Enhancements on the Performance of Thermoelectric Materials by Directional Solidification

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During the earlier NASA missions in 1977, Voyager 1 and Voyager 2 each were launched with three radioisotope thermoelectric generators (RTGs) of power which used 238Pu as the thermal energy source and SiGe as the thermoelectric conversion material. They have left the solar system and entered into interstellar space in 2012 and 2018, respectively, but the RTGs are still functioning mainly because there was no moving parts. High efficiency thermoelectric devices are also needed in many other terrestrial applications such as auto industry, nuclear power plants, and aerospace industry. The converting efficiency of thermoelectric material is rated by its Figure of Merit, *zT*, which varies with temperature and usually goes through a maximum zT_M at a temperature T_M. Most of the research efforts have been focused on raising the value of zT_M and the thermoelectric materials are usually processed by hot pressing or quench-annealing, which results in uniform properties throughout the processed ingot. When positioned in a thermal gradient, only a small section of the material operating in the temperature range near its T_M contributes to most of the converting efficiency while the rest of the sample operates at lower levels of efficiency. To improve its efficiency, thermoelectric properties need to vary continuously along its length, the so-called Functional-Gradient (FG) thermoelectric materials, such that the value of T_M of each individual thin layer matches the actual temperature along its thermal gradient. Such a high efficiency FG thermoelectric material with continuously monotonic variation of T_M can be accomplished by melt growth using the directional solidification technique and have been demonstrated in the n-type doped PbTe system. The results show that a segment of Cl-doped PbTe grown by directional solidification has an average *zT* value of 1.3 with T_M varying between 295 and 585^{o}C along its length, which provides an estimated converting efficiency of 12% comparing to 8% for a similar segment with uniform *zT* profile throughout its length. The efficiency calculation also reveals that if the operating temperature range can be extended by 100^{o}C, e.g., from 245 to 635^{o}C, it would enhance efficiency from 12% to 16% while *zT* remaining at 1.3. Thermal stability is another advantage for the method of melt growth over the methods of hot pressing or quench-annealing. During the process of melt crystal growth, the material is formed under a quasi-equilibrium condition, which results in homogeneous solid structure in a lower-energy state and, consequently, more thermally stable and mechanically robust. Consequently, the thermal stability of melt grown samples maintain their high values of converting efficiency during its long time operation at elevated temperatures.