Heterojunctioned non-metal binary composites silicon carbide/g-C3N4 with enhanced photocatalytic performance

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1. Introduction

Wastewaters containing synthetic dyes and pigments such as rhodamine B, methyl orange, and indigo carmine discharged from manufacturing industries inadequately addressed cause serious environmental pollution, directly affecting human health and well-being [1,2]. On account of their complicated aromatic structure and thermos-stability, most dyes are hardly decomposed by conventional physical or biochemical treatments. Instead, the photocatalytic technology, a sustainable and effective manner to conquer this limitation because the charge carriers are promoted to transfer in opposite directions through a smooth phase interfaces, so as to reduce the recombination efficiently and further promoting the photocatalytic performance [5,6]. In addition, incorporating a narrow band-gap component also conduces to the visible-light harvesting and then heighten the visible-light response of hybrid composites.

So far, the polymeric graphite-like carbon nitride (g-C3N4), recognized as a favorite metal-free polymeric material, has garnered particular attention in fields of water splitting for hydrogen evolving [7] and pollutant decomposition under visible light irradiation [8,9] by virtue of its appealing electronic properties as well as high thermal and chemical stability [10,11]. However, g-C3N4 served as a photocatalyst alone is real pinned down to its small specific surface area and severe recombination of photogenerated charge carriers [11,12]. A variety of attempts have been employed to modify g-C3N4, such as elements deposition [13,14], textural turning [12,15] and building a g-C3N4-based heterojunction with Bi3WO6 [16], HSbO3 [17], BiOCl [18], WO3 [19], Ag3PO4 [8], CuCr2O4 [20], and YVO4 [21] etc. Specifically, Liu et al. successfully synthesized chlorine-intercalated g-C3N4 through a soaking-copolylation method [22]. Huang et al. reported the synthesis of porous g-C3N4 thin nanosheets by means of a template-free thiourea-assisted hydrothermal protocol [23]. Tian et al. prepared a 3D
mesoporous ultrathin g-C3N4 through a precursor-recrystallization process [24]. These modified g-C3N4 samples showed the significant enhancement of photo-absorption and photocatalytic degradation capabilities. Moussavi et al. constructed a series of multicomponent g-C3N4/FeO4/Ag2O4/TiO2 composites by a facile ultrasonic-irradiation method [25] and g-C3N4/FeO4/Ag2O4/TiO2 composites via ultrasonic and calcination methods as well [26]. Akhund et al. prepared various quaternary g-C3N4/FeO4/AgI/Bi2S3 catalysts by adding different amount of Bi2S3 using a facile refluxing method [27] and further quaternary g-C3N4/FeO4/AgI/Ag2S catalysts by anchoring the AgI/Ag2S system on surface of g-C3N4/FeO4 in the same manner [28]. Among numerous modification strategies, the semiconductor coupling is regarded as an effective and efficacious manner to combine the advantages of intrinsic structural features from each component phase and possibly bring about a synergistic effect after hybridization [29–32].

SiC is another typical non-metallic semiconductor with an appropriate band gap of 2.3–3.3 eV [33], a more negative conduction band potential, a sufficient thermal and chemical stability, and a high mechanical strength [34], which render it extensively applied in power electronics, radio frequency devices, grinding materials [33], and to be a promising catalyst candidate under visible-light irradiation. Moreover, its high charge-carrier mobility can shuttle the photogenerated carriers swiftly before recombination from the bulk to the surface [33]. Unfortunately, the pure SiC actually exhibits a very weak photocatalytic activity, if any, from the visible to ultraviolet light as a result of the acute recombination of photogenerated charge carriers [35] and low optical response [36]. Gao et al. clearly stated the inferior photocatalytic capability of commercial α-SiC powder for water splitting under visible light in view of its small surface area [37]. Considering the potential applications, the photocatalytic performance of SiC is generally heightened by modified its microstructure and morphology such as the morphology control [38], noble metal deposition [39], and semiconductor coupling [35,40]. Wang et al. separately deposited Pt and IrO2 on micro-SiC surface, attaining a synergetic effect to suppress the carriers recombination and hereby enhancing the photocatalytic activity [41]. Kou et al. attempted to decompose toluene by porous TiO2/SiC nanocomposite films [42]. Wang et al. found that the average H2 evolution rate increased to 4572 μL g−1 h−1 as soon as the Pt/SiC nanowire hybrid was present [43]. If g-C3N4 is adopted as another ingredient to construct a composite, the well-matched band positions between SiC and g-C3N4 ought to kinetically facilitate the carriers transfer and separation, therefore giving rise to the enhanced photocatalytic degradation outcome.

In this work, we attempted to construct SiC/g-C3N4 heterojunction hybrids via a simple ultrasonic dispersion and calcination route. The as-synthesized samples were systematically characterized by XRD, SEM, TEM, FT-IR, XPS, UV–vis DRS, PL spectra, and N2 adsorption-desorption techniques. It was confirmed that SiC, a component with satisfactory visible-light absorption ability, was successfully deposited on the surface of g-C3N4 as irregular nanoparticles. What boosted photocatalytic efficiency over dyes degradation the produced composites take on comparing to bare SiC or g-C3N4 mainly owned to the favorable structural and electronic features of composites, such as strengthened light harvesting, uniform generation of heterojunction domains, and efficient separation of charge carriers along well-matched band structures. A possible photocatalysis mechanism was finally speculated based upon active radicals entrapping experiments.

2. Experiment

2.1. Materials and reagents

All chemicals of the reagent grade were utilized as received without further purifications and deionized water purified by a millipore system was used for syntheses and photocatalytic processes. Melamine, MO, disodium ethylenediaminetetraacetate dehydrate (EDTA-2Na), ter-ephthalic acid (TA), sodium hydroxide (NaOH), L-ascorbic acid, iso-propanol alcohol (IPA), and absolute ethanol were all purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Both SiC and RhB were provided by Shanghai Mstar Technology Ltd. and Shanghai SSS Reagent Co., Ltd. (Shanghai, China), respectively.

2.2. Samples fabrication

The pure g-C3N4 was produced by heating treated melamine in a semi-closed system. In a typical protocol, a desired amount of melamine with 50 mL absolute ethanol was ultrasonicated for 0.5 h and subsequently stirred for 2 h. A solid powder was segregated by filtration, dried at 60 °C for 12 h, carefully ground, charged in a semi-closed ceramic crucible, calcined in a furnace at 550 °C for 1 h with a heating rate of 10 °C min⁻¹, and finally collected as a pale-yellow powder.

As for the synthesis of SiC/g-C3N4 hybrid composites, a similar procedure was conducted to the above preparation except the addition of desired amount of SiC during agitation. Based upon the yield of pure g-C3N4 as described, changeable amounts of SiC were added and produced samples were labeled as SN0, SN1, SN5, SN8, SN20, and SN50, corresponding to the expected mass ratios of 0 (pure g-C3N4), 1%, 5%, 8%, 20%, and 50%, respectively. The N-TiO2 was also constructed for comparison via a sol-gel method as previously reported [44].

2.3. Characterization

The crystal structure and surface chemical composition were analyzed by a Bruker D8 Advance X-ray diffractometer (XRD, Cu Kα radiation source λ = 1.05406 Å) at 40 kV and 40 mA with a continuous scanning pattern in the range of 5–80° and X-ray photoelectron spectroscopy (XPS, Thermo Scientific ESCALAB 250Xi, exciting source Al Kα radiation, hν = 1486.8 eV). The Cls band was set on 284.6 eV as a reference to calibrate other binding energies. A scanning electron microscopy (SEM, QUANTA F250) and transmission electron microscopy (TEM, Tecnai G2 F20) were employed to measure the morphological and microstructural properties. The UV–vis diffuse reflectance spectra (UV–vis DRS) were analyzed on a spectrophotometer (Shimadzu UV2600, Japan) ranging from 200 to 800 nm for detecting optical features of samples and the BaSO4 was used as a reflectance standard. Fourier-transform infrared (FT-IR) spectra were taken on a Bruker V-70 Fourier transform-infrared spectrophotometer in the frequency range of 500–4000 cm⁻¹. Photoluminescence (PL) spectra were recorded on an Edinburge FLSP920 fluorescence spectrometer. N2 adsorption-desorption isotherms were evaluated on a Micromeritics ASAP2200HD88 system at 77 K and the pore size distribution was calculated by the Barrett-Joyner-Halenda (BJH) method. All samples were degassed at 120 °C for 4 h prior to measurements.

2.4. Photocatalytic activity evaluations

The photocatalytic behavior of as-prepared samples was checked over the degradation of dye RhB and MO in a photocatalytic reactor. A 300 W Xenon lamp (CEL-HXF300, AuLight, Beijing) was served as a visible light source with a 420–780 nm cut-off filter fixed to assure the presence of only visible light. The reactor stayed in a water channel with a continuous circulation of cold water to maintain a constant temperature and the light source was 20 cm away from the surface of aqueous suspension. The photocatalyst (20 mg) was immersed in an aqueous solution of RhB (20 mg L⁻¹, 80 mL) or MO (5 mg L⁻¹, 80 mL) under a continuous stir. Prior to the visible-light illumination, the suspension was strongly magnetically stirred in dark for 1 h to reach an adsorption-desorption balance between organic molecules and catalysts surface. During irradiation, 3 mL aliquot was taken from the suspension at every 30 min intervals and separated by centrifugation twice. The residue concentrations of RhB and MO were estimated on a UV–vis
3. Results and discussion

3.1. XRD patterns

Reagents IPA, L-ascorbic acid, or EDTA-2Na was released into the reaction mixture to enwrap active species such as hydroxyl radicals (OH), superoxide radicals (O₂⁻), and produced holes (h⁺), respectively. The procedure was similar to the photocatalytic capability test except that the capture reagent was added with a concentration of 5 mM. Since the TA could convert to a highly fluorescent 2-hydroxyterephthalic acid after reacting with generated -OH radicals, it is feasible to use TA (0.5 mM in a 2 mM NaOH aqueous solution) as a probe molecule to detect the amount of -OH radicals during photocatalytic process in the presence of sample SN8 at an excitation wavelength of 324 nm in PL emission spectrometer. The procedure was almost as the same as the one described above except the addition of TA instead of RhB.

3.2. SEM and TEM images

The surface morphology of as-prepared samples was visualized by SEM images. As depicted in Fig. 2A, the pure g-C₃N₄ prepared by the calcination of melamine displays numerous irregular large aggregates comprising lamellar structures. By contrast, a large number of irregular nanoparticles with the size around 60 nm are observed in the pure commercial SiC in Fig. 2B. As found in SN hybrids images shown in Figs. 2C-F, some irregularly-shaped SiC nanoparticles remarked with red arrows are uniformly deposited on the surface of g-C₃N₄ large aggregates and the number of SiC nanoparticles raises with the augmentation of SiC contents. Particularly, the accumulation of the small SiC nanoparticles induces the almost coverage of the entire surface of g-C₃N₄ large aggregates in sample SN50 according to Fig. 2F. The even deposition of SiC nanoparticles on surface of g-C₃N₄ in SEM images is responsible for the reinforcement of SiC diffraction peaks and the abatement of g-C₃N₄ diffraction peaks in XRD patterns.

TEM images were recorded to further investigate the morphology and microstructure of the pure g-C₃N₄ and composite SN8. As exhibited in Fig. 3A, the individual g-C₃N₄ is composed of lamellar nanosheet structures with some wrinkles at the edge. Notably, some pore-like domains can be easily found, which could be attributed to the slowly releasing of ammonia or other gaseous materials during the samples synthetic process at a high calcination temperature [46]. For the composite SN8 in Fig. 3B, the original lamellar structure of g-C₃N₄ is still remained with the presence of some small SiC nanoparticles clearly found on the boundary, remarked by a red dotted elliptical frame. These particles in TEM image is relatively small in size in comparison to those in SEM images, possibly attributing to the ultrasonic treatment prior to the TEM analysis.

3.3. FT-IR spectra

FT-IR spectra of pure SiC, g-C₃N₄, and SN hybrids were recorded to check surface chemical groups and bonding, as depicted in Fig. 4. The spectrum of pure g-C₃N₄, denoted as SN0, shows three typical absorption regions around 810, 1250–1650, and 3000–3600 cm⁻¹. The broad absorption band ranging from 3000 to 3600 cm⁻¹ is assigned to the stretching and bending vibrations of residual N-H or adsorbed O-H groups [67], while the peak at 1250–1650 cm⁻¹ is relevant to the typical stretching vibration of CN heterocycles and the sharp peak centered at 810 cm⁻¹ represents the characteristic breathing mode of triazine units [30]. As to the spectrum of pure SiC, an intensive absorption band at 858 cm⁻¹ can be ascribed to the Si-C stretching vibration modes [48], and both peaks at 470 cm⁻¹ and 1090 cm⁻¹ are indexed to the Si-O stretching vibrations, mainly caused by the slight oxidation of Si species on surface. The feature absorption peaks of g-C₃N₄ are well maintained, while the sharp peak positioned around 858 cm⁻¹, marked by a red square frame and its enlarged image placed on the right, is gradually widened with the increase of SiC contents to become a bump that is characteristic vibration of Si-C bonds, evidently signifying the coexistence of both components.

3.4. XPS analysis

XPS analysis was conducted to further explicate surface chemical compositions and elemental valence state in the as-prepared hybrid SN8, as seen in Fig. 5. The full scan XPS spectrum in Fig. 5A indicates the presence of Si, C, and N elements in sample SN8, confirming the coexistence of both ingredients of g-C₃N₄ and SiC. In addition, the element O is also detected and possibly originates from oxygen-containing species adsorbed or slight oxidation of Si species on surface. The high-resolution XPS spectra of C 1s in Fig. 5B contains three peaks with binding energies at 284.6 eV, 287.8 eV, and 288.3 eV, respectively indexing to the C-C bonds of adventitious external carbon [24], the defect-containing sp²-coordinated carbon atoms on g-C₃N₄ surface [50], and the sp³-hybridized carbons in the aromatic rings (N-C=N), revealing the existence of g-C₃N₄ phase [50]. The N 1s spectrum in Fig. 5C was deconvoluted into three component peaks centered at 398.3 eV, 399.7 eV, and 400.6 eV. The main N 1s peak at 398.3 eV...
Fig. 2. SEM images of samples (A) SN0, (B) SiC, (C) SN1, (D) SN8, (E) SN20, and (F) SN50.

Fig. 3. TEM images of samples (A) SN0 and (B) SN8.
corresponds to sp²-hybridized nitrogen in triazine rings (C=N-C) [51]. Another peak at 399.7 eV was assigned to the bringing N bonded to the tertiary N in N-(C)₃ [52], and a weak peak located at 400.6 eV was identified as amino groups carrying hydrogen (-NHₓ) [16]. As for Si 2p spectrum in Fig. 5D, both peaks at 100.5 eV and 102.6 eV are attributed to the Si–C and Si–O bonds [43], respectively, which is in good accordance with the result of FT-IR analysis.

3.5. UV–vis DRS spectra

The optical property and band gap feature of as-prepared samples were examined by UV–vis diffuse reflectance spectra in Fig. 6A. Pure SiC with a color of deep green shows a strong absorption from the ultraviolet to visible light region and thus can be a suitable component to construct an efficient hybrid system with g-C₃N₄ that presents an absorption edge at about 480 nm. For SN composites, the absorption intensities ranging from 420 nm to 800 nm was gradually strengthened and the absorption edges are markedly shifted to the long wavelength, namely bathochromic shift, with the increase of SiC addition, revealing the enhancement of visible-light harvesting and also an evidence of good interaction between both components in the hybrid system [32]. The band gap energy (E₉) of pure SiC and g-C₃N₄ is able to be estimated according to the following formula:

$$ahv = A(hv-E_\text{g})^{1/n}$$

where a, h, v and A are absorption coefficient, plank constant, light frequency, and a constant, respectively [5,19]. The value n above depends on the characteristic of optical transition in a semiconductor (n = 1 for the direct transition and n = 4 for the indirect transition) [18], which can be deduced by plotting ln(ahv) versus ln(hv-E₉) to form a straight line and the corresponding slope is the hinge because the material belongs to an indirect or direct transition semiconductor when the slope equals or unequals to 1, respectively. From the Fig. 6B, the slopes of both pure SiC and g-C₃N₄ are determined as 0.89 and 0.12, indicating that both original ingredients undergo a direct transition, that is, the value n as 1. Accordingly, the E₉ values of pure SiC and g-C₃N₄ were calculated to be 2.57 eV and 2.48 eV, respectively, determined from the intercept of the tangential line of (ahv)¹/² vs hv. It is general that the band edge potentials of VB and CB of pure SiC and g-C₃N₄ can be calculated using both empirical equations as below [6]:

$$E_{VB} = X - E_\text{g} + 0.5E_\text{g}$$

$$E_{CB} = E_{VB} - E_\text{g}$$

Fig. 4. FT-IR spectra of bare SiC, g-C₃N₄, and SNₓ hybrid composites.

Fig. 5. XPS survey spectrum (A) and corresponding high-resolution XPS spectra: C 1s (B), N 1s (C), and Si 2p (D) of sample SN8.
where $E_{VB}$, $E_{CB}$, $X$, and $E'$ are defined as the valence band (VB) and conduction band (CB) edge potentials, the Mulliken's electronegativity, and the energy of free electrons on the hydrogen scale (~4.5 eV), respectively [18]. The $X$ values for SiC and g-C$_3$N$_4$ are defined as 5.47 eV and 4.73 eV [6], respectively. Consequently, the VB and CB potentials of SiC and g-C$_3$N$_4$ can be estimated to be 2.21 eV and $-0.27$ eV, 1.52 eV and $-1.05$ eV, respectively. Apparently, both semiconductors SiC and g-C$_3$N$_4$ with well-matched electronic structures are beneficial to create heterojunction that ensure the efficient transfer and separation of photoinduced charge carriers and further advance photocatalytic performance.

### 3.6. PL

The PL spectra were measured to elucidate the transfer and separation efficiency of photogenerated charge carriers in as-prepared samples [5,53]. Generally, a relatively weak PL band means the low recombination rate in semiconductors [24]. Obviously, in Fig. 6D, the pure g-C$_3$N$_4$ shows a strong and wide emission band in the wavelength range of 400–600 nm, implying the high recombination of photoproduced electron-hole pairs. By comparison, the pure SiC exhibits a quite weak PL emission band. The SN series present band curves possessing both band features of these two components and moreover, the intensity of these curves reduces gradually accompanying the increase of SiC contents, suggesting the efficient charge carriers separation.
Table 1

<table>
<thead>
<tr>
<th>Samples</th>
<th>$S_{BET}$ (m$^2$ g$^{-1}$)</th>
<th>Average pore size (nm)</th>
<th>Pore volume ($\times 10^{-3}$ cm$^3$ g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC</td>
<td>46.1</td>
<td>7.84</td>
<td>9.02</td>
</tr>
<tr>
<td>SN0</td>
<td>13.2</td>
<td>13.4</td>
<td>4.61</td>
</tr>
<tr>
<td>SN1</td>
<td>12.9</td>
<td>13.6</td>
<td>4.14</td>
</tr>
<tr>
<td>SN5</td>
<td>16.8</td>
<td>15.8</td>
<td>6.61</td>
</tr>
<tr>
<td>SN8</td>
<td>17.9</td>
<td>15.4</td>
<td>6.68</td>
</tr>
<tr>
<td>SN20</td>
<td>20.1</td>
<td>15.6</td>
<td>7.82</td>
</tr>
<tr>
<td>SN50</td>
<td>22.2</td>
<td>13.9</td>
<td>7.76</td>
</tr>
</tbody>
</table>

caused by the formation of heterostructures.

3.7. N$_2$ adsorption-desorption isotherms

Fig. 7 displays the N$_2$ adsorption-desorption isotherms and the corresponding pore size distribution curves of samples SiC, SN0 and SN8. The adsorption-desorption isotherms of all samples in Fig. 7A can be classified as the typical type IV pattern with a H$_2$-type hysteresis loop based on the IUPAC classification, suggesting the formation of slit-like mesopores. Besides, the adsorption branches of these samples gradually and continuously increase along with the increase of relative pressures approaching to 1, which is quite similar to the type II isotherm and indicates the presence of macropores [48]. The appearances of both mesopores and macropores are confirmed in Fig. 7B, which are resulted from the aggregation of plate-like particles and bulky clusters, respectively. In addition, the specific surface areas ($S_{BET}$) of all samples were collected and summarized in Table 1. Compared with that of SN0, $S_{BET}$ values of binary composites are slightly enlarged with the enhancement of SiC contents, quite similar to the variation of average pore size and pore volumes. The slightly increased $S_{BET}$ and pore volumes are able to expose more active sites to contaminant molecules, thus benefiting their photocatalytic performance.

3.8. Photocatalytic degradation performance

The photocatalytic performance of as-synthesized samples was measured at room temperature by the degradation of RhB and MO under visible-light irradiation. Adsorption-desorption equilibria were achieved for all photocatalytic tests through a magnetic stir for 1 h in dark before exposing to the illumination. As depicted in Fig. 8A, the photolysis of RhB, a blank experiment without any catalysts, was carried out and can be negligible, demonstrating the sufficient photo and chemical stability of RhB. Both N-TiO$_2$ and SiC are of poor photocatalytic capabilities over RhB, providing degradation efficiencies of 15% and 11% after 150 min visible-light irradiation, respectively. Pure g-C$_3$N$_4$ exhibits a relatively low photocatalytic performance that can be enhanced by the binding of binary composites with another component SiC. Exactly as the results display, with the increase of SiC contents in SN composites, the photocatalytic outcome can be improved and then decreased beyond mass ratio of 8%. Consequently, the sample SN8 possesses the best photocatalytic degradation ability among all tested samples. The photocatalytic degradation reaction is in accordance with the pseudo-first-order kinetics and the corresponding apparent rate constant (k) can be deduced by the following equation:

$$\ln(C_f/C) = kt$$

where $C_f$ and $C$ are measured concentrations of RhB at the illumination time (t) of t = 0 and t [21]. Apparently, the sample SN8 in Fig. 8B manifests the highest apparent rate constant 0.00619 min$^{-1}$ that is 30.9 times, 1.2 times, and 5.2 times of those SiC, g-C$_3$N$_4$, and N-TiO$_2$, respectively.

Meanwhile, MO was also chosen as a representative model pollutant to evaluate the photocatalytic performance of as-obtained samples under the identical experimental condition, as shown in Fig. 8C. It has been found that either photolysis or degradation of MO molecules using SiC as a catalyst is ignorable. Both samples SN0 and N-TiO$_2$ are able to exert photocatalytic decompositions with enhanced efficiencies that can be further improved when composite SN8 is utilized. Correspondingly, the composite SN8 presents an apparent rate constant that is almost 6.7 times and 1.6 times as high as that of pure SiC and g-C$_3$N$_4$ samples in Fig. 8D.

During above photocatalytic processes, composites SN, particularly the sample SN8, exhibit enhanced degradation efficiencies in comparison to bare SiC and g-C$_3$N$_4$, which can possibly own to those reasons described below. Firstly, the visible-light absorption and utilization of SN composites are greatly strengthened since the bare SiC is strongly responsive to the visible light, as discussed in UV–vis DRS spectra. Secondly, well-matched band structures of both components tend to generate the straddling band alignments along the heterostructure edge that promote the transfer and separation of charge carriers effectively, favoring the best use of electrons and holes for degradation reactions. Thirdly, as to SN composites, the increase of SiC content facilitates the visible-light harvesting and beyond the optimal SiC content of 8%, an excess amount of SiC tends to cover the whole surface of g-C$_3$N$_4$ and further impede the excitation of g-C$_3$N$_4$. Therefore, composites SN with suitable physicochemical merits are able to trigger photocatalytic processes with satisfactory decomposition efficiencies.

3.9. Photocatalysis mechanism inspected

Reactive radical species such as -OH, -O$_2^-$, and holes possibly involved in the photocatalytic degradation processes were detected by adding some scavenger reagents in the presence of sample SN8 for the sake of the photocatalysis mechanism inspection [54]. Specifically, both reagents EDTA-2Na and IPA were added to respectively trap radical species h$^+$ and OH [19,51]. Photoproduced radicals -O$_2^-$ was ensnared by the introduction of L-ascorbic acid instead of p-benzoquinone since the latter was not quite stable in some photocatalytic processes [54]. In addition, the O$_2$ isolation experiment was performed by bubbling N$_2$ to further confirm the generation of radicals -O$_2^-$. As shown in Fig. 9A, the addition of reagent EDTA-2Na exerts almost no influence on the photocatalytic degradation of RhB molecules, while the presence of L-ascorbic acid greatly inhibited the removal efficiency. The crucial role of radicals -O$_2^-$ is also confirmed by the introduction of N$_2$ gas to expel dissolved O$_2$ molecules that readily convert to -O$_2^-$ species via a one-electron reduction path [8]. In addition, the photocatalytic degradation is somewhat restrained as soon as reagent IPA is involved, implying the minor effect of radicals -OH on photocatalytic processes.

The generation of radicals -OH was also detected through the addition of TA in Fig. 9B since TA reacts with -OH to generate a fluorescent product 2-hydroxy terephthalic acid at 425 nm [30,55]. It is clear that the intensity of fluorescent band in the wavelength range from 380 to 550 nm gradually increased with the extension of irradiation time, suggesting the indeed presence of oxidative radicals -OH in the reaction system.

According to band structures of both SiC and g-C$_3$N$_4$ components and active species trapping experiments, a primary photocatalytic mechanism is proposed to demonstrate the transfer and separation of electron-hole pairs and further degradation reactions, as exhibited in Fig. 10. Upon a visible-light irradiation, both semiconductors SiC and g-C$_3$N$_4$ are prone to excite and thus electrons and holes are produced at CB and VB. Because of the internal static electric field, electrons tend to transfer from the CB of g-C$_3$N$_4$ to that of SiC and holes migrate from the VB of SiC to that of g-C$_3$N$_4$. Therefore, electrons and holes are distributed in different components caused by the well-aligned band structures in composites. Electrons gathered at the CB of SiC react with surface-adsorbed oxygen molecules to produce radicals -O$_2^-$ as the CB level (−0.27 eV) is more negative than that of O$_2$/O$_2^-$ (−0.046 eV) [56]. Meanwhile, holes collected at the VB of g-C$_3$N$_4$ are insufficient to
react with OH or H₂O species to generate radicals ⋅OH since the VB level of g-C₃N₄ (1.52 eV) is more negative than E°(H₂O/⋅OH = +2.38 eV) [18], even E°(OH⁻/⋅OH = +1.99 eV) [57]. As a result, it is deduced that radicals ⋅OH may possibly generate via a two-electron oxidation pathway. As a result, the redistribution of electrons and holes and a series of subsequent reactions accelerate the separation of charge carriers and prolong the lifetime of charge carriers, thus boosting the photocatalytic degradation performance of SN composites.

4. Conclusions

In summary, a series of binary composites were successfully fabricated and further characterized through a collection of analytical techniques. SEM images depicted that SiC nanoparticles evenly deposited on the surface of g-C₃N₄ sheets and TEM images confirmed the presence of heterojunction domains at the edgy of phase boundary. Meanwhile, UV–vis DRS spectra demonstrated an obviously enhanced visible light harvesting compared to pure g-C₃N₄. The improved photocatalytic capability of these hybrid composites, especially the sample SN8, under visible-light irradiation might be caused by a synergistic effect, including the suitable morphology, strengthened visible-light harvesting, and well-aligned straddling band structures. A possible photocatalytic mechanism was eventually proposed according to the active species trapping experiments and band structures of both semiconductor components.

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**Fig. 8.** Photocatalytic degradation of RhB over series of as-prepared samples (A), the corresponding variation of apparent rate constants (B), photocatalytic degradation of MO (C), the corresponding variation of apparent rate constants (D).

**Fig. 9.** Active species trapping experiments using sample SN8 (A) and hydroxyl radicals quantification experiments of sample SN8.
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