Precise Stabilization of the Optical Frequency of WGM Resonators

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 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. 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 etalon 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 fluoride 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 WGM leads to Q > 10¹⁵ at 1.55 μm.

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