terials and design of the nematic-liquid-crystal cells have resulted in significant improvements in properties (e.g., short response times and birefringence) that are important for effective beam steering.

A beam deflector of this type is a multistage device. Each stage consists mainly of (1) a passive birefringent prism made of yttrium orthovanadate (YVO_4) [alternatively, it could be made of a uniaxial smectic A liquid crystal] and (2) a switchable polarization rotator in the form of a cell containing a twisted nematic liquid crystal. A linearly polarized laser beam that one seeks to deflect travels through the liquid-crystal cell on the way to the passive birefringent prism. If no voltage is applied across the cell ("off" state), passage though the cell changes the direction of polarization by 90°. If a suitable non-zero voltage is applied across the cell ("on" state), then the polarization direction remains unchanged after passage through the cell. Therefore, by virtue of birefringence, depending on which of the two selectable polarizations has been imparted to the beam by the liquid-crystal cell, the beam propagates through the crystal in either of two different directions.

If a beam deflector of this type contained N stages, then it would be possible to switch the input laser beam to any of 2^N different output directions through electrical switching of the liquid-crystal cells. The prototype device operates with an incident 633-nm-wavelength beam from a helium/neon laser. It contains 4 stages and, hence, can deflect the beam to any of $2^4 = 16$ output directions. In this case, the directions are separated by increments of 8 milliradians. To obtain a relatively short response time (0.5 ms), the cells are made from so-called dual-frequency nematic liquid crystals and operated in a special addressing scheme that features amplitude- and frequency-modulated driving voltage.

This work was done by John J. Pouch and Felix A. Miranda of Glenn Research Center; Liubov Kreminska, Oleg Pishnyak, Andrii Golovin, and Oleg D. Lavrentovich of Kent State University; and Bruce K. Winker of Rockwell Scientific Company LLC. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17947-1.

Narrow-Band WGM Optical Filters With Tunable FSRs

Microwave signals generated by optoelectronic oscillators can be tuned.

NASA's Jet Propulsion Laboratory, Pasadena, California

Optical resonators of the whispering-gallery-mode (WGM) type featuring DC-tunable free spectral ranges (FSRs) have been demonstrated. Previously, the FSRs of WGM optical resonators were determined solely by the resonator geometries and materials: hence, the FSR of such a resonator could be tailored by design, but once the resonator was constructed, its FSR was fixed. By making the FSR tunable, one makes it possible to adjust, during operation, the frequency of a microwave signal generated by an optoelectronic oscillator in which an WGM optical resonator is utilized as a narrow-band filter.

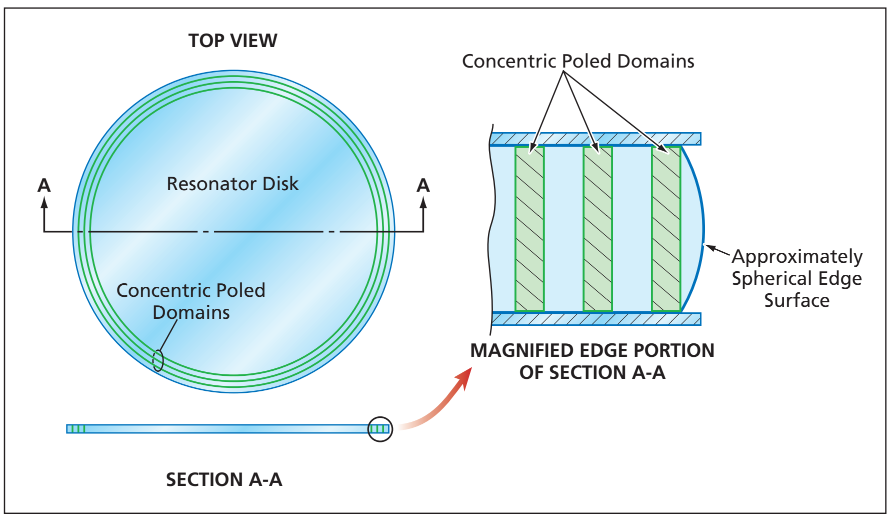

Figure 1. **Concentric Poled Domains** in a ferroelectric electro-optical resonator disk can be engineered to enable relative frequency shifting of adjacent radial resonator modes.

Each tunable WGM resonator was made from a disk of lithium niobate, 2.6 mm in diameter and 120 μm thick. The edge of the disk was rounded by polishing to an approximately spherical surface. A ferroelectric-domain structure characterized by a set of rings concentric with the axis of the disk (see Figure 1) was created by means of a poling process in which a 1-μm-diameter electrode was dragged across the top surface of the disk in the concentric-ring pattern while applying a 2.5-kV bias between the electrode and a conductor in contact with the bottom surface of the disk. After the poling process, the top and bottom surfaces of the disk were placed in contact with metal electrodes that, in turn, were connected to a regulated DC power supply that was variable from 0 to 150 V. When a DC bias electric field is applied in such a structure, the indices of refraction in the positively poled concentric rings and in the unflipped, negatively poled concentric regions change by different amounts.

The concentric-ring ferroelectric-domain structure of such a resonator can be engineered so that it overlaps with one or more radial resonator modes more than it does with other, adjacent modes. As a result, when the indices of refraction change in response to DC bias, some modes shift in frequency by amounts that differ from those of adjacent modes; the difference in frequency shift amounts to the desired change in the FSR between the affected adjacent modes.

A test was performed on each tunable resonator to observe the absorption spectrum of the resonator and the changes in frequencies of adjacent modes of interest as the applied DC bias voltage was varied.

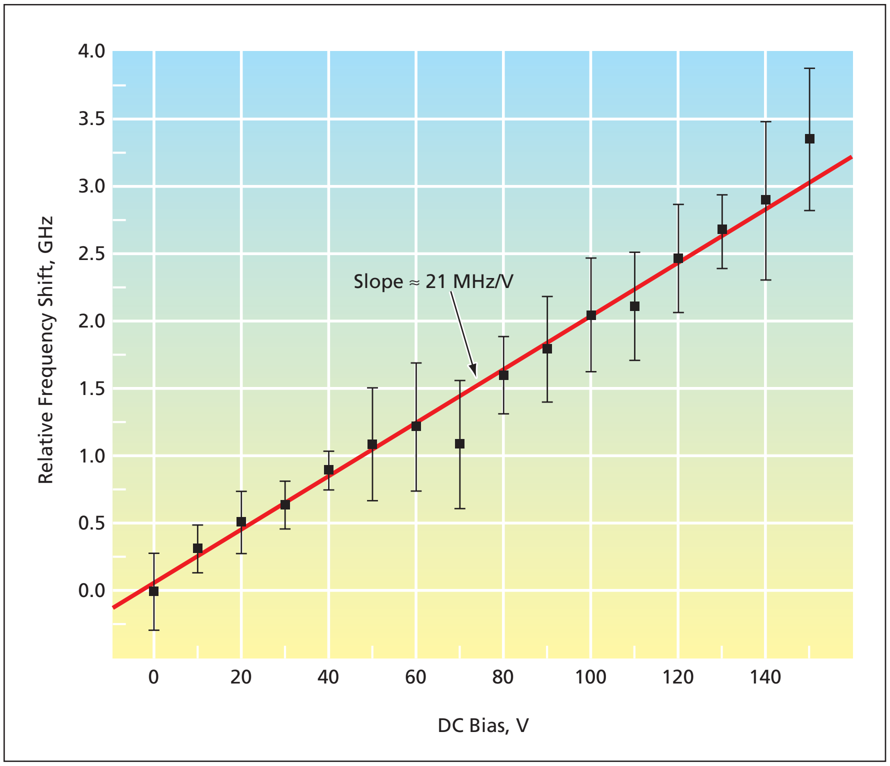

Figure 2. The **Relative Frequency Shift** between selected adjacent modes of an experimental resonator was found to vary with DC potential at a rate of about 21 MHz/V.

In this test, a probe optical beam having a nominal wavelength of 1.55 µm, scanned over a frequency range of 20 GHz, was coupled into the resonator through a diamond prism. Figure 2 presents some results of one such test, in which the frequency shift between two selected adjacent modes exhibited the desired variation with bias voltage.

This work was done by Makan Mohageg, Andrey Matsko, Anatoliy Savchenkov, Lute Maleki, Vladimir Iltchenko, and Dmitry Strekalov 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

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