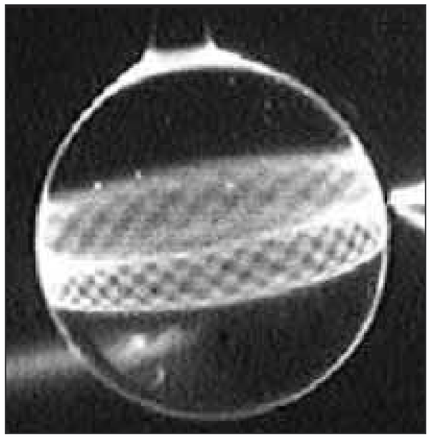
Delaying Trains of Short Light Pulses in WGM Resonators

Delays would not be limited by resonator ring-down times.

NASA's Jet Propulsion Laboratory, Pasadena, California

Suitably configured whispering-gallery-mode (WGM) optical resonators have been proposed as delay lines for trains of short light pulses. Until now, it has been common practice to implement an optical delay line as a coiled long optical fiber, which is bulky and tends to be noisy. An alternative has been to implement an optical delay line as a coupled-resonator optical waveguide (a chain of coupled optical resonators), which is compact but limits the width of the pulse spectrum to the width of an optical resonance and thereby places a lower limit on the duration of a pulse. In contrast, a delay line according to the proposal could be implemented as a single WGM resonator, and the pulses delayed by the resonator could be so short that their spectral widths could greatly exceed the spectral width of any single resonance.

The proposal emerged from theoretical and experimental studies of the propagation of a pulse train in a WGM resonator. An important element of the theoretical study was recognition that the traditional definition of group velocity — in effect, the velocity of a single pulse comprising a packet of waves propagating in a medium, the responsivity of which is a monotonous function of frequency — does not necessarily apply in the case of a WGM resonator or other medium having a spectrum consisting of discrete resonance peaks at different frequencies. A new definition of group velocity, applicable to a train of pulses propagating in such a medium, was introduced and found to lead to the discovery of previously unknown features of propagation.



A **Stationary Fluorescence Pattern** represents the intensity of interfering traveling light waves in a carefully selected combination of WGM modes in a microsphere optical resonator.

Notably, it was found that in a microsphere optical resonator that supports a suitable combination of WGM modes, the group velocity for a train of light pulses could be positive, zero, or negative. A positive group velocity could be so small that the delay could be much longer than the ring-down time of the resonator; a delay of such great length is impossible for a single pulse interacting with either a linearly responding lossless resonator or a coupled-resonator optical waveguide.

The phenomenon of "stopped light," which corresponds to a group velocity of zero (and, hence, to infinite delay), was demonstrated in experiments on a fused-silica microsphere of 300-μm diameter. Light from a diode laser at a nominal wavelength of 635 nm was swept through a 5-GHz frequency range at a repetition rate of 20 Hz and coupled into the resonator via an angle-cut optical fiber. The resonator was immersed in a solution containing a dye that fluoresces in response to evanescent-wave coupling of light from the WGM surface modes. When the tip of the angle-cut optical fiber was positioned and oriented to excite suitable combinations of WGM modes, stationary fluorescence patterns were observed (see figure).

This work was done by Andrey Matsko, Vladimir Iltchenko, Dmitry Strekalov, Anatoliy Savchenkov, and Lute Maleki of Caltech for NASA's Jet Propulsion Laboratory.

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Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
E-mail: iaoffice@jpl.nasa.gov

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