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Article

Gold-loaded graphene oxide/PDPB composites for the synchronous removal of Cr(VI) and phenol

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ABSTRACT

The construction of novel inorganic-organic hybrid nanomaterials for synchronous photocatalytic removal of heavy metal ions and organic pollutants has received significant attention. We successfully synthesized gold-loaded graphene oxide/PDPB (polymer poly(diphenylbutadiyne)) composites (Au-GO/PDPB) through a facile mechanical agitation and photoreduction method. The composites were characterized by XPS and TEM images, which confirmed the presence of GO and Au nanoparticles on the PDPB. The as-prepared Au-GO/PDPB composites displayed enhanced photocatalytic activity compared with that of pure PDPB for the synchronous photoreduction of hexavalent chromium (Cr(VI)) and photo-oxidation of phenol. We also determined the optimal loading mass of GO and Au nanoparticles on the PDPB; the Au₁-GO₂/PDPB (2.0 wt% GO and 1.0 wt% Au) composite displayed the best photocatalytic activity among all the catalysts. Our study provides a facile way to prepare inorganic-organic composites for the synchronous photocatalytic removal of heavy metal ions and organic pollutants.

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1. Introduction

In recent years, the emission of organic pollutants and toxic heavy metal ions in wastewater from the electroplating and dyeing industries has seriously endangered the environment [1,2]. Among these organic pollutants and heavy metal ions, the synchronous removal of hexavalent chromium (Cr(VI)) and phenol has attracted significant attention [3–5]. The development of novel multifunctional composites has provided a promising way to solve these environmental and energy issues [6–9]. Conjugated polymers, regarded as new energy materials,

have gained a lot of attention owing to their low cost, fast electron transport capacity, excellent electrochemical properties and high mechanical properties [10–12]. Recently, Remita et al. [13] reported conjugated polymer poly(diphenylbutadiyne) (PDPB) nanofibers synthesized by a soft template method, which displayed efficient removal of phenol under visible light. Since then, the investigation of PDPB nanofibers has developed fast owing to their response to visible light, stable properties and low preparation costs [14]. In our previous work [15], a PDPB/SnO₂ p-n heterojunction was synthesized by an in-situ strategy; the catalyst exhibited high photocatalytic activity for

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the removal of rhodamine B under solar light irradiation. Lei et al. [16] also reported a polymer composite of PDPB and g-C₃N₄ prepared through a facile impregnation method, which showed high photocatalytic removal of rhodamine B and phenol. However, the polymer PDPB nanofibers display some drawbacks that have limited their application, such as high hydrophobicity and quick recombination of photogenerated electrons and holes [13,15]. To overcome these drawbacks, we introduced graphene oxide (GO) and gold nanoparticles to improve the photocatalytic activity of PDPB. The use of GO has gained significant attention owing to its high surface area, good mechanical properties, excellent electronic conductivity, special photo-electrochemical properties and controllable bandgap [17–21]. Furthermore, graphene could also be regarded as a support material, which could allow semiconductor particles to be anchored on its surface. A lot of research has been done to prepare various composites such as TiO₂/graphene [22–24], Fe₂O₃/graphene [25,26] and Au/graphene [27].

In this paper, we prepared Au-GO/PDPB composites through a facile mechanical agitation and photoreduction method. The GO and Au nanoparticles could be used as an excellent electron transfer substrate and electron capture agent, respectively. Compared with pure PDPB, the as-prepared Au-GO/PDPB composites exhibited a high photocatalytic performance for the synchronous photocatalytic removal of Cr(VI) and phenol.

2. Experimental

2.1. Chemicals and materials

Ethanol, sodium chloride, distilled water, sodium dodecyl sulfate (SDS), 1,4-diphenylbutadiene (DPB), cyclohexane, benzoin methyl ether (BME), pentanol-1, chloroauric acid, graphite, concentrated sulfuric acid, potassium permanganate, hydrogen peroxide, sodium nitrate and phenol were used without further purification.

2.2. Synthesis of photocatalysts

2.2.1. Synthesis of PDPB nanofibers

The PDPB nanofibers were synthesized with some modifications of the reported procedure [13]. Typically, 0.035 g NaCl was dissolved in 2.0 mL distilled water in a quartz tube, then 1 g SDS was added to the mixture under vigorous agitation. After stirring for 5 h, a transparent and viscous micellar solution was formed. Then, 0.39 g DPB, 0.039 g BME and 5 mL cyclohexane were added into a beaker followed by ultrasonic treatment. After all the materials were completely dissolved, the solution was mixed with the previous micellar solution under vigorous stirring, which resulted in the formation of a white unstable emulsion. Afterwards, pentanol-1 (420 μ L) was added to the system with continuous vigorous stirring for 3 h. The quartz tube was irradiated under a 300 W Xenon lamp for 12 h from a distance of 5 cm. Finally, the orange products were extracted from the solution with 15 mL water and 15 mL ethanol and dried in a vacuum oven at 60 °C for 12 h.

2.2.2. Synthesis of graphene oxide

GO was synthesized by a modified Hummers method [28]. Typically, 50 mL of concentrated H₂SO₄ was added to a three-necked flask containing 2.0 g natural graphite powders and 1 g NaNO₃ in an ice bath, and the reaction mixture was mixed by mechanical agitation for 2 h. Then, 6 g KMnO₄ was added to the mixture within 3 h, and the temperature was kept under 5 °C. After reacting for 10 h, the temperature of the mixture was raised to 35 °C and maintained for 10 h. Then, 80 mL distilled water was slowly added to the system and the temperature was increased to 98 °C and maintained for 1 h. Afterwards, 280 mL distilled water and 80 mL 30% hydrogen peroxide were added to the system to end the reaction. After cooling to room temperature, the suspension was centrifuged and washed three times with 5% HCl solution. Then, the GO was freeze-dried at 60 °C overnight. Finally, 500 mg graphene oxide was dispersed into 1 L distilled water to obtain a GO aqueous solution with a concentration of 0.5 mg/mL.

2.2.3. Synthesis of GO/PDPB composites

The GO/PDPB composites were prepared with different loading mass of GO. In detail, 1, 2, 3, 4, 5, 10 or 20 mL of GO aqueous solution (0.5 mg/mL) was mixed with a suitable volume of distilled water to form a 20 mL solution. Then, 50 mg PDPB dissolved in 20 mL ethanol was added to the previous solution under vigorous stirring. After reacting for 24 h, the mixture was centrifuged and washed three times with distilled water and ethanol. Finally, the 1.0 wt%, 2.0 wt%, 3.0 wt%, 4.0 wt%, 5.0 wt% and 10 wt% GO/PDPB composites were dried in a vacuum oven at 60 °C for 12 h to obtain GO1/PDPB, GO2/PDPB, GO3/PDPB, GO4/PDPB, GO5/PDPB and GO10/PDPB, respectively.

2.2.4. Synthesis of Au-GO/PDPB composites

We used a photoreduction method to load Au nanoparticles on the GO/PDPB composites. In detail, 50 mg GO2/PDPB was dissolved in 10 mL methanol and 40 mL distilled water in a quartz tube. After stirring for 0.5 h, 250 μ L, 500 μ L or 1 mL of chloroauric acid (1 mg/mL) was added to the mixture. Afterwards, the system was irradiated under a 300 W Xenon lamp for 2 h. Then, the mixture was centrifuged and washed three times with distilled water and ethanol. Finally, 0.5 wt%, 1.0 wt% and 2.0 wt% Au-GO2/PDPB was dried in a vacuum oven at 60 °C for 12 h to obtain Au_{0.5}-GO2/PDPB, Au₁-GO2/PDPB and Au₂-GO2/PDPB, respectively.

2.3. Measurements of photocatalytic activity

The photocatalytic activity of each catalyst was measured in terms of the synchronous photodegradation of phenol and Cr⁶⁺ heavy metal ions. Typically, for each measurement, 20 mg of the catalyst was added into a quartz reactor containing 50 mL phenol (10 mg/L) and Cr⁶⁺ (10 mg/L) solution. Prior to the photoreaction, the suspension was stirred for 1 h in the dark to ensure the adsorption-desorption equilibrium of organic contaminants on the surface of the catalyst. Afterwards, at a given time interval, an analytical sample was taken from the

system and immediately centrifuged. The Cr^{6+} content was measured with a SHIMADZU 2450 UV-Vis spectrophotometer, whereas phenol was analyzed with a SHIMADZU SPD-M20A high-performance liquid chromatograph (HPLC).

2.4. Characterization

The morphologies of the catalysts were characterized by transmission electron microscopy (TEM, JEOL JEM-1400). X-ray diffraction (XRD) patterns of all the catalysts were detected in the range of 5° – 80° (2θ) using a Rigaku Ultima IV diffractometer ($\text{Cu } K_\alpha$ radiation, $\lambda = 0.15406 \text{ nm}$), operated at 40 kV and 40 mA. Photocurrent measurements were carried out on an electrochemical analyzer (CHI 660 D electrochemical station, CHI Instruments Inc) at room temperature. Transient photocurrent responses of different samples were obtained on a Zahner electrochemical workstation Zennium. A standard three-electrode system was used in Na_2SO_4 aqueous solution (0.5 mol/L) under various irradiation conditions using a 300 W Xenon lamp. The X-ray photoelectron spectroscopy (XPS) studies were carried out using a Perkin-Elmer PHI 5000C ESCA system with $\text{Al } K_\alpha$ radiation. The binding energy shift was referenced to the C 1s level at 284.6 eV as an internal standard. Infrared (IR) spectra were recorded with an FTIR spectrometer (Nicolet Magna 550) and KBr disks containing the powder sample. Raman measurements were performed using a Renishaw inVia Raman microscope with an excitation wavelength of 524.5 nm at room temperature.

3. Results and discussion

The synthesis of the Au-GO/PDPB composites consisted of two steps, as shown in Scheme 1. Firstly, the GO/PDPB composites were prepared through a facile mechanical agitation, with the polymer PDPB dispersed on GO randomly. We prepared GO/PDPB composites with different loading mass of GO including GO1/PDPB, GO2/PDPB, GO3/PDPB, GO4/PDPB, GO5/PDPB and GO10/PDPB; the optimum loading mass of GO was determined by a photocatalytic removal test of rhodamine B (RhB). Then, Au nanoparticles were loaded on the GO/PDPB composites with a favorable ratio by photoreduction of $\text{HAuCl}_4 \cdot 4\text{H}_2\text{O}$.

3.1. Characterizations and properties

The morphologies of the catalysts were analyzed by TEM. Fig. 1(a) shows the TEM image of pure PDPB, which had a nanofiber structure. The width of the PDPB nanofibers was $\sim 20 \text{ nm}$, and their lengths were a few micrometers. The morphologies of GO and GO2/PDPB are shown in Fig. 1(b) and

Fig. 1. TEM images of various samples. (a) pure PDPB; (b) GO; (c) GO2/PDPB; (d) Au₁-GO2/PDPB.

1(c). The structure of graphene was clearly evident in the TEM image of GO2/PDPB. The Au nanoparticles and polymer PDPB were observed in the Au₁-GO2/PDPB sample (Fig. 1(d)). The diameter of Au nanoparticles was $\sim 10 \text{ nm}$.

The crystalline structure of the catalysts was examined by XRD. The XRD patterns of pure PDPB and the GO/PDPB samples with different loading mass of GO are shown in Fig. 2(a). The sharp peaks observed at $2\theta = 14^\circ$, 20.4° , 24.7° and 29.1° were attributed to the characteristic peaks of PDPB [14]. The peak locations of PDPB did not change with the introduction of GO; however, the intensity of the signals became weaker. Fig. 2(b) shows the XRD patterns of PDPB, GO2/PDPB and Au-GO2/PDPB with different loading mass of Au nanoparticles. Similarly, with increasing loading amount of Au nanoparticles, the intensity of the PDPB signals decreased. In addition, the peaks of the GO and Au nanoparticles were not observed in the XRD patterns of these samples owing to the low loading mass of the GO and Au nanoparticles.

To investigate the interaction between PDPB and GO, infrared spectroscopy was used to detect the chemical bonds, as shown in Fig. 3. Pure PDPB showed characteristic peaks at 2850, 2919 and 3048 cm^{-1} , which were attributed to the C–H vibration of the polymer molecule chains [15]. Compared with pure PDPB, the intensity of the IR peaks of GO2/PDPB and GO10/PDPB significantly decreased without any changes in the location of the peaks. The interaction between PDPB and GO will lead to a decrease of C–H vibration of the GO/PDPB composites. The characteristic peak at 3452 cm^{-1} was attributed to the O–H vibration. Compared to GO2/PDPB, the enhanced intensity and boarder width of the O–H vibration signal in the GO10/PDPB sample indicated an increased loading amount of GO.

The chemical bonding of the compounds was further studied by Raman spectroscopy. The signals at 1600, 1500 and

Scheme 1. Schematic illustration of the synthesis pathway of Au-GO/PDPB.

Fig. 2. XRD patterns of various samples. (a) PDPB (1); G01/PDPB (2); G02/PDPB (3); G03/PDPB (4) and G04/PDPB (5); (b) PDPB (1); G02/PDPB (2); Au_{0.5}-GO2/PDPB (3); Au₁-GO2/PDPB (4) and Au₂-GO2/PDPB (5).

1000 cm^{-1} in the Raman spectrum were characteristic peaks of PDPB, as shown both in the pure PDPB and G02/PDPB samples (Fig. 4). The peak at 1600 cm^{-1} was attributed to the presence of aromatic compounds, which was caused by the C–C vibration in the benzene ring of PDPB. The peaks at 1500 and 1000 cm^{-1} were ascribed to the signals of the benzene ring [29]. The peaks at 900–1000 cm^{-1} were attributed to the C–O–C bond. However, the G02/PDPB composite showed some miscellaneous peaks in the range of 900–1000 cm^{-1} owing to the loading of GO. In addition, compared to pure PDPB, the G02/PDPB composite had an undulation in the range of 1625–1680 cm^{-1} , which was owing to the presence of C=C bonds in GO [30]. However, the intensity of these peaks was not high owing to the low loading of GO.

The surface composition and chemical states of the Au-GO/PDPB composites were investigated by XPS. Fig. 5(a) shows the C 1s XPS spectrum of the Au₁-GO2/PDPB composite. The peaks were corrected by referencing the C 1s level at 284.6 eV. The peaks at 286.5 and 289.2 eV were attributed to the C–O bond and O–C=O bonds, respectively. These characteristic peaks indicated the presence of GO in the Au₁-GO2/PDPB composite. Fig. 5(b) shows the Au 4f XPS spectrum of the

Au₁-GO2/PDPB composite. The Au 4f_{7/2} and Au 4f_{5/2} peaks were centered at 83.85 and 87.25 eV, respectively, which were different to the widely reported XPS spectra of Au⁰ at 84.0 and 87.7 eV [31]. The blueshift of the Au 4f peaks resulted from the electron transfer from the GO/PDPB composites to Au nanoparticles. Therefore, the Au nanoparticles were successfully loaded on the GO/PDPB composites through a facile photoreduction method.

3.2. Photochemical property measurement

To measure the light absorbance properties of the Au₁-GO2/PDPB composite, we used UV-Vis diffuse reflectance spectra to measure the response of the light absorbance (Fig. 6). The pure PDPB structures exhibited a broad absorption in the visible range, which was consistent with the reports in the literature [13]. After the loading of GO, the color of the GO/PDPB composites turned from orange to light yellow, as shown in Fig. 6 (inset). With the loading of GO, the solar light absorption of the GO/PDPB composites decreased. A similar phenomenon was also observed in the Au₁-GO2/PDPB composite. After the loading of Au nanoparticles on G02/PDPB, the absorption of the obtained composites also decreased. It is

Fig. 3. IR spectra of PDPB (1), G02/PDPB composite (2) and G010/PDPB composite (3).

Fig. 4. Raman spectra of PDPB (1) and G02/PDPB composites (2).

Fig. 5. XPS spectra of Au₁-GO₂/PDPB composites. (a) C 1s; (b) Au 4f.

difficult to explain the decreased absorption in the visible light region for the PDPB after the Au loading. There could be a relationship between the Au and PDPB, which decreases the color centers over the PDPB.

A transient photocurrent test was used to measure the photo-electrochemical properties of these samples. The photocurrent tests of these samples were performed in the dark or under solar light illumination using a xenon lamp equipped with an AM1.5 optical filter, as shown in Fig. 7. The results showed that the photocurrent of Au₁-GO₂/PDPB was much higher than that of pure PDPB and GO₂/PDPB. The photocurrent response of pure PDPB was approximately 4 nA/cm², whereas that of the Au₁-GO₂/PDPB composite was approximately 100 nA/cm², nearly 25 fold higher than the performance of pure PDPB. The Au₁-GO₂/PDPB composite had a much higher photocurrent than Au_{0.5}-GO₂/PDPB and Au₂-GO₂/PDPB, which indicated that the Au₁-GO₂/PDPB had the best transfer rate of photogenerated electron-hole pairs.

3.3. Photocatalytic activity measurement

To study the photocatalytic activity of the Au-GO/PDPB composites, we first determined the optimum loading mass of GO through photocatalytic removal of rhodamine B (RhB), as

shown in Fig. 8(a). The photocatalytic activities at different ratios of GO/PDPB were compared with the activities of pure PDPB. All the GO/PDPB composites had an enhanced photocatalytic activity compared with that of pure PDPB. The photocatalytic performance of PDPB was significantly limited because of its hydrophobicity. Therefore, the introduction of GO into the PDPB material improved the hydrophilic properties of the obtained catalysts. As shown in Fig. 8(b), 5.0 mg samples were mixed with 5.0 mL distilled water. After ultrasonication and shaking of the samples for 10 min, we analyzed the dispersibility of the different samples in water. The GO₂/PDPB and Au₁-GO₂/PDPB composites both had excellent water-solubility compared with that of pure PDPB. The composites could be uniformly dispersed in the RhB solution before the photocatalytic degradation test. Furthermore, the GO/PDPB composites showed enhanced separation of photogenerated electrons and holes compared with that of pure PDPB because of the outstanding electronic conductivity of GO. In addition, the GO₂/PDPB composite showed the best photocatalytic activity for the degradation of RhB among all these GO/PDPB composites, with a removal rate of 83% in 180 min. For the GO₁/PDPB composite, the electron transport capacity was insufficient owing to the low amount of GO. However, at a loading mass higher than 2 wt%, the excess GO

Fig. 6. UV-Vis diffuse reflectance spectra and the color (inset) of pure PDPB (1), GO₂/PDPB (2) and Au₁-GO₂/PDPB (3) composites.

Fig. 7. Transient photocurrent responses of pure PDPB (1); GO₂/PDPB (2); Au_{0.5}-GO₂/PDPB (3); Au₁-GO₂/PDPB (4) and Au₂-GO₂/PDPB (5).

Fig. 8. (a) Photocatalytic removal of RhB by pure PDPB and GO/PDPB with different loading mass of GO by simulated solar light (300W Xenon lamp with an AM 1.5 filter; RhB: 10 mg/L; Cat: 0.2 mg/mL). (b) Photograph of different samples showing their dispersibility in water; PDPB (1), GO2/PDPB composite (2), Au₁-GO2/PDPB composite (3) and magnified image of the PDPB water solution (inset).

would affect the light absorption of PDPB, which would lead to a decrease in its photocatalytic activity.

Therefore, we chose the GO2/PDPB composite to synthesize the Au-GO2/PDPB composites for synchronous photocatalytic removal of Cr(VI) and phenol. To determine the most efficient synchronous photocatalytic removal of phenol and reduction of Cr(VI), Au-GO2/PDPB composites with different loading mass of Au nanoparticles (Au_{0.5}-GO2/PDPB, Au₁-GO2/PDPB and Au₂-GO2/PDPB) were synthesized. As shown in Fig. 9(a), the Au₁-GO2/PDPB composite exhibited excellent catalytic activity for the reduction of Cr(VI), whereas pure PDPB exhibited quite weak activity. Simultaneously, the Au₁-GO2/PDPB composite also showed excellent catalytic activity for the oxidation of phenol (Fig. 9(b)); the removal rate of phenol reached 49.4%, and the corresponding reduction rate of Cr(VI) reached 77.4% in 4 h. The total organic carbon (TOC) removal rate of phenol over the Au₁-GO2/PDPB was 41.4% after 4 h irradiation.

The results showed that the loading mass of the Au nanoparticles had a significant effect on the photocatalytic activity of the Au-GO2/PDPB composites for the synchronous removal of Cr(VI) and phenol. In a previous study, Wu et al. [32] reported nitrogen-doped titania deposited with gold nanoparticles, which had an enhanced photocatalytic activity.

They gave a reasonable explanation for the influence of the load concentration of gold on the photocatalytic performance. When the deposited gold exceeded 5.0 wt %, the photoactivity of the composite reduced even though it had a higher visible light absorption. A higher gold content not only influences the penetration of light but also becomes a recombination center, resulting in a decrease of photoactivity. Conversely, fewer electronically active sites could be formed owing to low loading of Au nanoparticles, which would limit the improvement of its catalytic activity. Similarly, for the Au_{0.5}-GO2/PDPB composite, fewer electronically active sites could be formed owing to low loading mass of Au nanoparticles, which would limit the improvement of its catalytic activities. Conversely, and excess of Au nanoparticles would affect the light absorption of PDPB (Fig. 6) or introduce many recombination sites on the interface, which would lead to decreased photocatalytic activity of the Au₂-GO2/PDPB composite. We also observed the transient photocurrent responses (Fig. 7); the Au₁-GO2/PDPB had a much higher photocurrent than Au_{0.5}-GO2/PDPB and Au₂-GO2/PDPB, which indicated that the Au₁-GO2/PDPB composite would have a higher photocatalytic activity than the other composites.

Fig. 9. Synchronous photocatalytic removal properties of pure PDPB (1), GO2/PDPB (2), Au_{0.5}-GO2/PDPB (3), Au₁-GO2/PDPB (4) and Au₂-GO2/PDPB (5) (300 W Xenon lamp with an AM 1.5 filter; Cat: 0.4 mg/mL). (a) Reduction of Cr(VI) (10 mg/mL); (b) Oxidation of phenol (10 mg/mL).

Fig. 10. Mechanism of the synchronous photocatalytic removal of Cr(VI) and phenol by the Au-GO/PDPB composites under solar light irradiation.

3.4. Mechanism of synchronous photocatalytic removal of Cr(VI) and phenol

The proposed mechanism of the synchronous photocatalytic removal of Cr(VI) and phenol by the Au-GO/PDPB composites is illustrated in Fig. 10. Under solar light irradiation, electrons (e^-) and holes (h^+) are generated within the PDPB material. The electrons are excited to the CB of PDPB, whereas the holes remain in the VB. These electrons would move to the Au nanoparticles that are loaded on the surface of the PDPB, or transfer to the GO surface owing to the outstanding electronic conductivity of GO, and further transfer to the Au nanoparticles that are loaded on GO surface [33]. The electrons could reduce the Cr(VI) to Cr(III), whereas the hole could be used for the oxidation of phenol to CO_2 and H_2O . Therefore, in our system, the loading of Au nanoparticles and GO sheets leads to a high separation efficiency of electrons and holes and a longer lifetime of these carriers, which results in excellent performance in synchronous removal of Cr(VI) and phenol.

4. Conclusions

In summary, we used a facile way to synthesize Au-GO/PDPB composites, which exhibited good dispersibility in water and a high photocatalytic activity for the synchronous removal of Cr(VI) and phenol under solar light irradiation. Owing to the excellent light harvesting and effective separation of electrons and holes over the Au-GO/PDPB composites, the degradation rate of phenol reached 49.4%, and the corresponding reduction rate of Cr(VI) reached to 77.4% in 4 h. Therefore, the as-prepared catalysts presented a high solar-driven photocatalytic performance. Our study provides a facile way to prepare inorganic-organic hybrid composites with high solar light activities for the synchronous removal of heavy metal ions and organic pollutants.

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Graphical Abstract

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Gold-loaded graphene oxide/PDPB composites for the synchronous removal of Cr(VI) and phenol

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This work presents a simple way to prepare inorganic-organic Au-GO/PDPB composites, which exhibit enhanced photocatalytic activity compared with that of pure PDPB for the synchronous removal of Cr(VI) and phenol.

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金负载氧化石墨烯/PDPB复合材料用于同步去除六价铬离子和苯酚

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摘要: 近年来, 电镀和染料行业工业废水中排放的有机污染物和重金属离子严重危害着环境. 构建无机-有机新型纳米材料用于光催化去除重金属离子和有机污染物受到了广泛的关注. 共轭聚合物因其低廉的制造成本, 快速的电子传送能力, 优秀的电化学性能和高的机械性能, 它们作为一类新能源材料已经快速发展起来. Remita等使用软模板方法制备的一种共轭聚合物聚1,4-二苯基丁二炔(PDPB)在可见光下对苯酚表现出较好的去除率. 然而, 聚合物PDPB的一些缺陷限制了其应用, 比如高的疏水特性和快速的光生电子-空穴复合. 因此, 我们引入氧化石墨烯(GO)和金纳米粒子来提高PDPB的光催化活性. 通过简单的机械搅拌和光还原方法制备了Au-GO/PDPB复合材料. 通过TEM, XRD, XPS, 固体紫外和光电流测试等技术对催化剂进行了一系列表征, 结果发现氧化石墨烯作为优秀的电子传送基地, 金纳米粒子作为电子捕获剂, 在空间上实现了电子空穴的空间隔离, 从而大大提高了Au-GO/PDPB复合材料对于六价铬离子和苯酚的同步光去除的光催化活性.

XPS表征和TEM图像表明了GO和Au纳米粒子的存在. 其PDPB有着纳米纤维的结构, 宽度在20 nm左右, 长度在几个微米. 当复合了氧化石墨烯后, 可以明显看出氧化石墨烯的形态, 进一步光还原负载金纳米粒子, 同样可以在TEM图中观察到金纳米粒子的存在, 其直径在10 nm左右. 之后通过光催化同步去除六价铬离子和苯酚来探究Au-GO/PDPB复合材料的活性, 结果表明所制备的Au-GO/PDPB比纯的PDPB有着增强的光催化活性在同步光去除六价铬离子(Cr(VI))和苯酚中. 更进一步地是, 我们同样确定了GO和Au纳米离子的最佳负载量, 结果发现, Au₁-GO₂/PDPB复合材料(金的负载量为1 wt%, 氧化石墨烯的负载量为2 wt%)在所有催化剂中有着最好的光催化活性, 其在4 h内对苯酚的去除率达到49.4%, 相应的对于六价铬离子的还原率达到了77.4%. 我们的研究提供了一种构建有机-无机杂化复合材料的方法, 其在太阳光下对于有机污染物和重金属离子的同步去除有着高的光催化活性.

关键词: 光催化; 重金属离子; 有机污染物; 聚合物1,4-二苯基丁二炔(PDPB); 同步去除

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