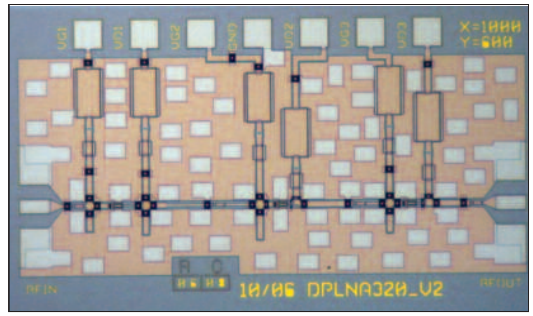
telescopes could make use of S-MMIC amplifiers for wideband, low noise, instantaneous frequency coverage, particularly in the case of heterodyne array receivers.

This work is aimed at pushing the MMIC and transistor technologies toward higher frequencies and, at these higher frequencies (>300 GHz), a wealth of spectral lines of molecular species exist and could be studied with more sensitive receivers. There are potential applications for future millimeter-wave Earth observational instruments such as the Scanning Microwave Limb Sounder, GeoSTAR, and other planetary instrument concepts being proposed, such as the Microwave Sounding Unit for Mars. These future instruments and missions need high-gain, low-noise amplifiers at or above 180 GHz. Implementation of high-gain, low-noise amplifiers would greatly improve the signal-to-noise ratio of future heterodyne receivers.



A **Chip Photograph** of the 320-GHz three-stage S-MMIC amplifier.

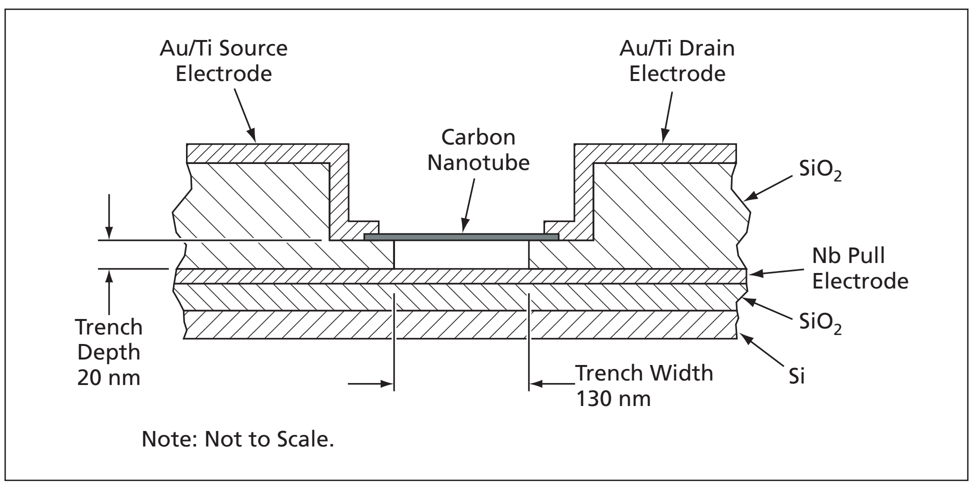
This work was done by David Pukala, Lorene Samoska, King Man Fung, and Todd Gaier of Caltech and William Deal, Richard Lai, Gerry Mei, and Stella Makishi of Northrop Grumman Corporation for NASA's Jet Propulsion Laboratory. The contributors would like to acknowledge the support of Dr. Mark Rosker and the Army Research Laboratory. This work was supported by the DARPA SWIFT Program and Army Research Laboratory under the DARPA MIPR no.06-U037 and ARL Contract no. W911QX-06-C-0050. Further information is contained in a TSP (see page 1). NPO-45046

Fast Electromechanical Switches Based on Carbon Nanotubes

Potential applications include computer memory, cell phones, and scientific instruments.

NASA's Jet Propulsion Laboratory, Pasadena, California

Electrostatically actuated nanoelectromechanical switches based on carbon nanotubes have been fabricated and tested in a continuing effort to develop high-speed switches for a variety of stationary and portable electronic equipment. As explained below, these devices offer advantages over electrostatically actuated microelectromechanical switches, which, heretofore, have represented the state of the art of rapid, highly miniaturized electromechanical switches. Potential applications for these devices include computer memories, cellular telephones, communication networks, scientific instrumentation, and general radiation-hard electronic equipment.



A **Carbon Nanotube Is Suspended** between source and drain electrodes over a pull electrode. By application of a suitable potential (typically a few volts), the nanotube is drawn into contact with the pull electrode.

A representative device of the present type includes a single-wall carbon nanotube suspended over a trench about 130 nm wide and 20 nm deep in an electrically insulating material. The ends of the carbon nanotube are connected to metal electrodes, denoted the source and drain electrodes. At bottom of the trench is another metal electrode, denoted the pull electrode (see figure). In the "off" or "open" switch state, no voltage is applied, and the nanotube remains out of contact with the pull electrode. When a sufficiently large electric potential (switching potential) is applied between the pull electrode and either or both of the source and drain electrodes, the resulting electrostatic attraction bends and stretches the nanotube into contact with the pull electrode, thereby putting the switch into the "on" or "closed" state, in which substantial current (typically as much as hundreds of nanoamperes) is conducted.

Devices of this type for use in initial experiments were fabricated on a thermally oxidized Si wafer, onto which Nb was sputter-deposited for use as the pull-electrode layer. Nb was chosen because its refractory nature would enable it to withstand the chemical and thermal conditions to be subsequently imposed for growing carbon nanotubes. A 200-nm-thick layer of SiO_2 was formed on top of the Nb layer by plasma-enhanced chemical vapor deposition. In the device regions, the SiO_2 layer was patterned to thin it to the 20-nm trench depth. The trenches were then patterned by electron-beam lithography and formed by reactive-ion etching of the pattern through the 20-nm-thick SiO_2 to the Nb layer.

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_4 and H_2 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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Refer to NPO-43343, volume and number of this NASA Tech Briefs *issue, and the page number.*

Solid-State High-Temperature Power Cells

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

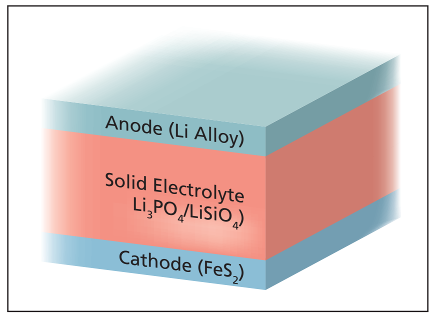
NASA's Jet Propulsion Laboratory, Pasadena, California

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_2, an electrolyte consisting of a crystalline solid solution of equimolar amounts of Li_3PO_4 and Li_4SiO_4, 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_3PO_4, SiO_2, and Li_3CO_2. 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 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 **All-Solid-State Cell** is capable of generating electric power at a temperature up to 500 °C.

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.

NASA's Jet Propulsion Laboratory, Pasadena, California

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 (including 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.