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Article

Simple synthesis of g-C₃N₄/rGO hybrid catalyst for the photocatalytic degradation of rhodamine B

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ABSTRACT

A hybrid catalyst of g-C₃N₄ (graphitic carbon nitride)/rGO (reduced graphene oxide) was prepared by directly heating a mixture of melamine and GO in air. g-C₃N₄ in the hybrid retained the structure of pristine g-C₃N₄, and the heterojunction between g-C₃N₄ and rGO was formed by π - π interaction. The highest photocatalytic efficiency for the degradation of rhodamine B (RhB) was with the melamine/GO mass ratio of 800/1, with a first order rate constant 2.6 times that of pristine g-C₃N₄. The enhanced photocatalytic activity was assigned to the rGO-promoted separation of photo-generated electron (e⁻)-hole (h⁺) pairs. In addition, the photocatalytic activity of g-C₃N₄/rGO was pH sensitive with a much increased photodegrading rate at low pH values. The first order rate constant was 8.6 times that of pristine g-C₃N₄ at pH = 1.98. The pH sensitive behavior resulted from the promoted oxidation of h⁺ with RhB by the consumption of e⁻ with the reaction of proton (H⁺) in which rGO acted as a good platform for transferring e⁻ through its atomic sheets.

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1. Introduction

Graphitic carbon nitride (g-C₃N₄), a non-metal semiconductor consisting of only carbon and nitrogen, has attracted interest in the photocatalysis field [1–6]. Its band gap is 2.7 eV, which is much smaller than that of TiO₂ (3.2 eV) [7]. So, compared to TiO₂, g-C₃N₄ can absorb visible light, and its electrons can be excited from the valence band (VB) to the conduction band (CB) under visible light irradiation. Apart from its excellent sunlight harvesting ability, g-C₃N₄ is very stable under irradiation even in acid and base solutions, which makes it a good photocatalyst in various hazardous environments [3–6].

However, the high recombination rate of the photo-generated e⁻-h⁺ pairs limits its practical applications. Many modifica-

tion methods have been tried to improve its photocatalytic activity, such as physical coupling [8,9], chemical doping [10,11], microstructural shaping [12–15] and surface modification [16]. Among these methods, physical coupling is very effective and easy to perform. Due to the different potential levels of the CB and VB in the two different coupling materials, the photo-generated e⁻ and h⁺ of g-C₃N₄ can be separated efficiently at the heterojunction, giving rise to enhanced photocatalytic activity. The materials chosen for the counterparts can be divided into four classes: metal sulfide or oxide (e.g., CdS [17] and TiO₂ [18]), noble metals (e.g., Au [19]), polymers (e.g., P3HT [20] and PANI [9]), and graphene-based materials (e.g., reduced graphene oxide (rGO) [8,21–25], GO [26] and carbon nanotubes [27]).

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Graphene or rGO is a very good candidate for the coupling because g-C₃N₄ and graphene are both 2D materials, and the atomic sheets of graphene can facilitate electron transfer. g-C₃N₄/rGO has been synthesized from the molecular-level mixture of urea/GO [8], cyanamide/GO [21,22], dicyandiamide/GO [23], and melamine/GO [24,25]. The heterojunction between g-C₃N₄ and rGO is formed by N bridging [8,23], O bridging [21], or van der Waals π - π stacking [25]. The introduction of rGO has led to increased photocatalytic activity [21–25]. However, all these coupling processes use a non-oxygen environment to make the hybrid, such as N₂ [22,25], Ar [8,21,23], H₂ [24] or hydrazine hydrate environment [25]. This is because GO can be reduced to rGO at high temperature in an inert or reductive atmosphere [28], which generally needs a complicated fabrication process.

GO itself is effective in modifying the photocatalysis of g-C₃N₄ when overlaid on the surface of g-C₃N₄ as a GO/g-C₃N₄ hybrid [26], even though the mechanism is not very clear. So, it may not be necessary to use a non-oxygen environment to fabricate the hybrid. That is, a g-C₃N₄/rGO hybrid can be prepared with the existence of oxygen, e.g., in air. On the one hand, g-C₃N₄ has been polymerized in air and it showed increased photocatalytic activity due to the increased specific surface area [29]. On the other hand, GO can be reduced in air in some mixtures, as reported in our previous experiments [30]. During the heat treatment in air, GO is oxidized and splits into smaller unit, some down to the quantum dot level. The high temperature makes the major contributions to the removal of the epoxy, carbonyl and carboxyl groups, leading to a partially or fully reduced GO, *i.e.*, rGO. Local reductive gases, such as the released NH₃, also contribute to the reduction [30].

In this work, we carried out a simple method to fabricate a g-C₃N₄/rGO hybrid by directly heating a mixture of melamine/GO in air. The chemical microstructure of the hybrid, photocatalytic performance for the degradation of rhodamine B (RhB), pH-response behavior, and the photocatalytic mechanism were studied. The hybrid showed much increased photocatalytic performance in acidic conditions under visible light irradiation.

2. Experimental

2.1. Preparation of the hybrid catalysts

GO dispersion was performed according to the modified Hummers method [27,29]. One gram of graphite and 6 g of KMnO₄ were put into a solution composed of concentrated H₂SO₄ (120 mL) and H₃PO₄ (13.3 mL). After 18 h under vigorous stirring at 50 °C, the mixture was cooled to room temperature. This was followed by adding some H₂O₂ to react with the residual KMnO₄. After filtration and washing, most of the acid and ions were removed. The GO was re-dispersed in water and dialyzed by dialysis bags of 8000–14000 Da to remove acid and ions completely.

Four grams of melamine and an amount of GO dispersion were mixed and put into deionised water. After vigorous stirring and oven drying, a grey melamine/GO mixture was ob-

tained. The mixture was put into a crucible and heated to 550 °C for 1 h in air. The g-C₃N₄/rGO hybrid was obtained after grinding and denoted as g-C₃N₄/rGO-*x*, where *x* means the mass ratio of melamine/GO. Pristine g-C₃N₄ was prepared in a similar procedure using only melamine. rGO was prepared by heating GO under the same heating conditions.

2.2. Characterization of the hybrid catalysts

Fourier transform infrared spectroscopy (FT-IR) spectra were recorded on a Bruker TENSOR-27 Fourier transform infrared spectrophotometer. The crystalline structure was investigated by X-ray diffraction (XRD) on a D8 ADVANCE instrument using Cu K α radiation. The scanning electron micrographs (SEM) were obtained on a JSM-6700F microscope. Transmission electron microscopy (TEM) images were obtained by a JEM-2100F electron microscope at an acceleration voltage of 200 kV with a CCD camera. X-ray photoelectron spectroscopy (XPS) was performed using a K α 1063 instrument with focused monochromatized Al K α radiation. UV-Vis diffuse reflectance spectra (DRS) were obtained on a HITACHI U4100 spectrophotometer using BaSO₄ as the reference. The BET specific surface area (*A*_{BET}) was determined by N₂ adsorption isotherm measurement at –196 °C on a Micromeritics ASAP 2010 system. Photoluminescence (PL) spectra in reflectance mode were recorded using an FL-3 transient fluorescence spectrometer. The dried sample was pressed into a solid state powder film with a relatively uniform thickness more than 1.0 mm.

2.3. Photocatalytic activity measurement

The photocatalytic activity of the as-synthesized samples was evaluated by the degradation of RhB under a 350 W Xe Lamp (XD350W-I, Changzhou Siyu Environmental Sci-Tech Co., Ltd.) with a 400 nm cut off filter. A photocatalyst sample (100 mg) was added into a 100 mL aqueous solution of RhB (10 mg/L). Prior to irradiation, the suspension was treated using ultrasound in the dark for 30 min to achieve adsorption-desorption equilibrium. A 350 W Xe Lamp was used as the visible light source to perform the photocatalytic experiment. During the degradation of RhB, 5 mL samples were taken out and centrifuged to remove the solid particles for analysis. The concentration of aqueous RhB was determined using a UV-vis spectrophotometer (SHIMADZU UVmin-1240) at 552.0 nm by measuring its absorbance. The RhB concentration was calculated by the Lambert-Beer equation. The photodegradation of RhB under visible light irradiation in the absence of the photocatalyst was also evaluated.

3. Results and discussion

3.1. Chemical and microstructural analysis

The chemical and crystalline structures of as-synthesized rGO, g-C₃N₄/rGO and g-C₃N₄ were studied first. The FT-IR spectra and XRD patterns are shown in Fig. 1. In the FT-IR spectrum of rGO shown in Fig. 1(a), there are no obvious absorption

Fig. 1. FT-IR spectra (a) and XRD patterns (b) of rGO, g-C₃N₄/rGO and g-C₃N₄.

bands that can be assigned to oxygen-containing groups, which is a typical characteristic feature of graphene. This indicated that GO was mostly reduced to rGO at the high temperature even in air. In the FT-IR spectra of g-C₃N₄/rGO and g-C₃N₄, there were three obvious bands at 810, 1200–1650 and 3150 cm⁻¹. The first two bands were assigned to the breathing mode and stretching modes of CN heterocyclic groups, while the last band belonged to the residual N–H groups [15].

XRD patterns are presented in Fig. 1(b). rGO only showed a graphitic peak at $2\theta = 26.2^\circ$ with an interlayer spacing of 0.34 nm, indicating the existence of graphene atomic layers [21–25]. For g-C₃N₄/rGO and g-C₃N₄, there was one weak peak at $2\theta = 13.1^\circ$, which was due to the (100) crystal face and showed the

interplanar distance between the nitride pores [3]. The strong peak at $2\theta = 27.4^\circ$ is the characteristic feature of the (002) crystal face and showed the interlayer stacking of the conjugated aromatic systems [1].

Both the FT-IR spectra and the XRD patterns were almost identical for g-C₃N₄/rGO and g-C₃N₄, revealing that GO had little effect on the thermal polymerization of melamine and the network of g-C₃N₄ was retained.

The microstructures of the as-synthesized rGO, g-C₃N₄/rGO and g-C₃N₄ were investigated using SEM and TEM, and shown in Fig. 2. At the high temperature, GO was reduced and curved flexible rGO was formed, as shown in Fig. 2(a) and (d). The diffraction ring indicated the graphene atomic sheets [27]. Pris-

Fig. 2. SEM (a–c) and TEM (d–f) images of rGO (a, d), g-C₃N₄/rGO-800 (b, e) and g-C₃N₄ (c, f). The insets in the TEM images are the diffraction rings of the samples.

tine g-C₃N₄ consists of irregular thick graphitic sheets as shown in Fig. 2(c) and (f). In the hybrid product of g-C₃N₄/rGO shown in Fig. 2(b) and (e), rGO was observed sandwiched in the matrix of g-C₃N₄ even though this was hard to recognize due to the very limited ratio of rGO. The overall microstructure of g-C₃N₄/rGO was very similar to that of pristine g-C₃N₄.

XPS was utilized to investigate the chemical composition and chemical bonding states of g-C₃N₄/rGO and g-C₃N₄, and shown in Fig. 3 and Table 1.

In Fig. 3(b), most of the oxygen molecules were from adsorbed oxygen on the surface of the sample. In the C 1s spectra, both samples contained two common carbon species at 288.3 and 284.6 eV, corresponding to the C=N=C coordination and graphitic carbon [9]. The carbon contents were 42.41% in g-C₃N₄ and 43.69% in g-C₃N₄/rGO-800. The latter was slightly higher due to the trace amount of rGO introduced. Compared to g-C₃N₄ (0.02), the ratio of graphitic carbon in all the carbon species in g-C₃N₄/rGO-800 was higher (0.04). The N 1s of g-C₃N₄/rGO and g-C₃N₄ can be deconvoluted into three peaks at 398.7, 399.7 and 401.0 eV. The main peak at 398.7 eV originated from the sp²-bonded N in the triazine rings in g-C₃N₄. The weak peaks at 399.7 and 401.0 eV indicated the presence of the tertiary nitrogen N-(C)₃ group and amino N-H [17]. As shown in Table 1, the ratio fraction of the tertiary nitrogen N-(C)₃ group was lower in g-C₃N₄/rGO-800. This may be due to less N-(C)₃ linkers in the hybrid material from the lowering of the dimensions of g-C₃N₄. In general, it can be deduced that there were no new groups in quantity in the hybrid. So π - π interac-

Table 1

Elemental analysis and chemical bonding ratios of g-C₃N₄/rGO-800 and g-C₃N₄.

Sample	C (%)	N (%)	O (%)	Graphitic C: C=N=C	N-H:N-(C) ₃ : C=N=C
g-C ₃ N ₄	42.41	56.42	1.13	0.02:1.00	0.28:0.38:1.00
g-C ₃ N ₄ /rGO-800	43.69	55.01	1.30	0.04:1.00	0.28:0.33:1.00

tion was the main interaction between g-C₃N₄ and rGO.

The optical absorption features are a reflection of the photocatalytic activity. This was studied using the DRS technique and shown in Fig. 4(f). The visible light absorption coefficient of g-C₃N₄/rGO showed an upshift with the increase of GO loading. The optical images shown in Fig. 4(a)–(e) had a good appearance as an indication for this result. This is because rGO has a high visible light absorption coefficient. But the wavelength threshold remained relatively stable and the band gap of g-C₃N₄/rGO was almost identical to that of pristine g-C₃N₄ (Fig. 4(g) and Table 2). This phenomenon also demonstrated the non-chemical bond contact between g-C₃N₄ and rGO, in agreement with the XPS analysis.

3.2. Photocatalytic properties

The photocatalytic activity of g-C₃N₄/rGO and g-C₃N₄ was evaluated for the photodegradation of RhB under visible light irradiation. As shown in Fig. 5(a), RhB is an anti-photocorrosion material and has no detectable degradation without a

Fig. 3. XPS spectra (a) and high resolution O 1s (b), C 1s (c) and N 1s (d) spectra of g-C₃N₄/rGO-800 and g-C₃N₄.

Fig. 4. Optical images of g-C₃N₄ (a), g-C₃N₄/rGO-5000 (b), g-C₃N₄/rGO-800 (c), g-C₃N₄/rGO-600 (d), and g-C₃N₄/rGO-200 (e); DRS (f) and band gaps (g) of g-C₃N₄/rGO and g-C₃N₄.

photocatalyst under irradiation. The initial lower concentration of RhB was due to the adsorption of RhB on the surface of the photocatalyst. Both g-C₃N₄/rGO and g-C₃N₄ can initiate the degradation of RhB under visible light irradiation.

It is known that the photodegradation of RhB follows first order reaction kinetics. Its rate constant (k) can be calculated by Eq. 1 [17–27]:

$$\ln(c/c_0) = -kt \quad (1)$$

where c is the concentration of RhB at time t , and c_0 is the initial concentration of RhB [18]. As shown in Fig. 5(b), the photocatalytic efficiency of g-C₃N₄/rGO-5000 (0.0199 min⁻¹), g-C₃N₄/rGO-800 (0.0411 min⁻¹) and g-C₃N₄/rGO-600 (0.0241 min⁻¹) for the degradation of RhB were 1.2, 2.6 and 1.5 times that of pristine g-C₃N₄ (0.0160 min⁻¹). Only g-C₃N₄/rGO-200 showed a decreased photocatalytic activity. Among the photocatalysts, g-C₃N₄/rGO-800 had the highest photocatalytic activity.

The influence of the pH value on the photocatalytic activity of g-C₃N₄/rGO for the degradation of RhB was also studied using g-C₃N₄/rGO-800 as the catalyst. This is shown in Fig. 5(c) and (d). The pH value was adjusted using HCl and NaOH solution. In the absence of g-C₃N₄/rGO-800, RhB has no detectable degradation in both acidic and alkaline conditions, which implies that RhB is resistant to acid and alkaline corrosion. The photodegrading rate of RhB has no significant change after 100

mg of NaCl was added into the photocatalytic system, which implies that free Na⁺ and Cl⁻ have no significant influence. As shown in Fig. 5(c) and (d), the photocatalytic activity of g-C₃N₄/rGO is pH sensitive, with a much increased photodegrading rate at low pH values. The first order rate constant (0.1389 min⁻¹) was 8.6 times that with pristine g-C₃N₄ at pH = 1.98. With the increase of pH value, the photodegrading rate of RhB decreased sharply. When the pH value was above 7, the degradation rate decreased to almost zero.

3.3. Photodegradation mechanism

The photocatalytic process of g-C₃N₄ for the degradation of RhB can be divided into three steps, *i.e.*, capture of photon, separation of e⁻-h⁺ pair and generation of reactive species. The three steps are affected by the band gap, recombination rate of e⁻-h⁺ pairs and specific surface area. As shown in Fig. 4 and Table 2, the band gap of g-C₃N₄/rGO was almost identical to that of pristine g-C₃N₄. Their optical absorption spectra are also similar. Compared to that of pristine g-C₃N₄ (47.87 m²/g), the specific surface area (A_{BET}) of g-C₃N₄/rGO (12.16 m²/g) decreased when rGO was added. We think that it is the mixing, stirring and oven drying process that led to a highly dense state in the melamine/GO mixture. This was difficult to make porous unlike the original melamine. This indicated that the surface area made little contribution to the enhanced photocatalytic activity. The recombination rate of e⁻-h⁺ pairs would be the key in the photocatalytic activity of g-C₃N₄/rGO for the degradation of RhB.

Photoluminescence (PL) is caused by the recombination of photo-generated e⁻ and h⁺. So the PL spectrum can be used to evaluate the recombination rate of e⁻ and h⁺. This is shown in Fig. 6(a). It was found that the fluorescence of g-C₃N₄/rGO was weaker than that of g-C₃N₄. A higher mass ratio of the GO load-

Table 2

Band gap, A_{BET} , relative fluorescence intensity and rate constant of g-C₃N₄/rGO and g-C₃N₄.

Sample	Band gap (eV)	A_{BET} (m ² /g)	I/I_0^a (%)	k (min ⁻¹)
g-C ₃ N ₄ /rGO-200	2.75	17.27	42.48	0.0142
g-C ₃ N ₄ /rGO-600	2.74	15.54	48.07	0.0241
g-C ₃ N ₄ /rGO-800	2.75	17.41	59.37	0.0411
g-C ₃ N ₄ /rGO-5000	2.78	12.16	85.22	0.0199
g-C ₃ N ₄	2.78	47.87	100.00	0.0160

^a Relative fluorescence intensity at 450 nm.

Fig. 5. Photocatalytic activity (a) and photodegradation efficiency (b) of g-C₃N₄/rGO and g-C₃N₄, and photocatalytic activity (c) and photodegradation efficiency (d) of g-C₃N₄/rGO-800 with different pH values.

ing gave a weaker fluorescence. So, it can be inferred that rGO transfers e⁻ from g-C₃N₄ and facilitates the separation of e⁻ and h⁺ [17,26]. The separation of e⁻ and h⁺ led to increased photocatalytic activity. However, the loading of rGO has an optimal content because excess rGO would have a light screening effect on g-C₃N₄ to decrease the photocatalytic activity.

Under visible light irradiation, an e⁻ of g-C₃N₄ is excited from the VB to the CB, which generates a pair of free e⁻ and h⁺. e⁻ can react with oxygen to produce superoxide radicals ($\cdot\text{O}_2^-$), hydrogen peroxide (H₂O₂) and hydroxyl radicals ($\cdot\text{OH}$) by the

following reactions [31]:

The effects of h⁺, $\cdot\text{O}_2^-$, H₂O₂ and $\cdot\text{OH}$ on the photodegradation of RhB are different. In order to evaluate their effects, the photodegradation of RhB was measured after adding different scavengers. This is shown in Fig. 6(b). The degradation of RhB increased after adding H₂O₂ (100 mmol/L) in g-C₃N₄, indicating

Fig. 6. PL spectra (a) of g-C₃N₄/rGO and g-C₃N₄ and photocatalytic activity (b) of g-C₃N₄/rGO-800 with different scavengers. (1) H₂O₂; (2) g-C₃N₄/rGO-800 + TEOA (10 mmol/L); (3) g-C₃N₄/rGO-800 (Ar); (4) g-C₃N₄/rGO-800 + IPA (100 mmol/L); (5) g-C₃N₄/rGO-800; (6) g-C₃N₄/rGO-800 + H₂O₂.

that $\cdot\text{OH}$ accelerated the degradation of RhB. H_2O_2 by itself has no effect on the photodegradation. The degradation rate of RhB decreased slightly after adding isopropanol (IPA (100 mmol/L), a $\cdot\text{OH}$ scavenger [32]). So, in terms of thermodynamics and kinetics, $\cdot\text{OH}$ is not an effective contributor. The degradation of RhB slowed down significantly on adding triethanolamine (TEOA (100 mmol/L), a h^+ scavenger [31]), indicating that h^+ is the major contributor, and $\cdot\text{O}_2^-$ and $\cdot\text{OH}$ are comparatively minor contribution species. Even though adding either IPA or TEOA can retard the catalytic process, the amount of the scavenger was quite different. When the amount of IPA was 100 mmol/L, while that of TEOA was 10 mmol/L, 10 mmol/L TEOA has a larger effect in retarding the catalytic process than 100 mmol/L IPA, so we deduce that holes contribute more than superoxide radicals.

Furthermore, it was obvious that O_2 was indispensable for the photocatalysis of g- $\text{C}_3\text{N}_4/\text{rGO}$ -800 for the degradation of RhB because O_2 can consume e^- and prevent the accumulation of e^- . So under acidic conditions, H^+ can react with e^- and promote the separation of e^- and h^+ indirectly, speeding up the photodegradation of RhB. Under alkaline conditions, OH^- consumes the majority of h^+ , resulting in a significant decrease of the photodegrading rate of RhB. After a series of reactions, H^+ and OH^- can be recovered and the pH value remains relatively stable.

In theory, even OH^- anions can completely consume holes, and photogenerated electrons are free to react with adsorbed water to form superoxide radicals that still have roles significantly for the degradation of RhB. But we know that holes can react with RhB directly in one step, while photogenerated electrons need two or more steps to react with RhB via superoxide radicals. OH^- anions can retard the formation of superoxide radicals by some thermodynamic reasons.

The photocatalytic mechanism of g- $\text{C}_3\text{N}_4/\text{rGO}$ for the degradation of RhB is summarized in Fig. 7. Under visible light, an

Fig. 7. Photocatalytic mechanism of g- $\text{C}_3\text{N}_4/\text{rGO}$ for the degradation of RhB.

e^- of g- C_3N_4 is excited from the VB to the CB and the e^- - h^+ pair is generated. h^+ makes the major contribution to the degradation of RhB. e^- transfers efficiently through the atomic sheets of rGO, so rGO can accelerate the separation of e^- - h^+ pairs. In addition, e^- can further react with O_2 to produce $\cdot\text{O}_2^-$ and $\cdot\text{OH}$, which also make contributions to the degradation of RhB.

4. Conclusions

A hybrid catalyst of g- $\text{C}_3\text{N}_4/\text{rGO}$ formed by π - π interaction was made successfully from melamine and GO in air. The hybrid catalyst of g- $\text{C}_3\text{N}_4/\text{rGO}$ synthesized with a mass ratio of 800/1 showed the best photocatalytic activity (0.0411 min^{-1}) for the degradation of RhB, which was 2.6 times that of pristine g- C_3N_4 (0.0160 min^{-1}). The catalyst also showed a pH-sensitive phenomenon with a much increased activity at low pH values (0.1389 min^{-1} at $\text{pH} = 1.98$). rGO, even in a very lower ratio in the hybrid, plays an important role in promoting the separation of e^- and h^+ . h^+ is the major contribution species while $\cdot\text{O}_2^-$ and $\cdot\text{OH}$ are minor contribution species in the photodegradation of RhB in the g- $\text{C}_3\text{N}_4/\text{rGO}$ system.

Graphical Abstract

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Simple synthesis of g- $\text{C}_3\text{N}_4/\text{rGO}$ hybrid catalyst for the photocatalytic degradation of rhodamine B

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A hybrid catalyst of g- $\text{C}_3\text{N}_4/\text{rGO}$ was prepared by directly heating a mixture of melamine and graphene oxide in air, which showed superior photocatalytic activity in the degradation of RhB under acidic conditions.

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g-C₃N₄/rGO杂化催化剂的简易合成及其对罗丹明B的光催化降解作用

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摘要: 在空气中直接加热三聚氰胺和氧化石墨烯(GO)的混合物制备了g-C₃N₄/rGO杂化催化剂. 实验结果表明, 混合物中的g-C₃N₄保留了石墨型氮化碳原始的特征结构, g-C₃N₄和还原的氧化石墨烯(rGO)之间的异质结主要通过 π - π 作用构筑. 当原料中三聚氰胺/GO的质量比是800/1时, 所得催化剂对罗丹明B的催化作用最强, 其一阶动力学常数是纯g-C₃N₄的2.6倍. 这种强化作用主要是由于rGO促进了光生电子-空穴对的分离. 此外, g-C₃N₄/rGO还表现出显著的pH值敏感特性, 催化降解速率随pH的降低而增加. 当pH = 1.98时, 其一阶动力学常数是纯g-C₃N₄的8.6倍. 这是由于酸性条件下质子(H⁺)消耗掉光生电子, 促进了空穴对罗丹明B的氧化作用, 其中rGO充当了一个快速的光生电子转移平台.

关键词: 氮化碳; 氧化石墨烯; 光催化; pH敏感性; 罗丹明B降解

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