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Design of Ball-Milling Experiments on Bi_2Te_3 Thermoelectric Material

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In this work, factorial ball-milling experiments have been applied to Bi_2Te_3 material, for the first time, aiming to investigate the effect of the main process parameters on the structural features and thermoelectric properties of the ball-milled materials. The selected main parameters were the duration of milling, the speed, and the ball-to-material ratio. Analysis suggests a strong effect of the speed and duration of processing, whereas the ball-to-material ratio is of minor importance. This approach is advantageous for better understanding of the milling mechanism and the importance of the role of each independent parameter as well as their interaction. All experiments led to nanocrystalline Bi_2Te_3, whose structural features were studied. The nanocrystalline size was estimated based on x-ray diffraction analysis, while transmission electron microscopy (TEM) studies were also performed to confirm the presence of nanoscale crystals. A mathematical model was developed based on statistical analysis for prediction of the crystalline size and the Seebeck coefficient of the nanopowders. The thermoelectric properties were also investigated on selected, highly dense pellets fabricated via hot-pressing of the nanopowders.

Key words: ANOVA, regression equation, nanostructured materials, thermoelectric properties

INTRODUCTION

Research on thermoelectrics has shown that there is great interest in bulk nanocrystalline materials with enhanced thermoelectric properties through the high-performance low-cost approach.[1] Thermoelectric performance is discussed in terms of the equation $ZT = \sigma S^2 T/\kappa$, where σ is the electrical conductivity, S is the Seebeck coefficient, and κ is the thermal conductivity at temperature T. The ZT enhancement in nanostructured material systems is mainly attributed to the reduction of the thermal conductivity by scattering phonons more effectively than electrons at grain boundary interfaces in nanostructures.[2–4] On the other hand, there are also reports that ZT can be enhanced by increasing the Seebeck coefficient.[5,6] There are a few works reporting the thermoelectric properties of nanocrystalline materials with different crystalline size,[6–9] but it is not yet known if there is any correlation of crystalline size with the properties of the materials.

The ball-milling process is advantageously used as a solid-state synthesis and/or processing method due to its ability to produce nanostructured materials in bulk form using simple equipment.[10] It has become a popular method because of its simplicity, applicability to essentially all classes of material, and the possibility for easy scale-up. From a practical perspective, it is well known that the ball-milling process involves many parameters and that optimization of the process may be complicated and material and time consuming. Milling time, ball-to-material weight ratio (BMR), grinding medium material, grinding ball size, use of process control

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