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Synergistic photodegradation of methylene blue by Sm doped Fe_2O_3 photocatalyst under sunlight

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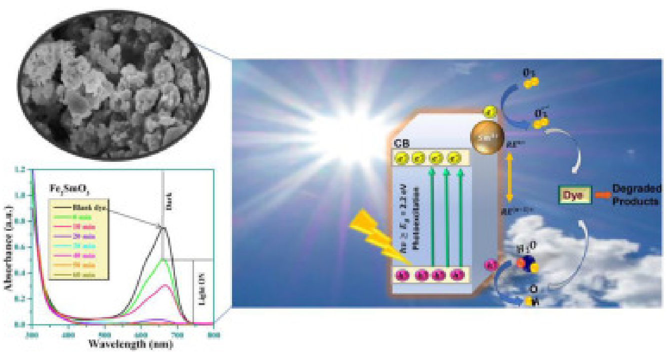
Abstract

The growing population led to an increase in water contamination, which urged researchers to develop an efficient, eco-friendly, and safe catalyst to remove these pollutants from water bodies. Herein the present study, the Sm-doped Fe_2O_3 photocatalyst was developed through a low-cost and facile sol-gel route to degrade methylene blue (MB) under sunlight. Various characterizations of the photocatalyst were performed by X-ray diffraction (XRD), Fourier transforms infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), photoluminescence (PL), and UV–vis spectrometry, current-voltage measurements (IV), and electrochemical impedance spectroscopy (EIS). The XRD confirmed the successful doping of Sm in Fe_2O_3 lattices. Remarkably, the adsorption were 14%, 10%, 34%, photo-reduction efficiencies were 78.2%, 79.1%, 65.8%, while complete degradation of dyes were 91.2, 89.1 and 99.8% for Fe_3O_3, Sm_2O_3 and Sm-doped Fe_2O_3, respectively, against methylene blue dye after 1.0h under sunlight illumination. Moreover, the enhanced photocatalytic performance of the doped catalyst was found to be due to the structural variation, lower energy bandgap, hindered recombination, and the efficient charge carriers separation/transportation at the surface. The effective synergistic photocatalytic performance proved its potential in water remediation.

Graphical abstract



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Introduction

The environmental hazardous, worldwide water contamination and cumulative global energy problems are mainly triggered by microorganisms, organic pigments, and dyes released from the textile industry. These industries are the most appealing threats to the community [1], [2], [3], [4], [5], [6], [7]. Organic dyes play a vital role in taking advantage of society and pose many adverse effects on the aquatic environment. Hence, to deal with this problem, several techniques have been used to overcome these challenges, like advanced oxidation procedures, chemical routes, biological treatment, adsorption, coagulation, membrane filtration and ozonation [8], [9], [10], [11], [12], [13], [14], [15], [16], [17]. However, most conventional methods have shown limitations like low performance, slow kinetics, and high cost [18,19]. Subsequently, it is crucial to understand an unconventional approach that can tackle all these problems. Among all these candidates, the solar photocatalysis technique is well-intentioned because of sustainable, low cost, easy setup, ambient temperature, and pressure, utilizing total solar spectrum energy, and greener method for dropping the damaging ecological influences of organic dyes [20], [21], [22], [23], [24], [25], [26].

Currently, immense efforts are being made to develop materials to deal with harmful and carcinogenic dyes by utilizing novel metal oxides-based material [27], [28], [29], [30]. Effective chemical modifications can be performed to materials by enhancing the energy gap, doping, combining different semiconductors, co-doping, adding structural directing agents, and composite formation [31], [32], [33], [34]. Among these approaches, doping of lanthanide metals to metal oxides has gained much attention due to superior electrical and photocatalytic properties. A conventional lanthanide operational material, Samarium Oxide (Sm_2O_3), has been used in photoelectronic fields [35,36]. Massive attempts have been made to synthesize Sm_2O_3 with different morphologies like microspheres [37], nanoparticles [38,39], nanorods [40], nanoplates [41], nanodisks [42], sub-micro spindles [43], and nanowires [44] with excellent photocatalytic performance. Gua-Ying Zhang etal. reported that Fe_2O_3 nanorods are thermodynamically stable, improved efficiency, are inexpensive and have high magnetic properties.

On the other hand, Fe_2O_3 has a small bandgap suitable for visible light and is highly resistant to photo corrosion [45]. Sharma etal. synthesized iron oxide with transition metals by sol-gel method, and the resulting material performed excellent photocatalytic degradation of methylene blue at 2.5 pH [46]. Wu etal. described iron oxide with copper as a catalyst for photochemical degradation to remove azo dye with enhanced photocatalytic functioning at acidic pH because of excellent adsorption properties [47]. Dhiman and co-workers introduced nickel-iron oxide with different morphologies, which performs well for oxidation and reduction reactions [48]. On the other hand, Fe_2O_3 is a commonly utilized n-type semiconductor in the fabrication of photocatalysts because of low cost, wide availability, and great long-term stability under ambient conditions. Because of their unique properties, rare earth elements have been widely investigated in recent decades. The photocatalytic activity of Fe_2O_3 has been enhanced through various techniques like coupling or a combination of both doping and composite formation. Among them, doping with different metal oxides to form heterojunctions in photocatalytic systems has become a primary focus of the researchers due to their unique properties not existing in the individual nanomaterial from the interfacial interaction at the nanoscale. Hence, Doping rare earth elements is a good way to improve the photocatalytic properties of the materials. And in this case, Sm is used to improve the photocatalytic properties of materials since it is a rare earth element and provides oxygen vacancies during the doping process. On the other hand, the influence of Sm doping on the photocatalytic characteristics of Fe_2O_3 has received very little attention in any field [49].

Due to some drawbacks and fundamentals, the above-mentioned reports pushed the researchers to formulate an easy, rapid, and cost-effective fabrication of lanthanide-based (Sm) dopped iron oxide as a photocatalyst, and also to increase the photo-responsive qualities, the doping, adding a structure-guiding agent, and maintaining a steady pH were all utilized. Hence, the rare earth metal doping, such as samarium, enhances the surface-to-volume ratio and the electrical, optical, photo-responsive, and magnetic properties of the host material [50]

The present work engrossed the fabrication of Fe_2O_3, $Sm_2O_{3,}$ and Sm doped Fe_2O_3 via the sol-gel route and employed it for photocatalytic activity under sunlight to degrade methylene blue (MB) as an organic pollutant. In the synthesis process, citric acid was used as a chelating agent to control the morphology of all synthesized materials. Doping of Sm in Fe_2O_3 can expect to prompt the transfer of electrons proficiently. The crystalline nature, morphological, optical, electrical, and electrochemical parameters of all the resultant products were analyzed via X-ray diffraction (XRD), FT-IR, scanning electron microscopy (SEM), photoluminescence (PL), UV–vis spectrometry, current-voltage measurements (IV), and electrochemical impedance spectroscopy (EIS). The proposed mechanism with the enhanced photocatalytic activity of Fe_2SmO_3 under sunlight was also explained below.

Section snippets

Reagents

The reagents used to produce the sample were iron nitrate monohydrate ($Fe(NO_3)_3{\cdot}1H_2O$), Sigma Aldrich 99.0%%, samarium nitrate hexahydrate ($Sm(NO_3)_2{\cdot}6H_2O$), Sigma Aldrich 99.0%%, citric acid (Sigma Aldrich, 99%), ammonia solution and the supplementary chemical was methylene blue (MB) as an organic pollutant. All the chemicals were of analytical grade and used as such received. Deionized water was consumed during the experiments.…

Material synthesis

The objective of the present study was to formulate the nanosized…

X-rays diffraction

Crystal structure as well as phase analysis of all developed materials were analyzed using X-ray diffraction. Fig. 1 Shows the XRD spectra of Fe_2O_3, $Sm_2O_{3,}$ and Sm-doped Fe_2O_3 nanopowder annealed at 500 °C for 5 h. The diffraction peaks of Fe_2O_3, $Sm_2O_{3,}$ and Sm-doped Fe_2O_3 correspond to standard data cards 00–039–0238 and 00–033–1146, respectively, which confirm the cubic phase formation. The distinct and sharp peaks suggest the high purity and crystallinity of materials with no additional peaks, …

Conclusion

In summary, pristine Fe_2O_3, $Sm_2O_{3,}$ and Sm-doped Fe_2O_3 photocatalysts were successfully prepared via a sol-gel protocol. XRD confirmed the formation of pristine Fe_2O_3, $Sm_2O_{3,}$ and Sm-doped Fe_2O_3 photocatalysts with no extra impurity peaks. The energy bandgap gets reduced by doping from 2.2 to 2.16 eV, making the doped sample an efficient catalyst under sunlight. PL results showed the lower recombination, and EIS and IV results exhibited higher conductivity and a more significant flow of charges…

Data availability statement

Data sharing is not applicable to this article as no data sets were generated during the present study.…

Declaration of Competing Interest

The authors confirm that they have no known financial or interpersonal conflicts that could have influenced the research presented in this paper. The manuscript has never been published before, and it is not being considered for publication elsewhere. It is also stated that the work is unique. The publication has the implicit or explicit consent of all authors as well as the relevant authorities where the work was done. If it is approved, it will not be published in the same form elsewhere, in…

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References (57)

V. Gómez *et al.*
Kinetic and adsorption study of acid dye removal using activated carbon
Chemosphere (2007)

R. Gusain *et al.*
Adsorptive removal and photocatalytic degradation of organic pollutants using metal oxides and their composites: a comprehensive review
Adv. Colloid Interface Sci. (2019)

K. Yao *et al.*
One-step synthesis of urchinlike SnS/SnS2 heterostructures with superior visible-light photocatalytic performance
Catal. Commun. (2017)

L. Yu *et al.*
Photoelectrocatalytic performance of TiO_2 nanoparticles incorporated TiO_2 nanotube arrays
Appl. Catal. B Environ. (2012)

V.K. Gupta *et al.*
Application of low-cost adsorbents for dye removal – a review
J. Environ. Manage. (2009)

W. Chu
Dye removal from textile dye wastewater using recycled alum sludge
Water Res. (2001)

T. Robinson *et al.*
Removal of dyes from a synthetic textile dye effluent by biosorption on apple pomace and wheat straw
Water Res. (2002)

H. Patel *et al.*
Removal of Congo Red dye from its aqueous solution using natural coagulants
J. Saudi Chem. Soc. (2012)

N. Kannan *et al.*
Kinetics and mechanism of removal of methylene blue by adsorption on various carbons—a comparative study
Dye. Pigment. (2001)

S.T. Yang *et al.*
Removal of methylene blue from aqueous solution by graphene oxide
J. Colloid Interface Sci. (2011)

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