Zeeman Refractive Index Detector

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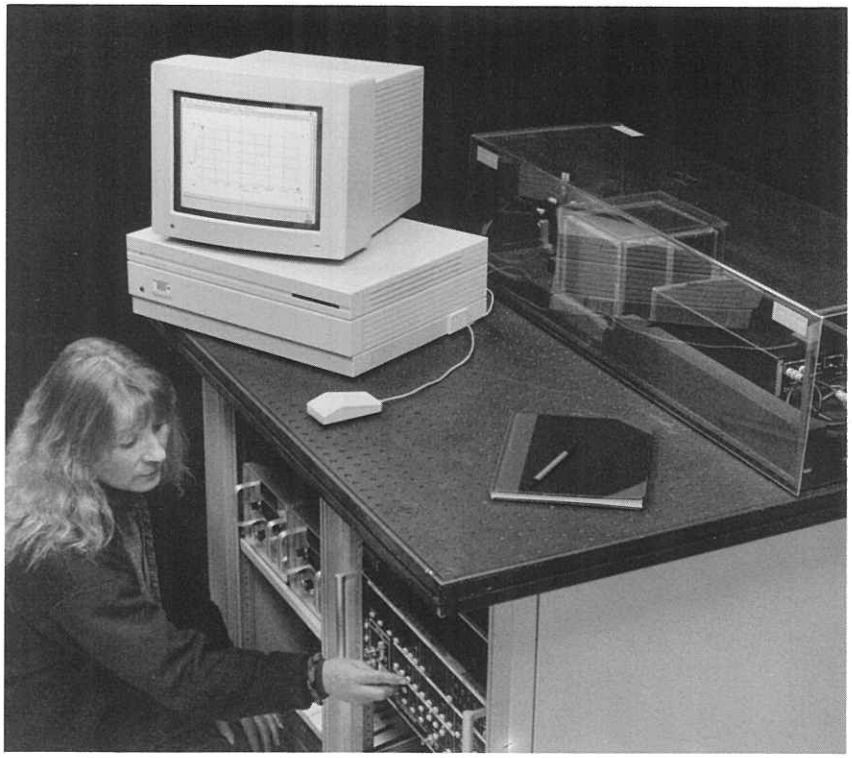

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Ultrasensitive interferometry can now be exploited by using a stable, robust instrument—the Zeeman Refractive Index Detector. The instrument can measure the refractive index (RI) changes as small as one part in a billion; it is ten times more stable than other RI detectors; and it is unaffected by vibration, changes in room temperature, and acoustical noise.

The ability to monitor gases and liquids for contaminants is important to maintaining successful chemical processes in the laboratory and in industry. Los Alamos National Laboratory researchers have developed a simple, generic detector that relies on ultrasensitive interferometry to monitor continuously a sample that changes over time, such as a flowing gas or liquid, for any kind of contaminant. The sample can be less than 1 microliter in volume, and the contaminant need not have special properties such as fluorescence, light absorption, or electrical conductivity to be detected. The detector can be useful for monitoring water supplies and to U.S. industry for the chemical processing and analysis of many products, including pharmaceuticals, tires, paints, and coatings.

For their invention, the developers received a 1992 R&D 100 Award; the awards are given annually by *Research and Development Magazine* for the one hundred most significant technical innovations of the year. The Laboratory holds two patents on the technology.

Description and Advantages

The key to the Zeeman Refractive Index Detector is its ability to monitor minute changes in the refractive index (RI) of a time-varying sample. The RI for a given material is defined as the speed of light in a vacuum divided by the speed of light in the material. For example, the RI for air is about 1.00023, and the RI for diamond is about 2.42. The Zeeman Refractive Index Detector maintains a flowing gas or liquid sample at a fixed temperature and pressure and measures changes in the speed of light as it passes through the sample. These changes can be as small as 30 centimeters per second (1 foot per second) out of 300 million meters per second, which indicates that the detected change in the RI can be as small as one part in a billion. When the temperature and pressure are constant, any change in the RI indicates that the composition of the sample has been changed by the presence of some contaminant.

To measure changes in the RI, our detector relies on a two-frequency, Zeeman-effect laser, which emits two collinear laser lines that are polarized at 90 degrees to each other. The interferometry needed to measure the changes requires that the two lines be spatially separated on the basis of their polarization. One laser line passes through the sample, the other through a reference material. After they are reunited, the two laser lines are allowed to interfere on a photodiode, producing a 250-kilohertz beat frequency, which is analogous to the beat frequency (the third tone) heard when two tuning forks of different frequencies are struck simultaneously—the third tone has a frequency equal to the difference between the other two frequencies. Comparing this beat frequency with a reference 250-kilohertz sine wave identifies changes in the phase of the beat frequency. Phase changes are the result of changes in the RI of the sample. We measure these phase changes using a lock-in amplifier with a resolution of 0.03 degrees (1/12,000 of a wavelength). The phase change is proportional to the change in the RI.

Our detector has numerous advantages over existing RI detectors and interferometers. Many other interferometers measure the intensity of light falling on a photodetector. Instead, by measuring phase changes, the Zeeman Refractive Index Detector obtains twice the resolution of other detectors—one part in one billion. In addition to its remarkable resolution, the detector has unprecedented stability—ten times that of existing RI detectors. It is virtually unaffected by mechanical vibration and acoustical noise, which instantly throw most conventional

For more information about the Zeeman Refractive Index Detector, please contact Kay Adams, Industrial Partnership Center, Los Alamos National Laboratory, P.O. Box 1663, Mail Stop K763, Los Alamos, NM 87545, Telephone (505) 665-9090, Fax (505) 665-3164.

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interferometers or RI detectors out of calibration. Also, our detector is self-calibrating, requiring no mechanical, optical, or electronic adjustments after it is assembled. It has a broad operating range: it measures minute changes at a resolution of one part per billion and simultaneously tracks changes a million times larger. Most conventional detectors do not have this range, or they must be recalibrated or reconfigured to accept a new range. Because the instrument works optically and thus noninvasively, without contaminating probes, it eliminates the problem of the measurement interfering with the process—always a concern in the laboratory and in industry.

Applications

In addition to monitoring contaminants, the detector can accurately measure very small or very rapid changes in the pressure, optical activity, or temperature of a sample. The detector has a wide variety of potential applications, including industrial process control, environmental monitoring, chromatography, polarimetry, biochemistry, spectrophotometry, flow cytometry, and interferometric microscopy. These uses are not mutually exclusive; the same instrument could easily be used for different applications. We hope to improve the sensitivity and temperature control of the detector in order to fully develop it for use as a gel electrophoresis detector in DNA work. We have already modified the instrument to detect unstained, untagged DNA in real time during gel electrophoresis, with a sensitivity of better than 1 nanogram of DNA.

Inventors Roger G. Johnston and W. Kevin Grace are members of the Physical Chemistry/Process Technology Group of the Chemical and Laser Sciences Division.

Johnston's research interests include inteferometry, light scattering, image processing, flow cytometry, and biotechnology. Using lasers for novel light-scattering measurements led to his interest in developing the Zeeman Refractive Index Detector. He earned his B.S. degree in physics from Carleton College and his M.S. and Ph.D. degrees in physics from the University of Colorado. As a student he did fluid dynamics research for the National Aeronautics and Space Administration and provided research assistance at Argonne National Laboratory and N. V. Philips Company. He joined the Laboratory in 1983 as a postdoctoral fellow and soon became a staff member, first in the Life Sciences Division and then in the Chemical and Laser Sciences Division. Since 1986 he has been a project leader for multidisciplinary research and development projects.

Grace has been at the Laboratory since 1981, where he has managed projects for the U.S. Army and others that involved developing a multiparameter light-scattering flow cytometer, two static


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Inventors of the Zeeman Refractive Index Detector are Roger G. Johnston (left) and W. Kevin Grace.

photopolarimeters, and a mobile ultraviolet lidar (light detection and ranging) system. His contribution to the Zeeman Refractive Index Detector included experience with ultrasensitive interferometry and its applications to flow cytometry, gel electrophoresis, and RI detection. These applications require a knowledge of interferometric optics, microkelvin temperature control, and low-expansion materials and design. Before coming to the Laboratory, he studied at the Albuquerque Technical Vocational Institute.