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Synthesis and application of lead telluride nanoparticles for degrediation of organic pollution

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ABSTRACT

PbTe nanoparticles were achieved from reaction of $Pb(NO)_3$ and $TeCl_4$ (as a new precursor for Tellur) in a relatively short time and low temperature in a hydrothermal process. The photocatalytic behavior of nanoparticles was evaluated using the degradation of a methyl orange (MeO) aqueous solution (as an organic pollution) under ultraviolet (UV) light irradiation. The results confirm that nanoparticles are promising materials with excellent performance in photocatalytic applications. In addition to, observations suggest that the as-obtained PbTe nanoparticles exhibit a strong PL peak at room temperature that might be ascribed to the high level transition in the PbTe semiconductor.

1. Introduction

Nanoscale materials are being pursued extensively because their crystal structures, optical, magnetic, electrical, and catalytic properties are strongly composition-, structure-, size-, and shape-dependent. Semiconductor nanocrystals have drawn attention due to their extreme quantum confinement effect and applications in electronic and optical devices [1–3]. Pb-chalcogenides indicate excellent electrical transport properties and low thermal conductivities at high temperatures (that is irregular for these materials which have a NaCl structure) [4,5]. PbTe has a large Bohr excitation radius (46 nm), which makes it an ideal candidate for investigating novel properties and behavior under quantum confinement conditions. In addition, PbTe is one of the best thermoelectric materials and is considered a favorable material for exchange of waste-heat into electricity [6]. Thermoelectric nanostructures can be used to create either refrigerators or power generators. Tellurides are notable materials owing to their great thermo power values and capability to generate both p and n type materials after doping for thermoelectric applications [7–9]. Lead telluride (PbTe) arguably is one of the most excellent solid state thermoelectric materials, and it can be used within the 323–900 K temperature range in photo detectors or energy generators. PbTe has an awesome chemical stability and high melting point (1197 K) [10]. Since the 1960s, PbTe enjoys semiconducting functionality in thermoelectric devices, solar cells, telecommunications and biological imaging [11–15]. Thus controlling the properties of PbTe by adapting size and morphology of the nanocrystals could lead to effective utilization. Thus far, some well-known structures of PbTe, such as nanoparticles, nanorods, nanosheets, hierarchical dendrites and flower-like structures have been synthesized by different chemical methods including chemical bath, solvothermal, microwave and sonochemical method [16–22].

Due to its low cost, high efficiency and potentiality for mass-production, the hydrothermal approach is the best among the various methods for the synthesis of PbTe, providing there is a promising approach for the production of crystals. Since the characteristics of nanostructures largely depend on their size and shape, controlling these factors are of paramount importance in their synthesis. Hydrothermal is a unique method for fabricating nanostructures with specific and controlled morphologies, whereas, other methods like sol–gel, sonochemical, etc., yield predominantly nanoparticle morphology. The hydrothermal method provides acceptable morphology orientation. Some conditions, e.g., high temperature and pressure, in this method grow different shapes in situ and form multiple morphologies such as nanoparticles, nanorods and nanoplates [23–26].

Herein, we have applied the hydrothermal method using $Pb(NO_3)_2$ and $TeCl_4$ as a starting materials and $N_2H_4{\cdot}H_2O$ as a reducing agent. The effects of different parameters such as reaction time, temperature, precursors, and type of reducing agents and presence of surfactant on the morphology of PbTe nanocrystals were investigated (Table 1).

2. Experimental

2.1. Materials and methods

$Pb(NO_3)_2$, $TeCl_4$, N_2H_4 H_2O, $Pb(CH_3COO)_2{\cdot}3H_2O$, Na_2SO_3, and KBH_4 were purchased from Merck Co. All of the chemicals were

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Table 1
Summarized of different effective parameters on the various reactions.

Sample. no.	Effect	Time (h)	Temperature (°C)	Precursors	Reductant	Product
1	Temperature	6	120	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black precipitate
2		6	140	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
3		6	160	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
4		6	180	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
5		6	200	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
6	Time	12	160	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
7		18	160	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
8		24	160	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
9		3	180	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
10		12	180	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
11		24	180	$Pb(NO_3)_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
12	Reducing agent	6	120	$Pb(NO_3)_2 + TeCl_4$	–	N.R
13		6	120	$Pb(NO_3)_2 + TeCl_4$	KBH_4	Black
14		6	120	$Pb(NO_3)_2 + TeCl_4$	Na_2SO_3	Gray
15	Precursors	6	120	$Pb(OAC)_2.3H_2O + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
16		6	120	$PbI_2 + TeCl_4$	$N_2H_4{\cdot}H_2O$	Black
17		6	120	$Pb(NO_3)_2$	$N_2H_4{\cdot}H_2O$	White
18		6	120	$TeCl_4$	$N_2H_4{\cdot}H_2O$	N.R.

used as received without further purifications. XRD patterns were recorded with a Philips, X-ray diffractometer using Ni-filtered CuKα radiation. SEM images were obtained by using a LEO instrument model 1455VP. Prior to taking images, the samples were coated with a very thin layer of Pt to make the sample surface conducting and to prevent charge accumulation to achieve a better contrast. The FT-IR spectra were recorded on Galaxy Series FTIR 5000 spectrophotometer. Room temperature photoluminescence was studied with a Perkin Elmer fluorescence instrument.

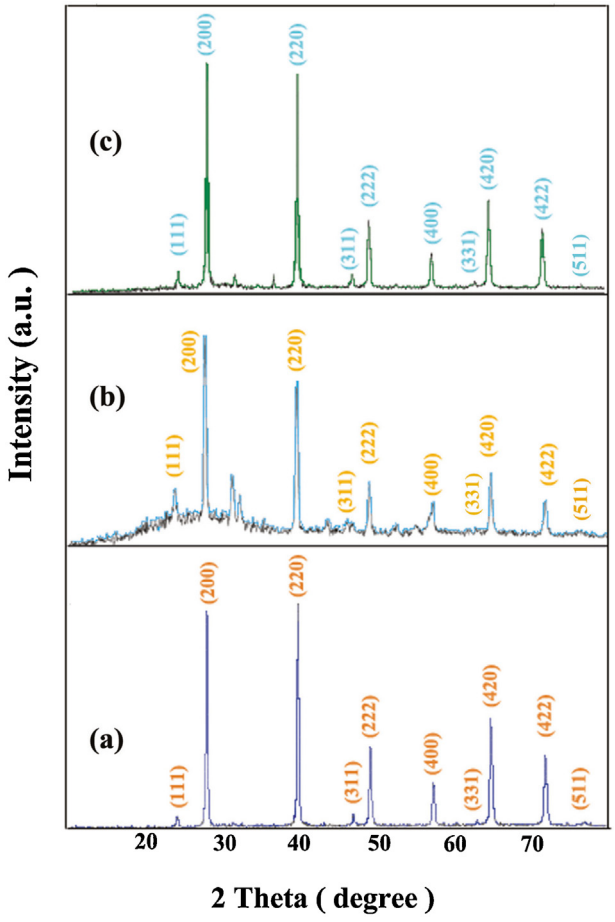

Fig. 1. XRD patterns of the PbTe (a) sample1, (b) sample 4, and (c) sample 11.

2.2. Synthesis of PbTe nanoparticles

In a typical synthesis, $Pb(NO_3)_2$ and $TeCl_4$ was dissolved in distilled water separately and mixed together with the help of magnetic stirrer, after that, $N_2H_4{\cdot}H_2O$ were mixed with this solution very slowly under stirring. After stirring, the reactants were put into a 250 ml capacity Teflon-lined autoclave. The autoclave was maintained at 120–200 °C for 3–24 h and then cooled to room temperature naturally. The black precipitate washed with alcohol and distilled water several times and dried in oven at 50 °C for 10 h.

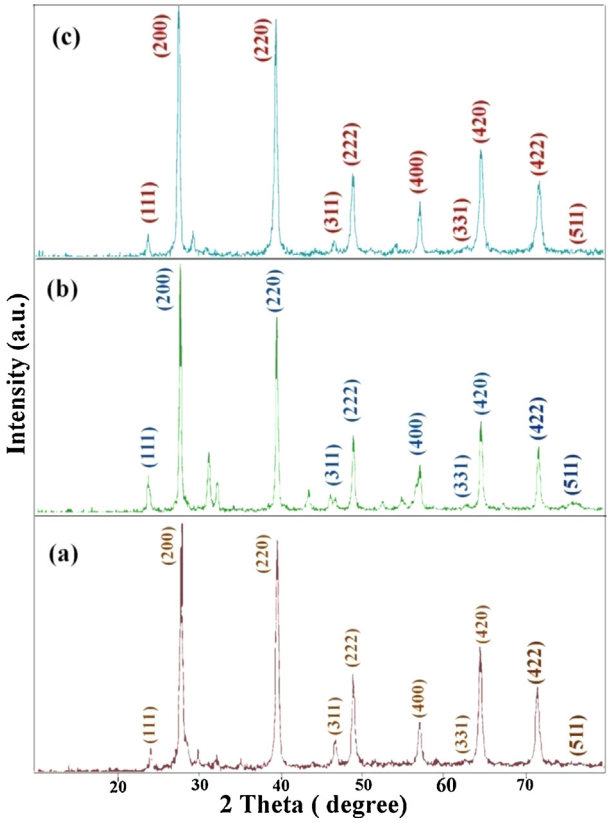

Fig. 2. XRD patterns of the PbTe (a) sample13, (b) sample 15, and (c) sample 16.