LGR
Los Gatos Research

THE LGR ADVANTAGE

It is all in the technology

Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS)

All LGR analyzers utilize a unique laser absorption technology called Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS). This LGR-patented technique offers superior performance, value and reliability compared to cavity ringdown spectroscopy (CRDS).

Cavity enhanced absorption was first developed as an ultra-sensitive detection method by LGR founder Anthony O'Keefe in 1988 (Review of Scientific Instruments (ISSN 0034-6748), vol. 59, Dec. 1988, p. 2544-2551) in the form of cavity ringdown spectroscopy (CRDS). While innovative, this first-generation technique requires sub-nanometer alignment of its internal optics, which translates directly into limitations in terms of high cost, reliability, and vulnerability to vibrations and temperature/pressure changes.

To overcome these drawbacks, scientists at LGR developed, and subsequently patented, a fourth-generation cavity enhanced laser absorption technology called OA-ICOS. This approach delivers superior performance, yet is orders-of-magnitude less sensitive to internal alignment of components and to variations in local temperature and pressure. As a result, OA-ICOS is ideal for use in commercial instruments for even the most demanding applications in remote locations.

The inherent advantages of OA-ICOS technology make LGR trace gas and stable isotope analyzers the best choice, whatever the application.

- **Parts-Per-Billion (ppb) Precision:** OA-ICOS avoids the expense and vulnerability of a sub-nanometer opto-mechanical setup. This enables it to easily deliver parts-per-billion precision (or better) quickly and in an easy-to-use package.
- **Wider Dynamic Range:** OA-ICOS directly measures absorption rather than only a cavity decay time. Therefore it offers a linear response over a significantly wider dynamic range than conventional CRDS (i.e. up to 100% mole fraction for some gases).
- **Best Performance:** OA-ICOS analyzer performance is not dependent on hyper-critical optical alignment, whereas older cavity-based techniques (e.g., CRDS) require sub-nanometer optical component alignment. This makes these older techniques very vulnerable to degraded performance due to vibrations, small physical shocks, and changes in temperature and pressure.
- **Field Serviced:** OA-ICOS performance is orders of magnitude less sensitive to internal alignment, so our rugged instruments are robust and reliable. And designed with simplicity in mind, in the rare instance that repair is necessary; ***LGR instruments may be easily serviced on site by anyone***.
- **Lower Manufacturing Cost:** OA-ICOS analyzer performance is not dependent on hyper-critical optical alignment, whereas older, conventional CRDS techniques require sub-nanometer optical component alignment. This necessitates the use of expensive electro-mechanical components and complex feedback loops as well as very time-consuming cleanroom assembly and elaborate testing.
- **Better Value:** OA-ICOS analyzer performance is completely unaffected by any minor shifts in optical alignment. This enables the use of simpler, lower-cost components and fewer feedback control systems, as well as simplifying our assembly process.
- **Minimal Downtime:** OA-ICOS technology does not require ultra-precise optical alignment. This means that a minimally trained user can easily remove a cavity mirror, if necessary, and then clean and replace it in only minutes, *with no impact on performance or expensive returns to the factory*.

With OA-ICOS you get:

Superior Performance

- All LGR analyzers deliver superior performance (in terms of accuracy, precision, sensitivity, linearity and dynamic range) and ease of use compared to any competitive technology.
- LGR trace gas and stable isotope analyzers deliver the world's best performance for applications such as climate research, water cycle studies, petrochemical exploration, and emissions compliance monitoring.

Unmatched Reliability

- All LGR analyzers combine state-of-the-art performance with robust operation and unmatched reliability, enabling continuous operation in challenging environments, as well as in mobile (truck, ship, aircraft) and remote applications.
- For these reasons, LGR trace gas and stable isotope analyzers deliver state-of-the art precision and unmatched reliability whether in the laboratory, in a helicopter, or at an unmanned arctic monitoring site.

Exceptional Value

- All LGR analyzers deliver exceptional value by providing superior performance over any other technology, while still remaining an economical instrument.
- By employing this simpler, more robust technology, LGR trace gas and stable isotope analyzers deliver state-of-the-art precision and accuracy for a cost that is approximately half that of the nearest competitor.

Simple Field-Maintenance

- All LGR analyzers are designed for simple field maintenance, avoiding the factory return that all competitive instruments require, even for simple optics cleaning.
- LGR analyzers reduce the downtime impact of accidental optics contamination to only minutes rather than the days or weeks required by conventional CRDS systems. Furthermore, in LGR instruments, the laser beam spot pattern covers practically the entire cavity mirror, in contrast to conventional CRDS, which only uses a small area in the center of the mirror. As a result, LGR instruments are much less affected by the presence of dust than conventional CRDS systems and thus require far less frequent service.

True Wavelength Scanning

- All LGR analyzers employ a unique laser absorption technology called Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS). Unlike older laser-based methods, such as cavity ringdown spectroscopy (CRDS), this approach utilizes true wavelength scanning to record fully resolved detailed absorption lineshapes, which are presented to the user in real time, a critical advantage that delivers several considerable benefits including:
    - Unmatched specificity
    - Superior accuracy
    - Widest linear dynamic range
    - Enhanced capabilities, e.g., multiple isotope ratios recorded simultaneously
    - Greater simplicity and higher value
    - Stable isotope calibration

After LGR's founder, Anthony O'Keefe, Ph.D., pioneered the development of CRDS*, scientists at LGR went on to develop OA-ICOS as an alternative cavity-based technique. Specifically, this method was created to achieve the same or better sensitivity, but without the hyper-critical alignment and laser wavelength control requirements. OA-ICOS has delivered on this goal by enabling the development of robust, rugged and portable instruments in a lower-cost platform that effectively spans the entire range of wavelengths that tunable lasers are available. But just as important, OA-ICOS also permits true continuous wavelength scanning that delivers a host of other advantages.

With first generation cavity techniques like CRDS, the laser wavelength has be matched and stabilized to one of the resonant modes of the cavity. In operation the laser wavelength is controlled to one part in 109, and successively

* Anthony O'Keefe; David A.G. Deacon (1988). "Cavity ring-down Optical Spectrometer for absorption measurements using pulsed laser sources". *Review of Scientific Instruments* 59: 2544.

stepped to record data at a small finite number of these resonant cavity modes. In contrast, OA-ICOS does not require mode matching and, as a result, the laser wavelength is smoothly and repetitively scanned over the entire spectral region of interest – see figure – to yield fully resolved complex absorption spectra that is always presented to the user.

Unmatched specificity. Most real samples contain multiple chemicals that can potentially absorb laser light within the probed spectral region. Any spectral overlap between absorption line(s) of other molecules can cause crosstalk by changing the shape and intensity of the target absorption line. In addition, variations in the concentrations of a gas with a permanent dipole (like CO_2 or H_2O) can even cause subtle changes in the shape of a non-overlapped line, for example CH_4 — a well-known effect called pressure broadening. Having a continuous scan of an extended spectrum at a few MHz resolution (as opposed to 300 MHz resolution for CRDS wavelength stepping) allows the instrument's analysis software to identify and precisely correct for both spectral overlap and/or broadening and for the presence of interferences. As a result, OA-ICOS delivers excellent specificity and is much less susceptible to crosstalk or effects of contamination than CRDS. Moreover, with OA-ICOS the entire measured spectrum is continuously displayed, enabling the user to unambiguously check for other species present in the sample. For example, LGR's Spectral Contamination Identifier software can accurately correct for the presence of contaminants in liquid water samples, whereas other methods that rely on insufficient spectral resolution cannot.

Superior accuracy. All cavity-based laser absorption methods can deliver parts-per-billion precision or better. In many applications, however, instrument precision is of limited value unless accompanied by absolute accuracy. True continuous wavelength scanning means that the precise height and fully resolved shape of target absorption lines can always be measured, even in the presence of other gas constituents in the sample. That's why OA-ICOS consistently delivers superior accuracy in independent comparisons. For example, LGR's Enhanced Performance series of instruments can provide absolute accuracy of 0.03% (or better) of measured mole fraction for several target species, even in complex flows containing many gases.

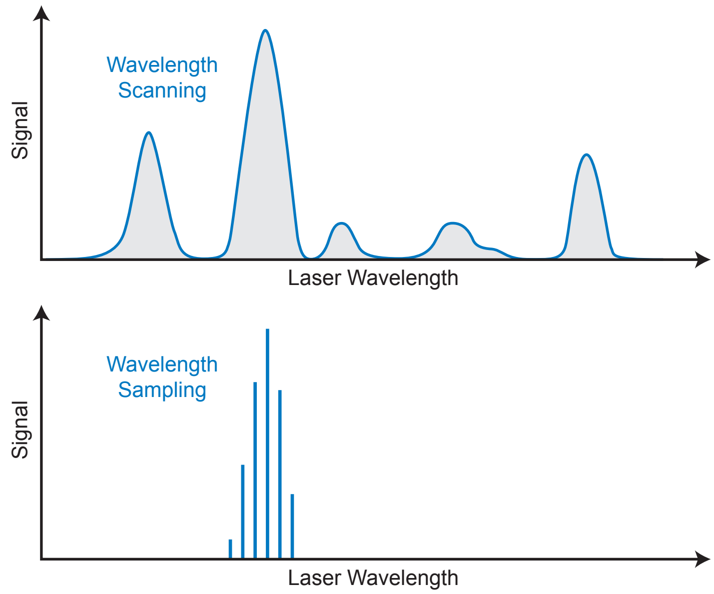

Figure. *(top) True continuous wavelength scanning capabilities of OA-ICOS allow direct measurements of fully resolved absorption lineshapes. (bottom) Discrete wavelength sampling measurements recorded using CRDS do not provide detailed absorption lineshapes. As a result, OA-ICOS instruments report measurements with higher accuracy and linearity, and are much less susceptible to cross interferences and errors due to contaminants.*

Extended linear dynamic range. Unlike CRDS, OA-ICOS records fully resolved absorption lineshapes continuously in real time and without the need for expensive high bandwidth photodetectors. In contrast, CRDS measures the ringdown time to infer absorption. While CRDS can be effective if the ringdown time is sufficiently long, when mole fraction of the target gas gets high, the ringdown time becomes too short to reliably measure. OA-ICOS directly measures absorption and thus can provide accurate measurements at very high concentrations. The inherently higher dynamic range of OA-ICOS (see specific product datasheets for details) is also extremely linear as a result of true continuous wavelength scanning. That's because subtle spectroscopy effects, such as pressure broadening, that are dependent on gas concentrations of all molecules in the sample, are specifically measured in detail. Techniques, no matter how stable, that rely on measurements at only a few discrete wavelengths in a scan cannot accurately measure these subtle effects and thus have limited linear range.

Enhanced capabilities — multiple species. Because the wavelength of the tunable laser can be scanned at high resolution over an extended region, an OA-ICOS instrument can simultaneously report detailed complex spectra that contain many lineshapes associated with several different molecules (e.g., CO_2, CH_4, CO) or from several different isotopologues (e.g., three types of nitrous oxide, ^{15}NNO, $N^{15}NO$, $NN^{18}O$) easily. For instance, an Industrial Emission Analyzer from LGR configured for monitoring gas from Syngas reactors, steel manufacturing facilities and other high temperature flows can simultaneously report accurate mole fractions for nine separate gases in real time. In contrast, CRDS instruments, which only measure at a limited number of wavelengths, cannot provide detailed measurements of many gases, isotopologues or isotope ratios.

Greater simplicity and higher value. True continuous wavelength scanning enables simpler, lower-cost instruments for two reasons. In earlier technologies like CRDS, wavelength sampling requires a high precision, costly and complex internal wavemeter to accurately measure the laser wavelengths at all times. (This is done to avoid measuring the wrong absorption line). Because OA-ICOS instruments from LGR scan an extended spectrum (and always display the measured spectrum to the user), there is no possibility of scanning the wrong line, eliminating the complexity and cost of an integrated custom wavemeter. In addition, for applications requiring simultaneous measurement of multiple species, a single laser can usually reach quantitative absorption lines for these different molecules, further enhancing instrument simplicity and value. For example, one version of LGR's Industrial Emissions Analyzer configured for measurements in Syngas generators and steel manufacturing facilities uses a single laser source to simultaneously measure many different gases: CO_2, H_2S, H_2O, CO, CH_4, NH_3, C_2H_4, and HCN. In contrast, a CRDS instrument based on wavelength sampling will usually need multiple lasers to measure multiple gases, greatly increasing instrument cost and complexity.

Stable Isotope Calibration. Any stable isotope measurement instrument requires periodic calibration, whether based on mass spectrometry or optical absorption. In the case of isotopic water, an independent comparative study confirmed that the calibration curve for an LGR instrument was constant and stable over time. In contrast, the calibration curve of a competitive CRDS-based isotopic water vapor analyzer kept changing, necessitating frequent re-measurement of this curve. The stability of the OA-ICOS isotope calibration curve is another consequence of true wavelength scanning, enabling the instrument to automatically correct for changes in sampling conditions and for variations in other non-measured gases.

[L G R] Los Gatos Research

Los Gatos Research, Inc.
67 East Evelyn Avenue, Suite 3
Mountain View, CA 94041-1529

Phone: +1 650–965–7772
Fax: +1 650–965–7074
Sales: sales@lgrinc.com

www.lgrinc.com