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.

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Precise Stabilization of the Optical Frequency of WGMRs

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

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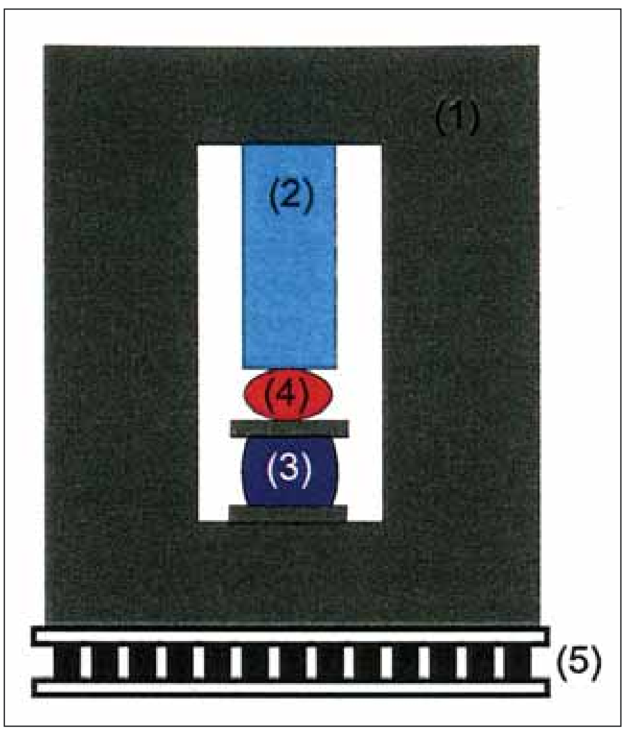
Crystalline whispering gallery mode resonators (CWGMRs) made of crystals with axial symmetry have ordinary and extraordinary families of optical modes. These modes have substantially different thermo-refractive constants. This results in a very sharp dependence of differential detuning of optical frequency on effective temperature. This frequency difference compared with clock gives an error signal for precise compensation of the random fluctuations of optical frequency. Certain crystals, like MgF_2, 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 MgF_2 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 multistep, 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 $Q>10^{11}$ at 1.55 µm.



A **Nonlinear Thermal Compensator** for an optical WGM resonator consists of (1) a rigid metal frame, (2) a glass or metal wedge-shaped spacer, and (3) a WGM resonator sandwiched between rigid spacers on the top and bottom. Temperature tuning is realized with a heater (5), and the nonlinearity is introduced by a nonlinear element (4).

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:

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