Materials

$Yb_{14}MnSb_{11}$ as a High-Efficiency Thermoelectric Material

This material could supplant the state-of-the-art material, SiGe.

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$Yb_{14}MnSb_{11}$ has been found to be well-suited for use as a p-type thermoelectric material in applications that involve hot-side temperatures in the approximate range of 1,200 to 1,300 K. The figure of merit that characterizes the thermal-to-electric power-conversion efficiency is greater for this material than for SiGe, which, until now, has been regarded as the state-of-the art high-temperature p-type thermoelectric material. Moreover, relative to SiGe, $Yb_{14}MnSb_{11}$ is better suited to incorporation into a segmented thermoelectric leg that includes the moderate-temperature p-type thermoelectric material $CeFe_4Sb_{12}$ and possibly other, lower-temperature p-type thermoelectric materials.

Interest in $Yb_{14}MnSb_{11}$ as a candidate high-temperature thermoelectric material was prompted in part by its unique electronic properties and complex crystalline structure, which place it in a class somewhere between (1) a class of semiconducting valence compounds known in the art as Zintl compounds and (2) the class of intermetallic compounds. From the perspective of chemistry, this classification of $Yb_{14}MnSb_{11}$ provides a first indication of a potentially rich library of compounds, the thermoelectric properties of which can be easily optimized.
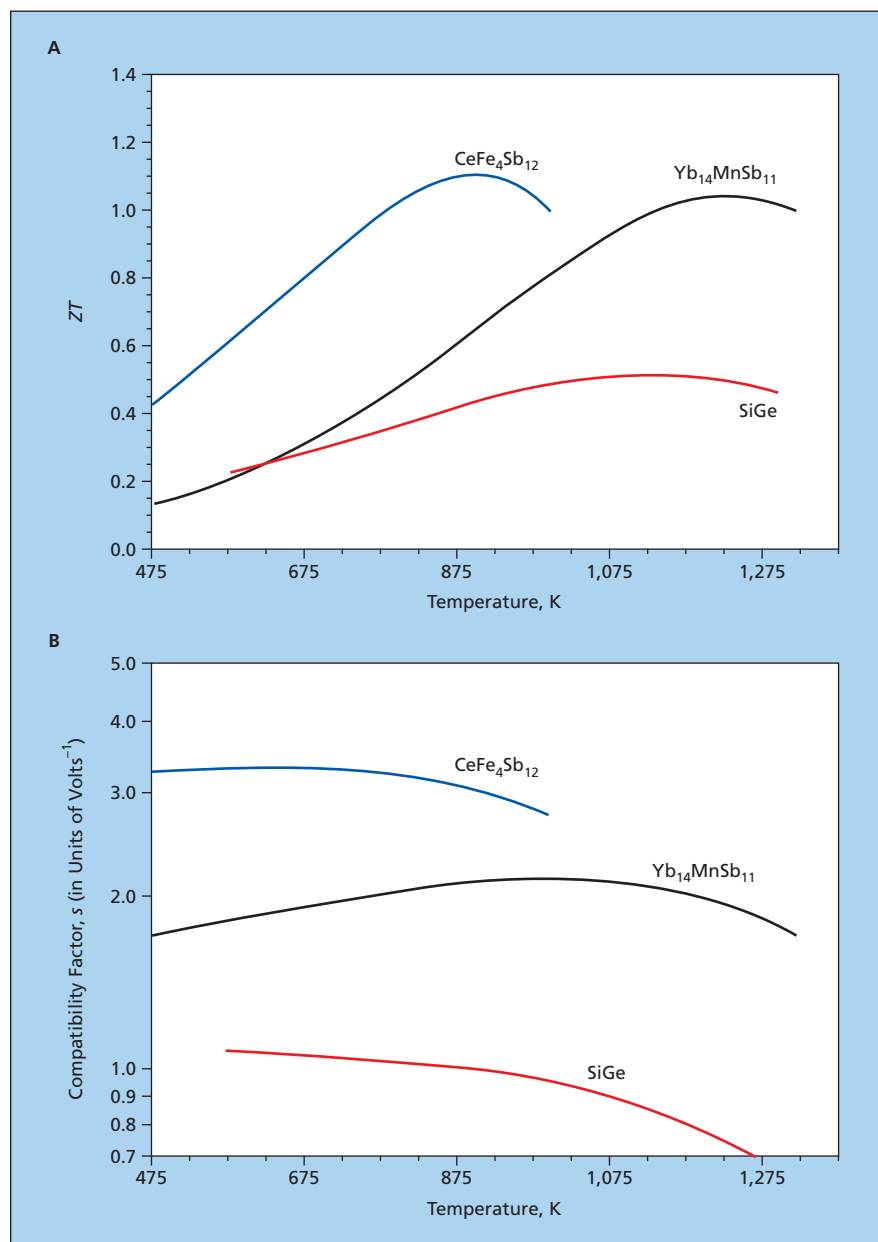
The concepts of the thermoelectric figure of merit and the thermoelectric compatibility factor are discussed in "Compatibility of Segments of Thermoelectric Generators" (NPO-30798), which appears on page 55. The traditional thermoelectric figure of merit, Z, is defined by the equation

$$Z = \alpha^2/\rho\kappa$$

where α is the Seebeck coefficient, ρ is the electrical resistivity, and κ is the thermal conductivity. Sometimes, in current usage, the term "thermoelectric figure of merit" signifies the product ZT, where T is the absolute temperature. The thermoelectric compatibility factor, s, is defined by the equation

$$s = [(1 + ZT)^{1/2} - 1]/\alpha T.$$

For maximum efficiency, s should not change with temperature, both within a single material, and throughout a seg-

mented thermoelectric-generator leg as a whole. It is in this sense that s serves as a basis for assessing both compatibility among segments and compatibility within a segment (self-compatibility). The degree to which s varies with tem-

perature along a given segment or differs among adjacent segments in a thermoelectric leg thus serves as a measure of incompatibility that one strives to minimize.

As shown in the upper part of the fig-

Thermoelectric Figures of Merit and Compatibility Factors of three compounds of interest as functions of temperature are plotted to illustrate the superiority of $Yb_{14}MnSb_{11}$ over SiGe.

ure, in the temperature range of 975 to 1,275 K, the ZT value of $Yb_{14}MnSb_{11}$ is approximately double that of SiGe. Moreover, as shown in the lower part of the figure, the s value of $Yb_{14}MnSb_{11}$ is much closer to that of $CeFe_4Sb_{12}$ than is the s value of SiGe. The net effect of the greater ZT and closer match of s of $Yb_{14}MnSb_{11}$, compared to those of SiGe, is that the thermal-to-electric power-conversion efficiency of a segmented $Yb_{14}MnSb_{11}/CeFe_4Sb_{12}$ leg operating between the given hot-side and cold-side temperatures is significantly greater than

that of a $SiGe/CeFe_4Sb_{12}$ leg operating between the same hot- and cold-side temperatures. For example, for a hot-side temperature of 1,275 K and a cold-side temperature of 775 K, the thermal-to-electric power-conversion efficiency of a segmented $Yb_{14}MnSb_{11}/CeFe_4Sb_{12}$ leg is about 7.3 percent, while that of a segmented $SiGe/CeFe_4Sb_{12}$ leg is about 4.5 percent.

Polyimide-Foam/Aerogel Composites for Thermal Insulation

These composites may also afford enhanced acoustic attenuation.

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Composites of specific types of polymer foams and aerogel particles or blankets have been proposed to obtain thermal insulation performance superior to those of the neat polyimide foams. These composites have potential to also provide enhanced properties for vibration dampening or acoustic attenuation. The specific type of polymer foam is denoted "TEEK-H," signifying a series, denoted "H," within a family of polyimide foams that were developed at NASA's Langley Research Center and are collectively denoted "TEEK" (an acronym of the inventors' names).

The specific types of aerogels include Nanogel® aerogel particles from Cabot Corporation in Billerica, MA. and of Spaceloft® aerogel blanket from Aspen Aerogels in Northborough, MA. The composites are inherently flame-retardant and exceptionally thermally stable.

There are numerous potential uses for these composites, at temperatures from cryogenic to high temperatures, in diverse applications that include aerospace vehicles, aircraft, ocean vessels, buildings, and industrial process equipment. Some low-temperature applications, for example, include cryogenic storage and transfer or the trans-

port of foods, medicines, and chemicals. Because of thermal cycling, aging, and weathering most polymer foams do not perform well at cryogenic temperatures and will undergo further cracking over time.

The TEEK polyimides are among the few exceptions to this pattern, and the proposed composites are intended to have all the desirable properties of TEEK-H foams, plus improved thermal performance along with enhanced vibration or acoustic-attenuation performance.

A composite panel as proposed would be fabricated by adding an appropriate amount of TEEK friable balloons into a mold to form a bottom layer. A piece of flexible aerogel blanket material, cut to the desired size and shape, would then be placed on the bottom TEEK layer and sandwiched between another top layer of polyimide friable balloons so that the aerogel blanket would become completely encased in an outer layer of TEEK friable balloons. Optionally, the process could be further repeated to produce multiple aerogel-blanket layers interspersed with and encased by TEEK friable balloons.

The sandwiching of aerogel bulk-fill particles would follow the same meth-

odology or could be mixed directly with friable balloons up to 40% weight loading of the aerogel particles to friable balloons. After sandwiching or mixing of the polymide and aerogel components, the mold, without a top cover, would be placed in a convection furnace and heated at a temperature of 250 °C for one hour. Then the top cover would be placed on the mold and the temperature increased to about 320 °C for between 1 and 3 hours for full imidization of the polyimide component. The resulting composite should have all the desirable properties of TEEK, and its effective thermal conductivity should be less than that of an approximately equally dense panel made of TEEK foam only. The heat transfer reduction is directly proportional to % loading of the aerogel component. The excellent structural integrity of the foam material is maintained in the composite formulations.