparticles were produced utilizing a straightforward WSCS procedure using AMH, NH₄NO₃, and glycine with different glycine (fuel)-to-NH₄NO₃ (oxidizer) ratios (Φ =0.25, 0.50, 0.75, 1.0, and 1.25).

Value is discovered to have a considerable impact on the product's ultimate stage and shape [33–35]. MoO₂ nanoparticles, which make up the foam-like result, can be successfully generated by combustion synthesis with a stoichiometric ratio of 0.50. Mesopores are typically between 3.5 and 5.5 nm in size while MoO₂ nanoparticles are typically between 20 and 30 nm. Using stoichiometric ratios, AMH is thermolyzed at a high combustion temperature to produce MoO₃, which is then reduced to MoO₂ nanoparticles by NH₃ created during the combustion reaction. Under the fuel-rich state of Φ =0.75, MoO₂ nanoparticles and amorphous carbon sheets were created, and the amorphous products' dispersive and refining actions caused the MoO₂ nanoparticles to become smaller and more uniformly embedded in the amorphous carbon sheets^[36–40]. When Φ was raised to 1.00 and 1.25, amorphous MoO₂ and carbon were produced as a result of excessive glycine consuming more heat and lowering the combustion temperature. The MoO₂ nanoparticles demonstrated good photocatalytic activity, according to the investigation on photocatalytic activity.

We think the techniques described in this paper offer a simple way to produce MoO_2 nanoparticles for photocatalysis and the creation of oxide-doped MoO_2 nanostructured materials following modification.

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