Thermoelectric Materials

A thermoelectric device creates a voltage when a different temperature on each side of a material is applied and creates a temperature difference when a voltage is applied. The direct conversion of temperature differences to electric voltage and vice versa, is named as the thermoelectric (TE) effect. This TE effect can be used to generate electricity, to measure temperature, to cool objects, or to heat them. The emerging global need for energy production, conservation and management has intensified interest in more effective means of power generation. The enhancements to the existing energy supply must come from a variety of renewable sources including solar, wind, biomass and others. But by no means should be expected, that thermoelectric energy conversion will solve the world's energy problems. Possible applications of the TE effect are: active cooling/warming, localized cooling, commercial coolers/warmers and luxury vehicles with cool/warm seats.

Thomas Seebeck found (in 1821) that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, if the junctions of the metals were maintained at two different temperatures. In this case the appearance of an electrical voltage is caused by a temperature gradient across a material. The inverse of this is known as "Peltier effect". The created voltage in a thermoelectric material is in the order of several microvolts per degree difference (conventionally in $\mu V/K$).

$$S = \frac{dV}{dT}$$

The performance of a TE material is directly dependent on the temperature gradient (Δ T) and an intrinsic material parameter: the thermoelectric figure of merit (ZT). The figure of merit represents the quality of performance of a TE material; sometimes it is multiplied by temperature and is dimensionless. [σ = electrical conductivity - how much the carriers can transport energy without Joule loss?; κ = thermal conductivity (κ = κ latt + κ el) - how small is the reverse flow of heat from the cold-side to the hot-side, opposing the electron-transport of heat?; *S*= Seebeck coefficient / thermoelectric power; T= average temperature ((T2 + T1) / 2)]. S^2* σ = power factor (PF).

$$ZT = \left(\frac{S^2 \sigma}{\kappa}\right)T$$

The value of (ZT) is usually proportional to the efficiency of the device and it is a very convenient figure for comparing the potential efficiency of devices using different materials. The parameters of ZT can be determined by details of the electronic structure and scattering of charge carriers, but they are not independently controllable. In this case it is very challenging to create high ZT, by achieving simultaneously high electronic conductivity (σ), high thermoelectric power (S) and low thermal conductivity (κ) in the same solid. Two approaches are aimed at increasing ZT: either the power factor is maximized and/or the thermal conductivity is minimized. The power factor (PF) can be maximized due to the development of new classes of materials, the optimization of existing materials through doping or the exploration of nanoscale materials. The thermal conductivity can be minimized due to solid solution alloying, the development of materials with intrinsically low thermal conductivity (material with cages; tunnels or introduction of point defects; "rattle effect": phonon damping) or nanostructuring. TE materials with a value of a ZT= 1 are already good, until now the best reported ZT values are in between 2 and 3. ZT values which are essential for thermoelectrics to compete with mechanical generation and refrigeration in efficiency lay in between 3 and 4.

Numerous TE materials have been developed in the past years, first single-phase materials (skutterudites, clathrates and metal oxides) and second chalcogenide compounds divided into anisotropic material (Bi₂Te₃) and isotropic Material (PbTe). These are followed by inhomogeneous nanostructured materials containing LAST-m (lead antimony silver telluride) and SALT-m (sodium antimony lead telluride), and in the end nanocomposite polycrystalline materials.

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