A Resonator for Low-Threshold Frequency Conversion

A nonlinear dielectric whispering-gallery resonator would be poled for quasi-phase-matching.

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A proposed toroidal or disklike dielectric optical resonator (dielectric optical cavity) would be made of an optically nonlinear material and would be optimized for use in parametric frequency conversion by imposition of a spatially periodic permanent electric polarization. The poling (see figure) would suppress dispersions caused by both the material and the geometry of the optical cavity, thereby effecting quasi-matching of the phases of high-resonance-quality (high-Q) whispering-gallery electromagnetic modes. The quasi-phase-matching of the modes would serve to maximize the interactions among them. Such a resonator might be a prototype of a family of compact, efficient nonlinear devices for operation over a broad range of optical wavelengths.

A little background information is prerequisite to a meaningful description of this proposal:

- Described in several prior NASA Tech Briefs articles, the whispering-gallery modes in a component of spheroidal, disklike, or toroidal shape are waveguide modes that propagate circumferentially and are concentrated in a narrow toroidal region centered on the equatorial plane and located near the outermost edge.

- For the sake of completeness, it must be stated that even though optical resonators of the type considered here are solid dielectric objects and light is confined within them by total internal reflection at dielectric interfaces without need for mirrors, such components are sometimes traditionally called cavities because their effects upon the light propagating within them are similar to those of true cavities bounded by mirrors.

- For a given set of electromagnetic modes interacting with each other in an optically nonlinear material (e.g., modes associated with the frequencies involved in a frequency-conversion scheme), the threshold power for oscillation depends on the mode volumes and the mode-overlap integral.

- Whispering-gallery modes are attractive in nonlinear optics because they maximize the effects of nonlinearities by occupying small volumes and affording high Q values.

In designing a cavity according to the proposal, one could reduce the mode volume and increase the mode-overlap integral, and thereby reduce the threshold power needed for oscillation, relative to those of a the nonlinear material in bulk form. The amplitude, configuration, and periodicity of the poling would be chosen so that the whispering-gallery modes to be quasi-phased-matched were the modes associated with the pump, signal, and idler frequencies involved in the parametric frequency conversion. It would be necessary to perform some complex computations, including calculation of quantum-mechanical mode
wave functions and evaluation of mode-overlap integrals, in order to analyze the performance of the cavity and design it for quasi-phase-matching.

The nonlinear cavity material would likely be commercially available flat, Z-cut LiNbO$_3$. The optimum poling geometry would be the one symmetrical about the center, shown on the left side of the figure. However, the imposition of centrally symmetric poling would be difficult. It would be much easier to use a slice of LiNbO$_3$ as supplied commercially with poling stripes; this would entail an increase in the threshold power for oscillation, relative to the optimum symmetrical poling pattern. On the other hand, the striped poling would enable the parametric generation of oscillations at multiple frequencies.

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