

# Gold Nanoparticle Labels Amplify Ellipsometric Signals

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The ellipsometric method reported in the immediately preceding article was developed in conjunction with a method of using gold nanoparticles as labels on biomolecules that one seeks to detect. The purpose of the labeling is to exploit the optical properties of the gold nanoparticles in order to amplify the measurable ellipsometric effects and thereby to enable ultrasensitive detection of the labeled biomolecules without need to develop more-complex ellipsometric instrumentation.

The colorimetric, polarization, light-scattering, and other optical properties of nanoparticles depend on their sizes and shapes. In the present method, these size-

and-shape-dependent properties are used to magnify the polarization of scattered light and the diattenuation and retardance of signals derived from ellipsometry. The size-and-shape-dependent optical properties of the nanoparticles make it possible to interrogate the nanoparticles by use of light of various wavelengths, as appropriate, to optimally detect particles of a specific type at high sensitivity.

Hence, by incorporating gold nanoparticles bound to biomolecules as primary or secondary labels, the performance of ellipsometry as a means of detecting the biomolecules can be improved. The use of gold nanoparticles as labels in ellipsometry has been found to

afford sensitivity that equals or exceeds the sensitivity achieved by use of fluorescence-based methods. Potential applications for ellipsometric detection of gold-nanoparticle-labeled biomolecules include monitoring molecules of interest in biological samples, *in-vitro* diagnostics, process monitoring, general environmental monitoring, and detection of biohazards.

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# Phase Matching of Diverse Modes in a WGM Resonator

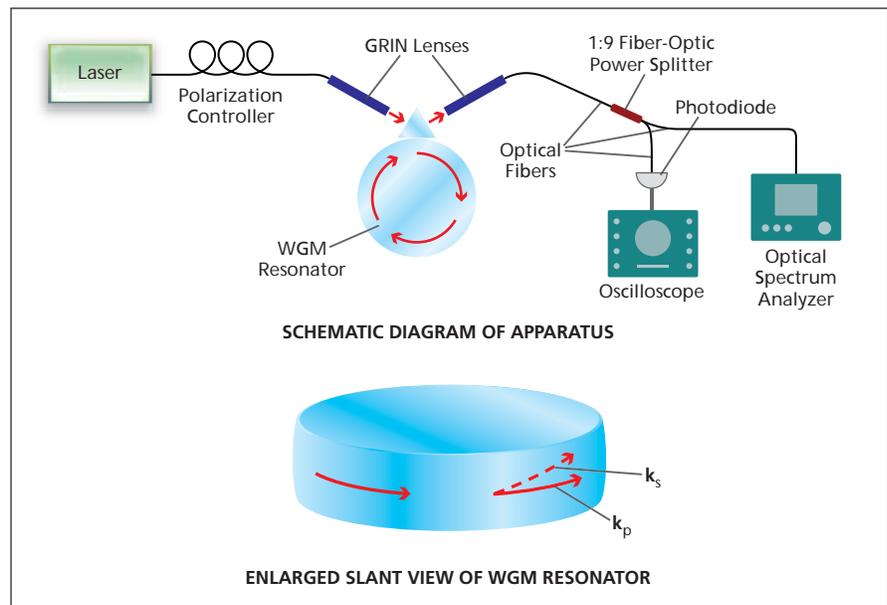
Phase matching is necessary for exploitation of nonlinear optical phenomena.

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Phase matching of diverse electromagnetic modes (specifically, coexisting optical and microwave modes) in a whispering-gallery-mode (WGM) resonator has been predicted theoretically and verified experimentally. Such phase matching is necessary for storage of microwave/terahertz and optical electromagnetic energy in the same resonator, as needed for exploitation of nonlinear optical phenomena.

WGM resonators are used in research on nonlinear optical phenomena at low optical intensities and as a basis for design and fabrication of novel optical devices. Examples of nonlinear optical phenomena recently demonstrated in WGM resonators include low-threshold Raman lasing, optomechanical oscillations, frequency doubling, and hyperparametric oscillations.

The present findings regarding phase matching were made in research on low-threshold, strongly nondegenerate parametric oscillations in lithium niobate WGM resonators. The principle of operation of such an oscillator is rooted in two previously observed phenomena: (1) stimulated Raman scattering by polaritons in lithium niobate and (2) phase matching of nonlinear optical processes via geometrical confinement of light. The oscillator is



Nonlinear Optical Phenomena are excited in a WGM resonator disk and the output spectrum is measured to obtain evidence of those phenomena. In the phenomenon of particular interest here, an optical pump photon of wave vector  $k_p$  is scattered into an optical signal photon of wave vector  $k_s$  and a microwave idler photon of wave vector  $k_i$ . The idler photon is not necessarily confined within WGM resonator if its wavelength exceeds the thickness of the resonator disk.

partly similar to terahertz oscillators based on lithium niobate crystals, the key difference being that a novel geometrical configuration of this oscillator supports oscillation in the continuous-wave regime. The high resonance quality factors ( $Q$  values) typical of WGM

resonators make it possible to achieve oscillation at a threshold signal level much lower than that in a non-WGM-resonator lithium niobate crystal.

The applicable theory states that the parametric interaction takes place in a WGM resonator if the photon-energy