cal power levels >5 kW. The usual approach taken to developing lower-power PEMFCs for applications like those listed above has been to simply shrink the basic plate-and-frame configuration to smaller dimensions. A conventional plate-and-frame fuel cell contains a membrane/electrode assembly in the form of a flat membrane with electrodes of the same active area bonded to both faces. In order to provide reactants to both electrodes, bipolar plates that contain flow passages are placed on both electrodes. The mass and volume overhead of the bipolar plates amounts to about 75 percent of the total mass and volume of a fuel-cell stack. Removing these bipolar plates in the micro-tubular fuel cell significantly increases the power density.

A micro-tubular fuel cell contains multiple membrane/electrode assemblies, each comprising a tubular proton-exchange membrane with the anode on the inner surface and the cathode on the outer surface (see figure). Targeted dimensions include an inner membrane diameter of 600 µm, membrane thickness of 50 µm, anode thickness of 25 µm, and cathode thickness of 125 µm. One end of each micro-tubular membrane/electrode assembly (µT-MEA) is closed, while the other end is open and connected to a current-collection manifold. At the open end of each µT-MEA, a conical anode current collector and diffuser is inserted in the tube, and a cathode current-collector/crimping ring is placed around the outside of the tube. Hydrogen gas diffuses into the interiors of the tubes, while air or oxygen is blown across the outside of the tubes in a cross-flow configuration.

The anode and cathode current collectors are connected by an end-plate assembly (not shown in the figure) in the hydrogen-gas manifold that defines the parallel and serial electrical connections of the µT-MEAs. Because each µT-MEA produces a relatively small current, parallel and serial connections can be made at their ends without incurring an unacceptably large amount of ohmic heating. Although the cylindrical geometry causes the current density at the anode in each µT-MEA to exceed that at the cathode, this feature detracts only slightly from cell performance because it is a fundamental property of any PEMFC that the anode polarization loss is much less than the cathode polarization loss at a given current density.

The elimination of the bipolar plates in favor of the much less bulky and massive manifold and current-collector assembly is the single greatest contribution to more efficient utilization of available volume and thus to increased power density. It has been estimated that after further optimization of dimensions, materials, and fabrication processes, it should be possible to make micro-tubular fuel cells with power densities as great as 6.4 W/g and 6.9 kW/L.

This work was done by Michael C. Kimble, Everett B. Anderson, Karen D. Jayne, and Alan S. Woodman of Physical Sciences Inc. for **Johnson Space Center**. *For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*

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

Physical Sciences Inc.
20 New England Business Center
Andover, MA 01810-1077
Telephone No.: (978) 689-0003
Fax No.: (978) 689-3232

Refer to MSC-23012, volume and number of this NASA Tech Briefs *issue, and the page number.*

Whispering-Gallery-Mode Tunable Narrow-Band-Pass Filter

Characteristics include wide tuning range, short tuning time, and compactness.

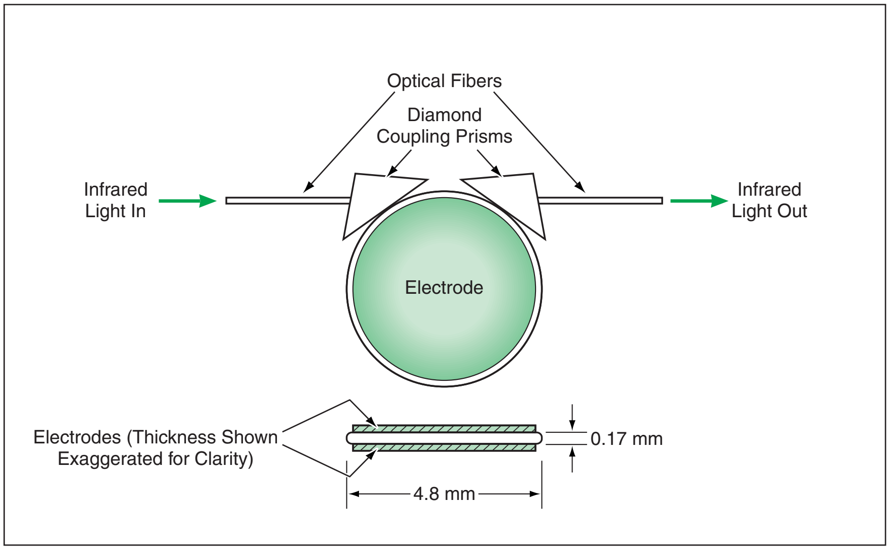
NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental tunable, narrow-band-pass electro-optical filter is based on a whispering-gallery resonator. This device is a prototype of tunable filters needed for the further development of reconfigurable networking wavelength-division multiplexers and communication systems that utilize radio-frequency (more specifically, microwave) subcarrier signals on optical carrier signals. The characteristics of whispering-gallery resonators that make them attractive for such applications include high tuning speed, compactness, wide tuning range, low power consumption, and compatibility with single-mode optical fibers. In addition, relative to Fabry-Perot resonators, these devices offer advantages of greater robustness and lower cost.

As described in several prior *NASA Tech Briefs* articles, a whispering-gallery resonator is a spheroidal, disklike, or toroidal body made of a highly transparent material. It is so named because it is designed to exploit whispering-gallery electromagnetic modes, which are waveguide modes that propagate circumferentially and are concentrated in a narrow toroidal region centered on the equatorial plane and located near the outermost edge.

The experimental whispering-gallery tunable filter (see figure) is made from a disk of Z-cut $LiNbO_3$ of 4.8-mm diameter and 0.17-mm thickness. The perimeter of the disk is rounded to a radius of curvature of 100 µm. Metal coats on the flat faces of the disk serve as electrodes for exploiting the electro-optical effect in $LiNbO_3$ for tuning. There is no metal coat on the rounded perimeter region, where the whispering-gallery modes propagate. Light is coupled from an input optical fiber into the whispering-gallery modes by means of a diamond prism. Another diamond prism is used to couple light from the whispering-gallery modes to an output optical fiber. This device is designed and operated to exploit transverse magnetic (TM) whispering-gallery modes, rather than transverse electric (TE) modes because the resonance quality factors (Q values) of the TM modes are higher. If Q values were not of major concern, it would be better to use the TE modes because the electro-optical shifts of the TE modes are 3 times those of the TM modes.

Although this filter has been operated only at wavelengths in the vicinity of 1.55 µm, it is capable of operating at wavelengths from ≈1.0 to ≈1.7 µm — a range limited only by absorption of light in $LiNbO_3$. The free spectral range [FSR (the frequency interval between successive resonances)] of the filter is 10 GHz and the bandwidth is 30 MHz; these figures translate to a finesse of about 300. In contrast, a typical Fabry-Perot filter has a finesse of 100 and a bandwidth of 125 MHz. (The finesse is the ratio between the FSR and the bandwidth. It is commonly used as a figure of merit of a



A **Whispering-Gallery-Mode Resonator** is made from a disk of $LiNbO_3$. The whispering-gallery modes are concentrated in the rounded outer edge region. The resonance frequencies are changed by applying a voltage to the electrodes.

Fabry-Perot filter and it approximates the maximum number of communication channels that can fit within one FSR). The filter has been found to be tunable over a frequency range somewhat greater than one FSR, the frequency varying linearly with applied potential at 42 MHz/V over the range of ±150 V. Although the tuning time of the filter is only 10 ns, the spectrum-shifting time, which is determined by the 30-MHz bandwidth, is ≤30 μs. For channels spaced 50 MHz apart, the filter suppresses cross-talk by about 20 dB.

One disadvantage of this device is an insertion loss of 9 dB. This loss has been attributed primarily to inefficiency of coupling by means of the diamond prisms. It may be possible to reduce the insertion loss by use of antireflection coats on the prisms or special gratings on high-index-of-refraction optical fibers.

This work was done by Anatoliy Savchenkov, Vladimir Iltchenko, Andrey Matsko, and Lute Maleki 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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-30896, volume and number of this NASA Tech Briefs *issue, and the page number.*