Abstract: In this study, the Ag₃PO₄/SnO₂ heterojunction on carbon cloth (Ag₃PO₄/SnO₂/CC) was successfully fabricated via a facile two-step process. The results showed that the Ag₃PO₄/SnO₂/CC heterojunction exhibited a remarkable photocatalytic performance for the degradation of Rhodamine B (RhB) and methylene blue (MB), under visible light irradiation. The calculated k values for the degradation of RhB and MB over Ag₃PO₄/SnO₂/CC are 0.04716 min⁻¹ and 0.04916 min⁻¹, which are higher than those calculated for the reactions over Ag₃PO₄/SnO₂, Ag₃PO₄/CC and SnO₂/CC, respectively. The enhanced photocatalytic activity could mainly be attributed to the improved separation efficiency of photogenerated electron-hole pairs, after the formation of the Ag₃PO₄/SnO₂/CC heterojunction. Moreover, carbon cloth with a large specific surface area and excellent conductivity was used as the substrate, which helped to increase the contact area of dye solution with photocatalysts and the rapid transfer of photogenerated electrons. Notably, when compared with the powder catalyst, the catalysts supported on carbon cloth are easier to quickly recycle from the pollutant solution, thereby reducing the probability of recontamination.

Keywords: Ag₃PO₄/SnO₂; heterojunction; carbon cloth; photocatalytic activity; visible light

1. Introduction

In the last few decades, with the rapid development of social economies and the continuous expansion of industrial production, environmental pollution has become one of the most important issues in society. In particular, the polluted water from organic dyes, such as Rhodamine B (RhB), has become a serious threat to the environment and human health [1–5]. Semiconductor photocatalysts can degrade organic pollutants in wastewater under solar light irradiation, saving energy and protecting the environment, and thus attracting tremendous attention [6–8]. However, traditional semiconductor photocatalysts can only respond to ultraviolet irradiation that occupies about 5% of solar light, which severely limits their practical applications in the utilization of solar light [9–13]. Therefore, it is urgent to develop photocatalysts that can be excited under visible light irradiation [14].

In recent years, silver-based photocatalysts have attracted widespread attention. Among them, Ag₃PO₄ has been extensively studied due to its narrow band gap (about 2.40 eV) and excellent photocatalytic activity under visible light [15–17]. However, the speedy recombination of photoexcited electron-hole pairs and poor light stability severely weakens its photocatalytic performance [18–22]. Subsequently, combining Ag₃PO₄ with other semiconductors to form heterojunction has proved to be a promising strategy [23–27].
As a direct wide-bandgap semiconductor, SnO$_2$ has been widely applied to catalysts, gas sensing and batteries [28–32]. Due to its good conductivity and stability, SnO$_2$ is often combined with other semiconductors to form heterojunction, which promotes the separation of photogenerated electron-hole pairs [33–35]. For example, Ag$_3$PO$_4$/SnO$_2$ [36,37], Ag$_3$PO$_4$/SnO$_2$/porcine bone [38], AgCl/SnO$_2$ [39] and Ag/AgCl/SnO$_2$ [40], show enhanced photocatalytic activity over a single photocatalyst.

In addition, in order to overcome the difficulty in recycling the powder photocatalyst, carbon cloth is usually used for photocatalyst support [5,41,42]. Xu et al. designed and prepared TiO$_2$/Bi$_2$WO$_6$ nanosheet heterojunctions on carbon fibers, as an effective and weaveable visible-light photocatalyst [5]. Shen et al. reported on the design and preparation of C$_3$N$_4$ nanosheets on carbon-fiber cloth as a filter-membrane-shaped photocatalyst [41]. Zhang et al. successfully prepared the heterostructures of CuS/ZnO/CFs, which showed improved photocatalytic activity in the degradation of methylene blue (MB), under visible light irradiation [42]. This is mainly because carbon cloth has a large specific surface area, excellent conductivity and good stability [43,44]. This not only facilitates the recovery of the photocatalyst, but also helps to increase the contact area of the photocatalyst with the organic dye solution and sunlight, in turn quickly transferring the photogenerated electrons to enhance the separation efficiency of photogenerated electron-hole pairs [45].

Herein, we synthesized Ag$_3$PO$_4$/SnO$_2$ heterojunction on carbon cloth using a two-step method. The results showed that the Ag$_3$PO$_4$/SnO$_2$/CC heterojunction exhibited a remarkable photocatalytic performance for the degradation of RhB under the visible light irradiation. Furthermore, the structure and possible mechanism of the enhanced photocatalytic activity of the Ag$_3$PO$_4$/SnO$_2$/CC heterojunction are discussed in detail.

2. Experimental

2.1. Synthesis of SnO$_2$ Nanorods on Carbon Cloth

A piece of carbon cloth (2.5 cm $\times$ 2.0 cm, WOS 1009, CeTech, Thickness: 0.33 mm, Basic Weight: 120 g/m$^2$) was put into concentrated HNO$_3$ at 100 °C for 90 min. It was then cleaned with deionized water and acetone for several times, and dried at 80 °C. The SnO$_2$ nanorods were grown on carbon cloth (SnO$_2$/CC) through a facile hydrothermal route [46]. 1.1 mol/L NaOH solution was added into 0.1 mol/L SnCl$_4$·5H$_2$O solution, drop by drop, under a constant stirring condition. After stirring for 30 min, the 35 mL mixture solution and the carbon cloth were added into a 50 mL Teflon-lined stainless steel autoclave, and hydrothermally treated at 200 °C for 12 h. Eventually, the carbon cloth was taken out, rinsed with deionized water and air-dried at 80 °C for 12 h.

2.2. Synthesis of Ag$_3$PO$_4$/SnO$_2$ Heterojunction on Carbon Cloth

The Ag$_3$PO$_4$/SnO$_2$ heterojunction on carbon cloth were produced through a facile dipping method [47]. More specifically, the SnO$_2$/CC was first placed into the 0.05 mol/L AgNO$_3$ solution for 20 h. Next, the SnO$_2$/CC was taken out and immersed into the 0.05 mol/L Na$_2$HPO$_4$ solution for 2 min. Subsequently, the SnO$_2$/CC was put back into the AgNO$_3$ solution for 2 min. The immersion process was repeated 20 times. Eventually, the prepared Ag$_3$PO$_4$/SnO$_2$/CC was cleaned with deionized water and dried at 80 °C for 12 h. For comparison, the Ag$_3$PO$_4$ grown on carbon cloth (Ag$_3$PO$_4$/CC), was fabricated in the same process.

2.3. Characterization

The as-prepared samples were characterized using the X-ray diffractometer (XRD, D8 advance, Bruker, Karlsruhe, Germany), field emission scanning electron microscope (FESEM, JSM-7800F, JEOL Ltd., Tokyo, Japan, precision: 0.8 nm), transmission electron microscope (TEM, JSM-2100F, 200 kV, Hitachinaka, Naka, Japan, Line resolution: 0.14 nm), high-resolution transmission electron microscope (HRTEM, FEI, TecnaiG2 F30, 200 kV, Hitachinaka, Naka, Japan), X-ray photoelectron spectroscopy (XPS, NEXSA, precision: $\pm 0.1\%$), and the Brunauer–Emmett–Teller method (BET, Micromeritics ASAP...
2460, precision: ±0.1%), respectively. The elemental mapping studies were carried out under the SEM. The photoluminescence (PL) properties were analyzed using the fluorescence spectrophotometer (F-7000, precision: 1 nm), with a Xe lamp. The UV-Vis diffuse reflectance spectroscopy was performed on a Shimadzu UV-3600 (precision: 0.1 nm) spectrophotometer. The absorption spectra of the as-prepared samples were obtained using an ultraviolet-visible spectrophotometer (UV-vis, U-3310, Hitachi Ltd., Tokyo, Japan).

2.4. Photocatalytic Activity

The photocatalytic activity of the as-prepared samples was evaluated by the photodegradation of RhB and MB, where a 300 W xenon light with a 420 nm cut off filter was chosen as the visible-light source. The synthesized SnO2/CC (SnO2: 30.6 mg), Ag3PO4/CC (Ag3PO4: 5.1 mg) and Ag3PO4/SnO2/CC (Ag3PO4: 8.2 mg) samples were put into the 50 mL RhB (4 × 10⁻⁵ mol/L) and MB (5 × 10⁻⁵ mol/L) aqueous solution. The mass loading of Ag3PO4 and SnO2 powder was weighed using an electronic analytical balance (ME104E, max weight: 120 g, precision: 0.1 mg, linear error: 0.2 mg), according to the reading difference between the substrates and loading samples. The suspension was stirred in the dark for 60 min to attain the adsorption-desorption equilibrium. During the irradiation experiment, approximately 3 mL of the suspensions was removed every 10 min. Finally, the concentration of RhB solution was monitored as a function of irradiation time, using the UV-vis spectrophotometer.

3. Results and Discussion

3.1. Microstructure and Morphology

The crystal structure of the synthesized samples is confirmed by XRD characterization, shown in Figure 1. For the pure CC sample, the diffraction peaks at around 26° and 44° correspond with the carbon cloth (JCPDS card No. 65-6212) [46]. All the diffraction peaks of the Ag3PO4/SnO2/CC sample can be indexed to the tetragonal rutile phase of SnO2 (JCPDS card No. 41-1445), Ag3PO4 (JCPDS card No. 06-0505) and CC [48,49]. No diffraction peaks belonging to the impurity phases were detected.

![Figure 1. XRD patterns of pure CC, Ag3PO4/CC, SnO2/CC and Ag3PO4/SnO2/CC.](image)

As illustrated in Figure 2a,b, SnO2 nanorods with a diameter of about 150–300 nm grow evenly on the surface of the carbon cloth. In contrast, it can be clearly seen from the photographs in Figure 2c that only a few Ag3PO4 particles are sparsely deposited on the carbon cloth. The enlarged SEM image shows that Ag3PO4 consists of spherical particles and some particles with irregular shapes. The SEM images of the Ag3PO4/SnO2/CC sample are shown in Figure 2e,f. When compared with the Ag3PO4/CC sample, many more Ag3PO4 particles with irregular shapes are deposited on the carbon cloth, which should be attributed to the manufacturing process. It can clearly be seen from the SEM results that the surface of the carbon cloth is smooth, while the SnO2/CC sample shows a rougher surface. When the SnO2/CC was put into the AgNO3 solution, many more Ag⁺ ions were easily adsorbed onto the surface.
of SnO2/CC. They then reacted with Na2HPO4 to generate Ag3PO4, which was more difficult to shed from the surface of SnO2/CC, compared to that on the carbon cloth. This is also evidenced by the weight of the synthesized samples.

![Figure 2](image1.png)

**Figure 2.** SEM images of the SnO2/CC (a,b), Ag3PO4/CC (c,d), Ag3PO4/SnO2/CC (e,f).

Furthermore, the elemental mapping analysis of the Ag3PO4/SnO2/CC sample for the detected elements Sn, O, Ag, P and C, is shown in Figure 3a–g. All five elements are uniformly distributed throughout the whole carbon fiber. In addition, Figure 3 clearly shows the distribution of Sn, O, Ag and P within the carbon fiber, which further confirms the formation of the Ag3PO4/SnO2/CC heterojunction structure [50].

![Figure 3](image2.png)

**Figure 3.** SEM image of Ag3PO4/SnO2/CC (a) and the elemental mapping images of C (b), Sn (c), O (d), Ag (e), P (f) and Ag3PO4/SnO2/CC (g).

The TEM image of the Ag3PO4/SnO2/CC is shown in Figure 4a, which clearly indicates that the Ag3PO4 particles are uniformly distributed on SnO2 nanorods. The HRTEM image of Ag3PO4/SnO2/CC is shown in Figure 4b, which clearly uncovers a set of fringes with an interplanar spacing of 0.246 nm ascribed to the (211) plane of Ag3PO4, and the other lattice fringe of 0.336 nm consistent with the (110) plane of SnO2 [48,51]. The results above confirm the formation of the Ag3PO4/SnO2 heterojunction.

XPS was utilized to further analyze the elemental compositions of the as-prepared samples (Figure 5). In the wide-scan, sharp peaks of Sn, Ag, P, O and C are detected in Ag3PO4/SnO2/CC (Figure 5a). Analysis of the XPS spectrum for Sn 3d, Ag 3d, and P 2p is shown in Figure 5b–d. The peaks located at 486.5 and 494.8 eV (Figure 5b), can be indexed to Sn 3d5/2 and Sn 3d3/2 in SnO2 [52]. Meanwhile, two sharp peaks at 367.7 and 373.8 eV (Figure 5c), can be ascribed to Ag 3d3/2 and Ag 3d5/2 of Ag+ ions, respectively [16]. The characteristic peak (P 2p) at 132.8 eV (Figure 5d), corresponds to P5+.
according to previous literature [18]. All these characterizations implied that the Ag₃PO₄/SnO₂/CC heterojunction was successfully prepared.

![TEM image of Ag₃PO₄/SnO₂/CC (a). HRTEM image of Ag₃PO₄/SnO₂/CC (b).](image)

**Figure 4.** TEM image of Ag₃PO₄/SnO₂/CC (a). HRTEM image of Ag₃PO₄/SnO₂/CC (b).

![XPS spectra of the Ag₃PO₄/SnO₂/CC: (a) survey spectrum, (b) Sn 3d, (c) Ag 3d, (d) P 2p.](image)

**Figure 5.** XPS spectra of the Ag₃PO₄/SnO₂/CC: (a) survey spectrum, (b) Sn 3d, (c) Ag 3d, (d) P 2p.

Figure 6a shows the UV-vis diffuse reflectance spectra of SnO₂, Ag₃PO₄, Ag₃PO₄/CC, SnO₂/CC and Ag₃PO₄/SnO₂/CC. As illustrated in Figure 6a, Ag₃PO₄ showed photoabsorption in the visible light region, and SnO₂ demonstrated no absorption of visible light. SnO₂/CC was similar to the absorption edge of pure SnO₂, while there was an obvious absorption tail in the long-wavelength region (400–800 nm), which could have resulted from the scattering and absorption of light among the texture and pore structure in CC [41]. Ag₃PO₄/CC differs from the absorption edge of pure Ag₃PO₄ in the short-wavelength region (200–400 nm). This may be related to the low content of Ag₃PO₄ deposited on carbon cloth. The obtained Ag₃PO₄/SnO₂/CC heterojunction performs a wide and strong absorption in the visible region, and it also has an increased absorption tail in the long-wavelength region (400–800 nm). Figure 6b displays the corresponding Tauc’s plots of (αhν)² vs. (hν) of Ag₃PO₄ and SnO₂, which showed that the band gap of Ag₃PO₄ and SnO₂ was estimated to be 2.42 and 3.6 eV, respectively.

![UV-vis diffuse reflectance spectra of the as-prepared samples (a). Plots of (αhν)² versus energy (hν) of the as-prepared Ag₃PO₄ and SnO₂ (b).](image)

**Figure 6.** UV-vis diffuse reflectance spectra of the as-prepared samples (a). Plots of (αhν)² versus energy (hν) of the as-prepared Ag₃PO₄ and SnO₂ (b).
3.2. Photocatalytic Performance

The photocatalytic performances of the synthesized SnO2/CC, Ag3PO4/CC, and Ag3PO4/SnO2/CC samples were evaluated by photodegradation of the RhB and MB aqueous solution under visible light irradiation at room temperature. The RhB and MB are the popular probe molecule in heterogeneous catalytic reactions, showing the absorption peak at around 554 nm and 663 nm in the absorption spectra, respectively. The adsorption activities of the as-synthesized samples were evaluated prior to irradiation, and the results are shown in the Supplementary Materials Figure S1. After treatment for 60 min, all the samples reached adsorption saturation. Figure 7a shows the relationship between the concentration of RhB solution (C/C0) and visible light irradiation time for the synthesized samples, where C0 represents the initial concentration of RhB after adsorption equilibrium, and C represents the corresponding concentration at a certain time interval. It was clearly observed that the RhB solution, without the photocatalyst, shows only a little degradation under visible light irradiation. This reveals that the RhB solution, without the photocatalyst, is very stable under visible light irradiation. As can be seen in Figure 7b, the degradation rate of the synthesized Ag3PO4/SnO2/CC sample at 70 min is about 95.9%, which is much higher than that of the synthesized Ag3PO4/SnO2 (79.2%), Ag3PO4/CC (54.3%) and SnO2/CC (7.7%) samples. The results show that the RhB solution can be almost completely degraded by the Ag3PO4/SnO2/CC sample under visible light irradiation. However, only a certain percentage of the RhB solution can be degraded by the Ag3PO4/CC and SnO2/CC samples under the same conditions. Figure 7c shows the plot of the photodegradation rate constant of RhB versus degradation time. This reaction follows the pseudo-first-order reaction kinetic, which can be expressed as ln(C/C0) = −kt, where k and t represent the reaction rate constant and the reaction time, respectively. As illustrated in Figure 7d, the calculated k for the degradation of RhB over Ag3PO4/SnO2/CC is 0.04716 min⁻¹, which is higher than those calculated for the reactions over Ag3PO4/SnO2 (0.02283 min⁻¹), Ag3PO4/CC (0.0113 min⁻¹) and SnO2/CC (0.00117 min⁻¹).

As shown in Figure 8a, the Ag3PO4/SnO2/CC heterojunction exhibited the highest degradation rate of MB (96.6%) under visible light irradiation within 70 min, which is far more than that of other catalysts. The reaction kinetics of MB photodegradation by various photocatalysts is also performed (Figure 8b). The value of k is determined to be 0.04916 min⁻¹, 0.0263 min⁻¹, 0.01347 min⁻¹, 0.00401 min⁻¹, and 0.00306 min⁻¹ for the Ag3PO4/SnO2/CC, Ag3PO4/SnO2, Ag3PO4/CC, SnO2/CC, and MB without a catalyst, respectively. The above results indicate that the photocatalytic efficiency of the sample significantly improved, when Ag3PO4 particles are deposited on the surface of SnO2/CC.

![Figure 7](image_url)

**Figure 7.** Time-course variation of C/C0 of RhB over various catalysts (a). The degradation rate of various catalysts (b). The plots of ln(C/C0) versus time of various catalysts (c). The calculated k for the degradation of RhB over various catalysts (d).
would migrate quickly to the surface of the carbon cloth, because of the one-dimensional structured Ag(BQ, 1.0 mmol) photocatalytic electrons in the CB of Ag3PO4 directly decompose the RhB into CO2, H2O, and other inorganic molecules [47].

Figure 8. (a) Time-course variation of C/C0 of MB over various catalysts, (b) The plots of ln(C0/C) versus time of various catalysts.

The stability and recycling of the Ag3PO4/SnO2/CC heterojunction were further analyzed and are shown in Figure 9a. After three cycling runs, the Ag3PO4/SnO2/CC photocatalysts still possess a high photocatalytic efficiency, up to 79.7%. The SEM image of Ag3PO4/SnO2/CC after photocatalysis is shown in the Supplementary Materials Figure S2, and the structure and morphology of Ag3PO4/SnO2/CC is still well-preserved. To further study the dominant reactive species in photodegradation, radical trapping experiments of Ag3PO4/SnO2/CC were carried out. In this experiment, benzoquinone (BQ, 1.0 mmol/L), ammonium oxalate (AO, 1.0 mmol/L), and isopropyl alcohol (IPA, 0.5 mL) were used as scavengers for -O2-, h+ and -OH, respectively [41]. The experimental results are displayed in Figure 9b, where 83.7%, 65.5% and 41.1% of RhB was degraded when the BQ, IPA and AO were added, respectively. This indicates that the photocatalytic reaction mainly depends on the h+, while -O2- and -OH only have a slight effect. Therefore, the highly enhanced photodegradation achieved on Ag3PO4/SnO2/CC can be assigned to its heterostructure.

Based on the experimental results above, a possible mechanism for highly efficient electron-hole separation is proposed, to explain the improved visible light photocatalytic properties of the Ag3PO4/SnO2/CC sample, as illustrated in Figure 10. The band structure of Ag3PO4 and SnO2 in the figure is drawn based on the data previously reported in other papers [36,38,51,53,54]. For the Ag3PO4/SnO2/CC heterojunction, the conduction band (CB) and valence band (VB) edge potentials of Ag3PO4 are more negative than that of SnO2 [36]. It is well-known that SnO2 has no absorption for degrading RhB molecules, and the holes remaining at the VB of SnO2 can generate excited-state electrons and holes under visible light irradiation [56]. When the sample is under the visible light irradiation, the excited-state electrons in the CB of Ag3PO4 can easily be transferred to the surface of SnO2. Subsequently, electrons would migrate quickly to the surface of the carbon cloth, because of the one-dimensional structured SnO2 nanorods and excellent conductivity of the carbon cloth [42]. This further improves the separation efficiency of photogenerated electron-hole pairs. Eventually, the electrons in the carbon cloth reduce O2 to produce -O2- for degrading RhB molecules, and the holes remaining at the VB of Ag3PO4 directly decompose the RhB into CO2, H2O, and other inorganic molecules [47].
In order to reveal the separation and recombination of photogenerated electron-hole pairs of catalysts, Supplementary Materials Figure S3 shows the PL spectra of Ag₃PO₄/CC and Ag₃PO₄/SnO₂/CC heterojunction. Generally, the lower PL intensity means that there is lower recombination of the photoinduced electron-hole pairs [57]. As shown in Supplementary Materials Figure S3, the PL intensity of Ag₃PO₄/SnO₂/CC heterojunction is weaker, when compared with that of Ag₃PO₄/CC, which can be attributed to the formation of the heterojunction between Ag₃PO₄ and SnO₂ on carbon cloth.

Furthermore, it can be seen from Supplementary Materials Table S1 [37, 58, 59] that the photocatalytic performance of the Ag₃PO₄/SnO₂/CC heterojunction is much better than most of the results previously reported. This phenomenon is mainly caused by the following factors: Above all, the Ag₃PO₄/SnO₂/CC heterojunction can effectively separate photogenerated electron-hole pairs, thereby improving the photocatalytic performance of the catalyst. Moreover, the carbon cloth with a large specific surface area serves as support for Ag₃PO₄/SnO₂, which can help increase the specific surface area of the photocatalyst, thereby increasing the contact area of the catalyst with dye solution and visible light. As shown in Supplementary Materials Figure S4, the specific surface area of the photocatalyst has been significantly improved when introducing carbon cloth substrates.

4. Conclusions

In summary, the Ag₃PO₄/SnO₂/CC heterojunction was successfully prepared via a facile two-step method. The structure and morphology characterization results of the as-prepared samples were described in detail. It can be clearly observed that many Ag₃PO₄ particles with irregular shapes are deposited on the surface of SnO₂/CC, forming the heterojunction. In the experiments using dye treatments, the Ag₃PO₄/SnO₂/CC heterojunction reveals a higher photocatalytic performance for removing various contaminants (Rhb, MB), than that of other as-prepared samples after 70 min under visible irradiation. This is mainly attributed to synergistic effects between the Ag₃PO₄ and SnO₂ on carbon cloth, which can facilitate charge transfer and suppress the recombination of photogenerated electron-hole pairs, leading to the enhanced photocatalytic performance. Notably, the catalyst stability was maintained after three cycles. The structure and morphology of Ag₃PO₄/SnO₂/CC after photocatalysis was still well-preserved. This indicates that the Ag₃PO₄/SnO₂/CC heterojunction is a competitive candidate as an excellent photocatalyst, which has a high practical significance and application value for the future.

Supplementary Materials: The following are available online at http://www.mdpi.com/2076-3417/10/9/3238/s1. Figure S1: The adsorption ability of the as-synthesized samples in the dark, Figure S2. The SEM image of Ag₃PO₄/SnO₂/CC after photocatalysis. Figure S3. PL spectra of Ag₃PO₄/CC and Ag₃PO₄/SnO₂/CC, Figure S4. Nitrogen adsorption-desorption isotherms of Ag₃PO₄/SnO₂ and Ag₃PO₄/SnO₂/CC, Table S1: Photocatalytic performance comparison of this work versus the previous published results.

Author Contributions: M.L. and G.W. conceived and designed the experiments; P.X. performed the experiments; Y.Z. and W.L. conducted sample characterizations. All authors participated in analysis of the experimental data and discussions of the results, as well as editing the manuscript. All authors have read and agreed to the published version of the manuscript.

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**References**

1. Xue, H.; Chen, Q.; Jiang, F.; Yuan, D.; Lv, G.; Liang, L.; Liu, L.; Hong, M. A regenerative metal-organic framework for reversible uptake of Cd (II): From effective adsorption to in situ detection. *Chem. Sci.* 2016, 7, 5983–5988. [CrossRef] [PubMed]

2. Desai, A.V.; Manna, B.; Karmakar, A.; Sahu, A.; Ghosh, S.K. A water-stable cationic metal-organic framework as a dual adsorbent of o xoanion pollutants. *Angew. Chem. Int. Ed.* 2016, 55, 7811–7815. [CrossRef] [PubMed]

3. Duan, S.; Li, J.; Liu, X.; Wang, Y.; Zeng, S.; Shao, D.; Hayat, T. HF-free synthesis of nanoscale metal-organic framework NMIL-100(Fe) as an efficient dye adsorbent. *ACS Sustain. Chem. Eng.* 2016, 4, 3368–3378. [CrossRef]

4. Wang, B.; Lv, X.-L.; Feng, D.; Xie, L.-H.; Zhang, J.; Li, M.; Xie, Y.; Li, J.-R.; Zhou, H.-C. Highly stable Zr(IV)-based metal–organic frameworks for the detection and removal of antibiotics and organic explosives in water. *J. Am. Chem. Soc.* 2016, 138, 6204–6216. [CrossRef]

5. Xu, P.; Shen, X.; Luo, L.; Shi, Z.; Liu, Z.; Chen, Z.; Zhu, M.; Zhang, L. Preparation of TiO2/Bl2WO6 nanostructured heterojunctions on carbon fibers as a weaveable visible-light photocatalyst/photoelectrode. *Environ. Sci. Nano.* 2018, 5, 327–337. [CrossRef]

6. Li, Y.-F.; Liu, Z.-P. Particle size, shape and activity for photocatalysis on titania anatase nanoparticles in aqueous surroundings. *J. Am. Chem. Soc.* 2011, 133, 15743–15752. [CrossRef]

7. Li, Z.; Luo, W.; Zhang, M.; Feng, J.; Zou, Z. Photoelectrochemical cells for solar hydrogen production: Current state of promising photoelectrodes, methods to improve their properties, and outlook. *Energy Environ. Sci.* 2013, 6, 347–370. [CrossRef]

8. Huang, Q.; Li, J. Enhanced photocatalytic and SERS properties of ZnO/Ag hierarchical multipods-shaped nanocomposites. *Mater. Lett.* 2017, 204, 85–88. [CrossRef]

9. Chen, X.; Liu, L.; Yu, P.Y.; Mao, S.S. Increasing solar absorption for photocatalysis with black hydrogenated titanium dioxide nanocrystals. *Science 2011*, 331, 746–750. [CrossRef]

10. Li, X.; Xia, T.; Xu, C.; Murowchick, J.; Chen, X. Synthesis and photoactivity of nanostructured CdS–TiO2 composite catalysts. *Catal. Today 2014*, 225, 64–73. [CrossRef]

11. Liu, M.; Xu, P.; Zhang, J.; Liu, B. Preparation of MoS2@ZnO heterostructure with enhanced photocatalytic activity. *Mater. Res. Express* 2019, 6, 045504. [CrossRef]

12. Du, Y.; Zhang, N.; Wang, C. Photo-catalytic degradation of trifluralin by SnO2-doped Cu2O crystals. *Catal. Commun.* 2010, 11, 670–674. [CrossRef]

13. Zhang, T.; Liu, Y.; Rao, Y.; Li, X.; Yuan, D.; Tang, S.; Zhao, Q. Enhanced photocatalytic activity of TiO2 with acetylene black and persulfate for degradation of tetracycline hydrochloride under visible light. *Chem. Eng. J.* 2020, 384, 123350. [CrossRef]

14. Wei, R.-B.; Huang, Z.-L.; Gu, G.-H.; Wang, Z.; Zeng, L.; Chen, Y.; Liu, Z.-Q. Dual-cocatalysts decorated rimois CdS spheres advancing highly-efficient visible-light photocatalytic hydrogen production. *Appl. Catal. B 2018*, 231, 101–107. [CrossRef]

15. Xu, J.-W.; Gao, Z.-D.; Han, K.; Liu, Y.; Song, Y.-Y. Synthesis of magnetically separable Ag3PO4/TiO2/Fe3O4 heterostructure with enhanced photocatalytic performance under visible light for photoinactivation of bacteria. *ACS Appl. Mater. Interfaces* 2014, 6, 15122–15131. [CrossRef]

16. Liu, L.; Qi, Y.; Lu, J.; Lin, S.; An, W.; Liang, Y.; Cui, W. A stable Ag3PO4@g-C3N4 hybrid core@shell composite with enhanced visible light photocatalytic degradation. *Appl. Catal. B 2016*, 183, 133–141. [CrossRef]

17. Li, N.; Miao, S.; Zheng, X.; Lai, J.; Lv, S.; Gu, X.; Zhang, M.; Yang, J.; Cui, S. Construction of Ag3PO4/BiNbO4 heterojunction photocatalysts with high activity for rhodamine B removal under simulated sunlight irradiation. *Ceram. Int.* 2019, 45, 24260–24268. [CrossRef]

18. Shao, N.; Wang, J.; Wang, D.; Corvini, P. Preparation of three-dimensional Ag3PO4/TiO2@MoS2 for enhanced visible-light photocatalytic activity and anti-photocorrosion. *Appl. Catal. B 2017*, 203, 964–978. [CrossRef]
19. Chen, F.; Yang, Q.; Li, X.; Zeng, G.; Wang, D.; Niu, C.; Zhao, J.; An, H.; Xie, T.; Deng, Y. Hierarchical assembly of graphene-bridged Ag$_3$PO$_4$/Ag/BiVO$_4$ (040) Z-scheme photocatalyst: An efficient, sustainable and heterogeneous catalyst with enhanced visible-light photoactivity towards tetracycline degradation under visible light irradiation. *Appl. Catal. B* 2017, 200, 330–342. [CrossRef]

20. Liu, L.; Ding, L.; Liu, Y.; An, W.; Lin, S.; Liang, Y.; Cui, W. A stable Ag$_3$PO$_4$@PANI core@shell hybrid: Enrichment photocatalytic degradation with π-π conjugation. *Appl. Catal. B* 2017, 201, 92–104. [CrossRef]

21. Yu, H.; Cao, G.; Chen, F.; Wang, X.; Yu, J.; Lei, M. Enhanced photocatalytic performance of Ag$_3$PO$_4$ by simtaneous loading of Ag nanoparticles and Fe (III) cocatalyst. *Appl. Catal. B* 2014, 160, 658–665. [CrossRef]

22. Wang, W.; Sun, K.; Liu, H. E...

23. Liu, L.; Ding, L.; Liu, Y.; An, W.; Lin, S.; Liang, Y.; Cui, W. A stable Ag$_3$PO$_4$@PANI core@shell hybrid: Enrichment photocatalytic degradation with π-π conjugation. *Appl. Catal. B* 2017, 201, 92–104. [CrossRef]

24. Reddy, C.V.; Babu, B.; Vattikuti, S.V.P.; Ravikumar, R.V.S.S.N.; Shim, J. Structural and optical properties of vanadium doped SnO$_2$ nanoparticles and Fe (III) cocatalyst. *J. Mater. Chem.* 2012, 22, 2140–2148. [CrossRef]

25. Li, X.; Hu, H.; Xu, L.; Cui, C.; Qian, D.; Li, S.; Zhu, W.; Wang, P.; Lin, P.; Pan, J.; et al. Z-schematic water splitting by the synergistic effect of a type-II heterostructure and a highly efficient oxygen evolution catalyst. *Appl. Surf. Sci.* 2018, 441, 61–68. [CrossRef]

26. Cai, L.; Jiang, H.; Wang, L. Enhanced photo-stability and photocatalytic activity of Ag$_3$PO$_4$ via modification with BiPO$_4$ and polypyrrole. *Appl. Surf. Sci.* 2017, 420, 43–52. [CrossRef]

27. An, Y.; Zheng, F.; Ma, X. Preparation and visible-light photocatalytic properties of the floating hollow glass microspheres-TiO$_2$/Ag$_3$PO$_4$ composites. *RSC Adv.* 2019, 9, 721–729. [CrossRef]

28. Wan, Q.; Wang, T.H. Single-crystalline Sb-doped SnO$_2$ nanowires: Synthesis and gas sensor application. *Chem. Commun.* 2005, 30, 3841–3843. [CrossRef]

29. Liu, Z.; Sun, D.D.; Guo, P.; Leckie, J.O. An efficient bicomponent TiO$_2$/SnO$_2$ nanofiber photocatalyst fabricated by electrospinning with a side-by-side dual spinneret method. *Nano Lett.* 2007, 7, 1081–1085. [CrossRef]

30. Wang, C.; Zhou, Y.; Ge, M.; Xu, X.; Zhang, Z.; Jiang, J.Z. Large-scale synthesis of SnO$_2$ nanosheets with high lithium storage capacity. *J. Am. Chem. Soc.* 2010, 132, 46–47. [CrossRef]

31. Wang, H.; Fu, F.; Zhang, F.; Wang, H.-E.; Kershaw, S.V.; Xu, J.; Sun, S.-G.; Rogach, A.L. Hydrothermal synthesis of hierarchical SnO$_2$ microspheres for gas sensing and lithium-ion batteries applications: Fluoride-mediated formation of solid and hollow structures. *J. Mater. Chem.* 2012, 22, 2140–2148. [CrossRef]

32. Tian, W.; Zhang, C.; Zhai, T.; Li, S.-L.; Wang, X.; Liao, M.; Tsukagoshi, K.; Golberg, D.; Bando, Y. Flexible SnO$_2$ hollow nanosphere film based high-performance ultraviolet photodetector. *Chem. Commun.* 2013, 49, 3739–3741. [CrossRef] [PubMed]

33. Zhang, H.; Feng, J.; Fei, T.; Liu, S.; Zhang, T. SnO$_2$ nanoparticles-reduced graphene oxide nanocomposites for NO$_2$ sensing at low operating temperature. *Sens. Actuators B Chem.* 2014, 190, 472–478. [CrossRef]

34. Reddy, C.V.; Babu, B.; Vattikuti, S.V.P.; Ravikumar, R.V.S.S.N.; Shim, J. Structural and optical properties of vanadium doped SnO$_2$ nanoparticles with high photocatalytic activities. *J. Lumin.* 2016, 179, 26–34. [CrossRef]

35. Lu, Z.; Luo, Y.; He, M.; Huo, P.; Chen, T.; Shi, W.; Yan, Y.; Pan, J.; Ma, Z.; Yang, S. Preparation and performance of a novel magnetic conductive imprinted photocatalyst for selective photodegradation of antibiotic solution. *RSC Adv.* 2013, 3, 18373–18382. [CrossRef]

36. Zhang, L.; Zhang, H.; Huang, H.; Liu, Y.; Kang, Z. Ag$_3$PO$_4$/SnO$_2$ semiconductor nanocomposites with enhanced photocatalytic activity and stability. *New J. Chem.* 2012, 36, 1541–1544. [CrossRef]

37. Li, F.; Zhang, G.; Song, Y. Preparation and photocatalytic mechanism of Ag$_3$PO$_4$/SnO$_2$ Composite Photocatalyst. *Nano* 2019, 14, 1950092. [CrossRef]

38. Chen, K.; Cao, M.; Ding, C.; Zheng, X. A green approach for the synthesis of novel Ag$_3$PO$_4$/SnO$_2$/porcine bone and its exploitation as a catalyst in the photodegradation of lignosulfonate into alkyl acids. *RSC Adv.* 2018, 8, 26782–26792. [CrossRef]

39. Amornpitoksu, P.; Suwanboon, S.; Kaorvaphong, S. Photocatalytic activity of AgCl/SnO$_2$ prepared by one-pot green synthesis. *Sustain. Chem. Pharm.* 2019, 14, 100190. [CrossRef]

40. Huang, S.; Chen, J.; Zhong, J.; Li, J.; Hu, W.; Li, M.; Huang, K.; Duan, R. Enhanced photocatalytic performance of Ag/AgCl/SnO$_2$ originating from efficient formation of O$_2$. *Mater. Chem. Phys.* 2017, 201, 35–41. [CrossRef]
41. Shen, X.; Zhang, T.; Xu, P.; Zhang, L.; Liu, J.; Chen, Z. Growth of C$_3$N$_4$ nanosheets on carbon-fiber cloth as flexible and macroscale filter-membrane-shaped photocatalyst for degrading the flowing wastewater. *Appl. Catal. B* 2017, 219, 425–431. [CrossRef]

42. Zhang, W.; Sun, Y.; Xiao, Z.; Li, W.; Li, B.; Huang, X.; Liu, X.; Hu, J. Heterostructures of CuS nanoparticle/ZnO nanorod arrays on carbon fibers with improved visible and solar light photocatalytic properties. *J. Mater. Chem. A* 2015, 3, 7304–7313. [CrossRef]

43. Xu, P.; Wang, G.; Yan, J.; Zhang, Z.; Xu, M.; Cai, S.; Ruan, X.; Deng, Z. Reversible and high-capacity SnO$_2$/carbon cloth composite electrode materials prepared by magnetron sputtering for Li-ion batteries. *Mater. Lett.* 2017, 190, 56–59. [CrossRef]

44. Shen, X.; Zhang, T.; Xu, P.; Zhang, L.; Liu, J.; Chen, Z. Growth of C$_3$N$_4$ nanosheets on carbon-fiber cloth by charge redistribution enhances performance in flexible anode for Li ion batteries. *Electrochim. Acta.* 2020, 330, 135312. [CrossRef]

45. Mei, J.; Zhang, D.; Li, N.; Zhang, M.; Gu, X.; Cui, S.; Yang, J. The synthesis of Ag$_3$PO$_4$/g-C$_3$N$_4$ nanocomposites and the application in the photocatalytic degradation of bisphenol A under visible light irradiation. *J. Alloys Compd.* 2018, 749, 715–723. [CrossRef]

46. Li, M.; Xu, P.; Wang, G.; Yan, J. SnO$_2$ Nanorod arrays grown on carbon cloth as a flexible bind-free electrode for high-performance lithium batteries. *J. Electron. Mater.* 2019, 48, 8206–8211. [CrossRef]

47. Liu, Y.; Wang, W.; Si, M.; Zhang, H. Carbon cloth-supported MoS$_2$/Ag$_2$S/Ag$_3$PO$_4$ composite with high photocatalytic activity and recyclability. *ChemCatChem* 2019, 11, 1017–1025.

48. Yan, J.; Tian, J.; Guan, W.; Qiao, Z.; Li, W.; You, J.; Huang, B. Ultra-low loading of Ag$_3$PO$_4$ on hierarchical In$_2$S$_3$ microspheres to improve the photocatalytic performance: The cocatalytic effect of Ag and Ag$_3$PO$_4$. *Appl. Catal. B* 2017, 202, 84–94. [CrossRef]

49. Wang, L.; Gu, X.; Zhao, L.; Wang, B.; Jia, C.; Xu, J.; Zhao, Y.; Zhang, J. ZnO@TiO$_2$ heterostructure arrays/carbon cloth by charge redistribution enhances performance in flexible anode for Li ion batteries. *Electrochim. Acta.* 2019, 295, 107–112. [CrossRef]

50. Mei, J.; Zhang, D.; Li, N.; Zhang, M.; Gu, X.; Miao, S.; Cui, S.; Yang, J. The synthesis of Ag$_3$PO$_4$/g-C$_3$N$_4$ nanocomposites and the application in the photocatalytic degradation of bisphenol A under visible light irradiation. *J. Alloys Compd.* 2018, 749, 715–723. [CrossRef]

51. Xu, M.; Yu, R.; Guo, Y.; Chen, C.; Han, Q.; Di, J.; Song, P.; Zheng, L.; Zhang, Z.; Yan, J.; et al. New strategy towards the assembly of hierarchical heterostructures of SnO$_2$/ZnO for NO$_2$ detection at a ppb level. *Inorg. Chem. Front.* 2019, 6, 2801–2809. [CrossRef]

52. Li, S.; Pan, J.; Li, H.; Liu, Y.; Ou, W.; Wang, J.; Song, C.; Zhao, W.; Zheng, Y.; Li, C. The transparent SnO$_2$/ZnO quantum dots/SnO$_2$ p-n junction towards the enhancement of photovoltaic conversion. *Chem. Eng. J.* 2019, 366, 305–312. [CrossRef]

53. Niu, M.; Huang, F.; Cui, L.; Huang, P.; Yu, Y.; Wang, Y. Hydrothermal synthesis, structural characteristics, and enhanced photocatalysis of SnO$_2$/α-Fe$_2$O$_3$ semiconductor nanoheterostructures. *ACS Nano* 2010, 4, 681–688. [CrossRef] [PubMed]

54. Xue, P.; Jia, S.; Chen, C.; Zhang, Z.; Yan, J.; Guo, Y.; Zhang, Y.; Zhao, W.; Yun, J.; Wang, Y. Microwave-assistant hydrothermal synthesis of SnO$_2@ZnO$ hierarchical nanostructures enhanced photocatalytic performance under visible light irradiation. *Mater. Res. Bull.* 2018, 106, 74–80. [CrossRef]

55. Chen, S.; Huang, D.; Zeng, G.; Xue, W.; Lei, L.; Xu, P.; Deng, R.; Li, J.; Cheng, M. In-situ synthesis of facet-dependent BiVO$_4$/Ag$_3$PO$_4$/PANI photocatalyst with enhanced visible-light-induced photocatalytic degradation performance: Synergism of interfacial coupling and hole-transfer. *Chem. Eng. J.* 2020, 382, 122840. [CrossRef]

56. He, Y.; Zhang, L.; Teng, B.; Fan, M. New application of Z-scheme Ag$_3$PO$_4$/g-C$_3$N$_4$ composite in converting CO$_2$ to fuel. *Environ. Sci. Technol.* 2015, 49, 649–656. [CrossRef]
Zhang, G.; Chen, D.; Li, N.; Xu, Q.; Li, H.; He, J.; Lu, J. SnS$_2$/SnO$_2$ heterostructured nanosheet arrays grown on carbon cloth for efficient photocatalytic reduction of Cr (VI). *J. Colloid Interface Sci.* **2018**, *514*, 306–315. [CrossRef]

Cui, Z.; Sun, Y.; Zhang, Z.; Xu, M.; Xin, B. Facile synthesis and photocatalytic activity of Ag$_3$PO$_4$ decorated MoS$_2$ nanoflakes on carbon fiber cloth. *Mater. Res. Bull.* **2018**, *100*, 345–352. [CrossRef]

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