

Element	Proportion in the Present Superalloy	Proportion in Nickel Alloy 718
Ni	Balance	Balance
Fe	24 to 34	17 to 19
Cr	17 to 19	16 to 18
Mo	3.0 to 5.0	2.5 to 3.5
Co	3.0 to 5.0	0.1 to 1.0
V	0.1 to 1.0	—
W	3.0 to 6.0	—
Ti	2.0 to 3.5	0.5 to 1.5
Nb	0.5 to 2.0	4.5 to 6.0
Al	0.1 to 0.5	0.2 to 0.8

Proportions of Chemical Elements in the two alloys are given in weight percentages.

$\gamma'$  phase, adding  $\gamma$ -matrix-strengthening elements to increase strength, and obtaining precipitate-free grain boundaries. Substantial amounts of chromium and nickel were also included to obtain excellent resistance to oxidation and corrosion. Microstructural stability was maintained through improved solid solubility of the  $\gamma$  ma-

trix along with the addition of alloying elements that retard  $\eta$ -phase precipitation. This alloy represents a material system that greatly extends ranges of composition beyond those of prior nickel-base superalloys that resist embrittlement by hydrogen.

This alloy is first processed by a combination of vacuum induction melting and vac-

uum arc remelting. Typically, the resulting alloy ingot is homogenized at a temperature of 2,100 °C for 24 hours and then hot-rolled in the range of 927 to 1,093 °C into 1.6-cm-thick plates. The plates are subjected to a solution heat treatment at 1,050 °C for 1 hour, followed by aging at 718 °C for 8 hours, then 621 °C for 8 hours.

The most novel property of this alloy is that it resists embrittlement by hydrogen while retaining tensile strength >175 kpsi (>1.2 GPa). This alloy exhibits a tensile elongation of more than 20 percent in hydrogen at a pressure of 5 kpsi ( $\approx$ 34 MPa) without loss of ductility. This amount of elongation corresponds to 50 percent more ductility than that exhibited by nickel alloy 718 under the same test conditions.

*This work was done by Jonathan Lee of Marshall Space Flight Center and Po-Shou Chen of Illinois Institute of Technology Research Institute. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead at sammy.a.nabors@nasa.gov. Refer to MFS -31781-1*

## Chemical Passivation of Li<sup>+</sup>-Conducting Solid Electrolytes

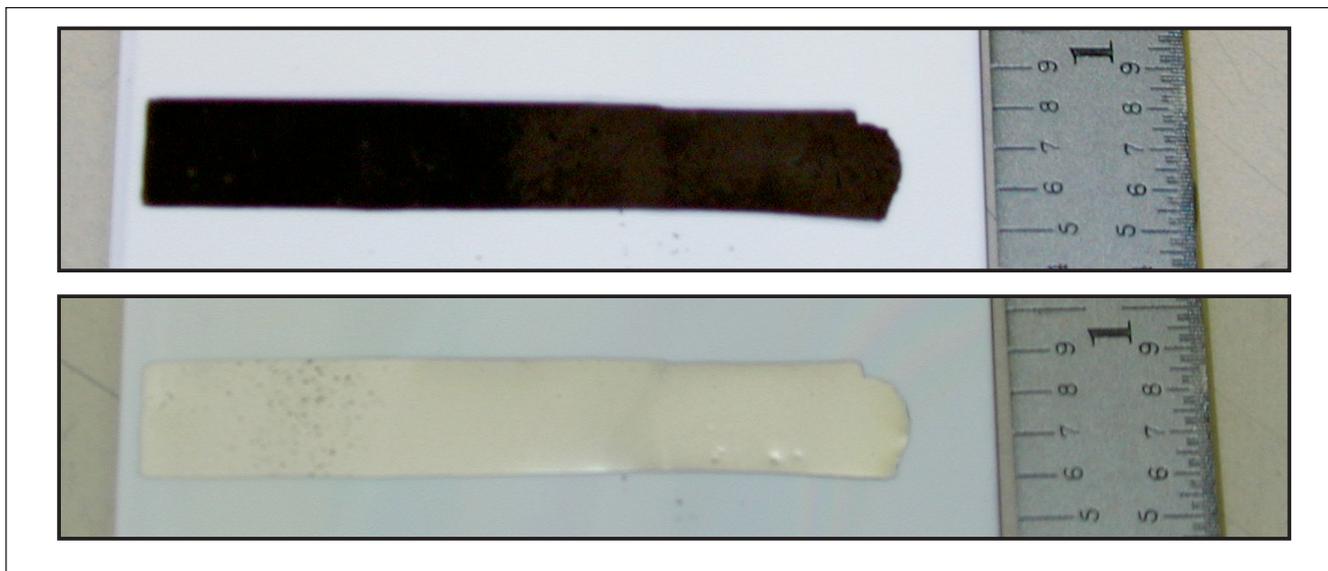
Such passivation could enable long-life lithium rechargeable cells.

NASA's Jet Propulsion Laboratory, Pasadena, California

Plates of a solid electrolyte that exhibits high conductivity for positive lithium ions can now be passivated to prevent them from reacting with metallic lithium. Such passivation could en-

able the construction and operation of high-performance, long-life lithium-based rechargeable electrochemical cells containing metallic lithium anodes. The advantage of this approach, in com-

parison with a possible alternative approach utilizing lithium-ion graphitic anodes, is that metallic lithium anodes could afford significantly greater energy-storage densities.



The Dark Strip in the Upper Photograph is the product of the chemical reaction of a deposited lithium film and an underlying solid-electrolyte plate. The corresponding somewhat shiny strip in the lower photograph is a lithium film deposited on a solid-electrolyte plate coated with LiPON. The dark spots in the Li film contain the reaction product formed at pinholes in the LiPON, where the Li film came into contact with the underlying solid electrolyte. This illustrates the importance of depositing pinhole-free LiPON films to protect solid-electrolyte plates.

A major impediment to the development of such cells has been the fact that the available solid electrolytes having the requisite high Li<sup>+</sup>-ion conductivity are too highly chemically reactive with metallic lithium to be useful, while those solid electrolytes that do not react excessively with metallic lithium have conductivities too low to be useful. The present passivation method exploits the best features of both extremes of the solid-electrolyte spectrum. The basic idea is to coat a higher-conductivity, higher-reactivity solid electrolyte with a lower-conductivity, lower-reactivity solid electrolyte. One can then safely deposit metallic lithium in contact with the lower-reactivity solid electrolyte without incurring the undesired chemical reactions. The thickness of the lower-reactivity electrolyte must be great enough to afford the desired passivation but not so great as to contribute excessively to the electrical resistance of the cell.

The feasibility of this method was demonstrated in experiments on plates of a commercial high-performance solid Li<sup>+</sup>-conducting electrolyte, the composition of which was not disclosed at the time of reporting the information for this article. The lower-conductivity, lower-reactivity solid electrolyte used for passivation was lithium phosphorus oxynitride (commonly abbreviated "LiPON" but more precisely abbreviated Li<sub>x</sub>PO<sub>y</sub>N<sub>z</sub>, where x, y, and z denote numbers that can differ from 1). The solid-electrolyte plates were 50.8-mm square with a thickness of 0.47 mm. Films of Li<sub>3.3</sub>PO<sub>3.8</sub>N<sub>0.22</sub> having thicknesses of the order of 1 μm were deposited on the plates by radio-frequency magnetron sputtering from an Li<sub>3</sub>PO<sub>4</sub> target in an atmosphere of N<sub>2</sub>. Pt and Cu electrodes were sputtered through a metal shadow mask, and the active lithium anode material was deposited by thermal evaporation through the same mask.

For comparison, some plates were not coated with LiPON and Li was de-

posited directly on them. In those cases, the deposited Li metal reacted immediately with the plates to form dark nonmetallic layers (see upper part of figure) that were electrically nonconductive. In contrast, for the plates that were first coated with LiPON and then with Li, films retained their metallic luster (see lower part of figure) and remained electrically conductive. Test cells containing Li anodes on LiPON-coated plates were constructed and tested by electrochemical impedance spectroscopy and cyclic voltammetry. The coated solid-electrolyte plates were found to support electrochemical plating and stripping of Li metal. The electrical resistances contributed by the LiPON layers were found to be small relative to overall cell impedances.

*This work was done by William West, Jay Whitacre, and James Lim of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-40478*

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## Organic/Inorganic Polymeric Composites for Heat-Transfer Reduction

*John F. Kennedy Space Center, Florida*

Organic/inorganic polymeric composite materials have been invented with significant reduction in heat-transfer properties. Measured decreases of 20–50 percent in thermal conductivity versus that of the unmodified polymer matrix have been attained. These novel composite materials also maintain mechanical properties of the unmodified polymer matrix. The present embodiments are applicable, but not limited to: racing applications, aerospace applications, textile industry, electronic applications, military hardware improve-

ments, and even food service industries. One specific application of the polymeric composition is for use in tanks, pipes, valves, structural supports, and components for hot or cold fluid process systems where heat flow through materials is problematic and not desired.

With respect to thermal conductivity and physical properties, these materials are superior alternatives to prior composite materials. These materials may prove useful as substitutes for metals in some cryogenic applications.

A material of this type can be made from a blend of thermoplastics, elastomers, and appropriate additives and processed on normal polymer processing equipment. The resulting processed organic/inorganic composite can be made into fibers, molded, or otherwise processed into useable articles.

*This work was performed by Trent Smith and Martha Williams of Kennedy Space Center. For further information, contact the Kennedy Innovative Partnerships Office at (321) 861-7158. KSC-12890*

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## Composite Cathodes for Dual-Rate Li-Ion Batteries

**A battery could have both high charge capacity and high rate capacity.**

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

Composite-material cathodes that enable Li-ion electrochemical cells and batteries to function at both high energy densities and high discharge rates are undergoing development. Until now, using commercially available cathode materials, it has been

possible to construct cells that have either capability for high-rate discharge or capability to store energy at average or high density, but not both capabilities. However, both capabilities are needed in robotic, standby-power, and other applications that involve duty cy-

cles that include long-duration, low-power portions and short-duration, high-power portions.

The electrochemically active ingredients of the present developmental composite cathode materials are the following:

- Carbon-coated LiFePO<sub>4</sub>, which has a spe-