Electrical power from heat: All-scale hierarchical thermoelectrics with and without earth-abundant materials

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The nanostructuring approach to highly efficient thermoelectrics has produced a paradigm shift and ushered in a new era of investigation for bulk thermoelectrics. The new approach shows considerable promise to enhance the "contra-indicated" parameters of high electrical conductivity and low thermal conductivity. Currently lead chalcogenides incorporating second phases hold the record in figure of merit for high temperature power generation applications (ZT of ~2.2 at 915 K). The nanostructuring approach to highly efficient thermoelectrics has produced a paradigm shift and ushered in a new era of investigation for bulk thermoelectrics. Nanostructures in bulk thermoelectrics enable effective phonon scattering of a significant portion of the phonon spectrum but phonons with long mean free paths remain largely unaffected. It is now possible to incorporate scattering of these long-wavelength heat-carrying phonons by controlling and tailoring the mesoscale architecture of nanostructured thermoelectric materials. Thus, by combining all relevant length-scales in a hierarchical fashion; from atomic-scale disorder and nanoscale endotaxial precipitates to mesoscale phonon scattering via grain boundaries; we can achieve a large enhancement in the thermoelectric performance of bulk materials. We call this a "panoscopic" approach to scattering of heat carrying phonons across integrated length-scales. The cost of lower earth-abundance elements such as tellurium in PbTe-based thermoelectric materials, however, can potentially limit their application, but substituting tellurium with more abundant sulfur or selenium can reduce the material costs. Utilizing techniques developed with PbTe-based materials, lead sulfide- and lead selenide-based specimens have achieved ZT values of 1.1 to 1.4 via doping and additions to optimize nanostructuring.