

polysilsesquioxane cages decorated with surface amines can be co-reacted with anhydride capped polyimide/polyamic acid.

Cross-linked polyimide aerogels with their high porosity, combined with higher strength, have excellent thermal as well as sound-insulating qualities. In

addition, their high specific surface area (e.g. on the order of 200–1,000 m<sup>2</sup>/g) should make them well suited for numerous applications, including as adsorbent beds for chemical separations, and as platforms for solid-state sensors.

*This work was done by Mary Ann B. Meador of Glenn Research Center. Further*

*information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18486-1.*

## ❖ Silica/Polymer and Silica/Polymer/Fiber Composite Aerogels

**These materials resist compression better than pure silica aerogels do.**

*Lyndon B. Johnson Space Center, Houston, Texas*

Aerogels that consist, variously, of neat silica/polymer alloys and silica/polymer alloy matrices reinforced with fibers have been developed as materials for flexible thermal-insulation blankets. In comparison with prior aerogel blankets, these aerogel blankets are more durable and less dusty. These blankets are also better able to resist and recover from compression — an important advantage in that maintenance of thickness is essential to maintenance of high thermal-insulation performance. These blankets are especially suitable as core materials for vacuum-insulated panels and vacuum-insulated boxes of advanced, nearly seamless design. (Inasmuch as heat leakage at seams is much greater than heat leakage elsewhere through such structures, advanced designs for high insulation performance should provide for minimization of the sizes and numbers of seams.)

A silica/polymer aerogel of the present type could be characterized, somewhat more precisely, as consisting of multiply bonded, linear polymer reinforcements within a silica aerogel matrix. Thus far, several different polymethacrylates (PMAs) have been incorporated into aerogel networks to

increase resistance to crushing and to improve other mechanical properties while minimally affecting thermal conductivity and density.

The polymethacrylate phases are strongly linked into the silica aerogel networks in these materials. Unlike in other organic/inorganic blended aerogels, the inorganic and organic phases are chemically bonded to each other, by both covalent and hydrogen bonds. In the process for making a silica/polymer alloy aerogel, the covalent bonds are introduced by prepolymerization of the methacrylate monomer with trimethoxysilylpropylmethacrylate, which serves as a phase cross-linker in that it contains both organic and inorganic monomer functional groups and hence acts as a connector between the organic and inorganic phases. Hydrogen bonds are formed between the silanol groups of the inorganic phase and the carboxyl groups of the organic phase. The polymerization process has been adapted to create interpenetrating PMA and silica-gel networks from monomers and prevent any phase separations that could otherwise be caused by an overgrowth of either phase.

Typically, the resulting PMA/silica aerogel, without or with fiber reinforcement, has a density and a thermal conductivity similar to those of pure silica aerogels. However, the PMA enhances mechanical properties. Specifically, flexural strength at rupture is increased to 102 psi ( $\approx 0.7$  MPa), about 50 times the flexural strength of typical pure silica aerogels. Resistance to compression is also increased: Applied pressure of 17.5 psi ( $\approx 0.12$  MPa) was found to reduce the thicknesses of several composite PMA/silica aerogels by only about 10 percent.

*This work was done by Danny Ou, Christopher J. Stepanian, and Xiangjun Hu of Aspen Aerogels, Inc., for Johnson Space Center. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## ❖ Alumina Paste Layer as a Sublimation Suppression Barrier for Yb<sub>14</sub>MnSb<sub>11</sub>

**This material can be applied to any thermoelectric couples requiring sublimation suppression.**

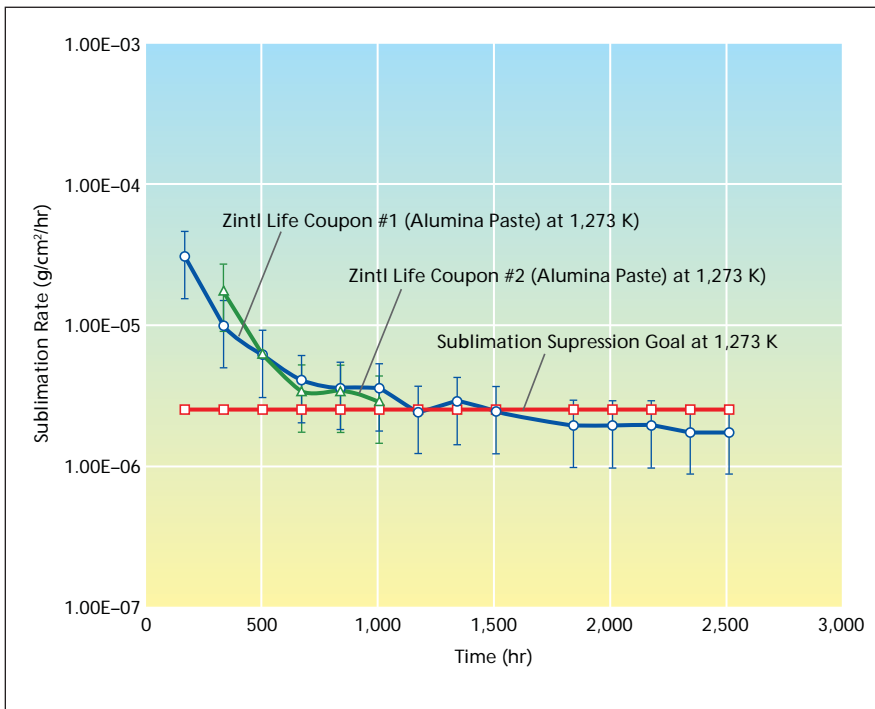
*NASA's Jet Propulsion Laboratory, Pasadena, California*

Sublimation is a major cause of degradation of thermoelectric power generation systems. Most thermoelectric materials tend to have peak values at the temperature where sublimation occurs. A sublimation barrier is needed that is

stable at operating temperatures, inert against thermoelectric materials, and able to withstand thermal cycling stress.

A porous alumina paste layer is suitable as a sublimation barrier for Yb<sub>14</sub>MnSb<sub>11</sub>. It can accommodate stress generated by

the thermal expansion discrepancy between the suppression layer and thermoelectric materials. Sublimation suppression is achieved by filling pores naturally with YbO<sub>2</sub>, a natural byproduct of sublimation. YbO<sub>2</sub> generated during the subli-



**Sublimation Rate Measurement** with  $\text{Yb}_{14}\text{MnSb}_{11}$  coupons with an alumina paste layer. The sublimation rate at the beginning of life is rather high, but the rate decreases steadily and after 1,500 hours, the rate reaches below the goal and the filling of the pore during sublimation is believed to be the reason for the rate decrease with time.

mation of  $\text{Yb}_{14}\text{MnSb}_{11}$  fills the porous structure of the alumina paste, causing sublimation to decrease with time as the pores become filled. During testing, it was found that application of this paste

caused an initial ten-fold decrease in sublimation, but this factor increased with time. At 1,500 hours of burnout time at 1,273 K, the decrease in sublimation was measured as much as 1,000 times lower.

A commercial alumina paste was applied to  $\text{Yb}_{14}\text{MnSb}_{11}$ . Both elements were polished to remove oxidation, then the paste was applied to the  $\text{Yb}_{14}\text{MnSb}_{11}$ . The  $\text{Yb}_{14}\text{MnSb}_{11}$  exhibited  $2 \times 10^{-6}$  to  $3 \times 10^{-6}$  g/cm<sup>2</sup> sublimation rate at 1,000 °C after initial burnout. With this rate, the sublimation barrier becomes suitable for 14-year operation, with less than 10 percent cross-section reduction at the hot side junction.

Using scanning electron microscope imaging, the alumina layer was found to be converted into a denser composite of alumina and ytterbia. This clogged, dense layer makes an effective sublimation barrier.

*This work was done by Jong-Ah Paik and Thierry Caillat of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to NPO-46845, volume and number of this NASA Tech Briefs issue, and the page number.*

## High-Temperature Solid Lubricant Coating

*John H. Glenn Research Center, Cleveland, Ohio*

NASA PS400 is a solid lubricant coating invented for high-temperature tribological applications. This plasma-sprayed coating is a variant of the previously patented PS304 coating, and has been formulated to provide higher density, smoother surface finish, and better dimensional stability.

This innovation is a new composite material that provides a means to reduce friction and wear in mechanical compo-

nents. PS400 is a blend of a nickel-molybdenum binder, chrome oxide hardener, silver lubricant, and barium fluoride/calcium fluoride eutectic lubricant that can either be sprayed or deposited by other means, such as powder metallurgy. The resulting composite material is then finished by grinding and polishing to produce a smooth, self-lubricating surface.

*This work was done by Christopher Della-Corte and Brian J. Edmonds of Glenn Research Center. Further information is contained in a TSP (see page 1). Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18561-1.*