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Nanostructured Semiconductors for Enhanced Waste Heat-to-Electricity Conversion

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INTRODUCTION & AIM

Nanostructured semiconductors provide a novel strategy to enhance thermoelectric (TE) performance.

These materials enable efficient conversion of waste heat into electricity.

Nanoscale engineering allows precise tuning of material properties.

Improve the thermoelectric figure of merit (ZT) by:

Increasing electrical conductivity.

Decreasing thermal conductivity via phonon scattering.

Overcome traditional limitations found in bulk semiconductors.

Enable development of compact, high-efficiency TE devices for energy recovery.

Applications include industrial waste heat recovery, automotive exhaust systems, and wearable power generators.

METHOD

◦Material Selection: Thermoelectric semiconductors (e.g., PbTe, Bi_2Te_3, SiGe) with high Seebeck potential.

◦Nanostructuring: Used ball milling, CVD, and sintering to create nanowires, films, and quantum dots.

◦Doping: Controlled doping to optimize carrier concentration and electrical performance.

◦Composite Design: Fabricated hybrid structures to improve phonon scattering and reduce thermal conductivity.

◦Characterization: Used XRD, SEM, TEM for structural analysis.

◦Property Measurement: Measured Seebeck coefficient, electrical & thermal conductivity.

◦Thermal Stability: Tested long-term performance under thermal cycling.

RESULTS & DISCUSSION

1. Reduction in Thermal Conductivity

Nanostructuring significantly suppresses lattice thermal conductivity.

Achieved by introducing twin planes, grain boundaries, or phase-separated nanostructures.

Enables higher thermoelectric efficiency while maintaining electrical transport properties.

2 Enhanced Electrical Properties

Nanostructures improve carrier mobility and density of states, optimizing electrical conductivity.

Techniques such as heavy doping and dimensional confinement increase the Seebeck coefficient.

Materials like carbon nanotubes and quantum dots enable strong thermoelectric responses.

3High-Temperature Stability

Thermoelectric materials must withstand thermal cycling and high operating temperatures.

Nanostructured compounds show improved thermal endurance with minimal performance loss.

Essential for applications in automotive, industrial waste heat, and aerospace systems.

4 Innovative Composite Materials

Hybrid and 2D nanocomposites (e.g., silicon-germanium blends) combine low thermal conductivity with enhanced electrical performance.

Superior phonon scattering and electronic transport control lead to higher energy conversion efficiency.

Strong candidates for next-generation thermoelectric generators.

CONCLUSION

Nanostructured semiconductors significantly improve thermoelectric performance by balancing electrical conductivity and reducing thermal conductivity.

Engineering at the nanoscale enables efficient waste heat recovery through higher Seebeck coefficients and optimized carrier transport.

Techniques like doping, interface control, and hybridization enhance the thermoelectric figure of merit (ZT).

These materials offer a sustainable solution for converting industrial and environmental heat into electricity.

Continued research is essential for improving long-term stability, scalability, and cost-effective fabrication.

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