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Enhancement of CdS nanoparticles photocatalytic activity by Pt and In_2O_3 doping for the degradation of malachite green dye in water

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ABSTRACT

A hydrothermal method was used to prepare CdS nanoparticles, and a photoassisted deposition method was used to prepare 0.5 wt% In_2O_3/CdS, 0.5 wt% Pt/CdS and 0.5 wt% Pt, In_2O_3/CdS nanoparticles. Different techniques, such as UV–Vis, XPS, TEM, XRD, PL and BET surface area, were used to characterize the prepared materials. The results reveal that the doping of Pt, In_2O_3 on the surface of CdS nanoparticles plays an important role in the control electron-hole recombination rate. The photocatalytic performance of CdS, 0.5 wt% In_2O_3/CdS, 0.5 wt% Pt/CdS, and 0.5 wt% Pt, In_2O_3/CdS nanoparticles was studied by measuring their photocatalytic oxidation of malachite green dye under visible light. Photocatalytic parameters such as the type of doped materials, photocatalyst dosage and photocatalytic stability were also studied. The photocatalytic activity of CdS is lower than that of doped cadmium sulphide nanoparticles. This can be attributed to the fact that the addition of Pt or In_2O_3 or both In_2O_3 and Pt to CdS nanoparticles decreases the electron-hole recombination rate or alternatively due to the transfer of electrons between the doped metal and CdS nanoparticles.

1. Introduction

Currently, extensive pollution is one of the most important problems affecting the lives and fates of humans on Earth. This extensive pollution occurs mainly to the anthropogenic activities, which accelerate every day to fulfill the needs and requirements of mankind. Water pollution is an example of this extensive pollution that not only affects the local environment but also extends its effect to other parts of the world. Water pollution is considered the most crucial form because it limits the amount of fresh water required for the existence of living organisms on Earth. Accordingly, international organizations, legislators, and societies work to solve this crucial problem either by legislation or through the introduction of new, rigorous limits and regulations. Meanwhile, scientists contribute greatly through extensive research to highlight and explore the effect of different pollutants and their environmental remediation. One of the most dangerous classes of pollutants are the organic compounds, which greatly affect human health and cause many diseases due to their persistent and detrimental effects to biological systems such as contamination of aquatic environments by organic pollutants with organic dyes caused by the discharge of different industrial activities. These redundant chemicals usually cause multiple environmental and health problems because they are classified as suspected carcinogens, and their presence in water inhibits photosynthesis due to the reduction of sunlight [1,2]. Therefore, it is very important to remove these organic dyes from wastewater discharges from different industrial effluents. Generally, industrial wastewater containing organic dyes can be treated using different treatment procedures such as adsorption by solid materials [3], membrane separation [4], membrane filtration [5], flocculation [6], electrocoagulation [7]; however, unfortunately, most of these methods are usually characterized with many limitations, such as low efficiency, long retention times, high cost, and problems with regeneration. One of the main concerns of research scientists is the search for new treatment procedures characterized by high removal efficiency and strong affinity towards organic dyes. One of the most promising technologies for the remediation of environmental pollution is photocatalytic degradation using photocatalysts, a method characterized by low cost, high feasibility, efficiency, and ease of application [8–13]. The photocatalytic degradation of different organic dyes was studied recently using different metal and metal oxides nanoparticles, as well as a mixture of metals and oxides. For example, photocatalytic degradation of organic dyes was studied using silver nanoparticles [14,15], palladium nanoparticles [16], and a multiphase CuInSe2 semiconductor [17]. Additionally, the photocatalytic degradation of organic dyes was studied using metal oxides such as titanium dioxide [18,19], zirconium oxide nanoparticles [20], and zinc oxide nanoparticles [21], or a mixture of silver oxide/bismuth oxide nanoparticles [22], or titanium dioxide/zinc oxide nanocomposites [23]. Additionally, nanocomposites based on metal and metal oxides were used for the photocatalytic degradation of organic dyes such as palladium/titanium dioxide [24], platinum/titanium dioxide [25], silver/zinc oxide [26], and thallium-doped Mn_3O_4 [27]. According to the

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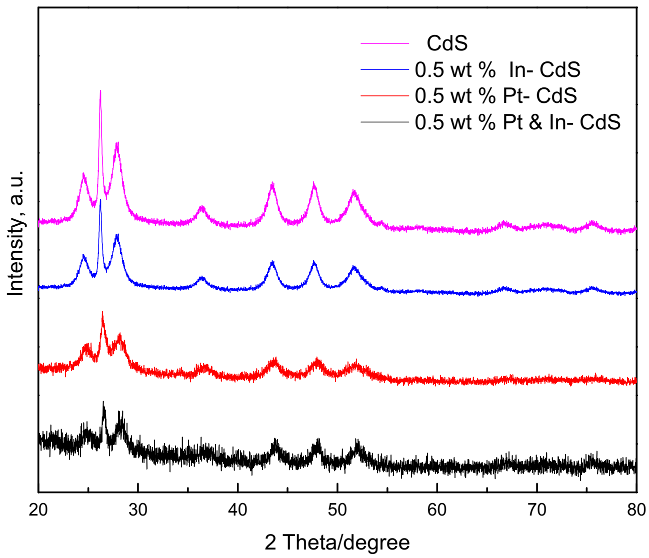

Fig. 1. XRD patterns of CdS and 0.5 wt% Pt/CdS, 0.5 wt% In_2O_3/CdS and 0.5 wt% Pt, In2O3/CdS nanoparticles.

above-mentioned studies, doping metal oxides with different metals greatly enhanced the photocatalytic activity of both the metal and metal oxide nanoparticles, thereby increasing the efficiency of the degradation process of different organic dyes in aqueous solution. Furthermore, CdS quantum dots showed great potential for the photocatalytic degradation of different organic dyes [28–30], as well as the ability to significantly enhance their photocatalytic activities for the degradation of organic pollutants upon doping with other metals and metal oxides [31–34].

In this study, enhancement of CdS nanoparticle photocatalytic degradation of malachite green by doping with platinum and indium oxide was investigated. The preparation procedure of the photocatalysts was optimized first by using different characterization techniques. The CdS, Pt/CdS, In_2O_3/CdS and Pt, In_2O_3/CdS nanoparticles were characterized by XRD, XPS, TEM, BET surface area UV–Vis, and PL techniques to identify the formation of CdS, the dispersion of Pt and/or In_2O_3 over the CdS, and the formation of stable nanoparticles. In addition, the stability and reusability of the doped CdS nanoparticles for the photocatalytic degradation of malachite green dye was investigated.

2. Experimental

2.1. Synthesis of the CdS nanoparticle

Hydrothermal methodology was used to prepare the CdS photocatalyst. In a typical synthesis, 20 mmol of thioacetamide and 5 mmol of $CdCl_2$ were dissolved in 80 ml of deionized water. The resulting mixture was heated for 24 h at 200 °C using a Teflon-lined stainless-steel autoclave. The materials were washed many times by

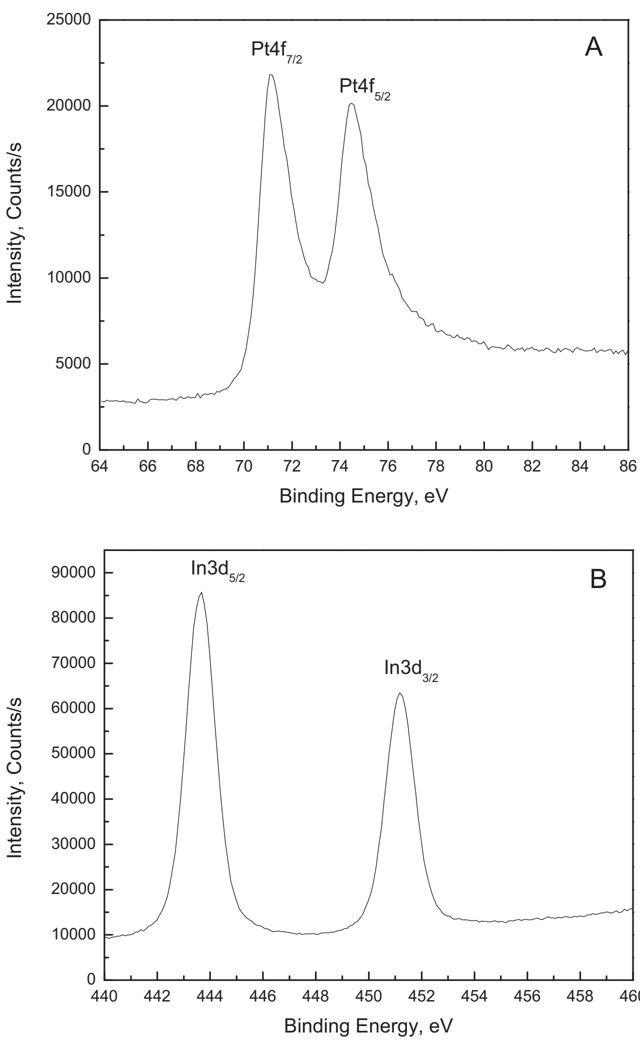

Fig. 2. XPS spectra of Pt 4f (A) and In 3d(B) of 0.5 wt% Pt, In_2O_3/CdS nanoparticle.

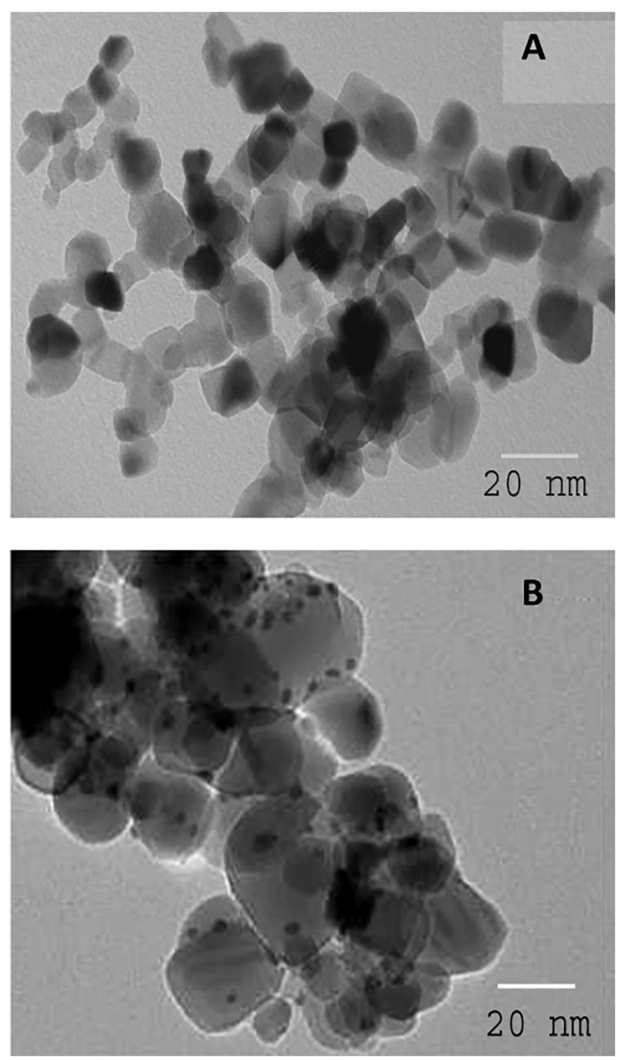

Fig. 3. TEM images of CdS (A) and 0.5 wt% Pt, In_2O_3/CdS (B) samples.