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$Ln_xPb_{1-x}Te(Ln:Nd^{3+},Yb^{3+})$ nanomaterials: Synthesis, characterization, physical properties, and optical properties

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ABSTRACT

$Ln_xPb_{1-x}Te(Ln:Nd^{3+},Yb^{3+})$ nanomaterials were synthesized using the facile hydrothermal method. The prepared samples were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray photoelectron spectroscopy (XPS). XRD analysis demonstrated that PbTe phase is cubic. By increasing the concentration of Ln^{3+} ions, the DRS spectra of PbTe shows blue shifts instead of red shifts due to bonding changes. XPS analysis of doped PbTe samples confirms the incorporation of Yb and Nd into the lattice. The electrical conductivity of Ln-doped PbTe is shown to be higher than that of pure PbTe, and increases with temperature.

Introduction

Thermoelectric (TE) materials are attracting increasing attention in the fields of energy harvesting and heat-to-electricity energy conversion [1]. Much attention has been paid to the IV–VI lead chalcogenide for applications in solar cells, TE devices, telecommunications, field effect transistors (FETs), photodetectors, and photovoltaics. The lead chalcogenide, compared to many traditional II–VI and III–V materials, has smaller band gaps and a larger Bohr radius [2]. PbTe, as a member of the lead chalcogenide family, is a preferred thermoelectric material, and was one of the first materials studied by Ioffe and his colleagues in the middle of the last century [3]. This compound has attracted significant attention due to its small band gap (0.31 eV at 300 K), high dielectric constant, high mobility and face-centered cubic structure (FCC). Compared to other semiconductor materials, the quantum size effect can be observed in large structures as a result of the large exciton Bohr radius of PbTe (46 nm) [4–6].

The optical properties and thermoelectric efficiency of PbTe depend, in order, on the deep defect electronic states in the neighborhood of the band gap, and on larger values of the dimensionless figure of merit ZT [7]. ZT is given by $ZT = S^2T/\rho\kappa$, where S, ρ, T, and κ are the Seebeck coefficient, electrical resistivity, absolute temperature, and thermal conductivity, respectively [8–10]. Therefore, it is necessary to maximize the value of ZT in order to large Seebeck coefficient, low electrical resistivity, and low thermal conductivity of the PbTe material [11].

Rare earth-substituted nanomaterials with various compositions have become increasingly vital in diverse areas such as novel photocatalysts, luminescent devices, light-emitting displays, biological labeling, and imaging [12–18]. This is due to the introduction of dopant levels within the bandgap and modification of the band structure. Various investigations have been conducted of PbTe doped with a lanthanide with the goal of enhancing the thermoelectric and optical properties [19–21]. There is no documentation in the literature of doping PbTe with ytterbium (Yb) and neodymium (Nd) as lanthanide ions. The incorporation of large electropositive ions such as lanthanides atoms (i.e., Yb and Nd) into PbTe could be considered, in order to affect its electronic, electrical, and physical properties. In the present work, we considered the preparation, and the structural, electrical, and optical properties of Yb^{+3} and Nd^{+3} co-doped with lead tellouride using a co-reduction method at a hydrothermal condition.

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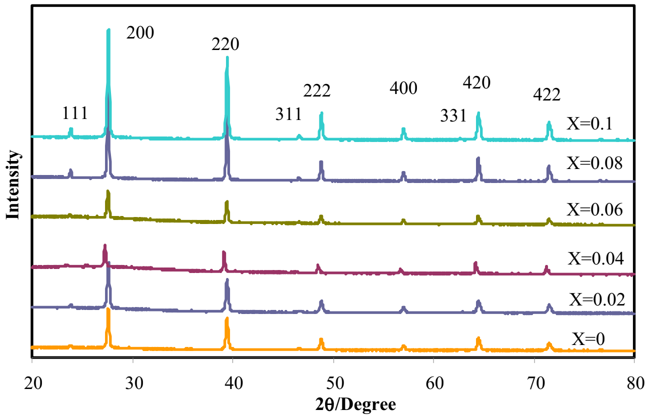

Fig. 1. XRD pattern of prepared PbTe and Nd-doped PbTe nanoparticles.

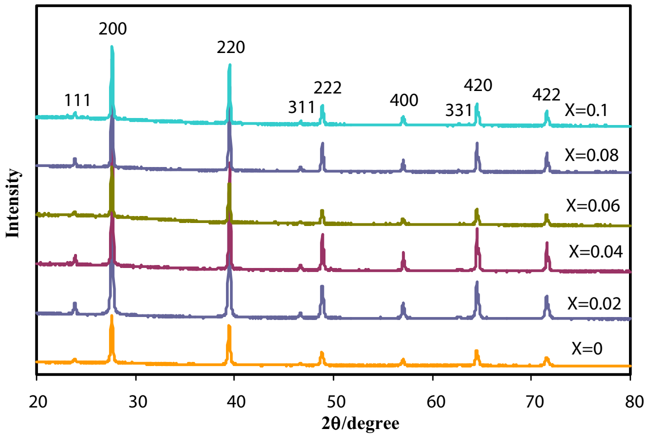

Fig. 2. XRD pattern of as-prepared PbTe and Yb-doped PbTe nanoparticles.

Experimental details

Materials

All chemicals used in this study were of analytical grade and were used without further purification. Lead (II) nitrate ($Pb(NO_3)_2$ 99%) was purchased from Kanto Chemical Company (Japan). Sodium hydroxide (NaOH 98%); sodium tellurite (Na_2TeO_3 100 mesh 99%); ytterbium (III) acetate hydrate ($Yb(C_2H_3O_2)_3 \cdot xH_2O$ H_2O 99.99%); $Nd(CH_3CO_2)_3 \cdot xH_2O$ Neodymium (III) acetate hydrate; and sodium borohydride ($NaBH_4$ 98%) were purchased from Sigma–Aldrich.

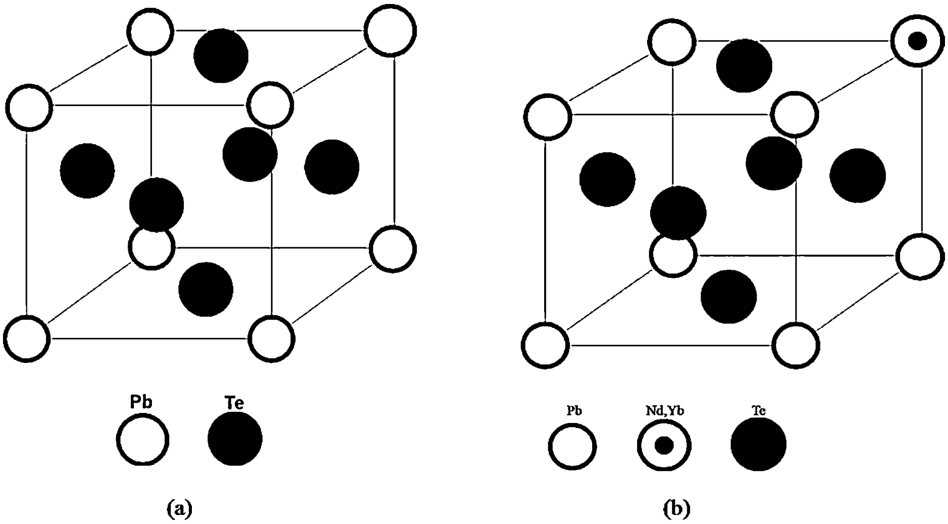

Fig. 3. (a) Structure of rock salt-type NaCl of the host lattice PbTe. For example, Nd or Yb is presented as a substitution impurity ion into the cation sublattice.

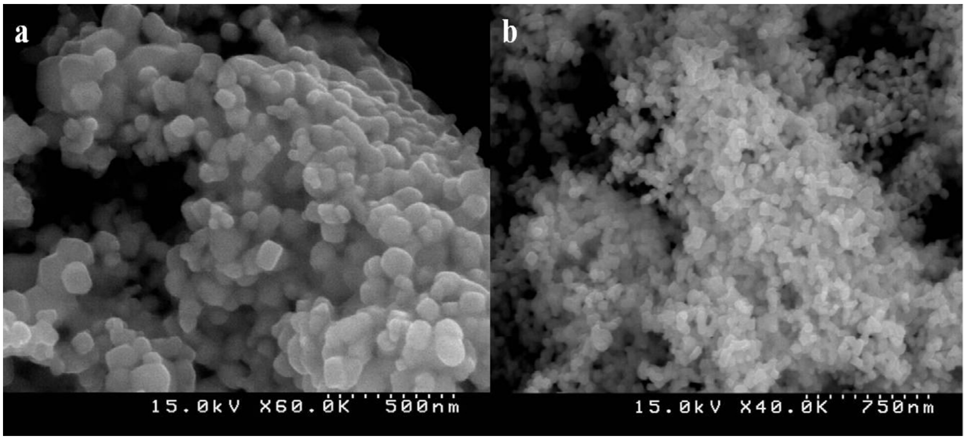

Fig. 4. SEM images of PbTe at two different magnifications.