

rials that have high strengths and other tailorable properties as described below.

The ceramic component of a material in this family consists of hollow ceramic spheres that have been formulated to be lightweight ( $0.5 \text{ g/cm}^3$ ) and have high crush strength [40–80 ksi ( $\approx 276$ – $552 \text{ MPa}$ )]. The hollow spheres are coated with a metal to enhance a specific performance — such as shielding against radiation (cosmic rays or x rays) or against electromagnetic interference at radio and lower frequencies, or a material to reduce the coefficient of thermal expansion (CTE) of the final composite material, and/or materials to mitigate any mismatch between the spheres and

the matrix metal. Because of the high crush strength of the spheres, the initial composite workpiece can be forged or extruded into a high-strength part. The total time taken in processing from the raw ingredients to a finished part is typically 10 to 14 days depending on machining required.

For purposes of further processing, the material behaves like a metal: It can be processed by conventional machining (including formation of threads) or electrical-discharge machining, and pieces of the material can be joined by techniques commonly used to join metal pieces. The material is also receptive to coating materials and exhibits highly variable thermal conductivity from

metal to ceramic depending on loading.

Typical mechanical properties of such a material include a density less than that of beryllium (ranging from  $1.2$ – $17 \text{ g/cm}^3$  while the density of beryllium is  $1.85 \text{ g/cm}^3$ ) and modulus as high as 25 Msi ( $\approx 170 \text{ GPa}$ ). In contrast, the modulus of aluminum is generally 14 Msi ( $\approx 97 \text{ GPa}$ ). The CTE, the thermal conductivity, and the specific heat can be tailored, through the formulation of the ceramic and metal matrix ingredients of the composite.

*This work was done by Dean M. Baker of Advanced Powder Solutions, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15348-1*

## Piezoelectrically Enhanced Photocathodes

**Attributes would include stability, high efficiency, and relative ease of fabrication.**

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

Doping of photocathodes with materials that have large piezoelectric coefficients has been proposed as an alternative means of increasing the desired photoemission of electrons. Treating cathode materials to increase emission of electrons is called “activation” in the art. It has been common practice to activate photocathodes by depositing thin layers of suitable metals (usually, cesium). Because cesium is unstable in air, fabrication of cesiated photocathodes and devices that contain them must be performed in sealed tubes under vacuum. It is difficult and costly to perform fabrication processes in enclosed, evacuated spaces. The proposed piezoelectrically enhanced photocathodes would have electron-emission properties similar to those of cesiated photocathodes but would be stable in air, and therefore could be fabricated more easily and at lower cost.

Candidate photocathodes include nitrides of elements in column III of the periodic table — especially compounds of the general formula  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  (where  $0 \leq x \leq 1$ ). These compounds have high piezoelectric coefficients and are suitable for obtaining response to ultraviolet light. Fabrication of a photocathode according to the proposal would include inducement of strain in cathode layers during growth of the layers on a substrate. The strain would be induced by exploiting structural mismatches among the various constituent materials of the cathode. Because of the piezoelectric effect in this material, the strain would give rise to strong electric fields that, in turn, would give rise to a high concentration of charge near the surface.

Examples of devices in which piezoelectrically enhanced photocathodes could be used include microchannel plates, electron-bombarded charge-coupled devices,

image tubes, and night-vision goggles. Piezoelectrically enhanced photocathode materials could also be used in making highly efficient monolithic photodetectors. Highly efficient and stable piezoelectrically enhanced, ultraviolet-sensitive photocathodes and photodetectors could be fabricated by use of novel techniques for growing piezoelectrically enhanced layers, in conjunction with thinning and dopant-selective etching techniques.

*This work was done by Robert A. Beach, Shouleh Nikzad, Lloyd Douglas Bell, and Robert Strittmatter of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

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## Iridium-Doped Ruthenium Oxide Catalyst for Oxygen Evolution

**Possible applications of this catalyst include fabrication of water electrolysis units in hydrogen generators.**

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

NASA requires a durable and efficient catalyst for the electrolysis of water in a polymer-electrolyte-membrane (PEM) cell. Ruthenium oxide in a slightly reduced form is known to be a very effi-

cient catalyst for the anodic oxidation of water to oxygen, but it degrades rapidly, reducing efficiency. To combat this tendency of ruthenium oxide to change oxidation states, it is combined with irid-

ium, which has a tendency to stabilize ruthenium oxide at oxygen evolution potentials. The novel oxygen evolution catalyst was fabricated under flowing argon in order to allow the iridium to

preferentially react with oxygen from the ruthenium oxide, and not oxygen from the environment.

Nanoparticulate iridium black and anhydrous ruthenium oxide are weighed out and mixed to 5–18 atomic percent. They are then heat treated at 300 °C under flowing argon (in order to create an inert environment) for a minimum of 14 hours. This temperature was chosen because it is approximately the creep temperature of ruthenium oxide, and is below the sintering temperature of both materials. In general, the temperature should always be below the sintering temperature of both materials. The iridium-doped ruthenium oxide catalyst is

then fabricated into a PEM-based membrane-electrode assembly (MEA), and then mounted into test cells.

The result is an electrolyzer system that can sustain electrolysis at twice the current density, and at the same efficiency as commercial catalysts in the range of 100–200 mA/cm<sup>2</sup>. At 200 mA/cm<sup>2</sup>, this new system operates at an efficiency of 85 percent, which is 2 percent greater than commercially available oxygen evolution catalysts. This means that this new catalyst can be used to regenerate fuel cell systems in space, and as a hydrogen generator on Earth.

*This work was done by Thomas I. Valdez, Sri R. Narayan, and Keith J. Billings of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

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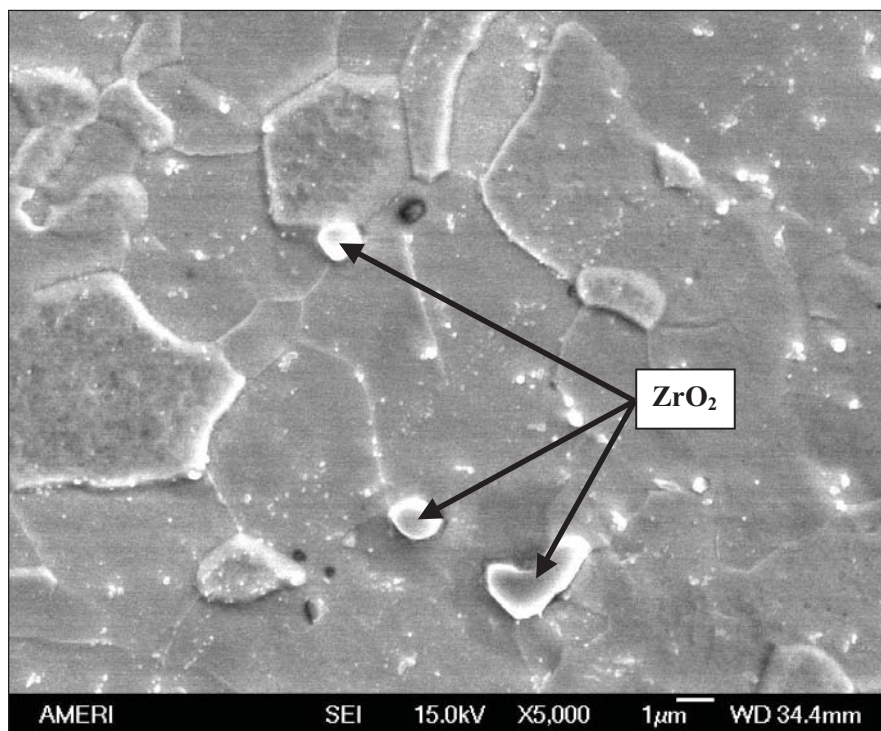
## Improved Mo-Re VPS Alloys for High-Temperature Uses

**Transition-metal ceramic dispersoids improve high-temperature properties.**

*Marshall Space Flight Center, Alabama*

Dispersion-strengthened molybdenum-rhenium alloys for vacuum plasma spraying (VPS) fabrication of high-temperature-resistant components are undergoing development. In comparison with otherwise equivalent non-dispersion-strengthened Mo-Re alloys, these alloys have improved high-temperature properties. Examples of VPS-fabricated high-temperature-resistant components for which these alloys are expected to be suitable include parts of aircraft and spacecraft engines, furnaces, and nuclear power plants; wear coatings; sputtering targets; x-ray targets; heat pipes in which liquid metals are used as working fluids; and heat exchangers in general. These alloys could also be useful as coating materials in some biomedical applications.

The alloys consist of 60 weight percent Mo with 40 weight percent Re made from (1) blends of elemental Mo and Re powders or (2) Re-coated Mo particles that have been subjected to a proprietary powder-alloying-and-spheroidization process. For most of the dispersion-strengthening experiments performed thus far in this development effort, 0.4 volume percent of transition-metal ceramic dispersoids were mixed into the feedstock powders. For one experiment, the proportion of dispersoid was 1 volume percent. In each case, the dispersoid consisted of either ZrN particles having sizes <45 µm, ZrO<sub>2</sub> particles having sizes of about 1 µm, HfO<sub>2</sub> parti-



This **Scanning Electron Micrograph** of a dispersion-strengthened specimen shows ZrO<sub>2</sub> particles at grain boundaries of the Mo-Re alloy.

cles having sizes <45 µm, or HfN particles having sizes <1 µm. These materials were chosen for evaluation on the basis of previously published thermodynamic stability data. For comparison, Mo-Re feedstock powders without dispersoids were also prepared.

Tubular alloy specimens were fabricated by VPS onto rotating graphite

mandrels as follows: In each case, the VPS chamber was evacuated, then the rotating graphite mandrel was preheated by the plasma spray gun. Once the desired preheat temperature was reached, one of the powders prepared as described above was made to flow to the gun, causing the alloy to be deposited on the mandrel. [A nearly iden-