

# Introduction to Thermoelectric Materials: Converting Heat into Electricity

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## Short Communication

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### ABOUT THE STUDY

The thermoelectric effect manifests itself strongly or conveniently in thermoelectric materials. The term "thermoelectric effect" describes situations in which either a temperature difference or an electric current can produce an electric potential. The Peltier effect, which uses an electric current to drive heat flow, the Thomson effect, which causes reversible heating or cooling within a conductor when there is both an electric current and a temperature gradient, are the more precise names for these phenomena. Despite the fact that all materials have a thermoelectric effect, it is usually too small to be of any value. Compared to metals, semiconductors' band structures offer better thermoelectric effects. The state density around the Fermi energy is asymmetric because the Fermi energy is below the conduction band. Since the conduction band's average electron energy is larger than the Fermi energy, the system is favourable for charge migration into a lower energy state.

In contrast, metals' conduction band is where the Fermi energy is located. As a result, the average conduction electron energy approaches the Fermi energy and the forces urging for charge transport are diminished. This makes the state density symmetric about the Fermi energy.

In light of this, semiconductors make perfect thermoelectric materials. At room temperature, bismuth telluride and its solid solutions are effective thermoelectric materials, making them appropriate for refrigeration applications about 300 K. Compounds made of bismuth telluride have been grown as single crystals using the Czochralski process. These compounds are often produced using melt or powder metallurgy methods and directional solidification. Due to the random orientation of the crystal grains, materials made using these techniques are less efficient than single-crystalline ones, but have better mechanical properties and are less sensitive to structural flaws and impurities because of the high optimum carrier concentration. By selecting a nonstoichiometric composition, which is accomplished by adding extra bismuth or tellurium atoms to the primary melt or by dopant impurities, the desired carrier concentration is attained. Halogens and group IV and V atoms are examples of potential dopants.  $\text{Bi}_2\text{Te}_3$  is somewhat degenerate because of the

tiny bandgap (0.16 eV), and at ambient temperature, the associated Fermi level should be close to the conduction band minimum. The large band-gap indicates that the intrinsic carrier concentration in  $\text{Bi}_2\text{Te}_3$  is high. Therefore, even for slight stoichiometric variations, minority carrier conduction cannot be disregarded. Due to tellurium's toxicity and scarcity, its use is restricted. Substitutional doping, in which a portion of the framework atoms are swapped out for dopant atoms, is the most straightforward method for synthesising and improving the thermoelectric characteristics of semiconducting type I clathrates [1-3]. Techniques for crystal formation and powder metallurgy have also been applied in the production of clathrate. Clathrates' structural and chemical characteristics make it possible to optimise their transport characteristics in relation to stoichiometry. The partial filling of the polyhedra permitted by the structure of type II materials allows for greater electrical property tuning and, consequently, better control of the doping level. Variants that are just partially filled can be created as semiconducting or even insulating materials. Homologous oxide compounds have layered superlattice structures that make them interesting candidates for use in high-temperature thermoelectric devices, such as those of the form  $(\text{SrTiO}_3)_n(\text{SrO})_m$ —the Ruddlesden-Popper phase. While preserving strong electronic conductivity within the layers, these materials have low thermal conductivity perpendicular to the layers. They have higher thermal stability than traditional high-ZT bismuth compounds, which makes them outstanding high-temperature thermoelectrics. Their ZT values can approach 2.4 for epitaxial  $\text{SrTiO}_3$  films [4-8]. Even though it is significantly more widespread than the aforementioned cuprokalinitite, the Sulphide Mineral Bornite ( $\text{Cu}_5\text{FeS}_4$ ) is named after an Austrian mineralogist. The thermoelectric performance of this metal ore was discovered to be enhanced following cation exchange with iron [9-11]. In order to allow cations (positively charged ions) within a parent crystal to exchange for those in solution without harming the anion sublattice (negatively charged crystal network), the parent crystal is surrounded by an electrolyte complex. This process is known as cation exchange. What is left are crystals with a varied content but the same basic structure. When creating complex heterostructures, scientists are given this kind of tremendous morphological control and homogeneity.

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