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# The Effect of Grain Size and Density on the Thermoelectric Properties of $Bi_2Te_3$-PbTe Compounds

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The effects of microstructure on thermoelectric properties were investigated in $Bi_2Te_3$-PbTe compounds of different grain size and density. Powders of two different sizes [0.1 $\mu$m to 1 $\mu$m (micropowder) and $<$50 nm (nanopowder)] were prepared from $Bi_2Te_3$-PbTe ingots by ball milling and high-energy ball milling. Three different samples were spark plasma sintered from each powder and the mixture of the two powders. The grain size and relative density of the sintered samples varied from 100 nm to a few micrometers and 89.7% to 97.3%, respectively. The dimensionless figure of merit $zT$ of the sample sintered from nanopowder was about 0.50 at 500 K, being about 3.3 times larger than that of the sample sintered from micropowder ($\sim$0.15 at 500 K), when the relative density of the former and the latter were 89.7% and 97.3%, respectively. The improved thermoelectric performance of the samples may originate from the decrease of the thermal conductivity, which was caused by the decrease of the grain size and the increase of the amount of pores.

**Key words:** Thermoelectric material, microstructure, $Bi_2Te_3$-PbTe binary compound, density, grain boundary

## INTRODUCTION

Research on utilizing thermoelectricity is attracting more and more attention as a promising technology for future energy harvesting.[1] Development of a thermoelectric module having high thermal-to-electrical energy conversion efficiency is one of the main goals of thermoelectric research. The performance of a thermoelectric material is characterized by the dimensionless figure of merit $zT = (S^2\sigma T)/\kappa$, where $S$ is the Seebeck coefficient, $\sigma$ is the electrical conductivity, and $\kappa$ is the thermal conductivity.[1] Therefore, increase of $S^2\sigma$ and/or decrease of $\kappa$ is needed to realize high conversion efficiency of thermoelectric materials.

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After it was proposed by Hicks et al.[2] that low-dimensional nanostructures such as quantum dots and superlattices could increase the $zT$ value, many research groups reported results for thermoelectric materials based on nanostructures with improved $zT$ values,[3–6] most of which were realized in the form of thin films. However, for practical applications of thermoelectric materials with nanostructures, the formation of nanostructures in bulk material is highly desired.

Recently Poudel et al.[7] reported $p$-type $Bi_xSb_{2-x}Te_3$ bulk compound with nanostructure having $zT$ value of about 1.4 at 100°C. They used high-energy ball milling and the hot-pressing method to prepare the nanostructured bulk material from a $Bi_xSb_{2-x}Te_3$ ingot, and the $zT$ value was increased by 30% to 40% compared with that of the ingot. They attributed the increase of the $zT$ value to the decrease of the thermal conductivity which