Physical Sciences

Graded-Index "Whispering-Gallery" Optical Microresonators

Improvements would include equidistant resonances and reduced evanescent field.

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Graded-index-of-refraction dielectric optical microresonators have been proposed as a superior alternative to prior dielectric optical microresonators, which include microspheres (described in several prior *NASA Tech Briefs* articles) and microtori wherein electromagnetic waves propagate along circumferential paths in "whispering-gallery" modes. The design and method of fabrication of the proposed microresonators would afford improved performance by exploiting a combination of the propagation characteristics of the whispering-gallery modes and the effect of a graded index of refraction on the modes.

The prior microresonators have been shown to be capable of functioning as compact, high-performance optical filters characterized by rarefied spectra of narrow resonance lines. For many applications, the frequency intervals between resonances are required to be equal. Unfortunately, the techniques used to fabricate the prior microresonators cannot be used to obtain equidistant resonances. The variation of frequency spacing of resonances is a consequence of the frequency dependence of the radial distribution of the whispering-gallery resonant modes: In a given microresonator that does not have a graded index of refraction, higher-frequency modes propagate on paths slightly closer to the surface, relative to lower-frequency modes. In other words, the higher-frequency modes propagate circumferentially at slightly larger radii and, consequently, slightly longer optical path lengths. The variation of optical path lengths results in nonuniform spacing of resonance frequencies.

Optical path length is a function of both distance (in the common geometrical sense) and the index of refraction. A microresonator according to the proposal would be fabricated from a graded-index-of-refraction cylinder. The parameters of the fabrication process would be chosen such that the index of refraction of the cylinder would decrease with radius by an amount calculated on the basis of the propagation characteristics of the desired resonances. Although higher-frequency modes would still travel geometrically longer distances, the indices of refraction at the larger radii would be lower (the waves would travel faster). With proper choice of the rate of decrease of the index of refraction with radius, the circumferential paths at all radii would have identical optical path lengths and consequently, to first order, the resonances would be equidistant in frequency.

Additional potential advantages of the proposal include the following:

- Fabrication should be straightforward: Graded-index-of-refraction optical components are widely available in the form of lenses and optical fibers. Such components can be formed into microresonators by use of standard mechanical- and flame-polishing techniques.
- The proposed grading of indices of refraction would push the whispering-gallery modes slightly deeper into the resonator material, so that the evanescent fields would be smaller. As a result, losses attributable to imperfections of surfaces would be less than in the prior microresonators.
- The designs of the prior microresonators exploit evanescent-field coupling via airgaps. Vibrations give rise to small changes in the airgaps, thereby causing fluctuations in coupling strength. In the proposed microresonators, the greater depth of propagation of the resonant modes would make it possible to use zero-gap coupling, so that vibration would no longer cause fluctuations in the strengths of coupled optical signals.

This work was done by Anatoliy Savchenkov, Lute Maleki, Vladimir Iltchenko, and Andrey Matsko of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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Manufacture of Sparse-Spectrum Optical Microresonators

Multiple units having the same spectral parameters could be produced.

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An alternative design for dielectric optical microresonators and a relatively simple process to fabricate them have been proposed. The proposed microresonators would exploit the same basic physical phenomena as those of microtorus optical resonators and of the microsphere optical resonators described in several prior *NASA Tech Briefs* articles. The resonances in such devices are associated with the propagation of electromagnetic waves along circumferential paths in "whispering-gallery" modes. The main advantage afforded by the proposal is that the design and the fab-