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RESEARCH

Silver Decorated α-MoO_3 Nanoparticles Synthesis for MB Dye Degradation and Heterostructure Photodetector Under Visible Light Irradiation

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Abstract
This paper reports the simple wet chemical method to synthesis pure molybdenum trioxide (MoO_3) and silver-doped molybdenum trioxide (Ag@MoO_3) nanorods including photocatalysts for removal of pollutants from wastewater and photodiode for optical communication. XRD analysis reveals the successful creation of orthorhombic structure in both MoO_3 and Ag@MoO_3. Minor deviation in position of predominant crystal planes as (110) and (120) is detected from X-ray diffraction (XRD) results with the size of the particle to be in the range of 27–31.4 nm. Field Emission Scanning Electron Microscopy (FE-SEM) images reveal that 15% Ag@MoO_3 sample has interwoven nanorods along with caterpillar-like structure. HR-TEM (High-resolution transmission electron microscopy) images provide the d-spacing values of the crystal planes are 0.389 nm and 0.345 nm respectively corresponds to the planes (110) and (041) respectively. Photoluminescence (PL) spectra reveal the three emission bands which are located at 425, 490 and 520 nm. Syntheses of pure MoO_3 and Ag@MoO_3 are used for the photocatalytic degradation of Methylene blue (MB) under UV-Vis light illumination. The optimized samples of Ag@MoO_3 and MoO_3 showed the degradation efficiency is 98.7% and 95.78% respectively after seven cycles. A photodiode device is created using high-quality crystalline particles and Ag contacts are deposited on Ag@MoO_3 using a metal with interdigitated electrodes. The ideality factor (n) values Ag-α-MoO_3 under bright and dark conditions are found to be 0.68 and 0.78 respectively. Under optimum conditions, the device showed a high current gain and sensitivity. Applications for wastewater treatment and optical communications are carried by the transition metal incorporation metal oxides.

Keywords Ag@MoO_3 Nanorods · Caterpillar Structure · MB Dye Degradation · Pseudo-first order Rate Constant · Spray Pyrolysis Technique · C-V Plot

1 Introduction

Semiconducting photocatalytic materials are substances that harness light energy to stimulate chemical reactions that decompose pollutants, produce energy, or facilitate a range of chemical transformations. MoO_3 is one of the best attracting metal oxide semiconductors reason being that it has fascinated the research fraternity [1, 2]. It can be utilized to degrade the organic pollutants, under splitting and CO_2 reduction under the natural sunlight. In transition metal oxides (TMOs), MoO_3 explores an interesting property of catalyst in many reactions, corrosion resistant, converts the photon energy into chemical energy and anti- bacterial agent due to good stability with non- toxic nature. It is a wide n-type semiconductor with anisotropic structure [3].

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MoO_3 has different kinds of polymorphs such as α-MoO_3, β-MoO_3 and h-MoO_3 [4]. Among these, orthorhombic structure of α-MoO_3 which basically adopts the inter-layered structure and this is essential oxidation product for all molybdenum compounds. A unique orthorhombic structure of α-MoO_3 has following lattice parameters a = 3.891 Å, b = 14.118 Å and c = 3.676 Å. The orthorhombic α-MoO_3 phase is composed of series of bi-layers structure that are oriented along [010] y-axis. Every bilayer is made of two sub-layers which are constructed by MoO_6 octahedra and produces uneven oxygen sites. It mainly interacts with "van der Waals" force [5] and weak-bonding which is also reflected in the inter-layer distance of ~6 Å. Metastable β-MoO_3 is formed by zig-zag chains of distorts MoO_6 octahedral which is interconnected by Chain-position [6]. As is known, h-MoO_3 maintains same phase conditions upto particular temperature of 440˚C after that phase transformation attains the form of orthorhombic α-MoO_3 [7].

Molybdenum is used to create a multitude of molybdenum compounds with valence states from 0 to +6. In addition, molybdenum compounds have disproportionate mixture of compounds due to difference valence states, and easily change their coordination number. In transition metal oxide α-MoO_3 is the finest material which explores the photochromic properties due to process of tunnelling induce electron-holes separation under illumination and enhance the colour with light absorption capability [8]. Over the past two decades, various synthesis technique have been used to prepare α-MoO_3 with distinguish morphologies, resulting in nano particles, nanoplates, nanorods, and lamellar pattern and yolk-shell spheres respectively [9]. In general, an enhanced electrochromic properties of the material is based to improve total-surface area and allow more ionic diffusion [10].

Hybrid materials are formed by cooperative multiple attractions towards each other due to interplay in between metals and semiconductors. Many multifunctional metal semiconductors nanostructure have been synthesized and mostly applied in photochemistry and also heterogeneous catalysis because of their unique characteristics. The Ag is incorporated on pristine material of MoO_3. It acts as a mediator for the efficient energy transfer. It is improving photocatalytic efficiency. In this process, it behaves as a surface Plasmon resonance center which can improve the absorption of light in the visible spectrum and provides additional energy to accelerate the reaction. Moreover, Ag doping can initiate additional active sites that promote the catalytic performance. According to the previous reports, the Ag decorated on the α-MoO_3 material elaborates its optical and structural properties with enhance the UV-Vis light activity for photocatalytic dye degradation [11]. Mostly, MB is suggested on photocatalytic degradation studies due to its high detectability, relevance as a pollutant, stability and the wealth of existing research that allows for consistent and comparative analysis [12, 13].

MoO_3 was synthesized through a facile salt methods using NH_4NO_3 such as a molten salt method by Huang et al. [14]. $MoO_3.5H_2O$ is prepared using by Co-precipitation synthesis process by Yuan et al. [15]. Zhang et al. prepared two-dimensional MoO_3 nanosheets through liquid exfoliation method [16]. Many types of MoO_3 have been synthesized in the past but the preparation process is more complex, no eco-friendly and creates some issues.

Metal oxide-based photodiodes have gained significant attention from researchers due to their wide range of applications in fields such as optical communications, pollution monitoring and missile plume detection [17]. Meanwhile MoO_3 films have been extensively utilized for gas sensing, storage devices, photochromic and electrochromic applications [18, 19]. There is limited research on MoO_3-based photodiodes. When Ag is combined with pristine MoO_3, it leads to reduce the recombination of photogenerated carriers and enormously increases the entire performance of the fabricated device. MoO_3 has high electrical conductivity and it has the potential to enhance the charge transport properties within the device. Furthermore, Ag doping is capable of improvement the electronic conductivity as well as increases the overall efficiency of the photodiode. To the best of our knowledge, MoO_3-based photodiodes on silicon substrates have not been reported. Silicon is a low-cost substrate that is commonly used in electronic/optoelectronic devices, making the development of a high-performance photodiode on a silicon substrate. Thus, it has motivated by the scientific community.

The objective of the present work is to synthesize one dimensional nanorods of α-MoO_3 and Ag is decorated MoO_3 by a simple chemical route with various doping concentrations of 5%, 10% and 15%. It is examined by various characterization techniques such as XRD, Energy Dispersive X-ray (EDX), FE-SEM and HR-TEM for structural analysis. PL, Fourier Transform Infrared (FTIR) and Raman for optical and electrical properties. The analysis has been undertaken to help explain the photocatalytic performance. Also, coated films is employed to develop the n-Ag-α-MoO_3/$_P$-Si structure diode and photodiode parameters are evaluated, calculated and discussed in detail.

2 Materials and Methods

2.1 Materials

All source materials purchased for the preparation of nanomaterials are of analytical grade and purchased from Merck.