



Lower-Conductivity Thermal-Barrier Coatings

Additional stabilizers are incorporated into yttria-stabilized zirconia.

John H. Glenn Research Center, Cleveland, Ohio

Thermal-barrier coatings (TBCs) that have both initial and post-exposure thermal conductivities lower than those of yttria-stabilized zirconia TBCs have been developed. TBCs are thin ceramic layers, generally applied by plasma spraying or physical vapor deposition, that are used to insulate air-cooled metallic components from hot gases in gas turbine and other heat engines. Heretofore, yttria-stabilized zirconia (nominally comprising 95.4 atomic percent ZrO_2 + 4.6 atomic percent Y_2O_3) has been the TBC material of choice. The lower-thermal-conductivity TBCs are modified versions of yttria-stabilized zirconia, the modifications consisting primarily in the addition of other oxides that impart microstructural and defect properties that favor lower thermal conductivity.

TBCs are characterized by porosity, typically between 5 and 20 percent. Porosity reduces the thermal conductivity of a TBC below the intrinsic conductivity of a fully dense (that is, non-porous) layer of the TBC material. The thermal conductivity of a TBC increases as its porosity is reduced by the sintering that occurs during use at high temperature. For future engines that will operate at higher gas temperatures, TBCs with greater degrees of both initial insulating

capability and retention of insulating capability will be needed.

The present lower-thermal-conductivity TBCs are made of Zr_1O_2 and Y_2O_3 doped with additional oxides that are chosen to perform three functions:

- Create thermodynamically stable, highly defective lattice structures with tailored ranges of defect-cluster sizes to exploit the effectiveness of such structures as means of attenuating and scattering phonons, thus reducing thermal conductivity;
- Produce of highly distorted lattice structures with essentially immobile defect clusters and/or nanoscale ordered phases, which effectively reduces concentrations of mobile defects and movements of atoms, thus increasing sintering-creep resistance; and
- Exploit the formation of complex nanoscale clusters of defects to increase the measures of such desired mechanical properties such as fracture toughness.

The additional oxides in a TBC according to this concept are typically selected as a pair — one from each of two groups of oxides denoted for this purpose as groups A and B. Group A includes scandia (Sc_2O_3) and ytterbia (Yb_2O_3). These oxides are highly stable, and the radii of their trivalent cations are smaller than

those of the primary dopant yttria. Group B includes neodymia (Nd_2O_3), samaria (Sm_2O_3), and gadolinia (Gd_2O_3) which are also highly stable, and their trivalent cations are larger than those of yttria.

Like yttria, the A and B oxides are regarded as stabilizers. Preferably, the total stabilizer content (yttria + A oxide + B oxide) should lie between 4 and 50 atomic percent. The concentration of yttria should exceed that of each of other stabilizers, and the concentrations of the A and B oxides should be approximately equal. Formulations other than the foregoing preferred one are also possible: Variations include the use of alternative group-A oxides (e.g., MgO_2 , NiO , Cr_2O_3), the use of two or more group-A and/or group-B oxides, substitution of hafnia for zirconia, and substitution of other primary stabilizers (e.g., dysprosia or erbia) for yttria.

This work was done by Robert A. Miller of Glenn Research Center and Dongming Zhu of Ohio Aerospace Institute. 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, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17039.

Process for Smoothing an Si Substrate After Etching of SiO_2

Reactive-ion etching can be tailored to minimize undesired side effects.

NASA's Jet Propulsion Laboratory, Pasadena, California

A reactive-ion etching (RIE) process for smoothing a silicon substrate has been devised. The process is especially useful for smoothing those silicon areas that have been exposed by etching a pattern of holes in a layer of silicon dioxide that covers the substrate. Applications in which one could utilize smooth silicon surfaces like those produced by this process include fabrication of optical waveguides, epitaxial deposition of silicon on selected areas of silicon substrates, and prepara-

tion of silicon substrates for deposition of adherent metal layers.

During etching away of a layer of SiO_2 that covers an Si substrate, a polymer becomes deposited on the substrate, and the substrate surface becomes rough (roughness height ≈ 50 nm) as a result of over-etching or of deposition of the polymer. While it is possible to smooth a silicon substrate by wet chemical etching, the undesired consequences of wet chemical etching can include compro-

promising the integrity of the SiO_2 sidewalls and undercutting of the adjacent areas of the silicon dioxide that are meant to be left intact.

The present RIE process results in anisotropic etching that removes the polymer and reduces height of roughness of the silicon substrate to <10 nm while leaving the SiO_2 sidewalls intact and vertical. Control over substrate versus sidewall etching (in particular, preferential etching of the substrate) is

achieved through selection of process parameters, including gas flow, power, and pressure. Such control is not uniformly and repeatably achievable in wet chemical etching. The recipe for the present RIE process is the following:

Etch 1 — A mixture of CF_4 and O_2 gases flowing at rates of 25 to 75 and 75 to 125 standard cubic centimeters per minute ($\text{stdcm}^3/\text{min}$), respectively; power between 44 and 55 W; and pressure between 45 and 55 mtorr (between

6.0 and 7.3 Pa). The etch rate lies between ≈ 3 and ≈ 6 nm/minute.

Etch 2 — O_2 gas flowing at 75 to 125 $\text{stdcm}^3/\text{min}$, power between 44 and 55 W, and pressure between 50 and 100 mtorr (between 6.7 and 13.3 Pa).

This work was done by Tasha Turner and Chi Wu 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-20777, volume and number of this NASA Tech Briefs issue, and the page number.

Flexible Composite-Material Pressure Vessel

Lyndon B. Johnson Space Center, Houston, Texas

A proposed lightweight pressure vessel would be made of a composite of high-tenacity continuous fibers and a flexible matrix material. The flexibility of this pressure vessel would render it (1) compactly stowable for transport and (2) more able to withstand impacts, relative to lightweight pressure vessels made of rigid composite materials. The vessel would be designed as a structural shell wherein the fibers would be predominantly bias-oriented, the orienta-

tions being optimized to make the fibers bear the tensile loads in the structure. Such efficient use of tension-bearing fibers would minimize or eliminate the need for stitching and fill (weft) fibers for strength. The vessel could be fabricated by techniques adapted from filament winding of prior composite-material vessels, perhaps in conjunction with the use of dry film adhesives. In addition to the high-bias main-body substructure described above, the vessel would in-

clude a low-bias end substructure to complete coverage and react peak loads. Axial elements would be overlaid to contain damage and to control fiber orientation around side openings. Fiber ring structures would be used as interfaces for connection to ancillary hardware.

This work was done by Glen Brown, Roy Haggard, and Paul A. Harris of Vertigo, Inc., for Johnson Space Center. Further information is contained in a TSP (see page 1).
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Treatment To Destroy Chlorohydrocarbon Liquids in the Ground

Emulsified iron is injected into the ground and left there.

John F. Kennedy Space Center, Florida

A relatively simple chemical treatment that involves the use of emulsified iron has been found to be effective in remediating groundwater contaminated with trichloroethylene and other dense chlorohydrocarbon liquids. These liquids are members of the class of dense, non-aqueous phase liquids (DNAPLs), which are commonly recognized to be particularly troublesome as environmental contaminants. The treatment converts these liquids into less-harmful products.

As a means of remediation of contaminated groundwater, this treatment takes less time and costs less than do traditional pump-and-treat processes. At some sites, long-term leakage and/or dissolution of chlorohydrocarbon liquids from pools and/or sorbed concentrations in rock and soil gives rise to a need to continue pump-and-treat processes for times as long as decades in order to maintain protection of human health and the environment. In contrast, the effects of the emulsified-iron

treatment are more lasting, decreasing the need for long-term treatment and monitoring of contaminated areas.

The material used in this treatment consists of iron particles with sizes of the order of nanometers to micrometers contained within the micelles of a surfactant-stabilized, biodegradable, oil-in-water emulsion. The emulsion is simple to prepare and consists of relatively inexpensive and environmentally acceptable ingredients: One typical formulation consists of 1.3 weight percent of a food-grade surfactant, 17.5 weight percent of iron particles, 23.2 weight percent of vegetable oil, and 58.0 weight percent of water.

The emulsion is injected into the ground via a push well. Free-phase chlorohydrocarbon molecules diffuse through the oil membranes of the emulsion particles to the surfaces of the iron particles, where dehalogenation takes place. The dehalogenation reactions generate hydrocarbon byproducts (primarily

ethylene in the case of trichloroethylene), which diffuse out of the emulsion micelles and are benign in nature.

Experiments have demonstrated several aspects of the effectiveness of this treatment by use of emulsified iron:

- This treatment is more effective in degrading free-phase trichloroethylene than is a similar treatment that uses only pure iron particles.
- Emulsions containing iron can be injected into soil matrices, where they become immobilized and remain immobile, even in the presence of flowing water.
- Iron emulsions can exert an effect equivalent to pulling globules of trichloroethylene into their micelles.
- No chlorinated byproducts from the degradation of trichloroethylene pass out of the micelles. The only degradation products that have been observed to leave the iron emulsions are ethylene as mentioned previously,