Journal of ELECTRONIC MATERIALS, Vol. 42, No. 7, 2013
DOI: 10.1007/s11664-012-2384-z

Titania Embedded with Nanostructured Sodium Titanate: Reduced Thermal Conductivity for Thermoelectric Application

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Titania embedded with layer-cracking nanostructures (sodium titanate) was synthesized by a hydrothermal method and a subsequent sintering process. The structure and morphology were determined by x-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and N_2 adsorption–desorption experiments. In thermoelectric investigations, this nanocomposite has reduced thermal conductivity, where the minimum reaches about 2.4 W/m K at 700°C. This value is relatively low among the transition-metal oxides. Strong boundary scattering at the interfaces of the layered nanostructures and point defect scattering resulting from volatilization of Na^+ ions seem to be main reasons for the suppression of phonon heat transfer. On the other hand, the power factor shows no apparent deterioration. Our results suggest that introduction of proper layer-cracking nanostructures into thermoelectric hosts might be effective to enhance their performance.

Key words: Thermoelectric materials, layer-cracking nanostructures, boundary scattering, point defect scattering, thermal conductivity

INTRODUCTION

The efficiency of thermoelectric materials has been substantially improved in the last decade, mostly due to the progress of nanotechnology.[1] This develops the potential of thermoelectric materials to revolutionize waste heat recovery and the refrigeration industry. It is well known that nanotechnology can be used to decrease the thermal conductivity (κ) without simultaneous reduction of the power factor ($S^2\sigma$), where the Seebeck coefficient (S) and electrical conductivity (σ) are associated with the charge carriers.[2,3] This effect results in a large enhancement in the efficiency as represented by the dimensionless figure of merit ZT ($ZT = TS^2\sigma/\kappa$, where T is the absolute temperature). So far, two typical examples, namely superlattices (quantum dot superlattices)[4,5] and bulk materials embedded with small-sized nanoinclusions,[6,7] have confirmed that boundary scattering of phonons at the interfaces of nanostructures can reduce the lattice thermal conductivity (κ_l) definitely without decreasing the power factor.

Another approach to search for materials with high thermoelectric performance is the phonon glass–electron crystal (PGEC) concept proposed by Slack.[8] The PGEC approach has stimulated a significant amount of new research and has brought about prominent improvements in ZT for skutterudites[9,10] and clathrates.[10,11] The key point of this concept is that the "rattling" motion of guest atoms strongly scatters phonons[12] or flattens the phonon

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(Received July 22, 2012; accepted December 12, 2012;