

Progress of g-C₃N₄ Material Modification and Its Photocatalytic Research

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Abstract: The g-C₃N₄ materials are widely used in the photocatalytic field because of the advantages such as good stability, but they also have defects such as small specific surface area and fast electron-hole pair complexation rate that limit their applications, so it is necessary to modify the g-C₃N₄ materials. In this paper, we study the modification methods of g-C₃N₄ materials and their applications in the fields of photocatalytic hydrogen production, pollutant degradation, and carbon dioxide reduction, and analyze the modification methods as well as the application progress and development prospects of the materials based on the existing literature. The results show that g-C₃N₄ can be modified with the help of doping, morphology modification and construction of heterojunction, and the modified g-materials can be better utilized in photocatalytic applications. g-C₃N₄ materials are facing challenges in preparation, applications and theoretical innovations, and the future can be focused on improving the preparation and modification methods of g-C₃N₄ and applying g-C₃N₄ materials in other fields such as electrochemistry.

Keywords: g-C₃N₄, Modification, Photocatalysis, Application, Semiconductor Material

1. Introduction

As global science and technology progress alongside the economic capabilities of nations, the issues of carbon emissions and associated environmental damage are intensifying. Projected man-made carbon dioxide emissions are expected to attain 41.6 billion tons in 2024, with 90 percent originating from fossil fuels. Consequently, the pursuit of new and cleaner energy sources has become a significant trend. Additionally, the exploitation of the environment is correlated with environmental pollution, necessitating effective strategies to address pollutants [1-2]. At present, the use of catalytic technology is becoming more and more mature. Among them, the semiconductor photocatalytic technology has enormous application potential for solving energy and environmental problems due to its full conversion of solar energy, green environmental protection, and high catalytic efficiency. Among the semiconductor photocatalytic materials, g-C₃N₄ has the advantages of good physicochemical stability, good visible light response, and simple preparation method, etc. However, g-C₃N₄ materials also have defects such as small specific surface area and high photogenerated carrier complexation rate, which limit their applications in photocatalysis [3]. To address material flaws, techniques such as metal/non-metal doping, morphological manipulation, and heterojunction fabrication are employed to enhance photocatalytic performance [4].

This paper focuses on the technological achievements in the modification of $g\text{-C}_3\text{N}_4$ materials and their research progress in the fields of photocatalytic hydrogen production, pollutant degradation, and carbon dioxide reduction. Based on the analysis of the existing literature, the material modification methods and the photocatalytic applications of the materials as well as the future development directions are reviewed. This study provides feasible theoretical references for more in-depth structural and performance optimization of $g\text{-C}_3\text{N}_4$ materials, and helps to clarify the development direction of $g\text{-C}_3\text{N}_4$ materials.

2. Modification methods for $g\text{-C}_3\text{N}_4$ materials

A $g\text{-C}_3\text{N}_4$ material is an n-type polymer semiconductor material consisting of a stack of $g\text{-C}_3\text{N}_4$ lamellae containing the basic structure of triazines or tri-s-triazines (Figure 1), which are mainly composed of carbon and nitrogen elements. The p_z orbital lone pair electron interactions provided by the C, N atoms in the material can form an aromatic conjugated system and are highly delocalized, which gives the $g\text{-C}_3\text{N}_4$ material photocatalytic properties as well as good heat, acid and alkali resistance properties, while the p_z orbitals of the C, N atoms are also the component warps of the conduction and valence bands of the $g\text{-C}_3\text{N}_4$ material. The positions of the conduction and valence bands of the $g\text{-C}_3\text{N}_4$ materials were determined to be -1.3 eV and 1.4 eV, respectively, which indicates that the C and N atoms are the active sites for redox reactions of thematerials[5].

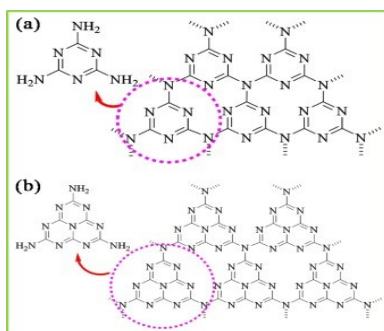


Figure 1: Structure of $g\text{-C}_3\text{N}_4$, (a) Triazine structure, (b) Tri-s-triazine structure [6]

However, the stacked structure of the $g\text{-C}_3\text{N}_4$ material leads to a smaller specific surface area of the material and therefore a smaller reaction contact area for photocatalysis, which is not conducive to the photocatalytic reaction, and the light-absorbing edge of this material is close to 450 nm, while the visible region is 400-700 nm, which indicates that the material is inefficient in the utilization of visiblelight[7]. In addition, the photogenerated electrons and holes involved in the photocatalytic reaction in the $g\text{-C}_3\text{N}_4$ material are compounded by the Coulomb force, which creates an obstacle for them to jump to the surface of the material and participate in the redox reaction[8].

Aiming at the advantages and defects of $g\text{-C}_3\text{N}_4$ materials mentioned above, the modification of materials mainly focuses on the direction of enhancing light trapping performance, improving the utilization of light energy, increasing the active sites of the material's photoresponsive reaction, and inhibiting electron-hole complexation. The primary modification methods currently encompass elemental doping, morphological alteration, and building [2].

2.1. Elemental admixture

Elemental doping, i.e., the introduction of foreign elemental atoms into the crystal structure of $g\text{-C}_3\text{N}_4$, which replaces in-situ atoms in the crystal structure or enter into structural gaps. The objectives of this method include: modulating the energy band structure of the $g\text{-C}_3\text{N}_4$ material so

that it can absorb visible light in a larger wavelength range and improve the utilization of visible light; affecting the electronic structure by introducing crystal structure defects or forming hybridized orbitals with carbon and nitrogen atoms to promote the separation of photogenerated electron-hole pairs and to prolong the carrier presence time [9-10].

2.1.1. Metal element doping

Metal element doping includes alkali metal doping, transition metal doping and precious metal doping [10]. Zhu Lin et al. found that alkali metal doping not only changes the energy band positions of $g\text{-C}_3\text{N}_4$ and enhances the redox ability of the material, but also doped alkali metals indirectly promote the separation of photogenerated carriers by affecting the charge distribution of other atoms [11]. For transition metal doping, on the one hand, the transition metal atoms can capture the photogenerated carriers and inhibit the electron-hole complex, and on the other hand, the d-orbital electrons of the transition metal atoms can regulate the forbidden bandwidth of the material by their leaps in the $g\text{-C}_3\text{N}_4$ crystal structure, which leads to the accelerated separation of photogenerated carriers. Noble metal nanoparticles exhibit surface plasmon resonance and surface equipartition exciton effects, enhancing the visible light responsiveness of noble metal nanoparticle-doped photocatalytic materials and facilitating the generation of photogenerated electrons [12-13]. Qiusi Li et al. prepared three doped $g\text{-C}_3\text{N}_4$ materials $x\text{-Na}^+/\text{g-C}_3\text{N}_4$ ($x=2, 4, 6$, representing the reaction time/h) classified according to the reaction time of the preparation process using the solution method, and then characterized and tested the materials and mixed methylene blue and $g\text{-C}_3\text{N}_4$, $x\text{-Na}^+/\text{g-C}_3\text{N}_4$ to investigate the effect of the Na^+ doping on the $g\text{-C}_3\text{N}_4$ structure and the photocatalytic methylene blue degradation reaction [14]. The characterization results show that Na^+ doping decreases the (002) crystal plane spacing of the $g\text{-C}_3\text{N}_4$ structure from 0.325 nm to 0.322 nm, and the π -conjugated system in the $g\text{-C}_3\text{N}_4$ structure has an increased out-of-domain range, which facilitates the migration of photogenerated carriers. Meanwhile, the charge density around Na^+ is larger, which provides sites for the physical adsorption of the material and facilitates the photocatalytic reaction to proceed. Among all the experimental materials, $4\text{-Na}^+/\text{g-C}_3\text{N}_4$ showed the best degradation of methylene blue, with a maximum degradation efficiency of 96.40%, which was nearly 1.5 times higher compared to the ordinary $g\text{-C}_3\text{N}_4$ materials. Mao Airong et al. mixed the $g\text{-C}_3\text{N}_4$ produced by high temperature roasting with iron sulfate and grinded and roasted it to obtain Fe-doped $g\text{-C}_3\text{N}_4$ powders with different compositional mass ratios. The resultant materials were evaluated utilizing X-ray diffractometry (XRD), field emission scanning electron microscopy (SEM), and additional instruments, and were employed in research on the photocatalytic-Fenton degradation of rhodamine B [15]. The results showed that Fe has the potential to degrade methylene blue in a variety of ways. In principle, Fe has good electrical conductivity, which can transport electrons on the conduction band in time and inhibit the complexation of photogenerated carriers, which can improve the photocatalytic performance of $g\text{-C}_3\text{N}_4$. From the experimental results, Fe doping destroys the crystal structure of $g\text{-C}_3\text{N}_4$ and increases the specific surface area of $g\text{-C}_3\text{N}_4$. Small mass ratio of Fe doping significantly increased the degradation rate of rhodamine B. The degradation rate of rhodamine B by 1% mass ratio of Fe-doped material was 63.1%, and the corresponding reaction rate constant was 4.5 times higher than that of the ordinary $g\text{-C}_3\text{N}_4$ material, which was the largest among all experimental materials.

2.1.2. Doping with non-metallic elements

Commonly used elements for non-metallic element doping include oxygen, sulfur, phosphorus, and boron. Doped non-metallic atoms can serve as novel active sites, alter the local charge density of the material, facilitate electron migration, introduce impurity energy levels, regulate the energy band

structure, and enhance the separation of photogenerated carriers by disrupting the g-material[2, 16, 17]. Bi Xiang et al. prepared ordinary g-C₃N₄ materials and P-doped g-C₃N₄ materials p_i - g - C₃N₄ (i=1,2,3,4 corresponding to pyrophosphoric acid, orthophosphoric acid, phosphite, hypophosphite and urea, respectively) with different phosphorus sources by thermal polycondensation and liquid-phase evaporation, and then characterized and tested the resulting materials[18]. The results of the specific surface area analyzer (BET) showed that the P doping leads to more pores in g-C₃N₄ materials, The specific surface area of the common g-C₃N₄ material is 96.19 m²/g, The specific surface area of p₂ - g - C₃N₄ is the largest of all the materials with 177.51 m²/g, This is directly supported by field emission scanning electron microscopy (SEM) and transmission electron microscopy (TEM) observations (Fig. 2, Fig. 3). Fourier transform infrared spectroscopy (FT-IR) results indicate that P doping introduces cyano to the surface of g-C₃N₄. X-ray photoelectron spectroscopy (XPS) results indicate the presence of N defects and N-P covalent bonds in P-doped g-C₃N₄, the latter representing the introduction of P impurity energy levels. Among all the XPS spectra, the peak of O 1s spectrum appeared at 532.2 eV and there was a blue shift in the spectrum of the P-doped material relative to that of the normal g-C₃N₄ (Fig. 4), indicating the presence of hydroxyl groups or adsorbed water, and the P-doped material could adsorb more oxygen species, which was attributed to the introduction of N defects bringing more adsorptive active sites for the g-C₃N₄, and the strong polar cyano group and the P-impurity energy level modulated the surface electronic distribution of the g-C₃N₄, which made it easy to bond with the oxygen species. The UV-Vis diffuse reflectance (DRS) absorption spectra showed that the light absorption range of P-doped g-C₃N₄ was broadened. Electrochemical ac impedance spectroscopy (EIS) shows that P doping enhances the charge transfer rate in the g-C₃N₄ structure. In the experiment of photocatalytic degradation of Cr(VI)-containing wastewater, the catalytic degradation rate of the p₂ - g - C₃N₄ group reached 65.8% in 2h, which was 12.65 times higher than that of ordinary g-C₃N₄.

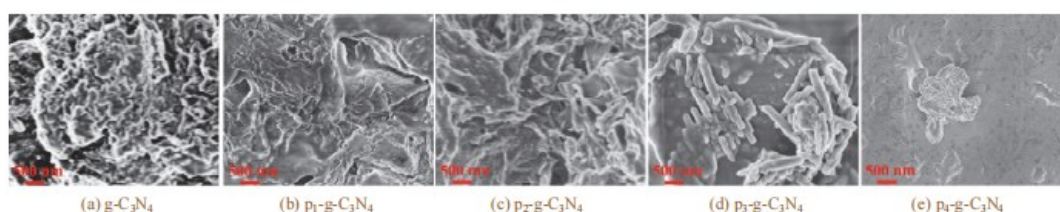


Figure 2: SEM images of g-C₃N₄ before and after doping by P[18]

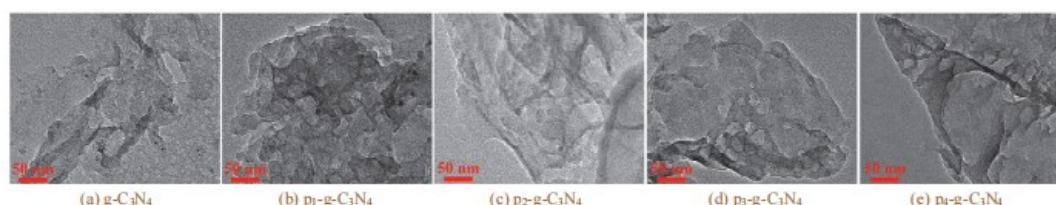


Figure 3: TEM images of g-c before and after doping by P[18]

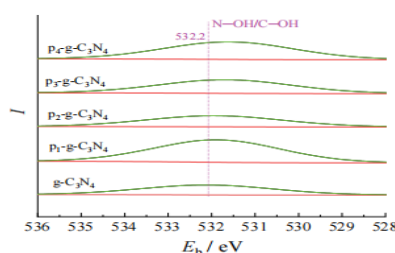


Figure 4: Fine O 1s spectra of g-c before and after P-doping[18]

2.2. Topography control

Reasonable morphology design of g-C₃N₄ can allow the material to have a larger specific surface area and more abundant active sites, which is favorable for the utilization of visible light absorption and separation of photogenerated carriers in the material. The g-C₃N₄ with different morphologies can be categorized into four types: zero-dimensional g-C₃N₄ (g-C₃N₄ quantum dots), one-dimensional g-C₃N₄ (g-C₃N₄ nanorods, micro nanotubes, etc.), two-dimensional g-C₃N₄ (g-C₃N₄ nanosheets), and three-dimensional g-C₃N₄ [19]. Different B-modified g-C₃N₄ materials x-B-HCN (x is the mass ratio of B₂O₃ and melamine) were prepared by hydrothermal and roasting steps using substances such as B₂O₃ and melamine as raw materials, followed by characterization tests by He Xingshi et. Field emission scanning electron microscopy (SEM) results showed (Fig. 5) that the interior of 0.1-B-HCN has a compact porous mesh structure and nanopores, and 0.15-B-HCN, 0.20-B-HCN, 0.25-B-HCN all have hollow tubular structures, which contribute to the increase of the specific surface area of the material and enhance the absorption of light [20]. Electrochemical ac impedance spectroscopy (EIS) showed that B doping promotes the transport of photogenerated electrons in the materials. In the photocatalytic reduction of CO₂ experiments, 0.20-B-HCN had the best photocatalytic performance, and the rate of CO generation reached 6.88 μmol/(g·h) for this group, the rate of CO production for the reaction involving g-C₃N₄ undoped with B was 1.24 μmol/(g·h), the former being 5.54 times higher than the latter. In the cyclic catalytic tests involving the 0.20-B-HCN group, the 0.20-B-HCN maintained its original structure after three cycles. Furthermore, the CO generation rate during the third cyclic reaction was 6.53 μmol/(g·h) representing 95% of the rate observed in the initial reaction of this group. These results indicate that 0.20-B-HCN exhibits excellent structural and reaction stability.

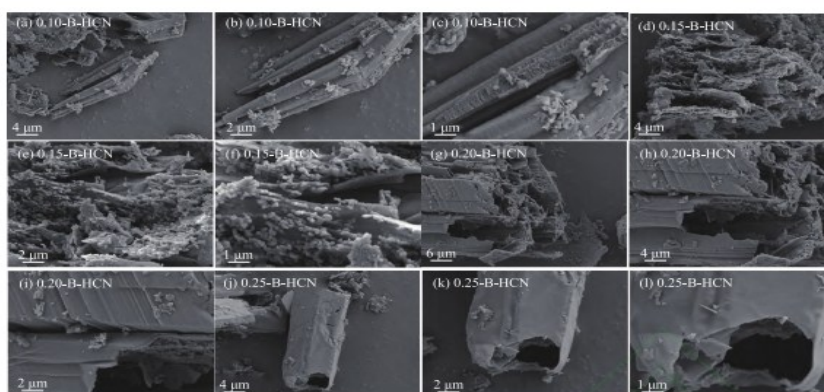


Figure 5: SEM image of x-B-HCN [20]

2.3. Construct heterojunctions

As a matter of fact, the photogenerated electrons and holes after the light excitation of $g\text{-C}_3\text{N}_4$ cannot be completely separated due to the electrostatic gravitational force between them, and the complete separation of photogenerated carriers needs to be realized by means of an external electric field to break away from the constraints of electrostatic interactions, and one of the most important ways to solve this problem is to construct heterojunctions. When two semiconductor materials with dissimilar compositions come into contact, an interchange of electrons and holes transpires at the interface owing to the disparity in carrier concentration between the materials, ultimately resulting in the formation of a space charge area at the interface. The method of constructing heterojunction is to realize the efficient separation of photogenerated carriers with the help of the electric field in the space charge region, thus improving the photocatalytic performance of the material. Maona prepared the photocatalyst $\text{Ag}/\text{NiO}/g\text{-C}_3\text{N}_4$ from melamine, $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ and AgNO_3 , and characterized it and experimented with photocatalytic degradation of hygromycin [21]. Optical analysis shows that the construction of the heterojunction extends the range of light absorption of the material. Time-resolved fluorescence spectroscopy (TRPL) shows that the transient decay of $\text{Ag}/\text{NiO}/g\text{-C}_3\text{N}_4$ is faster than that of $g\text{-C}_3\text{N}_4$. Meanwhile, the average transient fluorescence lifetimes of $\text{Ag}/\text{NiO}/g\text{-C}_3\text{N}_4$ and $g\text{-C}_3\text{N}_4$ are calculated to be 5.08 ns and 6.61 ns, respectively, which suggests that the materials have a lower probability of photo-induced electronic deactivation, which is conducive to the migratory separation of photogenerated carriers. Carrie Lei et al. prepared ZnO nanofibers and composite $\text{ZnO}/g\text{-C}_3\text{N}_4$ successively using electrostatic spinning and self-assembly techniques, and the migration of photogenerated electrons from ZnO to $g\text{-C}_3\text{N}_4$ occurred in this material in the presence of light, which proved the successful construction of $\text{ZnO}/g\text{-C}_3\text{N}_4$ heterojunction [22]. The results of photoluminescence spectroscopy (PL) and time-resolved fluorescence spectroscopy (TRPL) of the material showed that compared with the unmodified $g\text{-C}_3\text{N}_4$, the photogenerated carriers in $\text{ZnO}/g\text{-C}_3\text{N}_4$ had a slower rate of complexation and higher separation efficiency, and the charge transfer efficiency was higher, which was more favorable for the photocatalytic reaction.

3. Application of $g\text{-C}_3\text{N}_4$ materials in photocatalysis

3.1. Photocatalytic hydrogen production

Hydrogen production from photolyzed water is seen as a powerful means of solving the energy crisis. Sui Bingrong et al. prepared Cu-modified $g\text{-C}_3\text{N}_4$ materials using molecular self-assembly reaction and high-temperature thermal polymerization reaction, and the characterization results showed that the Cu-doped materials polymerized into tubular structure during high-temperature synthesis, which had a larger specific surface area and extended the range of the materials' light absorption. In the experiment of photocatalytic hydrogen production, the hydrogen production rate of ordinary $g\text{-C}_3\text{N}_4$ material was $6.3 \mu\text{mol/h}$ [23]. Among all the fabricated Cu-doped $g\text{-C}_3\text{N}_4$, the highest hydrogen production rate reached $71 \mu\text{mol/h}$, which was 11.0 times higher than that of ordinary $g\text{-C}_3\text{N}_4$. Zhengnan Lin et al. prepared S-doped tubular $g\text{-C}_3\text{N}_4$ /layered ZnIn_2S_4 heterojunction photocatalytic materials by supramolecular self-assembly and hydrothermal reaction method, and the characterization results showed that the materials have tubular structure and large effective adsorption volume, which contribute to the absorption and utilization of visible light and adsorption activation of water molecules, and the ordinary $g\text{-C}_3\text{N}_4$ hardly produces hydrogen in hydrogen production experiments, but the best catalytic effect was achieved with the mass ratio of S-doped tubular $g\text{-C}_3\text{N}_4$ to ZnIn_2S_4 of 1:10 [24]. The best catalytic effect of $1.64 \text{ mmol}/(\text{g} \cdot \text{h})$ was achieved for the prepared product.

3.2. Photocatalytic degradation of pollutants

Photocatalytic degradation of pollutants has received widespread attention as a green and efficient decontamination technology. Bei Huang et al. prepared Cl- and C-atom doped g-C₃N₄ materials by high-temperature calcination, which were labeled as Cl-CN and C-CN, respectively, in which the specific surface area and pore volume of Cl-CN were larger than those of ordinary g-C₃N₄ [25]. For the ozone degradation of iopanolol, the apparent rate constants of the reaction were improved by 67.63%, 50.08%, and 90%, respectively, with the addition of Cl-CN, and C-CN to the ozone system, and the degradation rates were good. and the degradation rates all reached more than 90% with good catalytic effect. Xu Li et al. prepared hydrated NaNbO₃ by hydrothermal method using Nb₂O₅ and NaOH, subsequently, it was mixed and milled with melamine and sintered to obtain the g-C₃N₄/NaNbO₃ composite catalyst [26]. The absorption edge of the composite material is 512 nm, and the absorption of sunlight in the range of 400~510 nm is significantly enhanced compared with that of the ordinary NaNbO₃ material, and in the degradation experiments of rhodamine B, the degradation rates of the g-C₃N₄, NaNbO₃, and g-C₃N₄/NaNbO₃ groups after 90 min of reaction are 71%, 19%, and 84%, respectively, the corresponding values of rate constants are $14.6 \times 10^{-3}/\text{min}$, $2.6 \times 10^{-3}/\text{min}$ and $21.3 \times 10^{-3}/\text{min}$ respectively. Because g-C₃N₄ broadens the visible light absorption range and the g-C₃N₄/NaNbO₃ heterojunction enhances the separation and migration of photogenerated carriers, the g-C₃N₄/NaNbO₃ composites outperform g-C₃N₄ and NaNbO₃.

3.3. Photocatalytic reduction of carbon dioxide

Photocatalytic reduction of carbon dioxide technology is expected to be used to mitigate the greenhouse effect caused by large-scale greenhouse gases due to its great application potential. Liao Haohong et al. synthesized the K-OMS-2/g-C₃N₄ material (KM-CN) using a hydrothermal method and subsequently characterized the material and tested its properties by photocatalytic reduction of CO₂ experiments [27]. Inductively coupled plasma emission spectroscopy (ICP-OES) tests showed that the K: Mn mass ratios of the KM-CN material and K-OMS-2 were 0.112 and 0.075, respectively, which indicated that more potassium ions into the pores of KM-CN led to the elevation of low-valent manganese, and that more low-valent manganese was favorable for the CO₂ adsorption reduction process. According to the results of UV-vis DRS, valence band-X-ray photoelectron spectroscopy (VB-XPS) and Mott-Schottky curves, the bandgap energies of K-OMS-2 and g-C₃N₄ were calculated to be 1.35 eV and 2.87 eV, respectively, and the valence band potentials relative to the reversible hydrogen electrode were 0.76 V and 2.39 V, while the conduction band potentials were both -0.59 V. The Mn 2p spectrum results from X-ray photoelectron spectroscopy (XPS) indicate an electron loss from Mn in the composites to high-valence manganese ions.

From the above results, it can be seen that the valence band potentials of K-OMS-2 and g-C₃N₄ are quite different, and the valence band potential of K-OMS-2 is smaller than that of H₂O/O₂, which is not easy to oxidize. Combined with the loss of electrons of Mn in K-OMS-2, it can be deduced that there exists a built-in electric field and a tendency to form a Z-type heterojunction between K-OMS-2 and g-C₃N₄. The heterojunction and the presence of low-valence-high-valence Mn electric pairs favor the separation of photogenerated carriers and the reduction process of CO₂ on K-OMS-2. For the photocatalytic reduction of CO₂ experiments, KM-CN-mix, a mixed abrasive material of K-OMS-2 and g-mix, was additionally prepared according to the Mn and g-C₃N₄ mass ratio of 1:1, and the experimental results are shown in Fig. 6, where the KM-CN system is obviously superior to the other groups, which corroborates the formation of a heterojunction system rather than a simple mixing of KM-CN, and also demonstrates the good photocatalytic reduction ability of KM-CN in the photocatalytic reduction of CO₂.

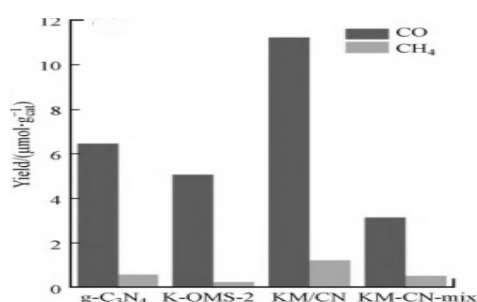


Figure 6: Experimental results of photocatalytic reduction of KM-CN and other materials[27]

4. Recent research progress and future trends

4.1. Current challenges

g-C₃N₄ materials, as more mature and abundant photocatalytic materials, still face development challenges:

(1) Among the prevalent preparation methods, certain techniques encounter issues of elevated energy consumption, such as thermal polymerization; others are facile to execute yet yield low productivity, like the stripping method; and some introduce environmentally detrimental substances during the preparation process, such as hard templates [2, 5].

(2) At present, the application scope of g-C₃N₄ is narrow, and most of the applications are still confined to the photocatalytic field, with relatively little involvement in other fields such as flexible electronics.

(3) Currently, there are fewer innovative studies proposing g-C₃N₄ microstructure optimization or refinement of the catalytic mechanism based mainly on theoretical calculations (e.g., density functional theory).

4.2. Future trends

Recent studies on g-C₃N₄ have focused on the photocatalytic application of composite g-C₃N₄ materials, such as the photocatalytic degradation of hygromycin by Co(OH)₂/g-C₃N₄ materials and the photocatalytic degradation of tetracycline by AgCoO₂/g-C₃N₄ materials[28-29]. There are still rich exploration possibilities for g-C₃N₄ as a photocatalytic material that is amenable to a variety of modification methods and has the potential for scale-up applications:

(1) Since the multilayer stacked block structure of g-C₃N₄ results in a small specific surface area of the material itself, researchers can explore more single-layer sheet g-C₃N₄ preparation methods.

(2) Utilizing current doping technology, investigate novel elemental co-doping strategies that effectively integrate the benefits of various elemental doping methods, such as optimizing the ratios of co-doped reactive chemicals and exploring new elemental combinations.

(3) Designing better g-C₃N₄ morphologies, especially 3D g-C₃N₄ morphologies, based on the existing morphologies of g-C₃N₄ materials such as nanotubes and microspheres. (For example, the nanoflower-like BiOOH/g-C₃N₄ composites designed by Lu Anyuan et al.) [30]

(4) Attempts were made to construct a new g-C₃N₄-based heterojunction system and to refine the mechanism of photogenerated carrier migration optimization within this system by observational calculations.

(5) g-C₃N₄ has the characteristics of dense structure and can realize photoelectric conversion, which makes it has the potential to be applied on a large scale in other fields such as battery anode and cathode material improvement, ion detection, and optoelectronic devices.

5. Conclusion

As a polymer semiconductor material, g-C₃N₄ has a wide range of photocatalytic application pathways. In order to overcome the defects of small specific surface area, high photogenerated carrier complexation rate and low visible light utilization of g-C₃N₄ as much as possible, it can be modified by using doping, morphology modification and construction of heterojunction, which essentially involves modifying the morphology and regulating the electronic structure of g-C₃N₄; meanwhile, the modified g-C₃N₄ can be applied in the fields of photocatalytic hydrogen production, photocatalytic degradation of pollutants, and photocatalytic reduction of carbon dioxide. However, the application fields of g-C₃N₄ need to be expanded, the preparation and modification methods of g-C₃N₄ need to be improved, and the theoretical system of g-C₃N₄ needs to be enriched. The research perspective of this paper is not comprehensive, and the properties and applications of g-C₃N₄ will be more widely explored when conducting future research.

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