Environmental Research 257 (2024) 119372

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Novel pyrochlore type europium stannate – tungsten disulfide heterostructure for light driven carbon dioxide reduction and nitrogen fixation

K. Yogesh Kumar [a], M.K. Prashanth [b], H. Shanavaz [a], L. Parashuram [c], Fahd Alharethy [d], Byong-Hun Jeon [e,*], M.S. Raghu [f,**]

[a] Department of Chemistry, Faculty of Engineering and Technology, Jain University, Bangalore, 562112, India
[b] Department of Chemistry, BNM Institute of Technology, Banashankari, Bangalore, 560070, India
[c] Department of Chemistry, Nitte Meenakshi Institute of Technology, Yelahanka, Bangalore, 560064, India
[d] Department of Chemistry, College of Science, King Saud University, 11451 Riyadh, Saudi Arabia
[e] Department of Earth Resources and Environmental Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 04763, Republic of Korea
[f] Department of Chemistry, New Horizon College of Engineering, Outer Ring Road, Bangalore, 560103, India

ARTICLE INFO

Keywords:
Pyrochlore
Heterostructure
Photocatalysis
CO_2 reduction
N_2 fixation

ABSTRACT

The reduction of carbon dioxide (CO_2) and nitrogen (N_2) to value-added products is a substantial area of research in the fields of sustainable chemistry and renewable energy that aims at reducing greenhouse gas emissions and the production of alternative fuels and chemicals. The current work deals with the synthesis of pyrochlore-type europium stannate ($Eu_2Sn_2O_7$: EuSnO), tungsten disulfide (WS_2:WS), and novel EuSnO/WS heterostructure by a simple and facile co-precipitation-aided hydrothermal method. Using different methods, the morphological and structural analyses of the prepared samples were characterized. It was confirmed that a heterostructure was formed between the cubic EuSnO and the layered WS. Synthesized materials were used for photocatalytic CO_2 and N_2 reduction under UV and visible light. The amount of CO and CH_4 evolved due to CO_2 reduction is high in EuSnO/WS (CO = 104, CH_4 = 64 μmol h^{-1} g^{-1}) compared to pure EuSnO (CO = 36, CH_4 = 70 μmol h^{-1} g^{-1}) and WS (CO = 22, CH_4 = 1.8 μmol h^{-1} g^{-1}) under visible light. The same trend was observed even in the N_2 fixation reaction under visible light, and the amount of NH_4^+ produced was found to be 13, 26, and 41 μmol h^{-1} g^{-1} in the presence of WS, EuSnO and EuSnO/WS, respectively. Enhanced light-driven activity towards CO_2 and N_2 reduction reactions in EuSnO/WS is due to the efficient charge separation through the formation of type-II heterostructure, which is in part associated with photocurrent response, photoluminescence, and electrochemical impedence spectroscopic (EIS) results. The EuSnO/WS heterostructure's exceptional stability and reusability may pique the attention of pyrochlore-based composite materials in photocatalytic energy and environmental applications.

1. Introduction

Because of the speed at which industrialization is progressing, the current generation is increasingly facing a major threat from CO_2 emissions. However, excessive reliance on fossil fuels is regarded as a critical concern for a carbon-dependent society (Liu and Li, 2022; Chen et al., 2020a; You et al., 2024). The main cause of ongoing global warming is the overuse of fossil fuels. In order to achieve a sustainable future, one should consider the most environmentally friendly way to reduce and ultimately eliminate CO_2 (Yogesh Kumar et al., 2023a,b; Hepburn et al., 2019). As a result, photoinduced CO_2 reduction is deliberated as a practical and safe method of achieving a society free of carbon (Sreedhar et al., 2021; Wang et al., 2021). The carbonaceous products of the photocatalytic CO_2 reduction reaction (CRR) have a lot of industrial applications, like chemical feedstock for the synthesis of plastics, synthetic fuels, fuel for energy production, and fuel for transportation, heating, and the production of electricity (Bao et al., 2023; Ubaidullah et al., 2023). On the other hand, ammonia (NH_3) finds

* Corresponding author.
** Corresponding author.
E-mail addresses: bhjeon@hanyang.ac.kr (B.-H. Jeon), raghuhassan2009@gmail.com, dr.msraghu@newhorizonindia.edu (M.S. Raghu).

https://doi.org/10.1016/j.envres.2024.119372
Received 15 February 2024; Received in revised form 24 April 2024; Accepted 5 June 2024
Available online 8 June 2024