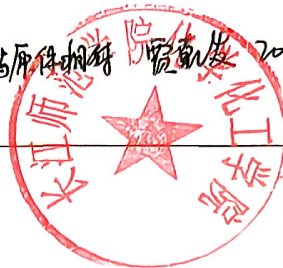


任现职以来以第一作者或 学校认可的通讯作者发表 论文情况



 **Quark 夸克**
高清扫描 还原文档

与原件相符 贾凯生 2026.9.10



科技检索报告

项目名称：孙晓瑞发表的论文在《SCI》数据库的收录情况

委托人：长江师范学院

委托日期：2025 年 09 月 15 日

查新机构（盖章）：教育部科技查新工作站 (L02)



完成日期：2025 年 09 月 16 日

教育部科技发展中心

二〇一三年制



项目名称	孙晓瑞发表的论文在《SCI》数据库收录情况					
查新机构	名称	教育部科技查新工作站(L02) 重庆大学科技查新站				
	通信地址	重庆大学			邮政编码	400044
	负责人	黄娟	电话	023-65106364	传真	023-65105224
	联系人	黄晓玲	电话	023-65106364		
	电子信箱	973184324@qq.com				
一、检索要求： 署名长江师范学院孙晓瑞发表的论文在《SCI》中的收录情况						
二、文献检索范围 《SCI-Expanded》 Science Citation Index Expanded 2021 年~2025 年						
三、检索结果： 根据用户委托，针对检索要求，通过数据库，对孙晓瑞发表的论文在《SCI》数据库中的收录引用情况进行检索，结论如下： 孙晓瑞发表的论文被《SCI》数据库收录 1 篇，为共同通讯作者。 论文的详细信息见附件。						



大学科技查新站
教育部科技查新工作站(L02)
重庆大学科技查新站
2025年09月16日
专用章

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一、所发论文期刊 JCR 分区如下

序号	篇名	刊名	影响因子
1	Photo-Fenton Process over an Fe-Free 3%-CuO/Sr0.76Ce0.16WO4 Photocatalyst under Simulated Sunlight	ACS OMEGA	4.132(2021)
	类别		分区
	CHEMISTRY, MULTIDISCIPLINARY (SCIE)		Q2

二、所发论文期刊中科院升级版分区如下

序号	题名	刊名	ISSN	Review	Open Access	年份
1	Photo-Fenton Process over an Fe-Free 3%-CuO/Sr0.76Ce0.16WO4 Photocatalyst under Simulated Sunlight	ACS OMEGA	2470-1343	否	是	2025
	类别	学科			分区	TOP 期刊
	大类分区	化学			3 区	否
	小类分区	CHEMISTRY, MULTIDISCIPLINARY 化学：综合			3 区	-

三、SCI 检索结果

第 1 条，共 1 条

文献标题: Photo-Fenton Process over an Fe-Free 3%-CuO/Sr0.76Ce0.16WO4 Photocatalyst under Simulated Sunlight

作者: Fu, MY (Fu, Mingyan); Yang, J (Yang, Jia); Sun, XR (Sun, Xiaorui); Tian, W (Tian, Wei); Yin, GH (Yin, Guihua); Tian, S (Tian, Sheng); Tan, MD (Tan, Mingdan); Liu, HF (Liu, Hongfu); Xing, XF (Xing, Xiaofeng); Huang, HS (Huang, Huisheng)

文献类型: Article

来源出版物: ACS OMEGA 出版年: OCT 19 2021 卷: 6 期: 41 页: 27297-27304 DOI:

10.1021/acsomega.1c04107 提前访问日期: OCT 2021

Web of Science 核心库的“被引频次”: 4

被引频次合计: 5

使用次数 (2013 年至今): 17

引用的参考文献数: 40

摘要: Photo-Fenton is a promising photocatalytic technology that utilizes sunlight. Herein, an Fe-free 3%-CuO/Sr0.76Ce0.16WO4 photocatalyst was synthesized to apply simulated wastewater degradation via a photo-Fenton process under simulated sunlight. The photodegradation efficiency of RhB solution over the 3%-CuO/Sr0.76Ce0.16WO4 photocatalyst is 93.2% in the first 3 h; its photocatalytic efficiency remains at 91.6% even after three cycle experiments. The kinetic constant of the 3%-CuO/Sr0.76Ce0.16WO4 photocatalyst is 0.0127 min⁻¹, which is 2.8-fold that of an intrinsic Sr0.76Ce0.16WO4 sample. The experiment of radical quenching revealed that the photogenerated electrons and holes are transferred to CuO to form hydroxyl radicals. Besides, the photocatalyst was characterized by scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), diffused reflectance spectroscopy (DRS), and X-ray photoelectron spectroscopy (XPS) measurements. It has some reference significance for the design of iron-free photocatalysts.

入藏号: WOS:000710449700048

PubMed ID: 34693150

语言: English

KeyWords Plus: HYDROGEN-PEROXIDE; QUANTUM DOTS; DEGRADATION; WATER; OXYGEN; NANOSHEETS; OXIDATION

作者地址: [Fu, Mingyan; Yang, Jia; Sun, Xiaorui; Tian, Wei; Yin, Guihua; Tian, Sheng; Tan, Mingdan; Liu, Hongfu; Xing, Xiaofeng; Huang, Huisheng] Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorganic Special Funct Mat, Chongqing 408100, Peoples R China



通讯作者地址: [Yang, Jia; Sun, Xiaorui] (corresponding author), Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China

电子邮件地址: yangjiayznu@163.com;sunxiaoruiyznu@163.com

Affiliation: ["Yangtze Normal University"]

出版商: AMER CHEMICAL SOC

出版商地址: 1155 16TH ST, NW, WASHINGTON, DC 20036 USA

Web of Science Index: Science Citation Index Expanded (SCI-EXPANDED)

Web of Science 类别: Chemistry, Multidisciplinary

研究方向: Chemistry

IDS 号: WL5MS

ISSN: 2470-1343

ISO 来源出版物缩写: ACS OMEGA

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基金资助机构	授权号
Chongqing Municipal Education Commission	['KJQN202101405', 'CXQT20026']
Talent Introduction Project of Yangtze Normal University	['2017KYQD22']

基金资助正文: This work was financially supported by Chongqing Municipal Education Commission (KJQN202101405 and CXQT20026) and Talent Introduction Project of Yangtze Normal University (2017KYQD22). The authors would like to thank Ting Du from Shiyanjia Lab (www.shiyanjia.com) for SEM analysis.

ESI 高被引论文: N

ESI 热点论文: N

输出日期: 2025 年 09 月 16 日

查新站





科技检索报告

项目名称：孙晓瑞发表的论文在《SCI》数据库的收录情况

委托人：长江师范学院

委托日期：2025 年 09 月 11 日

查新机构（盖章）：教育部科技查新工作站（L02）



完成日期：2025 年 09 月 12 日

教育部科技发展中心

二〇一三年制



项目名称	孙晓瑞发表的论文在《SCI》数据库收录情况					
查新机构	名称	教育部科技查新工作站(L02) 重庆大学科技查新站				
	通信地址	重庆大学			邮政编码	400044
	负责人	黄娟	电话	023-65106364	传真	023-65105224
	联系人	蔡佳	电话	023-65106364		
	电子信箱	984100324@qq.com				
一、检索要求： 署名长江师范学院孙晓瑞发表的论文在《SCI》中的收录情况						
二、文献检索范围 《SCI-Expanded》 Science Citation Index Expanded 2022 年～2025 年						
三、检索结果： 根据用户委托，针对检索要求，通过数据库，对孙晓瑞发表的论文在《SCI》数据库中的收录引用情况进行检索，结论如下： 孙晓瑞发表的论文被《SCI》数据库收录 6 篇，均为第一作者。论文在 Web Of Science 核心合集中被引共计 23 频次，他引共计 10 频次，他引期刊种数共计（未去重）9 种，他引作者人数共计（未去重）58 人。 论文的详细信息见附件。						
大学科技查新站 教育部科技查新工作站(L02) 重庆大学科技查新站 2025 年 09 月 12 日 专用章						

重庆大学



一、 所发论文期刊 JCR 分区如下

序号	篇名	刊名	影响因子
1	The photocatalytic performances of Bi2MTaO7 (M = Ga, In) photocatalysts for environmental cleaning under visible-light	INORGANIC CHEMISTRY COMMUNICATIONS	3.8(2022)
	类别	分区	
	CHEMISTRY, INORGANIC & NUCLEAR (SCIE)	Q1	
2	C3N4/Cu/ZnFe2O4 Ternary Nanocomposites: Removal of Environmental Pollutants by the Synergy of Physical Adsorption and Photocatalysis	CHEMISTRYSELECT	2.1(2022)
	类别	分区	
	CHEMISTRY, MULTIDISCIPLINARY (SCIE)	Q3	
3	A highly stable Au@InGaZnO4 composite split water under simulated sunlight	MATERIALS LETTERS	3.0(2022)
	类别	分区	
	PHYSICS, APPLIED (SCIE)	Q2	
	MATERIALS SCIENCE, MULTIDISCIPLINARY (SCIE)	Q3	
4	Ternary Nanocomposites of Copper/graphitic-Phase Carbon Nitride/rare-Earth Pentaborate for Photocatalytic Applications Under Simulated Sunlight Illumination	CHEMISTRYSELECT	2.0(2024)
	类别	分区	
	CHEMISTRY, MULTIDISCIPLINARY (SCIE)	Q3	
5	Two Novel Visible-Light-Active Borate Composites Photocatalysts: 2 %Pt/Gd0.85Ce0.15B5O9 and 2.5 %CuO/Gd0.90Ce0.10B5O9	CHEMISTRYSELECT	2.0(2024)
	类别	分区	
	CHEMISTRY, MULTIDISCIPLINARY (SCIE)	Q3	
6	A Mini Review on Borate Photocatalysts for Water Decomposition: Synthesis, Structure, and Further Challenges	MOLECULES	4.6(2024)
	类别	分区	
	CHEMISTRY, MULTIDISCIPLINARY (SCIE)	Q2	
	BIOCHEMISTRY & MOLECULAR BIOLOGY (SCIE)	Q2	

二、 所发论文期刊中科院升级版分区如下

序号	题名	刊名	ISSN	Review	Open Access	年份
1	The photocatalytic performances of Bi2MTaO7 (M = Ga, In) photocatalysts for environmental cleaning under visible-light	INORGANIC CHEMISTRY COMMUNICATIONS	1387-7003	否	否	2022
	类别	学科			分区	TOP 期刊
	大类分区	化学			4 区	否
	小类分区	CHEMISTRY, INORGANIC & NUCLEAR 无机化学与核化学			3 区	-



2	C3N4/Cu/ZnFe2O4 Ternary Nanocomposites: Removal of Environmental Pollutants by the Synergy of Physical Adsorption and Photocatalysis	CHEMISTRYSELE CT	2365-6549	否	否	2022
	类别	学科			分区	TOP 期刊
	大类分区	化学			4 区	否
	小类分区	CHEMISTRY, MULTIDISCIPLINARY 化学：综合			4 区	-
3	A highly stable Au@InGaZnO4 composite split water under simulated sunlight	MATERIALS LETTERS	0167-577X	否	否	2022
	类别	学科			分区	TOP 期刊
	大类分区	材料科学			3 区	否
	小类分区	PHYSICS, APPLIED 物理：应用			3 区	-
MATERIALS SCIENCE, MULTIDISCIPLINARY 材料科学：综合			4 区	-		
4	Ternary Nanocomposites of Copper/graphitic-Phase Carbon Nitride/rare-Earth Pentaborate for Photocatalytic Applications Under Simulated Sunlight Illumination	CHEMISTRYSELE CT	2365-6549	否	否	2025
	类别	学科			分区	TOP 期刊
	大类分区	化学			4 区	否
	小类分区	CHEMISTRY, MULTIDISCIPLINARY 化学：综合			4 区	-
5	Two Novel Visible-Light-Active Borate Composites Photocatalysts: 2 %Pt/Gd0.85Ce0.15 B5O9 and 2.5 %CuO/Gd0.90Ce0.10B5O9	CHEMISTRYSELE CT	2365-6549	否	否	2025
	类别	学科			分区	TOP 期刊
	大类分区	化学			4 区	否
	小类分区	CHEMISTRY, MULTIDISCIPLINARY 化学：综合			4 区	-



6	A Mini Review on Borate Photocatalysts for Water Decomposition: Synthesis, Structure, and Further Challenges	MOLECULES		否	是	2023
	类别	学科			分区	TOP 期刊
	大类分区	化学			2 区	否
	小类分区	BIOCHEMISTRY & MOLECULAR BIOLOGY 生化与分子生物学			3 区	-
		CHEMISTRY, MULTIDISCIPLINARY 化学：综合			3 区	-

三、SCI 检索结果

第 1 条，共 6 条

文献标题: The photocatalytic performances of Bi₂MTaO₇ (M = Ga, In) photocatalysts for environmental cleaning under visible-light

作者: Sun, XR (Sun, Xiaorui); Gu, MS (Gu, Mingshu); Yang, J (Yang, Jia); Ye, GH (Ye, Gaohong); Xiao, XG (Xiao, Xingguo); Chen, M (Chen, Min); Liu, MM (Liu, Miaomiao); Chen, ZL (Chen, Zuli); Huang, HS (Huang, Huisheng)

文献类型: Article

来源出版物: INORGANIC CHEMISTRY COMMUNICATIONS 出版年: MAY 2022 卷: 139 文

献号: 109390 DOI: 10.1016/j.inoche.2022.109390 提前访问日期: MAR 2022

Web of Science 核心库的“被引频次”: 8

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使用次数 (最近 180 天): 1

使用次数 (2013 年至今): 13

引用的参考文献数: 27

摘要: Herein, we present the Bi₂GaTaO₇ (BGTO) and Bi₂InTaO₇ (BITO) semiconductors as visible-light-driven photo catalysts for environmental cleaning, including photocatalytic oxidation of rhodamine B and reduction of dichromate ion. Experimental results show that both intrinsic and modified BGTO have better photocatalytic oxidation and reduction activities than that of BITO. The best cocatalysts for BGTO and BITO in photocatalytic degradation and reduction reactions are CuO and Ag, respectively, but the optimal amount is different. The kinetic constants of BGTO-3%Cu and BITO-2%Cu are 3.4-fold and 3.0-fold in comprise with the inherent BGTO and BITO, respectively. The kinetic constants of BGTO-4%Ag and BITO-4.5%Ag are 3.6-fold and 4.0-fold by comparing the intrinsic BGTO and BITO, respectively. The photocatalytic mechanisms of degradation and reduction reactions are also proposed in this paper.

入藏号: WOS:000788077500008

语言: English

作者关键词: Photocatalyst; Oxidation; Reduction; Rhodamine B; Dichromate ion; Semiconductors

KeyWords Plus: HYDROTHERMAL SYNTHESIS; WATER; PROPERTY

作者地址: [Sun, Xiaorui; Gu, Mingshu; Yang, Jia; Ye, Gaohong; Xiao, Xingguo; Chen, Min; Liu, Miaomiao; Chen, Zuli; Huang, Huisheng] Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China

通讯作者地址: [Yang, Jia; Huang, Huisheng] (corresponding author), Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China

电子邮件地址: yangjiayznu@163.com; h.s.huang@hotmail.com

Affiliation: ["Yangtze Normal University"]

作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Yang, Jia	ITU-9189-2023	



Yang, Jia	0000-0001-7404-096X
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Science and Technology Project of Chongqing Municipal Education Commission	['KJQN202101405', 'CXQT20026']

基金资助正文: Acknowledgment This work was financially supported by the Science and Technology Project of Chongqing Municipal Education Commission (KJQN202101405; CXQT20026) .
ESI 高被引论文: N
ESI 热点论文: N
输出日期: 2025 年 09 月 12 日

第 2 条, 共 6 条

文献标题: C3N4/Cu/ZnFe2O4 Ternary Nanocomposites: Removal of Environmental Pollutants by the Synergy of Physical Adsorption and Photocatalysis
作者: Sun, XR (Sun, Xiaorui);Liu, HF (Liu, Hongfu);Yang, J (Yang, Jia);Fu, MY (Fu, Mingyan);Tan, MD (Tan, Mingdan);Yin, GH (Yin, Guihua);Shi, WB (Shi, Wenbing);Huang, HS (Huang, Huisheng);Shi, JW (Shi, Jianwei)
文献类型: Article
来源出版物: CHEMISTRYSELECT 出版年: JAN 27 2022 卷: 7 期:4 文献号:e202103959 DOI: 10.1002/slct.202103959
Web of Science 核心库的“被引频次”: 5
被引频次合计: 5
使用次数 (最近 180 天): 1
使用次数 (2013 年至今): 20
引用的参考文献数: 19
摘要: Although binary composites can enhance the separation efficiency of photo-generated carriers to a certain extent, there is still space for further improvement. Here, we focus on using copper, a cheap transition metal, as an electron channel to improve the photo-generated carrier separation efficiency of ZnFe2O4 (ZFO) and C3N4 (CN) composites. The kinetic constants of sample 40 %-ZFO/CN for photodegradation reaction are 2.96 and 1.98 times than that of pure sample ZFO and CN under the same conditions. However, the kinetic constants of 3 %Cu@40 %-ZFO/CN are 7.33 and 4.92 times than that of pure sample ZFO and CN, respectively. This is probably due to the physical adsorption performances of ternary composites for pollutants are significantly stronger than those of binary composites. The best photocatalysts achieved 90 % degradation efficiency within 15 minutes. A more reasonable photocatalytic mechanism model was proposed. Photo-generated hole, superoxide anion, and hydroxyl radical all play an important role in the photocatalytic reaction. The importance of them is superoxide anion > photo-generated hole > singlet oxygen > hydroxyl radical from high to low.
入藏号: WOS:000747387800017
语言: English
作者关键词: Adsorption; Copper; Composites; Photocatalysis; Separation Efficiency
KeyWords Plus: DEGRADATION; WATER
作者地址: [Sun, Xiaorui; Liu, Hongfu; Yang, Jia; Fu, Mingyan; Tan, Mingdan; Yin, Guihua; Shi, Wenbing; Huang, Huisheng; Shi, Jianwei] Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing 408100, Peoples R China



[Sun, Xiaorui; Yang, Jia; Shi, Wenbing; Huang, Huisheng; Shi, Jianwei] Yangtze Normal Univ,
Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China
通讯作者地址: [Yang, Jia; Huang, Huisheng] (corresponding author), Yangtze Normal Univ, Coll
Chem & Chem Engn, Chongqing 408100, Peoples R China
[Yang, Jia; Huang, Huisheng] (corresponding author), Yangtze Normal Univ, Chongqing Key Lab
Inorgan Special Funct Mat, Chongqing 408100, Peoples R China
电子邮件地址: yangjiayznu@163.com; h.s.huang@hotmail.com
Affiliation: ["Yangtze Normal University", "Yangtze Normal University"]
作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Liu, Hongfu	AAL-1918-2020	
Yang, Jia		0000-0001-7404-096X
Yang, Jia	ITU-9189-2023	
Shi, Jianwei	ABF-7467-2020	

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Talent Introduction Project of Yangtze Normal University	['2017KYQD22']

基金资助正文: This work was financially supported by Chongqing Municipal Education
Commission (KJQN202101405; CXQT20026), Talent Introduction Project of Yangtze Normal
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ESI 热点论文: N
输出日期: 2025 年 09 月 12 日

第 3 条, 共 6 条

文献标题: A highly stable Au@InGaZnO4 composite split water under simulated sunlight
作者: Sun, XR (Sun, Xiaorui);Gu, MS (Gu, Mingshu);Yang, J (Yang, Jia);Liao, LS (Liao,
Lingshan);Tian, S (Tian, Sheng);Huang, HS (Huang, Huisheng)
文献类型: Article
来源出版物: MATERIALS LETTERS 出版年: MAY 15 2022 卷: 315 文献号:131958 DOI:
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Web of Science 核心库的“被引频次”: 7
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使用次数 (2013 年至今): 16
引用的参考文献数: 17

摘要: Herein, we reported a systematic investigation of splitting water over the InGaZnO4 (IGZO)
based composite materials. One IGZO sample which modified with gold nanoparticles had the ability
to generate hydrogen in simulated sunlight. The sample with an optimal H-2 generation rate is
2Au@IGZO, which is 2.1 times and 1.4 times than the intrinsic sample under the ultraviolet light and
simulated sunlight, respectively. This excellent photocatalytic performance can be attributed to the
effect of gold quantum dots around 8 nm in diameter. The composite still maintained almost no
attenuation of hydrogen generation performance after 55 h of ultraviolet light.



入藏号: WOS:000767840900002
语言: English
作者关键词: Photocatalysis; Composite materials; Hydrogen generation; Nanoparticles; Quantum dot
KeyWords Plus: PHOTOCATALYTIC ACTIVITY; NANOPARTICLES
作者地址: [Sun, Xiaorui; Gu, Mingshu; Yang, Jia; Liao, Lingshan; Tian, Sheng; Huang, Huisheng]
Yangtze Normal Univ, Chongqing Key Lab Inorgan Special Funct Mat, Coll Chem & Chem Engn, Chongqing 408100, Peoples R China
通讯作者地址: [Yang, Jia] (corresponding author), Yangtze Normal Univ, Chongqing Key Lab Inorgan Special Funct Mat, Coll Chem & Chem Engn, Chongqing 408100, Peoples R China
电子邮件地址: yangjiayznu@163.com
Affiliation: ["Yangtze Normal University"]
作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Yang, Jia	ITU-9189-2023	
Yang, Jia		0000-0001-7404-096X

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研究方向: Materials Science; Physics
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文献标题: Ternary Nanocomposites of Copper/graphitic-Phase Carbon Nitride/rare-Earth Pentaborate for Photocatalytic Applications Under Simulated Sunlight Illumination
作者: Sun, XR (Sun, Xiaorui);Chen, ZL (Chen, Zuli);Chen, M (Chen, Min);Li, Y (Li, Yan);Yang, J (Yang, Jia)
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摘要: A wide variety of borate materials are emerging as photocatalysts. Usually, the borates possess a large bandgap which limits their absorption of visible light, and the strategy of preparing nanocomposites is an effective way to enhance the absorption of light. X-ray powder diffraction, infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy were used to show that a three-component nanocomposites was successfully prepared. For the photo-degraded reactions of rhodamine B(RhB) and doxycycline hydrochloride(DH), the optimum



composition of the ternary composite is a molar ratio of Gd_{0.9}Ce_{0.1}B₅O₉(GCBO) and g-C₃N₄(CN) of 7 : 93, besides the mass of Cu is 2 % of the sum of the above two masses, and the ternary composite is abbreviated as 2Cu/CN@GCBO-7. The kinetic constant for the photodegradation of RhB of sample 2Cu/CN@GCBO-7 is 0.0580 min⁻¹, which is 3.6 and 3.8 times that of non-composite CN and GCBO. The mechanism postulated by free radical quenching experiments suggests that the importance of the three radicals is hole >(OH)-O-⋅>O-⋅(2)- in the photodegradation reaction. In addition, the kinetic constant for the photodegradation of DH of sample 2Cu/CN@GCBO-7 is 0.0018 min⁻¹, and the sample 2Cu/CN@GCBO-7 has a hydrogen evolution rate of 11.8 mu mol/h/g.

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语言: English

作者关键词: borate; nanocomposites; photocatalysis; photodegradation; graphitic-phase carbon nitride

KeyWords Plus: RHODAMINE-B; DEGRADATION

作者地址: [Sun, Xiaorui; Chen, Zuli; Chen, Min; Yang, Jia] Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China [Yang, Jia] Guilin Univ Technol, Coll Mat Sci & Engn, Guangxi Minist Prov Jointly Constructed Cultivat B, Guilin 541004, Peoples R China

[Li, Yan] Guilin Univ Technol, Coll Chem & Bioengn, Guangxi Key Lab Electrochem & Magnetochem Funct Ma, Guilin 541004, Peoples R China

通讯作者地址: [Yang, Jia] (corresponding author), Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China [Yang, Jia] (corresponding author), Guilin Univ Technol, Coll Mat Sci & Engn, Guangxi Minist Prov Jointly Constructed Cultivat B, Guilin 541004, Peoples R China

电子邮件地址: yangjiayznu@163.com

Affiliation: ["Yangtze Normal University", "Guilin University of Technology", "Guilin University of Technology"]

作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Yang, Jia		0000-0001-7404-096X
Yang, Jia	ITU-9189-2023	

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文献标题: Two Novel Visible-Light-Active Borate Composites Photocatalysts: 2 %Pt/Gd_{0.85}Ce_{0.15}B₅O₉ and 2.5 %CuO/Gd_{0.90}Ce_{0.10}B₅O₉



作者: Sun, XR (Sun, Xiaorui);Xie, YX (Xie, Yaxin);Liu, SM (Liu, Shumin);Li, Y (Li, Yan);Zhao, XF (Zhao, Xianfeng);Yang, J (Yang, Jia);Huang, HS (Huang, Huisheng)

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摘要: One of the important research components of photocatalytic research is the development of new photocatalysts, and recent studies have shown the rise of borate-type photocatalysts. This paper focuses on the photoreduction of potassium dichromate and the photodegradation of rhodamine B by two borate composites under simulated sunlight. A coral-like borate was obtained by sol-gel preparation and then assembled by photodeposition with Pt nanoparticles dots or CuO particles to obtain the new composites with excellent performance. The kinetic constants of photocatalytic properties of 2 %Pt/Gd0.85Ce0.15B5O9 and 2.5 %CuO/Gd0.90Ce0.10B5O9 samples in the reduction and degradation reactions are 0.0050 min⁻¹ and 0.0150 min⁻¹, which are 25 and 4.2 times of the intrinsic GdB5O9 sample respectively. The results of the study indicate the research promise of developing new visible photocatalysts based on borates, especially for photocatalytic applications for pollutant removal.

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作者地址: [Sun, Xiaorui; Xie, Yaxin; Liu, Shumin; Yang, Jia; Huang, Huisheng] Yangtze Normal Univ, Coll Chem & Chem Engr, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China

[Yang, Jia] Guilin Univ Technol, Coll Mat Sci & Engr, Guangxi Minist Prov Jointly Constructed Cultivat B, Guilin 541004, Peoples R China

[Li, Yan; Zhao, Xianfeng; Yang, Jia] Guilin Univ Technol, Coll Chem & Bioengn, Guangxi Key Lab Electrochem & Magnetochem Funct, Guilin 541004, Peoples R China

通讯作者地址: [Yang, Jia; Huang, Huisheng] (corresponding author), Yangtze Normal Univ, Coll Chem & Chem Engr, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China

[Yang, Jia] (corresponding author), Guilin Univ Technol, Coll Mat Sci & Engr, Guangxi Minist Prov Jointly Constructed Cultivat B, Guilin 541004, Peoples R China

[Yang, Jia] (corresponding author), Guilin Univ Technol, Coll Chem & Bioengn, Guangxi Key Lab Electrochem & Magnetochem Funct, Guilin 541004, Peoples R China

电子邮件地址: h.s.huang@hotmail.com; yangjiayznu@163.com

Affiliation: ["Yangtze Normal University", "Guilin University of Technology", "Guilin University of Technology"]

作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Yang, Jia		0000-0001-7404-096X
Xie, Yaxin	KEH-4726-2024	
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第 6 条, 共 6 条

文献标题: A Mini Review on Borate Photocatalysts for Water Decomposition: Synthesis, Structure, and Further Challenges

作者: Sun, XR (Sun, Xiaorui); Yang, J (Yang, Jia)

文献类型: Review

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摘要: The development of novel photocatalysts, both visible and UV-responsive, for water decomposition reactions is of great importance. Here we focused on the application of the borates as photocatalysts in water decomposition reactions, including water splitting reaction, hydrogen evolution half-reaction, and oxygen evolution half-reaction. In addition, the rates of photocatalytic hydrogen evolution and oxygen evolution by these borate photocatalysts in different water decomposition reactions were summarized. Further, the review summarized the synthetic chemistry and structural features of existing borate photocatalysts for water decomposition reactions. Synthetic chemistry mainly includes high-temperature solid-state method, sol-gel method, precipitation method, hydrothermal method, boric acid flux method, and high-pressure method. Next, we summarized the crystal structures of the borate photocatalysts, with a particular focus on the form of the B-O unit and metal-oxygen polyhedral in the borates, and used this to classify borate photocatalysts, which are rarely mentioned in the current photocatalysis literature. Finally, we analyzed the relationship between the structural features of the borate photocatalysts and photocatalytic performance to discuss the further challenges faced by the borate photocatalysts for water decomposition reactions.

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作者地址: [Sun, Xiaorui; Yang, Jia] Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China
[Yang, Jia] Guilin Univ Technol, Coll Mat Sci & Engn, MOE Key Lab New Proc Technol Nonferrous Met & Mat, Guilin 541004, Peoples R China

[Yang, Jia] Guangxi Univ Key Lab Nonferrous Met Oxide Elect Fu, Guangxi Key Lab Opt & Elect Mat & Devices, Guilin 541004, Peoples R China

通讯作者地址: [Yang, Jia] (corresponding author), Yangtze Normal Univ, Coll Chem & Chem Engn, Chongqing Key Lab Inorgan Special Funct Mat, Chongqing 408100, Peoples R China
[Yang, Jia] (corresponding author), Guilin Univ Technol, Coll Mat Sci & Engn, MOE Key Lab



New Proc Technol Nonferrous Met & Mat, Guilin 541004, Peoples R China
[Yang, Jia] (corresponding author), Guangxi Univ Key Lab Nonferrous Met Oxide Elect Fu,
Guangxi Key Lab Opt & Elect Mat & Devices, Guilin 541004, Peoples R China
电子邮件地址: sunxiaoruiyznu@163.com; yangjiayznu@163.com
Affiliation: ["Yangtze Normal University", "Guilin University of Technology", ""]
作者识别号:

作者	Web of Science ResearcherID	ORCID 号
Yang, Jia	ITU-9189-2023	
Yang, Jia		0000-0001-7404-096X

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1	The photocatalytic performances of Bi ₂ MTaO ₇ (M = Ga, In) photocatalysts for environmental cleaning under visible-light	INORGANIC CHEMISTRY COMMUNICATIO NS;139;MAY 2022	8	6	6	38
2	C ₃ N ₄ /Cu/ZnFe ₂ O ₄ Ternary Nanocomposites: Removal of Environmental Pollutants by the Synergy of Physical Adsorption and Photocatalysis	CHEMISTRYSELE CT;7 (4);JAN 27 2022	5	2	1	5
3	A highly stable Au@InGaZnO ₄ composite split water under simulated sunlight	MATERIALS LETTERS;315;MA Y 15 2022	7	1	1	6
4	Ternary Nanocomposites of Copper/graphitic-Phase Carbon Nitride/rare-Earth Pentaborate for Photocatalytic Applications Under Simulated Sunlight Illumination	CHEMISTRYSELE CT;9 (21);JUN 4 2024	0	0	0	0
5	Two Novel Visible-Light-Active Borate Composites Photocatalysts: 2 %Pt/Gd _{0.85} Ce _{0.15} B ₅ O ₉ and 2.5 %CuO/Gd _{0.90} Ce _{0.10} B ₅ O ₉	CHEMISTRYSELE CT;9 (22);JUN 11 2024	0	0	0	0



6	A Mini Review on Borate Photocatalysts for Water Decomposition: Synthesis, Structure, and Further Challenges	MOLECULES;29 (7);APR 2024	3	1	1	9
合计			23	10	9	58

试 卷



Photo-Fenton Process over an Fe-Free 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ Photocatalyst under Simulated Sunlight

Mingyan Fu, Jia Yang,* Xiaorui Sun,* Wei Tian, Guihua Yin, Sheng Tian, Mingdan Tan, Hongfu Liu, Xiaofeng Xing, and Huisheng Huang



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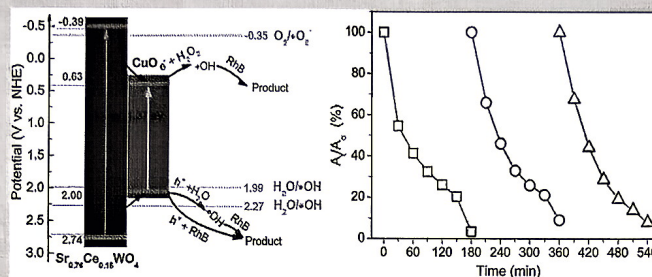
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ABSTRACT: Photo-Fenton is a promising photocatalytic technology that utilizes sunlight. Herein, an Fe-free 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ photocatalyst was synthesized to apply simulated wastewater degradation via a photo-Fenton process under simulated sunlight. The photodegradation efficiency of RhB solution over the 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ photocatalyst is 93.2% in the first 3 h; its photocatalytic efficiency remains at 91.6% even after three cycle experiments. The kinetic constant of the 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ photocatalyst is 0.0127 min⁻¹, which is 2.8-fold that of an intrinsic Sr_{0.76}Ce_{0.16}WO₄ sample. The experiment of radical quenching revealed that the photogenerated electrons and holes are transferred to CuO to form hydroxyl radicals. Besides, the photocatalyst was characterized by scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), diffused reflectance spectroscopy (DRS), and X-ray photoelectron spectroscopy (XPS) measurements. It has some reference significance for the design of iron-free photocatalysts.

1. INTRODUCTION

Environmental protection has been facing a huge challenge with the increasing development of industries,^{1,2} i.e., printing and dyeing industry, leather tanning, pharmaceutical industry, petrochemical engineering, and so on. The organic content in wastewater as a harmful byproduct is generated in these industrial processes. It is necessary to remove contaminants via any advantageous method. The Fenton reaction is an effective method for the nonselective decomposition of organic pollutants, which is due to the powerful oxidation ability of hydroxyl radicals.^{3,4} Faheem et al. reported Cu₂O-CuFe₂O₄ microparticles to degrade phenol at a pH of 4 in the presence of H₂O₂.⁵ The Fenton agent is widely utilized for the degradation of organic content solutions. However, the reaction is only effective in an acidic aqueous environment.^{6,7}

To eliminate the limitation of the pH value in the Fenton reaction, the photo-Fenton reaction was developed as a selective strategy for the decomposition of organic contaminants.^{8,9} Generally, the Fe element is a key component of the catalyst that is utilized in the photo-Fenton reaction. For instance, without adjusting the pH value of the reaction

solution, an Fe₂O₃-decorated TiO₂ nanotube shows an excellent methyl orange decomposition performance of 90% in 10 min.¹⁰ When the initial pH value of rhodamine 6G is 6.9, a 1 wt % iron-containing TiO₂ photocatalyst displays almost complete color removal after 90 min of the photoreaction.¹¹ The Bi₂Ga_{3.2}Fe_{0.8}O₉ photocatalyst presents a nearly 100% photodegradation activity of RhB at neutral conditions.¹² The Fe element in the photocatalyst plays the role of an active site to facilitate the production of [•]OH. However, the possible existence of ferromagnetism may cause the photocatalyst to disperse unevenly in the solution via a magnetic agitator, which is unfavorable for the photocatalytic reaction.

Recently, an iron-free semiconducting material was utilized in the photo-Fenton reaction. A ZnS/SnO₂ nanosheet acts in

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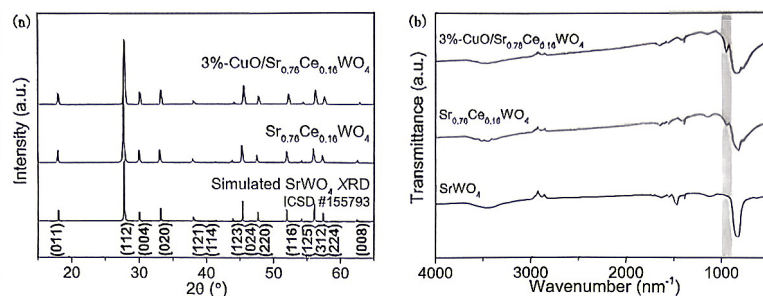


Figure 1. (a) Simulated XRD pattern of SrWO₄ and the powder XRD pattern of the Sr_{0.76}Ce_{0.16}WO₄ sample. (b) FT-IR spectra of Sr_{0.76}Ce_{0.16}WO₄ and SrWO₄.

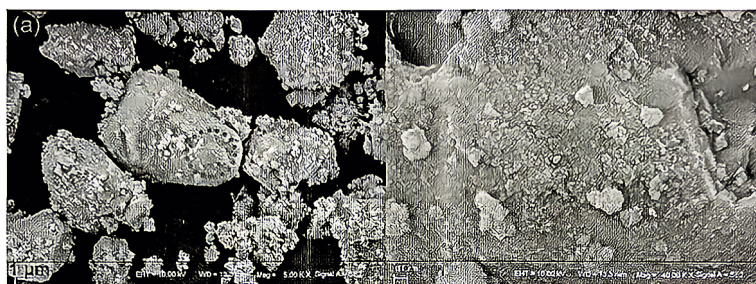


Figure 2. SEM images of the 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ photocatalyst in different scale plates: (a) 1 μm and (b) 100 nm.

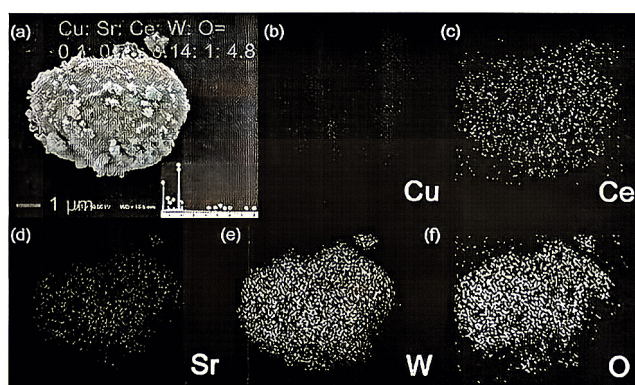


Figure 3. (a) EDS image of the 3%-CuO/Sr_{0.76}Ce_{0.16}WO₄ sample. (b–f) The mapping images for Cu, Ce, Sr, W, and O, respectively.

the degradation reaction of roxithromycin and clarithromycin antibiotics under ultraviolet light.¹³ A supramolecular Cu-containing polymeric structure was synthesized for the degradation of naphthol blue black in water via the photo-Fenton process.¹⁴ A series of Cu_xP₂O_{5+x} ($x = 2, 3, 4$) semiconducting materials were obtained via a traditional solid-state method, which were utilized in the photo-Fenton reaction for the first time under visible–infrared light irradiation.¹⁵ Herein, an iron-free material, Sr_{0.76}Ce_{0.16}WO₄, was used as a photocatalyst for the photo-Fenton degradation of simulated wastewater. Four kinds of metal elements, CuO, Ag, Au, and Pt, were loaded on the as-prepared photocatalyst via the

photodeposition method. A pseudo first-order kinetic constant was employed to quantitatively assess the photocatalytic performance of RhB.^{16,17}

2. RESULTS AND DISCUSSION

Figure 1a shows that the Sr_{0.76}Ce_{0.16}WO₄ sample was successfully synthesized without any impurities compared to the simulated XRD pattern of SrWO₄.¹⁸ The sample has high crystallinity, revealed by the sharp characteristic peak (112) and its high intensity. In addition, other diffraction peaks are consistent with the standard XRD pattern. Figure 1b displays the Fourier transform infrared (FT-IR) spectra of





■ Catalysis

C₃N₄/Cu/ZnFe₂O₄ Ternary Nanocomposites: Removal of Environmental Pollutants by the Synergy of Physical Adsorption and PhotocatalysisXiaorui Sun^{+, [a, b]} Hongfu Liu^{+, [a]} Jia Yang,^{*, [a, b]} Mingyan Fu,^[a] Mingdan Tan,^[a] Guihua Yin,^[a] Wenbing Shi,^[a, b] Huisheng Huang,^{*, [a, b]} and Jianwei Shi^[a, b]

Although binary composites can enhance the separation efficiency of photo-generated carriers to a certain extent, there is still space for further improvement. Here, we focus on using copper, a cheap transition metal, as an electron channel to improve the photo-generated carrier separation efficiency of ZnFe₂O₄ (ZFO) and C₃N₄ (CN) composites. The kinetic constants of sample 40%-ZFO/CN for photodegradation reaction are 2.96 and 1.98 times than that of pure sample ZFO and CN under the same conditions. However, the kinetic constants of 3% Cu@40%-ZFO/CN are 7.33 and 4.92 times than that of pure

sample ZFO and CN, respectively. This is probably due to the physical adsorption performances of ternary composites for pollutants are significantly stronger than those of binary composites. The best photocatalysts achieved 90% degradation efficiency within 15 minutes. A more reasonable photocatalytic mechanism model was proposed. Photo-generated hole, superoxide anion, and hydroxyl radical all play an important role in the photocatalytic reaction. The importance of them is superoxide anion > photo-generated hole > singlet oxygen > hydroxyl radical from high to low.

Introduction

A single semiconducting material as a photocatalyst is often limited by the light absorption ability, the separation and migration efficiency of photo-generated carriers, so the photocatalytic activity is relatively low.^[1] To enhance the photocatalytic activity, it is often necessary to load cocatalyst, to construct heterojunction, to synthesize composites, and other means to achieve the purpose.^[1,2] Loading cocatalyst does not always improving the photocatalytic performance of the original photocatalyst,^[3] and this method can be utilized to further improve the performance of heterojunction and composite.^[4] There are many kinds of heterojunctions, which require more than two kinds of semiconducting materials to form ohmic-contact, and its synthesis is a challenge.^[5] The Composites are much easier to synthesize, where one component is two-dimensional, and the other is in close contact with each other.

The metal-free g-C₃N₄ was widely studied as a photocatalyst since 2009.^[6] Although it is simple to calcine urea or melamine

at ~500 °C can obtaining the material. However, its obvious drawback is that the photo-generate charges are recombined rapidly due to the intrinsic drawbacks.^[7] The design and fabrication of the CN with another semiconductor to form a composite is a common way to enhance the separation efficiency of photo-generated carriers. Liu et al. reported an outstanding carbon nanodot-C₃N₄ nanocomposite via a two-electron pathway for water splitting.^[8] About environmental photocatalysis, so many kinds of semiconductors, i.e., TiO₂, CeO₂, Bi₂O₃, BiOCl, Co₃O₄, ZFO, were studied for decomposing organic pollutants.^[7,9,10]

Due to the advantages of stable chemical property, low price, and suitable bandgap of ZFO, many studies have shown that ZFO/CN composites are excellent photocatalysts for environmental purification. For example, various dyes and antibiotics, including rhodamine B (RhB), methylene blue, acridine orange, orange II, and spiramycin, were degraded by ZFO/CN composite under visible light.^[4,9–12] However, these studies rarely consider the process of adsorption how to influence the decolorization.

In this paper, the solid-phase method was utilized to prepare ZFO and CN, and then the alcohol-thermal method was used to prepare the binary composite. Then the third component was introduced by in situ photodeposition to obtain the ternary composite.^[13] RhB aqueous solution was utilized to evaluate the adsorption and photodegradation efficiencies of the composite photocatalyst. The adsorption equilibrium of each reaction takes an hour and a half. Under the experimental conditions of this paper, a photocatalyst with the best photocatalytic performance is the 3%Cu@40%-ZFO/CN sample.

[a] X. Sun,^{*} H. Liu,^{*} Dr. J. Yang, M. Fu, M. Tan, G. Yin, Dr. W. Shi, Dr. H. Huang, J. Shi

College of Chemistry and Chemical Engineering,
Yangtze Normal University, Fuling,
Chongqing 408100, P.R.China
E-mail: yangjiayznu@163.com
h.s.huang@hotmail.com

[b] X. Sun,^{*} Dr. J. Yang, Dr. W. Shi, Dr. H. Huang, J. Shi
Chongqing Key Laboratory of Inorganic Special Functional Materials,
Yangtze Normal University, Fuling,
Chongqing 408100, P.R.China

[*] The authors X. Sun and H. Liu contributed equally to this article.

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Results and Discussion

Structure and morphology of composites

The measurements to detect the structural information of the CN/ZFO binary composite are displayed in Figure 1. The standard X-ray diffraction (XRD) patterns of CN and ZFO were given at the bottom of Figure 1a as the references, which can be compared with the different ratios of the CN/ZFO nano-composites. From the down to the up, the characteristic peaks of ZFO are appeared and enhanced via the increase of ZFO; On the contrary, as shown in the yellow rectangle, the characteristic peak of CN (002) is quickly decreased.^[7] From this, it can be concluded that the 20%-ZFO/CN, 40%-ZFO/CN, 60%-ZFO/CN, and 80%-ZFO/CN samples at least the mixture of the pure ZFO and CN components, whether there is a strong interaction between the two components requires other measurements. Figure 1b shows the Raman spectra of the above samples. Under the same testing conditions, the characteristic peaks of pure sample CN and ZFO were located at 3355.4 and

1513.0 cm^{-1} , respectively, while the characteristic peaks of other mixed samples began to shift from high wavenumber to low wavenumber with the increase of ZFO. It indicates that there is an interaction between ZFO and CN in the composites. In addition, the Raman peak of CN at 245.0 remained unchanged at first with the increase of ZFO. When ZFO increased to 60% or above, the peak began to split and disappeared.

Based on XRD and Raman analytic results, it can be concluded that ZFO/CN composites are successfully prepared. This conclusion was further verified by Fourier transform infrared spectroscopy (FT-IR) results. Pure CN has a sharp characteristic peak at 812.6 cm^{-1} , representing a typical triazine ring structure (see Figure 1c).^[14] Shown in the green box, the peak decreases rapidly as ZFO increasing. The yellow box shows the characteristic peak of ZFO, which represents the Fe–O vibration.^[11] With the increase of CN, the peak is slightly lower toward the higher wavenumber, which means a strong interaction between CN and ZFO. The third component (Cu) in

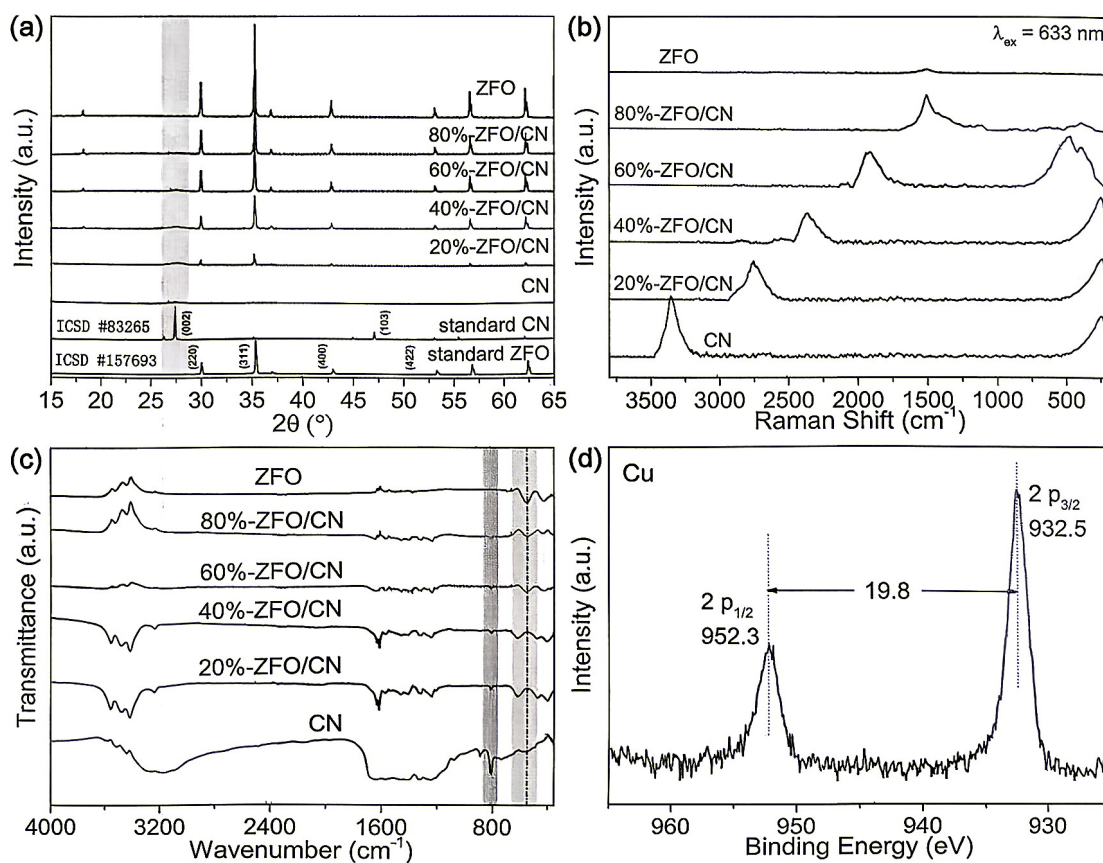
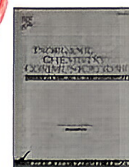


Figure 1. (a) The XRD patterns, (b) Raman spectra images, and (c) FT-IR spectrums of binary composites; (d) High-resolution spectra XPS spectra of Cu in the ternary composite.





Short communication

The photocatalytic performances of Bi_2MTaO_7 ($M = \text{Ga}, \text{In}$) photocatalysts for environmental cleaning under visible-light

Xiaorui Sun, Mingshu Gu, Jia Yang^{*}, Gaohong Ye, Xingguo Xiao, Min Chen, Miaomiao Liu, Zuli Chen, Huisheng Huang^{*}

Chongqing Key Laboratory of Inorganic Special Functional Materials, College of Chemistry and Chemical Engineering, Yangtze Normal University, Puling, Chongqing 408100, PR China



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ABSTRACT

Herein, we present the $\text{Bi}_2\text{GaTaO}_7$ (BGTO) and $\text{Bi}_2\text{InTaO}_7$ (BITO) semiconductors as visible-light-driven photocatalysts for environmental cleaning, including photocatalytic oxidation of rhodamine B and reduction of dichromate ion. Experimental results show that both intrinsic and modified BGTO have better photocatalytic oxidation and reduction activities than that of BITO. The best cocatalysts for BGTO and BITO in photocatalytic degradation and reduction reactions are CuO and Ag, respectively, but the optimal amount is different. The kinetic constants of BGTO-3%Cu and BITO-2%Cu are 3.4-fold and 3.0-fold in comprise with the inherent BGTO and BITO, respectively. The kinetic constants of BGTO-4%Ag and BITO-4.5%Ag are 3.6-fold and 4.0-fold by comparing the intrinsic BGTO and BITO, respectively. The photocatalytic mechanisms of degradation and reduction reactions are also proposed in this paper.

1. Introduction

To keep the water body clean, technologies including adsorption, microwave catalysis, and photocatalysis are being investigated for treating wastewater [1,2]. However, adsorption does not involve chemical reactions, making it difficult to break down pollutants in depth [3]. Microwave catalysis can decompose pollutants more thoroughly due to the introduction of additional energy [4], but its operating costs are relatively high.

Hence, the past times have witnessed a persistently increasing interest in heterogeneous photocatalysis for environmental cleaning [5]. The photocatalytic process not only can decompose a large number of organic materials, especially the variety of dyes [6], but also can eliminate many kinds of highly toxic heavy metal ions, such as the Cr^{6+} , Hg^{2+} [7]. So many semiconductors have been discovered as novel photocatalysts for the application of photocatalysis in photocatalytic history, such as TiO_2 , InTaO_4 :Ni, C_3N_4 , and so on [8–10].

Several pyrochlore-type compounds have been reported for the photocatalytic reactions of decomposing organic material. $\text{Bi}_2\text{MnNbO}_7$ ($M = \text{Al}^{3+}$, Ga^{3+} , In^{3+} , La^{3+} , Y^{3+}), Bi_2GaVO_7 , $\text{Bi}_2\text{Zr}_2\text{O}_7$, $\text{Bi}_2\text{Ce}_2\text{O}_7$ were prepared as photocatalyst as well [11–14]. These literatures usually reported that the photocatalyst acted in one kind of photocatalytic

reaction to prove it's a new photocatalyst. There is a lack of research on the application of these photocatalysts in the photocatalytic reduction reaction.

The environmental photocatalytic properties of BGTO and BITO samples have not been systematically studied in previous studies. To consider the wastewater may have the organic material and inorganic metal ion, the rhodamine B (RhB) and $\text{Cr}_2\text{O}_7^{2-}$ were selected as the model pollutants to test their photocatalytic redox performances.

2. Experimental section

The BGTO and BITO samples were prepared by a solid-state reaction. The chemical reagents Bi_2O_3 (Macklin, AR), Ga_2O_3 (Damas-beta, 99.99%), In_2O_3 (Macklin, 99.9%), and Ta_2O_5 (Macklin, 99.99%) were utilized without any purification. The two compounds were preheated at 800 °C for ten h and then heated at 1100 °C for 15 h, respectively. Further, CuO, Ag, Au, and Pt were loaded on the as-prepared samples via a photo-deposition method. i.e., the “BITO-4.5%Ag” means that 4.5 wt% Ag species were loaded on the BITO. The “BGTO-3%Cu” means that 3.0 wt% CuO was loaded on the BGTO.

X-ray diffraction (XRD), scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and ultraviolet diffuse reflectance

^{*} Corresponding authors.

E-mail addresses: yangjiayznu@163.com (J. Yang), h.s.huang@hotmail.com (H. Huang).

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spectroscopy (DRS) were used to characterize the as-prepared samples. The next step is to use these samples as a photocatalyst to test the photocatalytic oxidation of RhB and reduction of $\text{Cr}_2\text{O}_7^{2-}$ properties, and test the absorbance with a spectrophotometer. Characterizations, photocatalytic experiments, and the Mulliken Electronegativity method [15] are detailed in supporting information.

3. Results and discussion

Although pyrochlore-type materials have been widely studied as photocatalysts, there is still a lack of research on material with an intrinsic visible light response. In this paper, we study the photocatalytic REDOX properties of BGTO and BITO by referring to our previous works, such as the use of CuO and Ag as cocatalysts. Fig. 1a displays the XRD patterns of the BGTO and BITO samples, with the Miller indices of their prominent diffraction peaks. They are pure samples by comparing with their corresponding standard patterns. Because the ionic radius of In^{3+} is larger than the ionic radius of Ga^{3+} , which leads the diffraction peaks of BITO skewing to a small 2θ angle in comparison with BGTO [16]. Based on the (222) peaks of BGTO and BITO, the average particle sizes of them are 513.8 and 482.7 nm, respectively, calculated by Scherrer's formula [17].

Figure 1b-c shows the SEM images of BGTO and BITO, which displays the morphology are similar. The sizes of their particles are in the range between ~ 100 nm to ~ 1.5 μm , which is not inconsistent with the particle size calculated according to the diffraction pattern. The mapping images displayed that the containing chemical elements are

uniformly distributed in corresponding samples and the proportion of metal elements also accords with a stoichiometric ratio of them (see Fig. S1-2). Fig. 1d displays that the FTIR images of BGTO and BITO have three zones with peaks. The peaks at the range $3180\text{--}3652\text{ cm}^{-1}$ and $1580\text{--}1670\text{ cm}^{-1}$ are attributed to the stretching and bending mode of O-H from the water adsorbed by the sample and surface hydroxyl groups of the sample [18]. The peaks between 350 and 715 cm^{-1} are attributed to the Ta-O bond and Ga-O/In-O bond [19,20].

The morphologies of samples BGTO-3%Cu and BITO-4.5%Ag were observed by TEM, and the distribution of cocatalysts on the samples was observed. At a larger field of view, Fig. 2a and c show that the BGTO and BITO morphology is mainly composed of irregular particles of sub-micron and micron scale. Fig. 2b shows that CuO with a crystal plane spacing of $2.55\text{ \AA}$ is loaded on the edge of the BGTO sample. Fig. 2d shows that spherical Ag particles with a crystal plane spacing of $2.41\text{ \AA}$ are loaded on the edge of the BITO sample. In addition, the crystal plane index observed from BGTO and BITO is the same, which is the (004).

Fig. 3a shows the survey XPS images of the BGTO and BITO samples, which displayed that the two samples have the same element as Bi, Ta, and O, except the Ga and In. There is no difference between BGTO and BITO in the high-resolution XPS spectra of Bi4f, Ta4f, and O1s. These Bi, Ta, and O elements have chemical valences of +3, +5, and -2, respectively. Fig. 3e shows the high-resolution of In 3d and Ga 3d peaks, which means the chemical valences of them are +3. What needs to be explained is the Bi 5d at the peak of $\sim 25.46\text{ eV}$ in the Ta 4f high-resolution spectrum. Based on the above measurements, which indicate the two samples were successfully synthesized via the solid-state

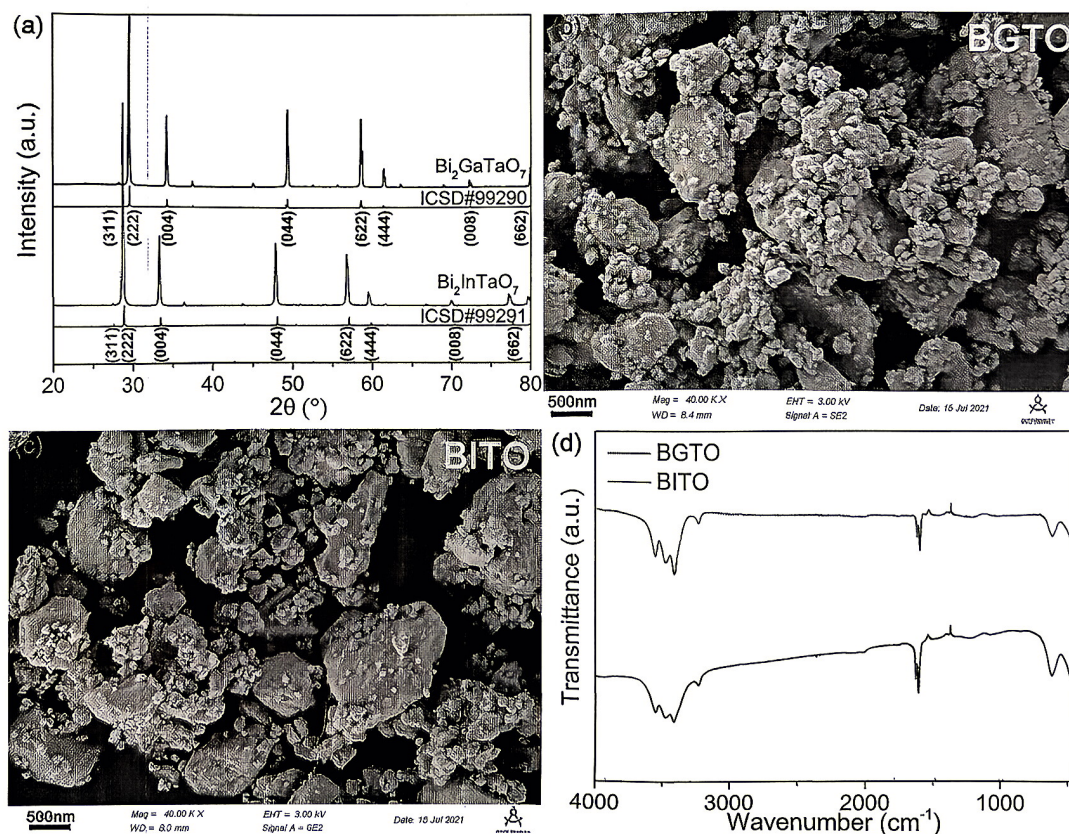


Fig. 1. (a) The XRD patterns of BGTO and BITO samples; The SEM images of (b) BGTO and (c) BITO in the scale of 500 nm; (d) The FTIR image of BGTO and BITO.





A highly stable Au@InGaZnO₄ composite split water under simulated sunlight

Xiaorui Sun, Mingshu Gu, Jia Yang^{*}, Lingshan Liao, Sheng Tian, Huisheng Huang

Chongqing Key Laboratory of Inorganic Special Functional Materials, College of Chemistry and Chemical Engineering, Yangtze Normal University, Fuling, Chongqing 408100, PR China

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ABSTRACT

Herein, we reported a systematic investigation of splitting water over the InGaZnO₄ (IGZO) based composite materials. One IGZO sample which modified with gold nanoparticles had the ability to generate hydrogen in simulated sunlight. The sample with an optimal H₂ generation rate is 2Au@IGZO, which is 2.1 times and 1.4 times than the intrinsic sample under the ultraviolet light and simulated sunlight, respectively. This excellent photocatalytic performance can be attributed to the effect of gold quantum dots around 8 nm in diameter. The composite still maintained almost no attenuation of hydrogen generation performance after 55 h of ultraviolet light.

1. Introduction

TiO₂ is a star material in photocatalysis, mainly due to its stable structure, environmental friendliness, low price, and long history of being developed as photocatalysts [1]. The bandgap of TiO₂ is around 3.2 eV, which only has response under the ultraviolet light. Therefore, many methods have improved their light absorption range, such as doping, constructing heterojunctions, and synthesizing composites [2].

The heterojunctions or composites were composed of TiO₂ and gold nanoparticles have been widely studied for various photocatalytic reactions. An Au-loaded titania nanotube was prepared for the methyl orange degradation [3]. A mesoporous Au/TiO₂ composite enhances photocatalytic performances for phenol-oxidation and chromium-reduction reactions [4]. An Au/TiO₂ thin film was synthesized for the azo-dye decomposition [5]. The strategy is so simple and effective that it can be applied to other photocatalysts, such as ZnO film [6], Bi₂S₃ nanorod [7], g-C₃N₄ [8], KNbO₃ nanowire [9], and La-doped NaTaO₃ [10].

In the author's cognition, IGZO is a semiconducting material with research value for split water. Based on a literature survey found that only Z. Zou et al. reported that IGZO has the capacity of water decomposition under ultraviolet light to generate hydrogen, and its photocatalytic performance is improved by loading 0.2 wt% Pt or 1 wt% NiO_x [11]. The Au quantum dots were assembled on IGZO as composite for H₂ generation under simulated sunlight irradiation.

2. Experimental

The IGZO was prepared as following, 0.3634 g ZnO, 0.4183 g Ga₂O₃, and 0.0930 g Al₂O₃ were mixed evenly in an agate mortar by hand. And then, the mixture was preheated at 700 °C for 10 h, heated at 1000 °C for 15 h, and finally heated at 1100 °C for 10 h, respectively. It needs to be carefully ground for half an hour after each time of calcination. Some metals are loaded on the IGZO to obtain composites via the photo-deposition method for the aim of improving its photocatalytic activity. 2Au@IGZO means that 2 wt% Au was loaded on IGZO.

The structural information of photocatalyst was measured by Powder X-ray diffraction (XRD, PANalytical X'pert diffractometer), Micro-Raman Spectrum (Raman, OPTOSKY ATR8300MP). Morphology and composition information of photocatalyst was collected by a scanning electron microscopy (SEM, ZEISS Gemini 300), transmission electron microscopy (TEM, FEI Talos F200S), and X-ray photoelectron spectroscopy (XPS, Thermo Scientific K-Alpha⁺). The light absorption capacity of the photocatalyst was measured by ultraviolet diffuse reflectance spectroscopy (DRS, Hitachi U-4100).

Photocatalytic H₂ generation experiments were conducted on a purchased device (Beijing Perfect Light Ltd. Co., Labsolar system). Hydrogen generation was carried out on a 20 mg catalyst using 50 mL 10% triethanolamine (TEOA) solution as a sacrificial agent under ultraviolet light (300 W Hg-lamp) or simulated solar (300 W Xe-lamp without optical filter) illumination.

^{*} Corresponding author.

E-mail address: yangjiayznu@163.com (J. Yang).

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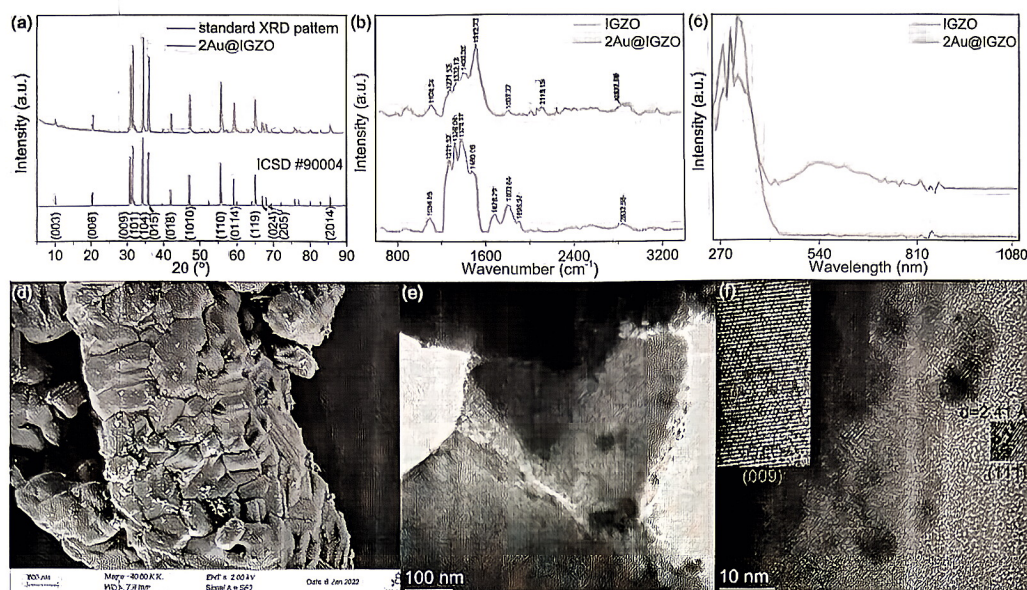


Fig. 1. (a) The XRD patterns of 2Au@IGZO; (b) The Raman and (c) DRS spectrums of 2Au@IGZO and IGZO samples; (d) The SEM, (e) Low- and (f) High-magnification TEM images of 2Au@IGZO.

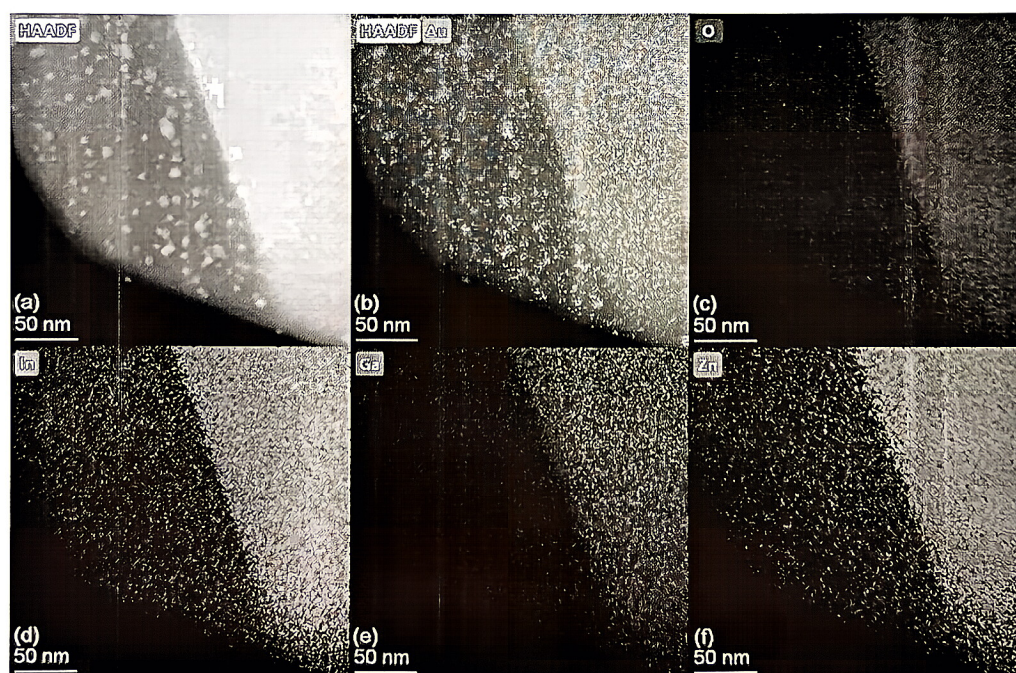


Fig. 2. (a) The mapping zone, mapping images of (b) Au, (c) O, (d) In, (e) Ga, and (f) Zn of 2Au@IGZO.

3. Results and discussion

Fig. 1a showing the XRD pattern of the 2Au@IGZO sample is a pure phase by comparing the standard XRD pattern of IGZO. Since only a tiny

amount of gold nanoparticles on the surface of IGZO could not be detected by XRD, the Raman was used to detect 2Au@IGZO [12]. The Raman spectrums of IGZO and 2Au@IGZO displayed that the loaded-Au changed the relative intensity and position of the peaks of IGZO (see



Ternary Nanocomposites of Copper/graphitic-Phase Carbon Nitride/rare-Earth Pentaborate for Photocatalytic Applications Under Simulated Sunlight Illumination

Xiaorui Sun^{+, [a]} Zuli Chen^{+, [a]} Min Chen,^[a] Yan Li,^[c] and Jia Yang^{*, [a, b]}

A wide variety of borate materials are emerging as photocatalysts. Usually, the borates possess a large bandgap which limits their absorption of visible light, and the strategy of preparing nanocomposites is an effective way to enhance the absorption of light. X-ray powder diffraction, infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy were used to show that a three-component nanocomposites was successfully prepared. For the photo-degraded reactions of rhodamine B (RhB) and doxycycline hydrochloride (DH), the optimum composition of the ternary composite is a molar ratio of $\text{Gd}_{0.9}\text{Ce}_{0.1}\text{B}_5\text{O}_{13}$ (GCBO) and $\text{g-C}_3\text{N}_4$ (CN) of 7:93, besides the mass of Cu is 2% of the

sum of the above two masses, and the ternary composite is abbreviated as $2\text{Cu}/\text{CN}/\text{GCBO}-7$. The kinetic constant for the photodegradation of RhB of sample $2\text{Cu}/\text{CN}/\text{GCBO}-7$ is 0.0580 min^{-1} , which is 3.6 and 3.8 times that of non-composite CN and GCBO. The mechanism postulated by free radical quenching experiments suggests that the importance of the three radicals is $\text{hole} > \cdot\text{OH} > \cdot\text{O}_2^-$ in the photodegradation reaction. In addition, the kinetic constant for the photodegradation of DH of sample $2\text{Cu}/\text{CN}/\text{GCBO}-7$ is 0.0018 min^{-1} , and the sample $2\text{Cu}/\text{CN}/\text{GCBO}-7$ has a hydrogen evolution rate of $11.8 \mu\text{mol}/\text{h}/\text{g}$.

Introduction

Nanocomposites have been used in a wide range of research fields such as humidity sensors,^[1–3] wearable biomonitoring,^[4,5] NO_2 monitoring,^[6] photodegradation,^[7,8] and photocatalytic hydrogen evolution.^[9] This is due to the abundance of alternative materials that can make up composites, such as oxides, sulfides, carbon materials, polymers, etc. The study of photocatalytic performance has received the most attention from us, and it is a matter of careful consideration as to which kind of semiconducting materials to select for the construction of composites.

Borate materials are a promising new class of alternative materials for photocatalysts. Especially, their applications in environmental photocatalytic reactions are remarkable.^[10] For example, X Fan et al. reported many new borates as photo-

catalysts for the degradation of chlorophenols.^[11] The borates such as $\text{Bi}_2\text{CaB}_2\text{O}_7$, $\text{Bi}_2\text{O}_3[\text{BO}_2(\text{OH})]$, $\text{Cu}_3\text{B}_2\text{O}_6$, and $4\text{ZnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ were used for the degradation of various dyes under light irradiation, such as RhB, methylene blue, methylene orange, and acid violet 7.^[12–15] However, the borates that can utilize visible light are still few. For instance, the better ones are $\text{SrBi}_2\text{B}_2\text{O}_7$,^[16] CsCdBO_3 ^[17] etc. To solve the problem of poor utilization of visible light by borate-based photocatalysts, two pathways have been reported in the literature.^[10] One pathway is to prepare new borate materials, which are intrinsically equipped to absorb visible light. The other is to prepare composites, such as $\text{Cu}_3\text{B}_2\text{O}_6/\text{CuB}_2\text{O}_4$,^[18] $\text{Cu}_3\text{B}_2\text{O}_6/\text{g-C}_3\text{N}_4$,^[19] and $\text{Li}_3\text{BO}_3/\text{CuO}$,^[20] etc. Both pathways significantly enhanced the photocatalytic performances of the borate-based photocatalyst.

In our work, both strategies are used to prepare neo-borate photocatalysts with $\text{g-C}_3\text{N}_4$ to construct composites. A hydrothermal method was used to make borates and graphitic-phase carbon nitride connect together, which further enhanced the separation efficiency of the photogenerated carriers of the composites by photo-deposition of copper. The composites of borate/ $\text{g-C}_3\text{N}_4$ exhibit excellent performance in photocatalytic applications, such as photodegradation of RhB, photodegradation of DH, and photocatalytic hydrogen evolution. This provides a way to study new borate photocatalysts with visible light response.

[a] X. Sun,⁺ Z. Chen,⁺ M. Chen, J. Yang

Chongqing Key Laboratory of Inorganic Special Functional Materials,
College of Chemistry and Chemical Engineering, Yangtze Normal University,
Fuling, Chongqing 408100, P. R. China
E-mail: yangjiayznu@163.com

[b] J. Yang

Guangxi Ministry-Province Jointly-Constructed Cultivation Base for State
Key Laboratory of Processing for Nonferrous Metal and Featured Materials,
College of Materials Science and Engineering, Guilin University of Technol-
ogy, Guilin 541004, P. R. China

[c] Y. Li

Guangxi Key Laboratory of Electrochemical and Magnetochemical Func-
tional Materials, College of Chemistry and Bioengineering, Guilin University
of Technology, Guilin 541004, P. R. China

[*] These authors contributed equally to this work.

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Results and Discussion

Analysis of Photocatalyst Characterization

Figure 1a shows that the diffraction peaks of CN@GCBO-0 at Bragg angles of 27.4° (002) and 12.7° (100) are attributed to the conjugated aromatics and the in-plane triazine structure, respectively.^[21] The diffractogram of CN@GCBO-100 has almost no diffraction peaks compared with the standard card, which indicates that the hydrothermal treatment process has a destructive effect on the structure of GCBO (Figure 1a). This can also explain the diffraction peaks of almost only g- C_3N_4 in CN@GCBO-7. Using the Raman spectrum of CN@GCBO-0 as a reference, the intensity of the peaks of CN@GCBO-7 and 2Cu/CN@GCBO-7 at higher wavenumbers increased with the addition of GCBO and shifted slightly to lower wavenumbers. The positions of the two peaks of CN@GCBO-100 were also significantly different when the sample did not contain CN. In particular, 2Cu/CN@GCBO-7 was detected by X-ray powder diffraction (XRD) for the diffraction peaks of copper-containing compounds, but there was a noticeable shift in the position of the low-wavenumber peak in the Raman spectrum.

Then in the infrared spectroscopy (IR) only similar conclusions can be obtained in the XRD pattern, with significantly different spectra for CN@GCBO-0 and CN@GCBO-100, however, the spectra of 2Cu/CN@GCBO-7 are almost indistinguishable from those of the samples without Cu. The peaks in the light cyan rectangular box in the figure are typical of those produced by the triazine ring.^[9] Finally, the bandgaps of CN@GCBO-0, CN@GCBO-7, 2Cu/CN@GCBO-7, and CN@GCBO-100 are 2.84, 2.96, 2.96, and 3.06 eV, respectively, as seen in the UV-vis diffuse reflectance spectroscopy (DRS) (see Figure 1d). The bandgap of CN compounded with GCBO is slightly increased, which is not suitable for absorbing visible light, but it is an enhancement for the reduction performance of the composite.^[22] In addition, Cu-containing substances were confirmed to be indeed present, which significantly enhanced the visible light absorption of the composites in the range of 550–850 nm.^[23]

The morphology of sample 2Cu/CN@GCBO-7 was dense and flower-like (see Figure 2a). Figure 2b shows a partial magnification of the flake sample showing the curl, which can be identified as a typical morphological feature of CN based on our previously reported results.^[24,25] No other shape of an impure sample was seen to appear in the scanning electron microscopy

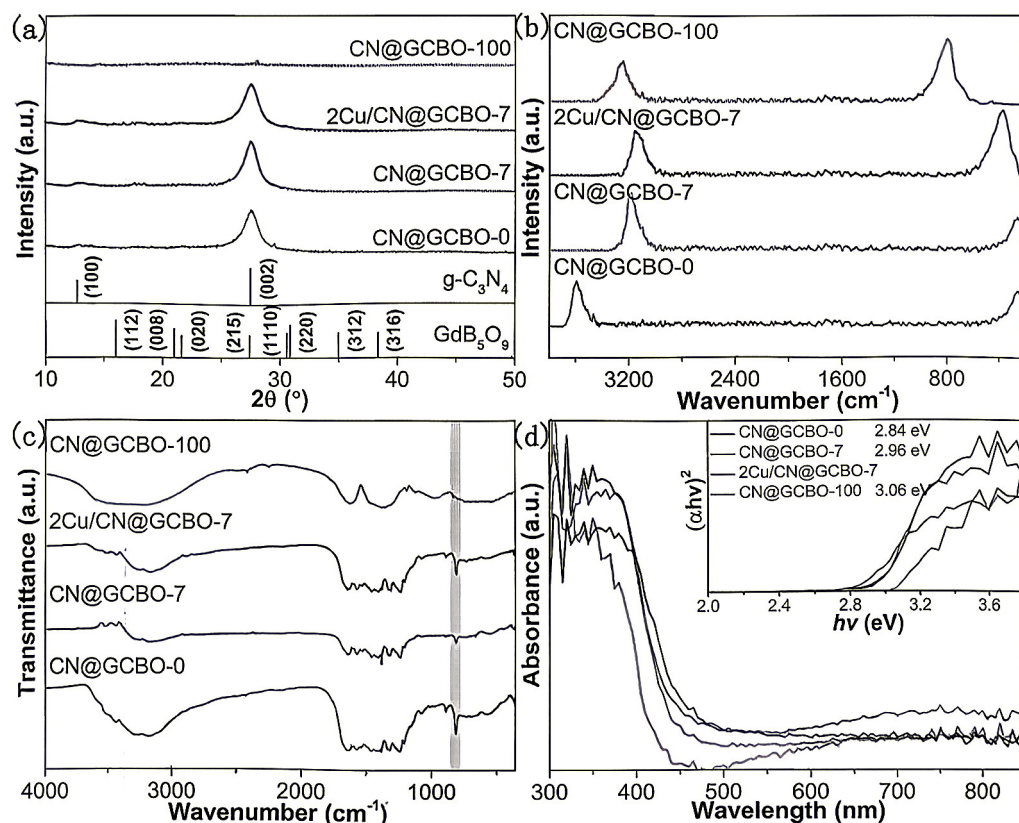


Figure 1. (a) XRD plots, (b) Raman plots, (c) IR plots, and (d) DRS plots of CN@GCBO-0, CN@GCBO-7, 2Cu/CN@GCBO-7 and CN@GCBO-100.



Two Novel Visible-Light-Active Borate Composites Photocatalysts: 2 %Pt/Gd_{0.85}Ce_{0.15}B₅O₉ and 2.5 % CuO/Gd_{0.90}Ce_{0.10}B₅O₉

Xiaorui Sun,^[a] Yaxin Xie,^[a] Shumin Liu,^[a] Yan Li,^[c] Xianfeng Zhao,^[c] Jia Yang,^{*,[a, b, c]} and Huisheng Huang^{*,[a]}

One of the important research components of photocatalytic research is the development of new photocatalysts, and recent studies have shown the rise of borate-type photocatalysts. This paper focuses on the photoreduction of potassium dichromate and the photodegradation of rhodamine B by two borate composites under simulated sunlight. A coral-like borate was obtained by sol-gel preparation and then assembled by photo-deposition with Pt nanoparticles dots or CuO particles to obtain

the new composites with excellent performance. The kinetic constants of photocatalytic properties of 2%Pt/Gd_{0.85}Ce_{0.15}B₅O₉ and 2.5%CuO/Gd_{0.90}Ce_{0.10}B₅O₉ samples in the reduction and degradation reactions are 0.0050 min⁻¹ and 0.0150 min⁻¹, which are 25 and 4.2 times of the intrinsic GdB₅O₉ sample respectively. The results of the study indicate the research promise of developing new visible photocatalysts based on borates, especially for photocatalytic applications for pollutant removal.

Introduction

The borate is a promising photocatalyst, however, there are still few studies.^[1] Borate photocatalysts show potential for application in many types of photocatalytic reactions. Such as dechlorination for chlorophenol,^[2] decomposition of water,^[3,4] Carbon dioxide reduction,^[5] and photodegradation reaction.^[6–12] Therefore, the development of new photocatalysts from tens of thousands of boric acid materials is of great research value.

The borates are very much studied as fluorescent materials and nonlinear optical materials. Due to the large bandgap of most borates, they tend to undergo photocatalytic reactions only under UV illumination. For example, the photodegradation of various dyes, B₂O₃,^[6] Bi₁₃BO_{20.95},^[7] Bi₂CaB₂O₇,^[8] Bi₂ZnOB₂O₆,^[9] Cu₃B₂O₆,^[10] YBO₃,^[11] and 4ZnO·B₂O₃·H₂O^[12] were reported active under ultraviolet light. The photodecomposition of chlorophenol or tetracycline, K_{3–x}Na_xB₆O₁₀Br,^[13] InBO₃,^[14] KBaB₅O₉,^[15] NaBaB₅O₉,^[15] Na₃VO₂B₆O₁₁,^[16] and Zn₄B₆O₁₃,^[17] except SrBi₂B₂O₇

and FeBO₃·(C, N),^[12] have only been reported for ultraviolet light illumination.

Up to now, a small number of borate photocatalysts exhibit photocatalytic activity under visible light illumination. For instance, the Bi₄B₂O₉,^[19] BiO₂[BO₂(OH)],^[19] CsCdBO₃,^[20] and FeBO₃^[21] displayed photocatalytic performances in visible light. And it is known from a review previously reported by the authors that there are no studies on the mineralization of inorganic heavy metal ions, such as reducing hexavalent chromium ions, in borate photocatalysis. Herein, we introduce 2%Pt/Gd_{0.85}Ce_{0.15}B₅O₉ and 2.5%CuO/Gd_{0.90}Ce_{0.10}B₅O₉ as novel borate photocatalyst and study the photo-reduction of dichromate by borate for the first time and the photodegradation of rhodamine B (RhB).

Results and Discussion

The XRD patterns of the GdB₅O₉, 2.5 %CuO/Gd_{0.90}Ce_{0.10}B₅O₉, and 2 %Pt/Gd_{0.85}Ce_{0.15}B₅O₉ samples show these samples are successfully synthesized (see Figure 1a). X. Sun et. al reported that the diffraction peaks of GdB₅O₉ have an expanding tendency with the increasing substitution of Ce³⁺, which causes the diffraction pattern to shift to a lower angle.^[21] By observing the characteristic diffraction peak of (112), a similar phenomenon appears in Figure 1a, because the ionic radius of Ce³⁺ is larger than that of Gd³⁺. The XRD technology cannot detect the low content of cocatalysts, which requires SEM, TEM, and XPS for supplementary analysis. The morphologies of intrinsic and Ce-doped GdB₅O₉ are coral-like.^[22] The particle sizes of GdB₅O₉ and 2.5 % CuO/Gd_{0.90}Ce_{0.10}B₅O₉ samples are 57~991 nm and 79~854 nm, respectively (see Figure 1b and c). However, smaller particles are aggregated on the 2.5%CuO/Gd_{0.90}Ce_{0.10}B₅O₉ sample, which may be CuO. Pt nanoparticles smaller than 10 nm were distributed on the surface of the 2%Pt/Gd_{0.85}Ce_{0.15}B₅O₉ sample

[a] X. Sun, Y. Xie, S. Liu, J. Yang, H. Huang
Chongqing Key Laboratory of Inorganic Special Functional Materials,
College of Chemistry and Chemical Engineering, Yangtze Normal University,
Fuling, Chongqing 408100, P. R. China
E-mail: h.s.huang@hotmail.com
yangjiayznu@163.com

[b] J. Yang
Guangxi Ministry-Province Jointly-Constructed Cultivation Base for State
Key Laboratory of Processing for Nonferrous Metal and Featured Materials,
College of Materials Science and Engineering, Guilin University of Technol-
ogy, Guilin 541004, P. R. China

[c] Y. Li, X. Zhao, J. Yang
Guangxi Key Laboratory of Electrochemical and Magnetochemical Func-
tional Materials, College of Chemistry and Bioengineering, Guilin University
of Technology, Guilin 541004, P. R. China

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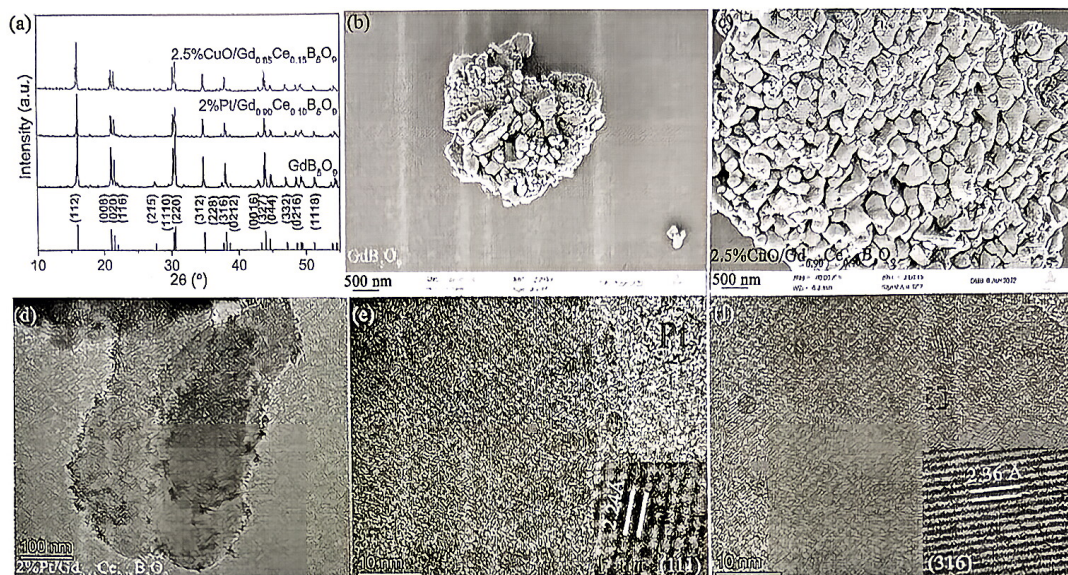


Figure 1. (a) The XRD patterns of GdB_2O_9 , $2.5\%\text{CuO}/\text{Gd}_{0.90}\text{Ce}_{0.10}\text{B}_5\text{O}_9$, and $2\%\text{Pt}/\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$; The SEM images of (b) GdB_2O_9 and (c) $2.5\%\text{CuO}/\text{Gd}_{0.90}\text{Ce}_{0.10}\text{B}_5\text{O}_9$, respectively; The TEM images of $2\%\text{Pt}/\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$ (d) in large scale, (e) with Pt nanoparticle, and (f) high-resolution fringe of $\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$.

(see Figure 1d and e). Nanoscale noble metal particles are beneficial to the improvement of photocatalytic activity, including energy photocatalytic and environmental photocatalytic reactions.^[23–25] The crystal face spacing measured by the high-resolution lattice fringe is 2.24 and 2.36 angstroms, which mean the (111) and (316) crystal face of the Pt and $\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$ sample (see Figure 1e and f).

The test of mapping images on the $2\%\text{Pt}/\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$ and $2.5\%\text{CuO}/\text{Gd}_{0.90}\text{Ce}_{0.10}\text{B}_5\text{O}_9$ samples are carried out by the attachments of TEM and SEM, respectively (see Figure 2). The Gd, Ce, B, and O are uniformly distributed on the $2\%\text{Pt}/\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$ sample, and the distribution of Pt is consistent with the surface-loaded Pt-nanoparticle region (see Figure 2a–g). Similarly, Gd, Ce, Cu, and O are uniformly distributed over the $2.5\%\text{CuO}/\text{Gd}_{0.90}\text{Ce}_{0.10}\text{B}_5\text{O}_9$ sample (see Figure 2 h). However,

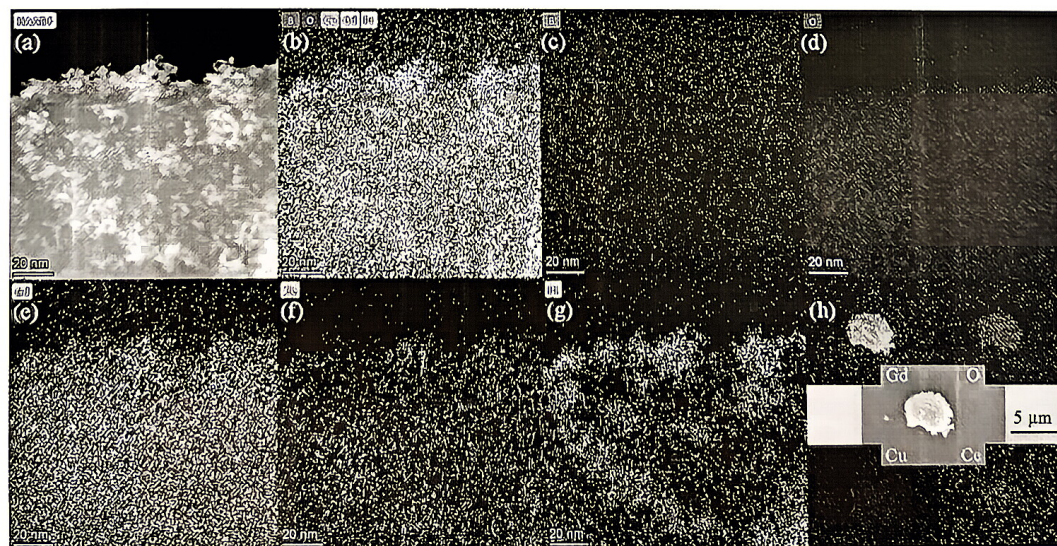


Figure 2. (a) The mapping zone, mapping images of (b) total elements, (c) B, (d) O, (e) Gd, (f) Ce, and (g) Pt of $2\%\text{Pt}/\text{Gd}_{0.85}\text{Ce}_{0.15}\text{B}_5\text{O}_9$ by the attachment of TEM. (h) The mapping zone, mapping images of Gd, O, Cu, and Ce of $2.5\%\text{CuO}/\text{Gd}_{0.90}\text{Ce}_{0.10}\text{B}_5\text{O}_9$ by the attachment of SEM.





Review

A Mini Review on Borate Photocatalysts for Water Decomposition: Synthesis, Structure, and Further Challenges

Xiaorui Sun ¹ and Jia Yang ^{1,2,3,*}

- ¹ Chongqing Key Laboratory of Inorganic Special Functional Materials, College of Chemistry and Chemical Engineering, Yangtze Normal University, Fuling, Chongqing 408100, China; sunxiaoruiyznu@163.com
 - ² MOE Key Laboratory of New Processing Technology for Nonferrous Metals and Materials, College of Materials Science and Engineering, Guilin University of Technology, Guilin 541004, China
 - ³ Guangxi Key Laboratory of Optical and Electronic Materials and Devices, Guangxi Universities Key Laboratory of Nonferrous Metal Oxide Electronic Functional Materials and Devices, Guilin 541004, China
- * Correspondence: yangjiayznu@163.com; Tel.: +86-18716372096

Abstract: The development of novel photocatalysts, both visible and UV-responsive, for water decomposition reactions is of great importance. Here we focused on the application of the borates as photocatalysts in water decomposition reactions, including water splitting reaction, hydrogen evolution half-reaction, and oxygen evolution half-reaction. In addition, the rates of photocatalytic hydrogen evolution and oxygen evolution by these borate photocatalysts in different water decomposition reactions were summarized. Further, the review summarized the synthetic chemistry and structural features of existing borate photocatalysts for water decomposition reactions. Synthetic chemistry mainly includes high-temperature solid-state method, sol-gel method, precipitation method, hydrothermal method, boric acid flux method, and high-pressure method. Next, we summarized the crystal structures of the borate photocatalysts, with a particular focus on the form of the B-O unit and metal-oxygen polyhedral in the borates, and used this to classify borate photocatalysts, which are rarely mentioned in the current photocatalysis literature. Finally, we analyzed the relationship between the structural features of the borate photocatalysts and photocatalytic performance to discuss the further challenges faced by the borate photocatalysts for water decomposition reactions.

Keywords: borate; photocatalyst; water decomposition; synthetic chemistry; structural feature



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1. Introduction

The importance of the carbon cycle is well-known, which is due to the many arguments made by scientific researchers and the publicity given to it by governments over the past few decades. The hydrogen cycle is important as well. Hydrogen has a very large number of applications, such as a direct clean energy source, hydrogen fuel cells, chemical feedstock, and so on [1,2]. The feedstocks from which hydrogen production is sourced are natural gas, water, coal, and biomass [3]. Of these, water is readily available and the cheapest of the important materials. Hydrogen production from water now has two important technological paths: electrolysis of water [4] and photolysis of water [5]. Due to the advantages of powder photocatalysts in hydrogen evolution by photocatalytic reaction, such as ease of handling and scale-up, we will next focus on the study of water decomposition by light irradiation.

In terms of what most photocatalytic researchers know about the photocatalytic decomposition of water, it is generally accepted that this line of research began with the Honda-Fujishima effect reported by two researchers at the University of Tokyo in 1972 [6,7]. Based on the effect, more and more semiconductors are being studied as photocatalysts, and as of now, the reported photocatalysts include organic polymers [8,9], inorganic compounds [10–12], and even organic-inorganic complexes [13,14]. From the periodic table of elements, these photocatalysts can be further classified as halates [15,16],



oxides [17,18], sulfides [19,20], selenides [21,22], nitrides [23,24], phosphates [25,26], carbon materials [27,28], borates [11,29], tantalates [30,31], niobates [32,33], tungstates [34–36], etc. Among them, the borates are new photocatalysts that have emerged in the last decade or so and have attracted much attention because of their rich structures.

There is already a wide variety of natural borates, and the addition of synthetic borates has resulted in more than 3900 species of borates in existence [37]. Microstructurally, zero-, one-, two-, and three-dimensional structures are included in borates [11], suggesting that borates are structurally tunable. The ability of borates to become well-known fluorescent and nonlinear optical materials also benefits from these structural features [38–41]. With the rise of photocatalytic research, exploring the photocatalytic performances of existing borate materials has attracted the attention of many researchers.

In this review, we summarized all borate photocatalysts using for photocatalytic water decomposition reactions, including water splitting reaction, photocatalytic hydrogen evolution half-reaction, and photocatalytic oxygen evolution half-reaction, to give researchers a complete picture of the current state of research. The synthetic chemistry and structural features of borate photocatalysts are discussed in depth. Our insights into existing borate photocatalysts for water decomposition reactions are presented based on the structure-determined property perspective, and possible challenges and corresponding solutions are suggested.

2. Fundamentals of Borate Photocatalytic Water Decomposition Reactions

2.1. The Mechanism of the Water Decomposition Reaction of Borate Photocatalysts

The basic principle of water splitting over borate photocatalysts is the same as that over other types of photocatalysts. As shown in Figure 1a, the large brown ball represents a borate photocatalyst, the small green ball represents a co-catalyst that assists in hydrogen evolution, and the small cyan ball represents a co-catalyst that assists in oxygen evolution. The photocatalytic water splitting reaction generally has three steps: (I) The first step is that the borate photocatalyst absorbs light and is excited by light to produce photogenerated electron-hole pairs. (II) The second step is the migration of photogenerated electron-hole pairs to the photocatalyst after separation; photogenerated electrons tend to accumulate on hydrogen evolution co-catalysts, while photogenerated holes tend to accumulate on oxygen evolution co-catalysts. (III) Photogenerated electrons and protons on a hydrogen evolution co-catalyst produce hydrogen, and photogenerated holes and water molecules on an oxygen evolution co-catalyst produce oxygen.

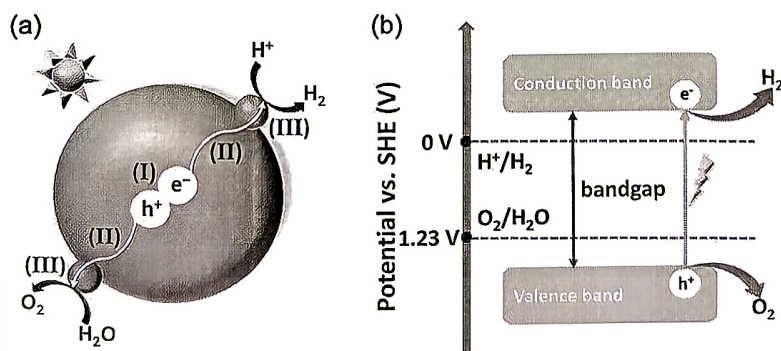


Figure 1. (a) Schematic illustration of water splitting over a borate photocatalyst: (I) light absorption and generation of photogenerated electron-hole pairs, (II) charge separation and migration to the surface of the co-catalyst, and (III) hydrogen and oxygen evolution reactions over the co-catalyst. (b) Schematic representation of the energy levels of water splitting subject to one-step excitation on a photocatalyst.

