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Recent advances in thermoelectric materials

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ABSTRACT

Thermoelectric materials are crucial in renewable energy conversion technologies to solve the global energy crisis. They have been proven to be suitable for high-end technological applications such as missiles and spacecraft. The thermoelectric performance of devices depends primarily on the type of materials used and their properties such as their Seebeck coefficient, electrical conductivity, thermal conductivity, and thermal stability. Classic inorganic materials have become important due to their enhanced thermoelectric responses compared with organic materials. In this review, we focus on the physical and chemical properties of various thermoelectric materials. Newly emerging materials such as carbon nanomaterials, electronically conducting polymers, and their nanocomposites are also briefly discussed. Strategies for improving the thermoelectric performance of materials are proposed, along with an insight into semiconductor physics. Approaches such as nanostructuring, nanocomposites, and doping are found to enhance thermoelectric responses by simultaneously tuning various properties within a material. A recent trend in thermoelectric research shows that high-performance thermoelectric materials such as inorganic materials and carbon nanomaterials/electronically conducting polymer nanocomposites may be suitable for power generation and energy sustainability in the near future.

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Abbreviations: α, Seebeck coefficient; γ, acoustic phonon Grüneisen parameter; θ_D, Debye temperature; κ, total thermal conductivity; $\kappa_{lattice}$, lattice thermal conductivity; κ_C, κ_e, charge-carrier thermal conductivity; μ, mobility; η, efficiency; ρ, density; σ, electrical conductivity; a, lattice parameter; C_p, specific heat; h, Planck's constant; k_B, Boltzmann constant; T_{cold}, cold-end temperature; T_{hot}, hot-end temperature; ZT, figure of merit; ASSET, atomic-scale structural engineering of thermoelectrics; CVD, chemical vapor deposition; CNTs, carbon nanotubes; DOS, density of states; DMSO, dimethyl sulfoxide; EG, ethylene glycol; fH, full-Heusler; HP, hot pressing; HH, half-Heusler; LAST, $AgPb_mSbTe_{2+m}$; LASTT, $AgPb_mSn_nSbTe_{2+m+n}$; MWCNTs, multiwalled carbon nanotubes; NPs, nanoparticles; PEDOT, poly(3,4-ethylenedioxythiophene); PEDOT:Tos, PEDOT:tosylate; PGEC, phonon glass electron crystal; PTH, polythiophene; PSS, poly(styrenesulfonate); PANI, polyaniline; PVDF, polyvinylidene difluoride; QDSL, quantum dot superlattice; SEM, scanning electron microscope; SWCNTs, single-walled carbon nanotubes; SPS, spark plasma sintering; Tos, tosylate; vol%, volume percent.

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1. Introduction

Humankind is facing a serious increasing demand for energy. With the decrease in fossil fuels, renewable energy sources will be essential for resolving the power crisis in the future. In this respect, energy conversion technologies such as solar cells and fuel cells are highly relevant, although their global commercialization is limited by their poor efficiency, high cost, and