Design Principle of Telluride-Based Nanowire Heterostructures for Potential Thermoelectric Applications

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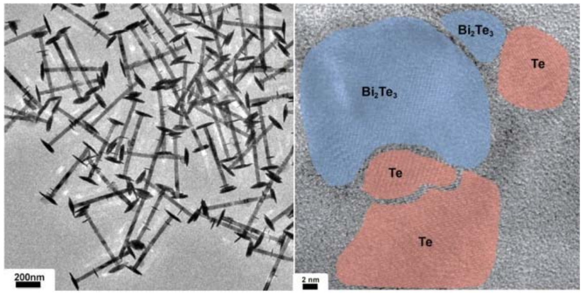

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Introduction

- Thermoelectric (TE) devices, which can perform a direct conversion between thermal and electrical energy, have attracted great attention due to their promising potential in improving the energy efficiency and in solid-state cooling.

- Low efficiency of the most of the TE materials prohibits their wide applications.

- Certain TE materials, such as Bi_2Te_3/Sb_2Te_3 superlattice film (ZT ~ 2.4) and $AgPb_mSbTe_{2+m}$ bulk crystals (ZT ~ 2.2), although possessing high performance due to the improved phonon scattering at nanoscale interfaces and grain boundaries, require very complicated material composition or an extremely expensive/time-consuming manufacture process such as molecular beam epitaxy.

- Theoretical predictions and initial experimental results have suggested that one-dimensional (1D) nanostructures, especially the nanowire heterostructures, which take the advantages of both quantum confinement to enhance the power factor and phonon scattering at nanowire surface and compositional interfaces to lower thermal conductivity, could offer a much higher ZT value.

Introduction

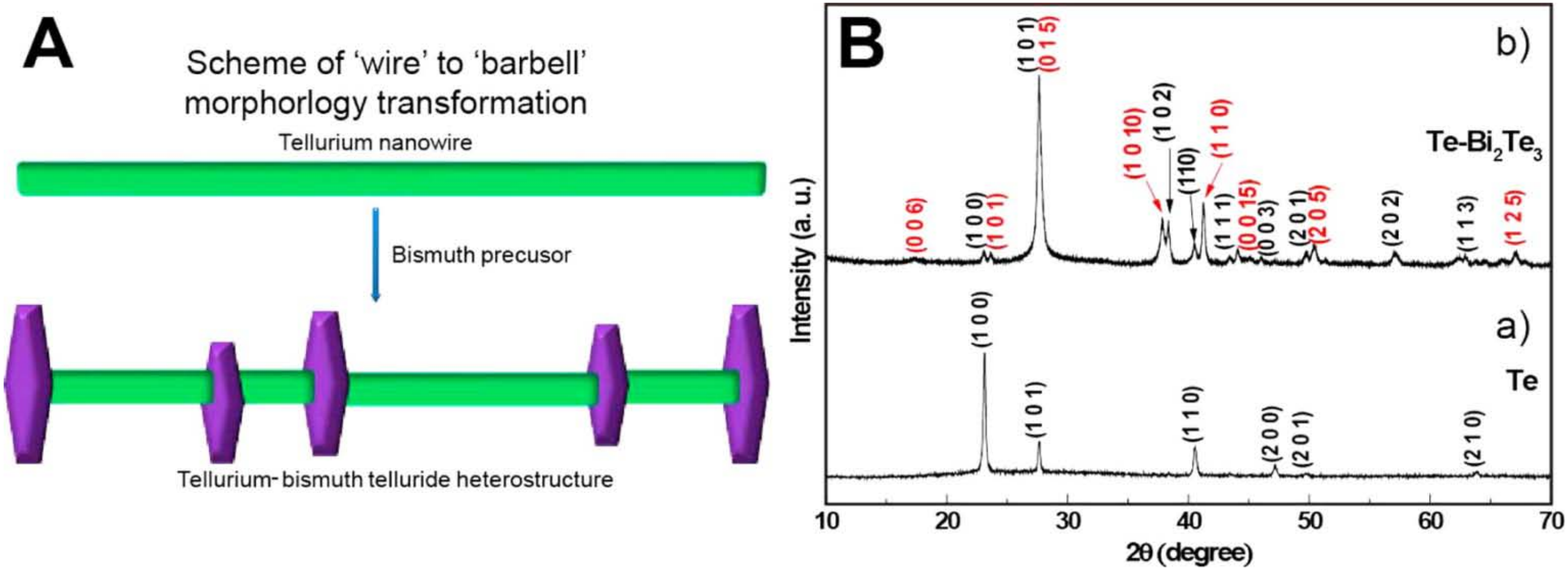
- 1D nanowire heterostructures have been demonstrated through the chemical vapor deposition process based on vapor−liquid−solid (VLS) growth mechanism as well as the pulsed electrodeposition, but the main challenge is to obtain high-quality thermoelectric nanowire heterostructures in a simple yet scalable way.

In this paper

- A catalyst-free synthesis of $Te-Bi_2Te_3$ “barbell” nanowire heterostructures with a narrow diameter and length distribution is demonstrated. Rough control over density of the hexagonal Bi_2Te_3 plates on the Te nanowire bodies was obtained by varying the reaction conditions.

- Conversion to of these NWs into other nanowire heterostructures such as $PbTe-Bi_2Te_3$ was also demonstrated.

- Largely enhanced Seebeck coefficient and greatly reduced thermal conductivity, leading to an enhanced thermoelectric figure of merit was observed in the hot-pressed nanostructured bulk pellets made from the $Te-Bi_2Te_3$ heterostructures.



(A) Schematic of tellurium nanowire formed in the first step and tellurium–bismuth telluride heterostructure after adding bismuth precursor in the second step. (B) X-ray diffraction (XRD) patterns of Te nanowires and Te–Bi_2Te_3 heterogeneous nanostructures after the injection of Bi precursor solution (the black marks stand for the peaks from Te, and the red stand for Bi_2Te_3).

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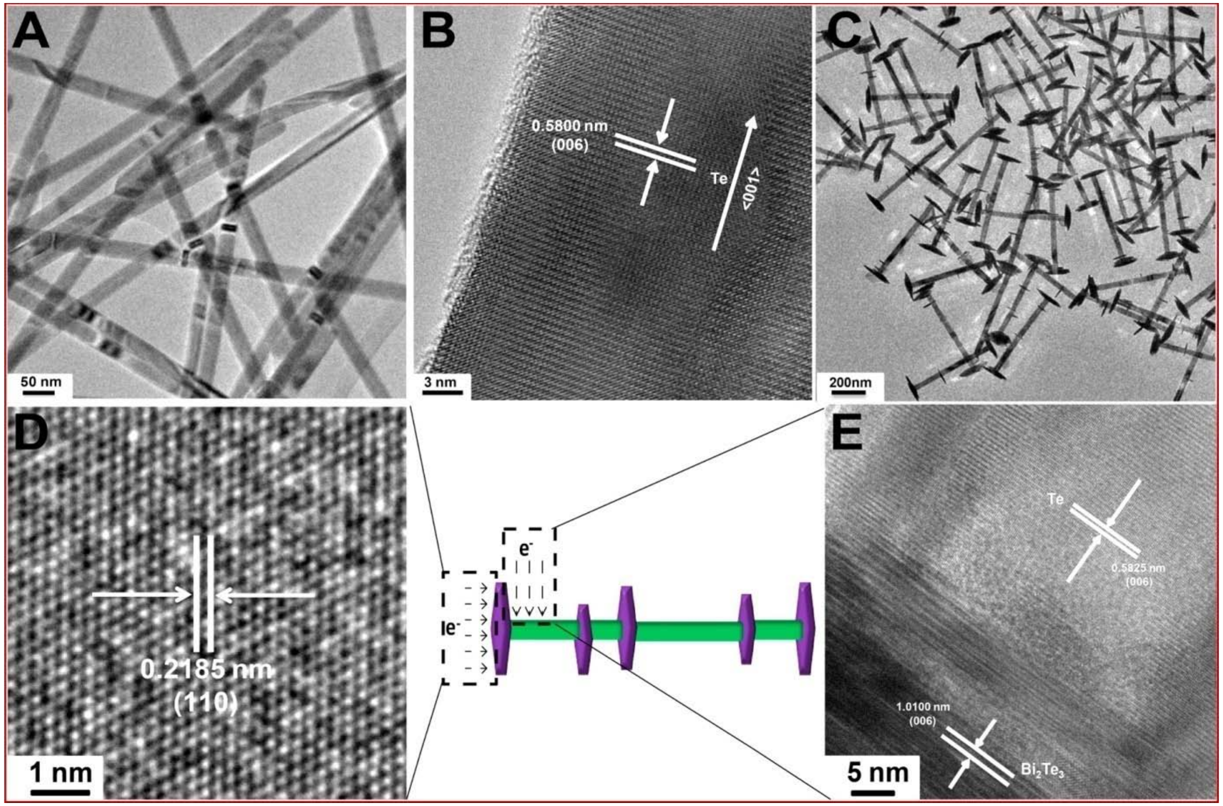

TEM images of Te nanowires and Te–Bi_2Te_3 nanowire-multiple plates heterostructure: (A) low magnification and (B) HRTEM images of tellurium nanowire; (C) low magnification and (D, E) HRTEM images of the Te–Bi_2Te_3 heterostructure. The scheme indicates the regions/view directions studied by HRTEM. Part D shows the top view of the Bi_2Te_3 plate, and part E shows the side view of Bi2Te3 plate and the junction between Te and Bi_2Te_3.

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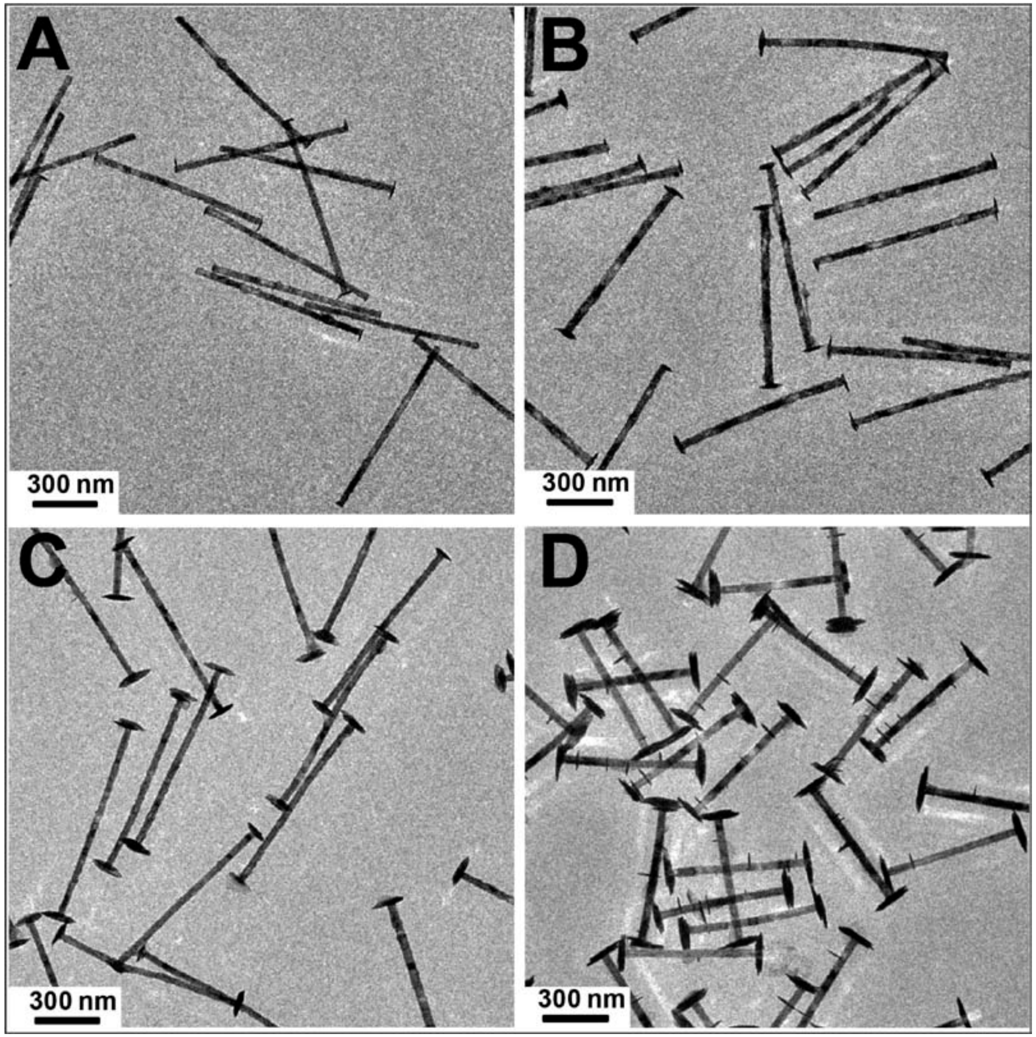

Evolution of “barbell” morphology by adding different amounts of hydrazine hydrate in the reaction: (A) 0.6 mL; (B) 0.5 mL; (C) 0.4 mL; and (D) 0.3 mL.

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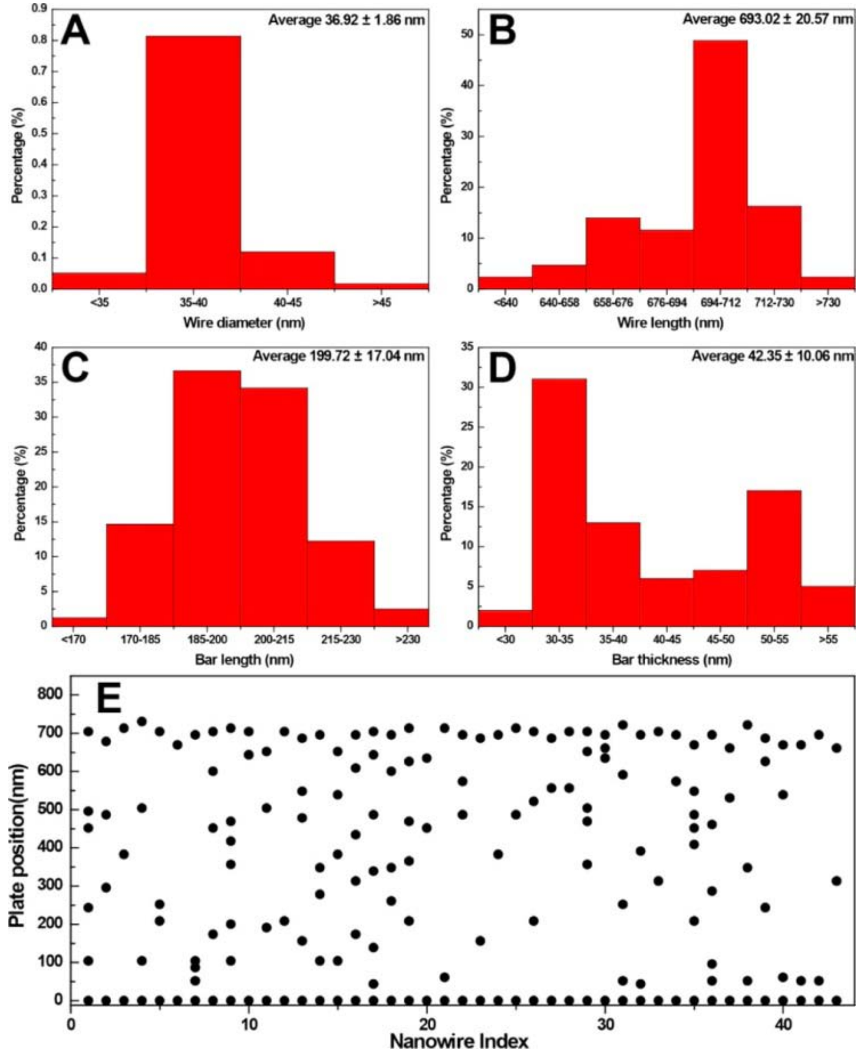

(A and B) Distribution of wire diameter and length; (C and D) distribution of bar length and thickness at the two ends of the wires; the reason for the two peaks in D is because two plates pile up at the ends of some wires; (E) the positions of the Bi2Te3 plates (black dots) on the nanowire heterostructures; the dots lined up perpendicularly to the *x*-axis are on a single wire.

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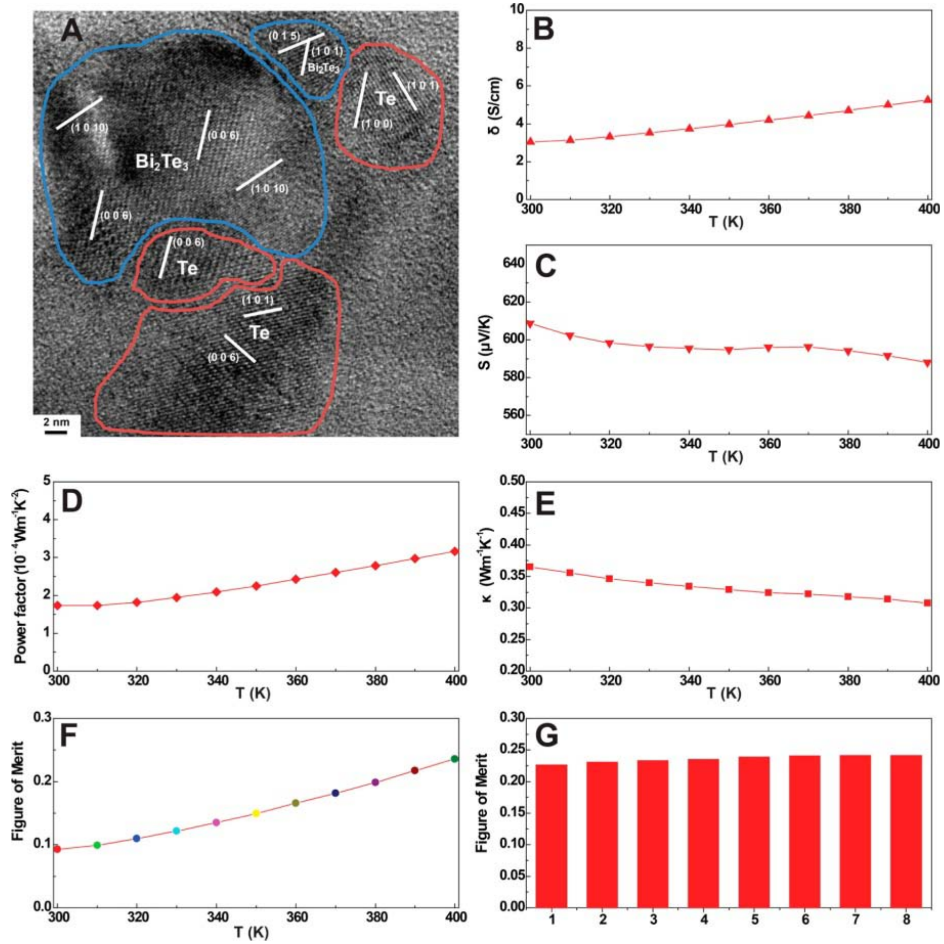

Thermoelectric properties of bulk nanocomposite pellet made by hot pressing the as-obtained Te–Bi_2Te_3 nanowire heterostructures. (A) Cross section HRTEM image of hot-pressed sample which clearly shows nanoscale grain boundaries preserved inside the sample; (B) electric conductivity, (C) Seebeck coefficient, (D) power factor, (E) thermal conductivity, (F) ZT of a typical sample measured between 300 and 400 K, and (G) the distribution of peak ZT from different samples.

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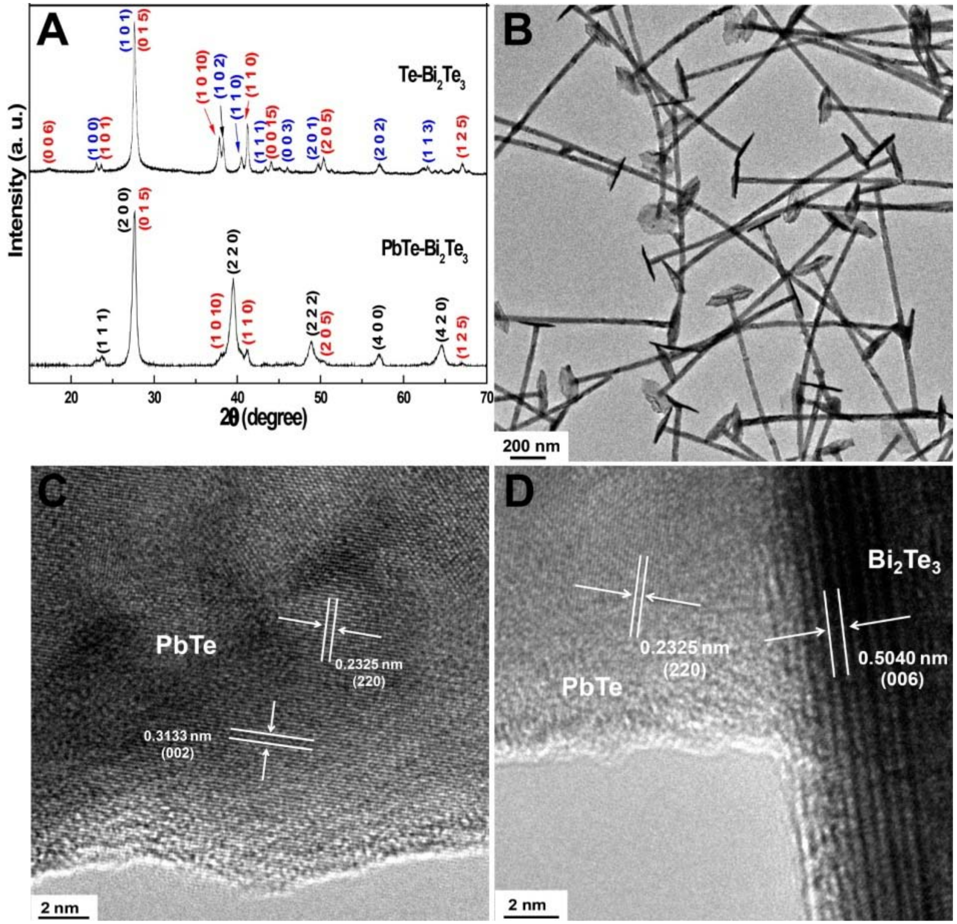

(A) XRD patterns of Te–Bi_2Te_3 heterostructures and PbTe–Bi_2Te_3 heterostructures after the injection of Pb precursor solution (the black marks stand for the peaks from PbTe, the red for the ones from Bi_2Te_3, and the blue for the ones from Te). (B) The TEM image of PbTe–Bi_2Te_3 barbell heterostructures. Parts C and D are the HRTEM images of PbTe nanowire body (C) and the junction between PbTe nanowire body and Bi_2Te_3 plates (D).

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Summery

- A rational solution phase synthetic approach was developed that will instantly open up great wealth of opportunities for the fundamental studies about the electron and phonon interactions in the unique platforms of telluride-based nanowire heterostructures.

- Initial physical characterizations demonstrate a significantly improved thermoelectric performance due to the enhanced phonon scattering at nanowire heterostructure surface and interface, which could significantly inspire further advances in using novel nanowire heterostructures for thermoelectric energy conversion.

- This approach can be further generalized to prepare other telluride-based nanowire heterostructures, such as $Ag_2Te-Bi_2Te_3$, $Sb_2Te_3- Bi_2Te_3$, $Cu_2Te-Bi_2Te_3$, $SnTe-Bi_2Te_3$, and so forth.

Thank You