Journal of Alloys and Compounds 565 (2013) 73–78

Contents lists available at SciVerse ScienceDirect

Journal of Alloys and Compounds

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

Sb_2Te_3 nanoplates: Preparation, reaction mechanism and electrochemical property

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ARTICLE INFO

Article history:
Received 30 December 2012
Received in revised form 24 February 2013
Accepted 2 March 2013
Available online 14 March 2013

Keywords:
Sb_2Te_3
Nanoplates
Electrochemical property

ABSTRACT

A rapid chemical method has been developed for the synthesis of the Sb_2Te_3 nanoplates with rhombohedral crystalline phase. The method is based on the template-engaged synthesis in which the Te nanorods were used as template reagents. On the basis of a series of experiments and characterizations, the effect factors and the formation mechanism of the Sb_2Te_3 nanoplates were discussed. Furthermore, the electrochemical property of the Sb_2Te_3 nanoplates was determined by the voltammetric technique.

1. Introduction

Chalcogenides of V–VI groups (especially V_2VI_3-type) are useful semiconductors, which found applications in television cameras with photo-conducting targets, infrared spectroscopy, electronic and optoelectronic devices, and thermoelectric devices [1–4]. Recently, the antimony chalcogenides have attracted much attention due to their interesting properties and great potential applications [5–8]. As a kind of chalcogenides, antimony telluride has much more technological prospects [7–13]. Generally, antimony telluride bulk material was prepared by the solid reaction between elemental Sb and Te using microwave irradiation [14]. Compared with the conventional bulk materials, nanomaterials have attracted considerable attention due to their distinctive geometries, novel physical and chemical properties, and potential applications in numerous areas such as nanoscale electronics and photonics [15,16]. Going with the increasing interest in the nanostructured materials and nanodevices, a number of methods for the synthesis of the antimony telluride nanomaterials with different morphologies have been developed. Antimony telluride hollow nanosphere was synthesized via a thermal evaporation process [17]. It was especially important that antimony telluride film was prepared by the magnetron sputtering method [18]. Although it is a challenge to fabricate antimony telluride into nanostructured materials that could be applied to design various nanodevices, some strategies for the synthesis of antimony telluride nanostructures have been devised [19–21].

Several chemical methods, such as the solvothermal process and hydrothermal treatment, have been successfully employed for the fabrication of Sb_2Te_3 nanostructures. Mehta et al. have prepared Sb_2Te_3 nanosheets [22], Wang et al. have prepared Sb_2Te_3 nanorings [23], Shi et al. have prepared Sb_2Te_3 nanobelts [21], Dong et al. have prepared Sb_2Te_3 nanorods [24], Shi et al. have prepared Sb_2Te_3 nanoforks [25], Kim et al. have prepared Sb_2Te_3 nanoparticles [26]. However, these reported approaches suffer from the limits of unavoidable impurities in the products. It is still desirable to develop simple methods for the synthesis of Sb_2Te_3 nanostructures with well defined morphologies.

In this paper, Sb_2Te_3 nanoplates were synthesized via a simple hydrothermal route, in which the Te nanorods as-obtained were used as template reagents. The hydrothermal method involves heating of reactants in the water in a high-pressure system such as an autoclave. The pressure in the autoclave depends on the reaction temperature and the quantity of reaction medium. We have always been interested in the synthesis of metal selenide and metal telluride nanostructures, using this method. All the processes take place inside the autoclave, including dissolution of the mixture, movement of the solution and the growth of the nanomaterials. We have developed a facile method to prepare Sb_2Te_3 nanoplates and used Te nanorods as a new Te source. The Te nanorods can be fast reduced by hydrazine and formed into Te^{2-} ions, which have influence on the particles sizes and morphologies of the resulting samples and is the basis of this synthetic route. It is important that the effect factors and the formation mechanism of Sb_2Te_3 nanoplates via a hydrothermal method in the presence of Te nanorods are investigated. This method is simple, convenient and cost effective synthetic procedure and provided an efficient

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http://dx.doi.org/10.1016/j.jallcom.2013.03.005

way to the synthesis of tellurides materials. In addition, for their thermoelectric applications, the electrochemical property of the Sb_2Te_3 nanoplates was studied by the voltammetric technique.

2. Experimental section

2.1. Synthesis

The reagents are of analytical grade and were used in experiments without further purification. The Te nanorods that would be used as the template reagents were prepared as described in the literature [27]. With the Te nanorods as-obtained, Sb_2Te_3 nanoplates were typically synthesized as follows. First, under magnetic stirring, 0.2 mmol(0.0456 g) $SbCl_3$ was added into 8 mL hydrazine ($N_2H_4{\cdot}H_2O$). Then, 0.3 mmol(0.0384 g) Te nanorods was added into 5 mL deionized water. After ultrasonic irradiation at room temperature for 30 min, the Te nanorods solution was added into $SbCl_3$ solution under magnetic stirring. Finally, the mixed solution was added into a Teflon-lined stainless steel autoclave (15 mL), the vessel was immediately closed tightly and heated to 150 °C, and kept at this temperature for 5 h. The reaction took place at an autogenic pressure depending on the amount of distilled water added. After cooling the sample to room temperature, the product was obtained by centrifuge-separating and water washing the gray-black precipitate formed in the solution.

2.2. Characterization

The products as-obtained were characterized by scanning electron microscopy (SEM, X-650, HITACHI), X-ray diffraction (XRD, Japan Rigaku D/max-RA X-ray diffractometer, with graphite monochromatized Cu $K\alpha_1$ radiation, $\lambda = 0.15406$ nm), X-ray photoelectron spectroscopy (XPS, ESCALAB MKII, UK, Al Kα 1486.6 eV). The electrochemical behavior of the products was studied by potential scan voltammetry on an electrochemical system (Lanlike, Tianjin, China). The electrochemical cell was made up of a given electrolyte solution and a three-electrode system. Prior to voltammetry experiment, the surface of CPE was polished with fine paper and the electrolyte solution was degassed with N_2. The potential scan rate was 50 mV/s for all electrochemical experiments, except the situation specialized.

3. Results and discussion

The SEM image (Fig. 1a) for the as obtained Te product discloses its rod-like morphology. The XRD pattern (Fig. 1b) indicates that the Te product is composed of a hexagonal crystalline phase whose unit cell constants are $a = 0.4450$ nm and $c = 0.5996$ nm, corresponding well to those in the literature (JCPDS Card, No. 36-1452). Fig. 1c shows the plate-like morphology of the typical Sb_2Te_3 product, whose crystalline phase was determined by XRD (Fig. 1d). Clearly, all of the diffraction peaks including (006), (009), (015), (107), (018), (10$\underline{1}$0), (01$\underline{1}$1), (110), (00$\underline{1}$5), (10$\underline{1}$3), (01$\underline{1}$4), (119), (205), (00$\underline{1}$8), (01$\underline{1}$7), (02$\underline{1}$0), (10$\underline{1}$9), (01$\underline{2}$0), (125), (02$\underline{1}$6), (21$\underline{1}$0) and (300) on the XRD pattern can be indexed to the rhombohedral Sb_2Te_3 phase, and the unit cell constants calculated from the diffraction peaks are $a = 0.4262$ nm, $c = 3.045$ nm, which are consistent with those in the literature (JCPDS Card, No. 15-0874).

To understand the chemical situation of elements in the product, the XPS test was performed, and the results are shown in Fig. 2. Observing the XPS spectra of the Sb_2Te_3 sample, the binding energies obtained from the XPS spectra are 531.1 and 572.9 eV for $Sb3d_{5/2}$ (Fig. 2a) and $Te3d_{5/2}$ (Fig. 2b), respectively [28–30], which means that the product is composed of Sb (III+) and Te (II−). In addition, according to the quantification of XPS

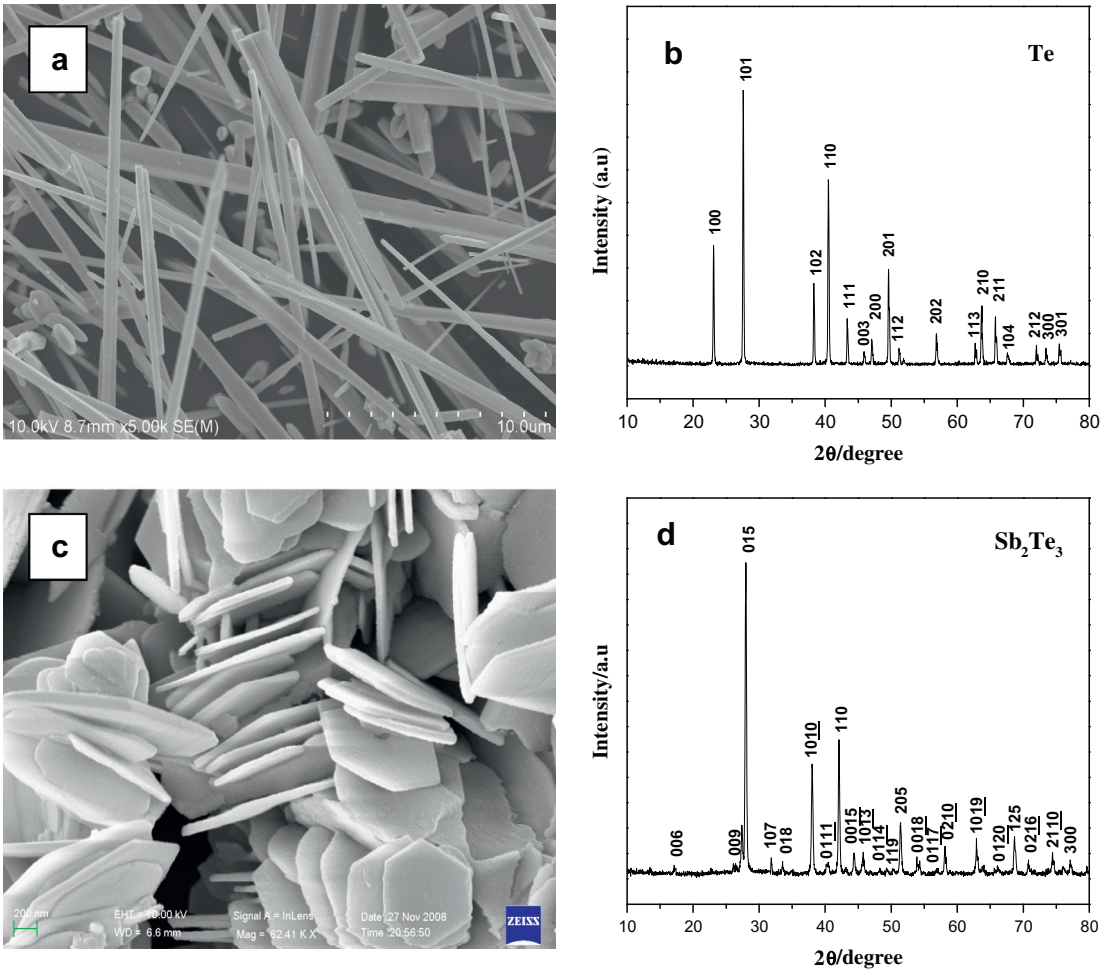

Fig. 1. SEM images and XRD patterns of the Te template (a and b) and Sb_2Te_3 product (c and d).