

radius. The modeled data indicates distinct spectral features for both the real and the imaginary part of the dielectric function. An ellipsometric measurement would determine this distinct feature and thus can be used to measure nanoparticle concentration. By “ellipsometric responses” is meant the intensities of light measured in various polarization states as

functions of the angle of incidence and the polarization states of the incident light. These calculated ellipsometric responses are used as calibration curves: Data from subsequent ellipsometric measurements on real specimens are compared with the calibration curves. The concentration of the nanoparticles on a specimen is assumed to be that of the calibration

curve that most closely matches the data pertaining to that specimen.

*This work was done by Srivatsa Venkatasubbarao and Lothar U Kempen of Intelligent Optical Systems, Inc. and Russell Chipman of the University of Arizona for Marshall Space Flight Center. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at [sammy.a.nabors@nasa.gov](mailto:sammy.a.nabors@nasa.gov). MFS-32506-1*

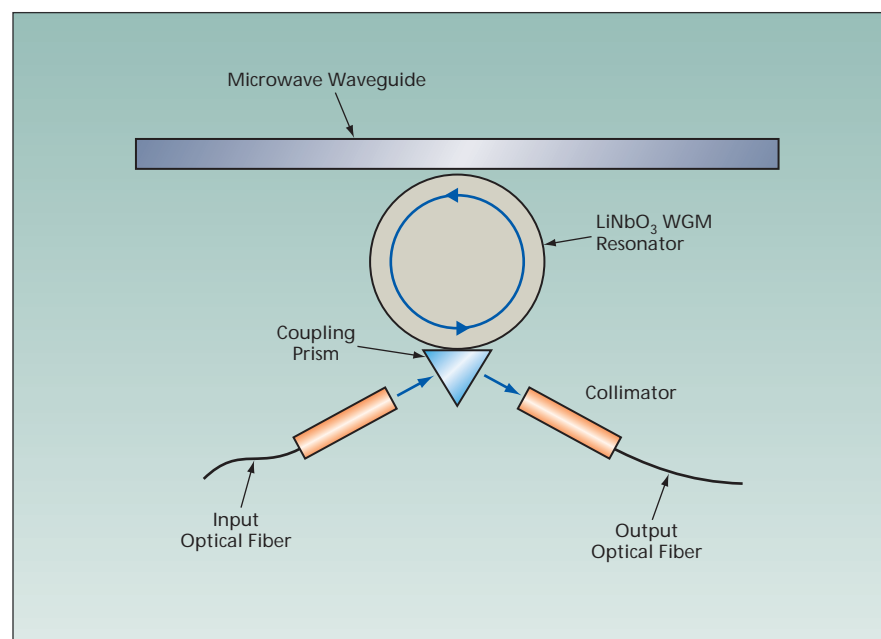
## Microwave-to-Optical Conversion in WGM Resonators

**Three-wave mixing, resonance, and low loss would result in high efficiency.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Microwave-to-optical frequency converters based on whispering-gallery-mode (WGM) resonators have been proposed as mixers for the input ends of microwave receivers in which, downstream of the input ends, signals would be processed photonically. A frequency converter as proposed (see figure) would exploit the nonlinearity of the electromagnetic response of a WGM resonator made of  $\text{LiNbO}_3$  or another suitable ferroelectric material. Up-conversion would take place by three-wave mixing in the resonator.

The WGM resonator would be designed and fabricated to obtain (1) resonance at both the microwave and the optical operating frequencies and (2) phase matching among the input and output microwave and optical signals as described in the immediately preceding article. Because the resonator would be all dielectric — there would be no metal electrodes — signal losses would be very low and, consequently, the resonance quality factors ( $Q$  values) of the microwave and optical fields would be very large. The long lifetimes associated with the large  $Q$  values would enable attainment of high efficiency of nonlinear interaction with low saturation



This Frequency Up-Converter would exploit three-way mixing among a microwave and two optical signals.

power. It is anticipated that efficiency would be especially well enhanced by the combination of optical and microwave resonances in operation at input signal frequencies between 90 and 300 GHz.

*This work was done by Anatoliy Savchenkov, Dmitry Strelakov, Nan Yu, Andrey Matsko, and Lute Maleki of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45121*

## Four-Pass Coupler for Laser-Diode-Pumped Solid-State Laser

**A smaller laser slab can be made to perform comparably to a larger one.**

*Goddard Space Flight Center, Greenbelt, Maryland*

A four-pass optical coupler affords increased (in comparison with related prior two-pass optical couplers) utilization of light generated by a laser diode in side pumping of a solid-state laser

slab. The original application for which this coupler was conceived involves a neodymium-doped yttrium aluminum garnet (Nd:YAG) crystal slab, which, when pumped by a row of laser diodes

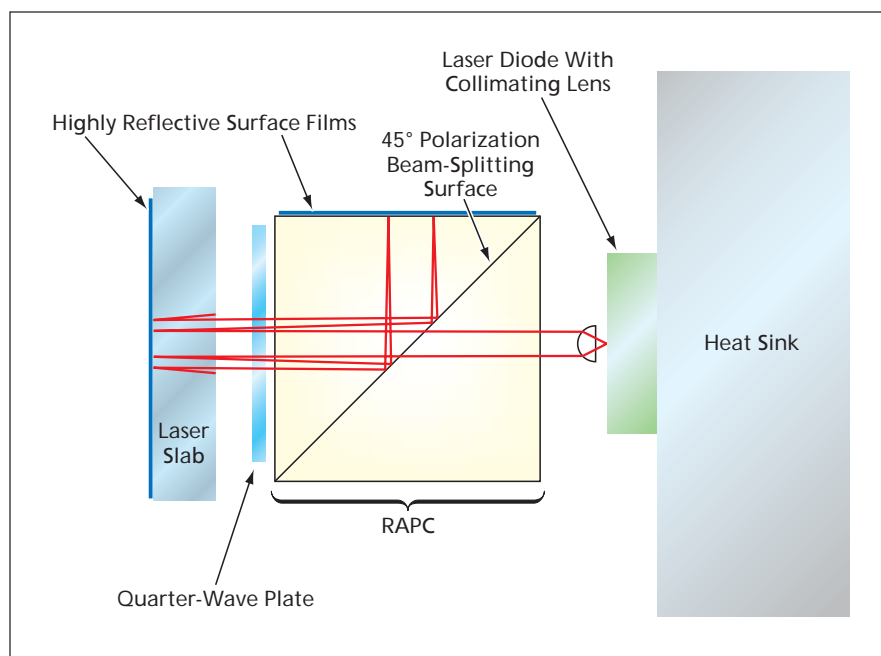
at a wavelength of 809 nm, lases at a wavelength of 1,064 nm.

Heretofore, typically, a thin laser slab has been pumped in two passes, the second pass occurring by virtue of re-

flection of pump light from a highly reflective thin film on the side opposite the side through which the pump light enters. In two-pass pumping, a Nd:YAG slab having a thickness of 2 mm (which is typical) absorbs about 84 percent of the 809-nm pump light power, leaving about 16 percent of the pump light power to travel back toward the laser diodes. This unused power can cause localized heating of the laser diodes, thereby reducing their lifetimes. Moreover, if the slab is thinner than 2 mm, then even more unused power travels back toward the laser diodes.

The four-pass optical coupler captures most of this unused pump light and sends it back to the laser slab for two more passes. As a result, the slab absorbs more pump light, as though it were twice as thick. The gain and laser cavity beam quality of a smaller laser slab in conjunction with this optical coupler can thus be made comparable to those of a larger two-pass-pumped laser slab.

The four-pass coupler (see figure) consists of a right-angle polarization cube (RAPC) with a quarter-wave plate on the side facing the laser slab and highly reflective film coating one of the perpendicular sides. The RAPC transmits p-polarized light (light polarized parallel to the plane of incidence) and reflects s-polarized light (light polarized perpendicular to the plane of incidence). Each laser diode emits a collimated beam and is oriented so that the beam is p-polarized (vertically polarized in the figure). The p-polarized beam passes through the RAPC, and then through the quarter-wave plate, which converts it to a rotationally polarized beam. The beam then passes into the laser slab for



The Four-Pass Coupler is interposed between the laser diodes and the laser slab. This view is along the longitudinal laser axis. The laser diodes, of which only one is shown here, are arranged in a row parallel to the axis.

a first pump pass, reflection, and second pump pass in the usual manner.

The pump light remaining after the second pass leaves the laser slab and travels back into the RAPC via the quarter-wave plate, which converts this light to s polarization. This s-polarized beam is reflected from the internal 45° polarization beam-splitting surface of the RAPC, sending the beam to the reflective coated RAPC surface at normal incidence. After reflection from this surface, this beam is reflected by the 45° surface toward the laser slab and is converted to rotational polarization by the quarter-wave plate. The beam then

makes two more passes through the laser slab in the usual manner.

Any pump beam power remaining after the fourth pass is converted to p polarization by the quarter-wave plate and travels back to the laser diode. However, when the coupler is designed correctly in conjunction with the other laser components, the fraction of pump power returning to the laser diode is too small to exert a significant adverse effect on the laser-diode lifetime or performance.

*This work was done by Donald B. Coyle of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-14961-1*

## Low-Resolution Raman-Spectroscopy Combustion Thermometry

**This method offers advantages over related prior Raman-spectroscopy-based methods.**

*John H. Glenn Research Center, Cleveland, Ohio*

A method of optical thermometry, now undergoing development, involves low-resolution measurement of the spectrum of spontaneous Raman scattering (SRS) from N<sub>2</sub> and O<sub>2</sub> molecules. The method is especially suitable for measuring temperatures in high-pressure combustion environments that contain N<sub>2</sub>, O<sub>2</sub>, or N<sub>2</sub>/O<sub>2</sub> mixtures (including air).

Methods based on SRS (in which scattered light is shifted in wavelength by amounts that depend on vibrational and rotational energy levels of laser-illuminated molecules) have been popular means of probing flames because they are almost the only methods that provide spatially and temporally resolved concentrations and temperatures of multiple molecular species in turbulent

combustion. The present SRS-based method differs from prior SRS-based methods that have various drawbacks, a description of which would exceed the scope of this article. Two main differences between this and prior SRS-based methods are that

- It involves analysis in the frequency (equivalently, wavelength) domain, in contradistinction to analysis in the in-