Thermoelectrics generating electricity from waste heat is a step closer

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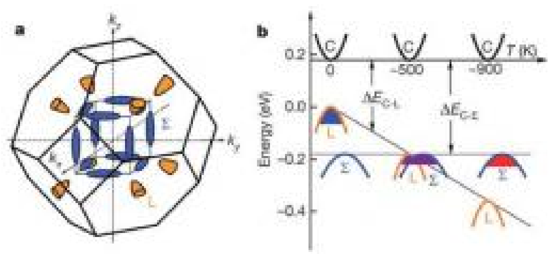

Image credit: Nature, doi:10.1038/nature09996.

(PhysOrg.com) -- Scientists in China and the US have modified a common thermoelectric material to vastly improve its thermoelectric properties. The development could lead to new devices capable of converting waste heat into useful amounts of electricity.

A thermoelectric material consists of alternating n-type and p-type semiconductors that together convert heat into electricity. In theory the heat could be sourced from any process that generates heat, but at present the materials are too inefficient to provide a commercially feasible way of generating electricity from waste heat, such as that produced in car exhausts.

The most common thermoelectric p-type material in use is based on lead telluride (PbTe) and devices based on this material have been used in satellites, with heat sourced from radioisotopes, and in niche markets on

Earth, where the heat is generated by burning fuels such as gas.

The efficiency of the thermoelectric material is expressed as a "thermoelectric figure of merit," ZT, which is a dimensionless figure derived from several factors including the electrical conductivity and thermal conductivity. The figure of merit needs to be over 1.5 for the material to be capable of generating useful amounts of electricity in commercial applications. PbTe thermoelectric materials are capable of withstanding high temperatures, but their figures of merit are around 0.8, which makes them suitable only for niche markets such as satellites.

Now physicists from the California Institute of Technology and the Chinese Academy of Sciences have modified the amount of tellurium in the PbTe alloy and added selenium and sodium to produce a material with a figure of merit of 1.8 at 850K, which lead author Dr. Jeffrey Snyder described as "extraordinary."

In previous research Snyder and colleagues had achieved a ZT of 1.5 by doping PbTe with thallium and 1.4 by using sodium. Adding selenium to the mix improved the electrical conductivity while also reducing the thermal conductivity. The selenium increases the number of "degenerate valleys" in the electronic band structure of the material, and this boosts the electrical conductivity and raises the ZT figure. Known thermoelectrics have a typical valley degeneracy of less than six, but the number for the new material is 12 or greater.

Dr. Snyder said he thought a figure of merit of 1.8 was the highest ever to be reproduced in independent laboratories. He also suggested that doping other thermoelectrics in the same way should improve their performance.

Dr. Snyder said the team is now working on creating a promising n-type material and in improving the p-type material's effectiveness at higher temperatures. The paper is published in *Nature*.

More information: Convergence of electronic bands for high performance bulk thermoelectrics, *Nature* 473, 66–69 (05 May 2011) doi:10.1038/nature09996

Abstract

Thermoelectric generators, which directly convert heat into electricity, have long been relegated to use in space-based or other niche applications, but are now being actively considered for a variety of practical waste heat recovery systems—such as the conversion of car exhaust heat into electricity. Although these devices can be very reliable and compact, the thermoelectric materials themselves are relatively inefficient: to facilitate widespread application, it will be desirable to identify or develop materials that have an intensive thermoelectric materials figure of merit, zT, above 1.5 (ref. 1). Many different concepts have been used in the search for new materials with high thermoelectric efficiency, such as the use of nanostructuring to reduce phonon thermal conductivity2, 3, 4, which has led to the investigation of a variety of complex material systems5. In this vein, it is well known6, 7 that a high valley degeneracy (typically ≤6 for known thermoelectrics) in the electronic bands is conducive to high zT, and this in turn has stimulated attempts to engineer such degeneracy by adopting low-dimensional nanostructures8, 9, 10. Here we demonstrate that it is possible to direct the convergence of many valleys in a bulk material by tuning the doping and composition. By this route, we achieve a convergence of at least 12 valleys in doped PbTe1 − xSex alloys, leading to an extraordinary zT value of 1.8 at about 850 kelvin. Band engineering to converge the valence (or conduction) bands to achieve high valley degeneracy should be a general strategy in the search for and improvement of bulk thermoelectric materials, because it simultaneously leads to a high Seebeck coefficient and high electrical conductivity.