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Trends and opportunities in composite thermoelectrics

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Traditional thermoelectric research faces persistent challenges arising from inherent trade-offs among the Seebeck coefficient, electrical conductivity, and thermal conductivity. Despite extensive efforts through doping, alloying, and microstructural modifications, the figure-of-merit (ZT) of modified single-phase thermoelectric materials remains well below the theoretical Mahan–Sofo limit of 3.0, restricting device performance. This Report is to demonstrate how recent progress in composite thermoelectrics is reshaping the research landscape. I will first outline the mechanisms of composite effects that influence thermoelectric properties, which establish the foundation for diverse strategies to enhance ZT and facilitate materials design. Then, the feasibility and effectiveness of these strategies are examined, with particular emphasis on interfacial engineering and the transitions in minority phase. The growing roles of artificial intelligence and additive manufacturing in materials processing are also discussed. It is evident that except for the higher achievable ZT compared to single-phase materials, composite can offer superior mechanical robustness and properties favored by different applicational scenarios. Moreover, composite thermoelectric devices with desirable conversion efficiency can be applied in broadened fields. Given these advances, it is reasonable to anticipate that the development of composite thermoelectrics will remain strong and may lead to a paradigm shift in future.

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