



A 0.5-nm-thick layer of Fe was deposited, then patterned into catalyst islands for initiating growth of carbon nanotubes by means of photolithography and liftoff. To grow the carbon nanotubes, the workpiece as processed thus far was then placed in a chemical-vapor-deposition furnace, wherein it was exposed to an atmosphere of flowing CH<sub>4</sub> and H<sub>2</sub> at a temperature of 850 °C for 10 minutes. Next, a layer of Au/Ti was deposited and patterned in a lift-off process to form the source and drain electrodes in contact with the ends of the nanotubes.

Tests have confirmed the expected advantages of these devices over the older

electrostatically actuated microelectromechanical switches, which are characterized by response times of ≈1 μs and switching potentials between 60 and 70 V. The present devices are not only smaller but are characterized by response times of a few nanoseconds and switching potentials of a few volts. Hence, the present devices are expected to be better suited for applications in which there are requirements for highly miniaturized, high-speed electronic switches that can be operated from low-voltage (e.g., battery) power sources.

*This work was done by Anupama Kaul, Eric Wong, and Larry Epp of Caltech for NASA's Jet Propulsion Laboratory.*

*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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## Solid-State High-Temperature Power Cells

**These cells can be used in batteries for high-temperature applications.**

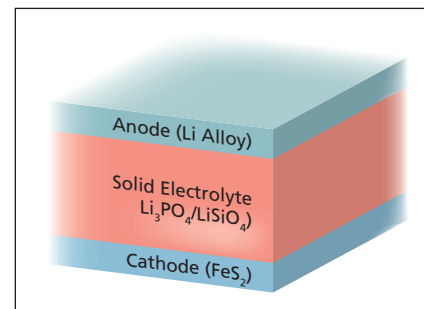
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All-solid-state electrochemical power cells have been fabricated and tested in a continuing effort to develop batteries for instruments for use in environments as hot as 500 °C. Batteries of this type are needed for exploration of Venus, and could be used on Earth for such applications as measuring physical and chemical conditions in geothermal and oil wells, processing furnaces, and combustion engines.

In the state-of-the-art predecessors of the present solid-state power cells, fully packaged molten eutectic salts are used as electrolytes. The molten-salt-based cells can be susceptible to significant amounts of self-discharge and corrosion when used for extended times at elevated temperatures. In contrast, all-solid-state cells such as the present ones are expected to be capable of operating for many days at temperatures up to 500 °C, without significant self-discharge.

The solid-state cell described here includes a cathode made of FeS<sub>2</sub>, an electrolyte consisting of a crystalline solid solution of equimolar amounts of Li<sub>3</sub>PO<sub>4</sub> and Li<sub>4</sub>SiO<sub>4</sub>, and an anode made of an alloy of Li and Si (see figure). The starting material for making the solid electrolyte is a stoichiometric mixture of Li<sub>3</sub>PO<sub>4</sub>, SiO<sub>2</sub>, and Li<sub>3</sub>CO<sub>2</sub>. This mixture is ball-milled, then calcined for two hours at a temperature of 1,100 °C, then placed in a die atop the cathode material. Next, the layers in the die are squeezed together at a pressure between 60 and 120 MPa for one hour at a temperature of 600 °C to form a unitary structure comprising the solid electrolyte and cathode bonded together. Finally, the lithium-alloy anode is pressure-bonded to the solid electrolyte layer, using an intermediate layer of pure lithium.

In one test of a cell of this type, a discharge rate of about 1 mA per gram of cathode material was sustained for 72



This **All-Solid-State Cell** is capable of generating electric power at a temperature up to 500 °C.

hours at a temperature of about 460 °C. This is about three times the discharge rate required to support some of the longer duration Venus-exploration mission scenarios.

*This work was done by Jay Whitacre and William West of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44396*

## Fast Offset Laser Phase-Locking System

**Phases can be locked within a microcycle; known phase noise can be added.**

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Figure 1 shows a simplified block diagram of an improved optoelectronic system for locking the phase of one laser to that of another laser with an adjustable offset frequency specified by the user. In comparison with prior systems, this system exhibits higher performance (in-

cluding higher stability) and is much easier to use. The system is based on a field-programmable gate array (FPGA) and operates almost entirely digitally; hence, it is easily adaptable to many different systems. The system achieves phase stability of less than a microcycle.

It was developed to satisfy the phase-stability requirement for a planned spaceborne gravitational-wave-detecting heterodyne laser interferometer (LISA). The system has potential terrestrial utility in communications, lidar, and other applications.