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

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

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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 LiNbO3 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 LiNbO3 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 LiNbO3. 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.

A 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 Ilchenko, Andrey Matsko, and Lute Maleki of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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