- Satisfaction of the optical and terahertz resonance-frequency requirement is a straightforward matter, inasmuch as the optical and terahertz spectra can be measured. However, satisfaction of the phase-matching requirement is more difficult. The approach followed in the present development is to perform computer simulations of the microwave and optical signals circulating in the resonator to test for phase matching.
- To enable excitation of the terahertz WGM resonator mode, it is also necessary to ensure phase matching between that mode and the incoming terahertz radiation. In the present development, the incoming signal is coupled into the WGM resonator via a tapered waveguide in the form of a fused silica rod. The phase-matching requirement is satisfied at one point along the taper; the rod is positioned with this point in proximity to the WGM resonator.
- To maximize the conversion efficiency, it is necessary to maximize the spatial overlap among the terahertz and optical modes in the WGM resonator. In the absence of a special design effort to address this issue, there would be little such overlap because, as a consequence of a large difference between wavelengths, the optical and terahertz modes would be concentrated at different depths from the rim of a WGM resonator. In the present development, overlap is ensured by constructing the WGM resonator as a ring (see figure) so thin that the optical and terahertz modes are effectively forced to overlap.

This work was done by Dmitry Strekalov, Anatoliy Savchenkov, Andrey Matsko, and Nan Yu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).
NPO-45508

Determining Concentration of Nanoparticles From Ellipsometry

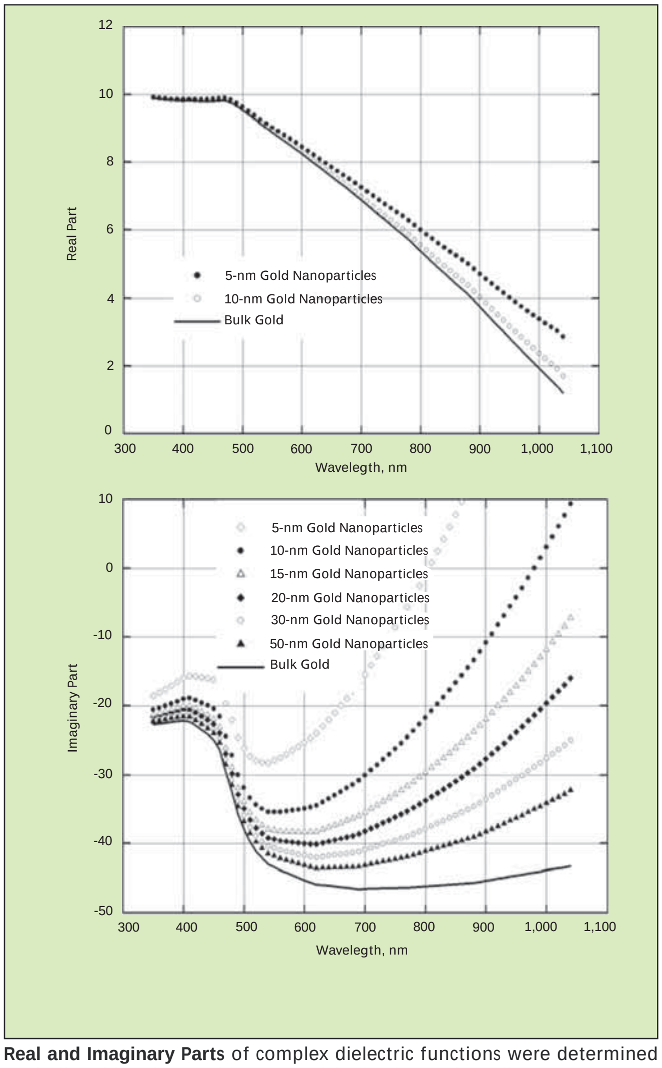
Counting of particles is not necessary.

Marshall Space Flight Center, Alabama

A method of using ellipsometry or polarization analysis of light in total internal reflection of a surface to determine the number density of gold nanoparticles on a smooth substrate has been developed. The method can be modified to enable determination of densities of sparse distributions of nanoparticles in general, and is expected to be especially useful for measuring gold-nanoparticle-labeled biomolecules on microarrays.

The method is based on theoretical calculations of the ellipsometric responses of gold nanoparticles. Elements of the calculations include the following:

- For simplicity, the gold nanoparticles are assumed to be spherical and to have the same radius.
- The distribution of gold nanoparticles is assumed to be a sub-monolayer (that is, sparser than a monolayer).
- The optical response of the sub-monolayer is modeled by use of a thin-island-film theory, according to which the polarizabilities parallel and perpendicular to the substrate are functions of the wavelength of light, the dielectric functions (permittivities expressed as complex functions of frequency or wavelength) of the gold and the suspending medium (in this case, the suspending medium is air), the fraction of the substrate area covered by the nanoparticles, and the radius of the nanoparticles.
- For the purpose of the thin-island-film theory, the dielectric function of the gold nanoparticles is modeled as the known dielectric function of bulk gold plus a correction term that is necessitated by the fact that the mean free path length for electrons in gold decreases with decreasing radius, in such a manner as to cause the imaginary part of the dielectric function to increase with decreasing radius (see figure). The correction term is a function of the nanoparticle radius, the wavelength of light, the mean free path and the Fermi speed of electrons in bulk gold, the plasma frequency of gold, and the speed of light in a vacuum.



Real and Imaginary Parts of complex dielectric functions were determined for bulk gold and for gold nanoparticles having various diameters.

These models are used to calculate ellipsometric responses for various concentrations of gold nanoparticles having an assumed 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. MFS-32506-1

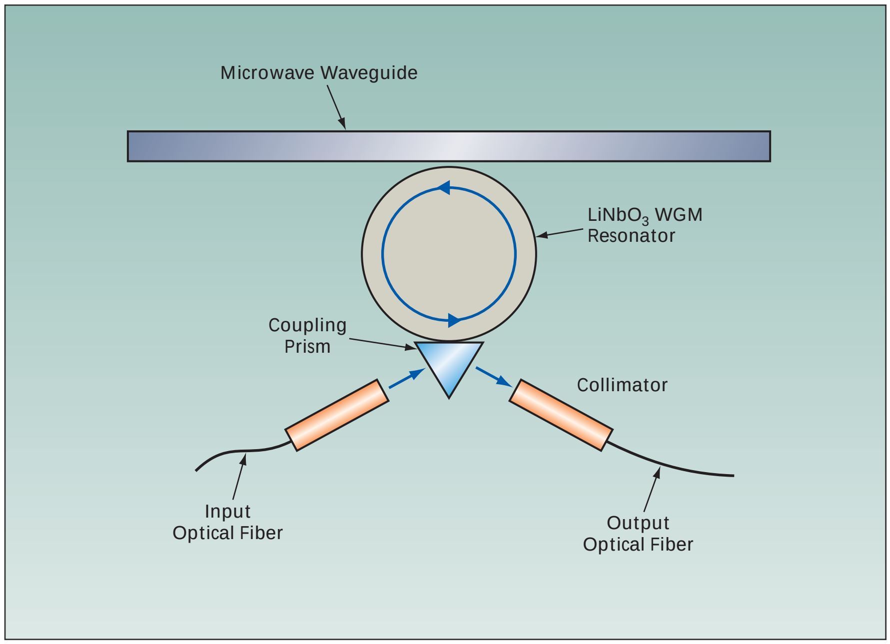
Microwave-to-Optical Conversion in WGM Resonators

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 $LiNbO_3$ 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 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 **Frequency Up-Converter** would exploit three-way mixing among a microwave and two optical signals.

This work was done by Anatoliy Savchenkov, Dmitry Strekalov, 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-