Series-Coupled Pairs of Silica Microresonators

Pass bands are narrower and flatter than those of single microresonators.

NASA's Jet Propulsion Laboratory, Pasadena, California

Series-coupled pairs of whispering-gallery-mode optical microresonators have been demonstrated as prototypes of stable, narrow-band-pass photonic filters. Characteristics that are generally considered desirable in a photonic or other narrow-band-pass filter include response as nearly flat as possible across the pass band, sharp roll-off, and high rejection of signals outside the pass band. A single microresonator exhibits a Lorentzian filter function: its peak response cannot be made flatter and its roll-off cannot be made sharper. However, as a matter of basic principle applicable to resonators in general, it is possible to (1) use multiple resonators, operating in series or parallel, to obtain a roll-off sharper, and out-of-band rejection greater, relative to those of a Lorentzian filter function and (2) to make the peak response (the response within the pass band) flatter by tuning the resonators to slightly different resonance frequencies that span the pass band.

The first of the two microresonators in each series-coupled pair was a microtorus made of germania-doped silica (containing about 19 mole percent germania), which is a material used for the cores of some optical fibers. The reasons for choosing this material is that exposing it to ultraviolet light causes it to undergo a chemical change that makes the peak response as nearly flat as possible across the pass band, sharp roll-off, and high rejection of signals outside the pass band. Selection of suitable materials is central to the design of narrow-band-pass filters for laser frequency stabilization and optical signal processing. A Lorentzian filter function is easier to describe in detail, can be summarized as follows: The method calls for a complex combination of room-temperature and cryogenic test procedures and associated data-reduction procedures formulated to minimize systematic test errors and reveal subtle thermomechanical and optical effects, and thereby to characterize surface-figure errors at ambient and cryogenic temperatures. One notable feature of the method is the use of interferometric techniques to quickly align the mirror under test when it is in the cryogenic chamber. Once the mirror has been aligned and thermal equilibrium has been established, measurements are performed on both mirror and window surfaces to obtain the data needed to computationally eliminate the optical effects of the window.

This work was done by Victor John Chambers, Raymond G. Ohl, and Ronald G. Mink of Goddard Space Flight Center and Steven Arnold of Diffraction International Ltd. Further information is contained in a TSP (see page 1), GSC-14789-1.
most efficient for producing the desired photochemical reaction) was focused into the germania-doped microresonator. The current applied to the photodiode was modulated with a sawtooth waveform in order to sweep the laser wavelength repeatedly through a frequency range that included the pass band and surrounding frequencies. Using knowledge of the laser frequency vs. time, along with the measurements of photocurrent vs. time, it was possible to determine the magnitude of the filter spectrum. From time to time, the argon-ion laser was turned on to tune the germania-doped microresonator, and then the spectrum determined. Care was taken to discriminate against the transient contribution of laser-induced thermal expansion to the change in the spectrum. The process was repeated until the desired separation between the two resonance frequencies was obtained (for example, see figure).

This work was done by Anatoliy Savchenkov, Vladimir Iltchenko, Lute Maleki, and Tim Handley of Caltech for NASA's Jet Propulsion Laboratory.

Precise Stabilization of the Optical Frequency of WGMRs

This technique results in whispering gallery mode resonators with absolute frequency stability.

NASA's Jet Propulsion Laboratory, Pasadena, California

Crystalline whispering gallery mode resonators (CWGMRs) made of crystals with axial symmetry have ordinary and extraordinary families of optical modes. These modes have substantially different thermo-refractive constants. This results in a very sharp dependence of differential detuning of optical frequency on effective temperature. This frequency difference compared with clock gives an effective temperature. This frequency difference compared with clock gives an error signal for precise compensation of the random fluctuations of optical frequency. Certain crystals, like MgF₂, have "turnover" points where the thermo-refractive effect is completely nullified.

An advantage for applications using WGMRs for frequency stabilization is in the possibility of manufacturing resonators out of practically any optically transparent crystal. It is known that there are crystals with negative and zero thermal expansion at some specific temperatures. Doping changes properties of the crystals and it is possible to create an optically transparent crystal with zero thermal expansion at room temperature. With this innovation's stabilization technique, the resultant WGMR will have absolute frequency stability.

The expansion of the resonator's body can be completely compensated for by nonlinear elements. This results in compensation of linear thermal expansion (see figure). In three-mode, the MgF₂ resonator, if tuned at the turnover thermal point, can compensate for all types of random thermal-related frequency drift. Simplified dual-mode method is also available. This creates miniature optical resonators with good short- and long-term stability for passive secondary frequency ethalon and an active resonator for active secondary frequency standard (a narrowband laser with long-term stability).

Optical losses due to media imperfection were addressed through a multi-step, asymptotic processing of the resonator. This technique has been initially developed to reduce microwave absorption in dielectric resonators. One part of this process consists of mechanical polishing performed after high-temperature annealing by placing the fluorite WGMR in a 3-foot-long (0.91-m-long), air-filled, transparent tube of annealed fused silica and then into a 20-cm-long horizontal tube furnace with a heated furnace core. The annealing process improves the transparency of the material because an increased temperature results in the enhancement of the mobility of defects induced by the fabrication process, and also reduces any residual stress birefringence. The increased mobility leads to the recombination of defects and their migration to the surface. The straightforward annealing of a WGMR leads to Q>10¹¹ at 1.55 µm.

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

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
E-mail: iaoffice@pl.nasa.gov
Refer to NPO-30828, volume and number of this NASA Tech Briefs issue, and the page number.