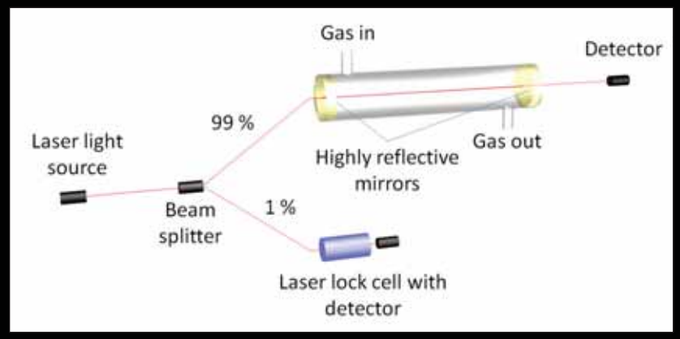
Orders of magnitude: Addressing the semiconductor industry's exponential needs

Peter Berg, Bernt Meßtechnik GmbH and Fred Conroy, Tiger Optics LLC review the progress made in the last 10 years.

Figure 1: Tiger Optics CW-CRDS Schematic



moisture ◆ measurement

Tiger Optics reduced the lower detection limits (LDL) by a factor of ten times (10x) or more when compared to existing on-line moisture analyzer technologies such as the electrolytic process using Faraday's Law or the quartz-crystal microbalance (QCM). Not only did the MTO-1000 offer lower detection limits; it also provided the user with an absolute measurement that did not require the use of zero or span gases. The semiconductor industry took heed. In its fabrication plants, the margin of success can hinge on the purity of required gases.

Moisture Measurement via Ring-down Spectroscopy

The Tiger Optics' core technology is based on continuous wave cavity ring-down spectroscopy (CW-CRDS). The measurement principle is shown in Figure 1. A laser beam in the near-infrared (NIR) realm is coupled to a measurement cell, with parallel, highly reflective mirrors at either end. The dielectric coating of the mirrors reflects more than 99.999 percent of the light within a specific, rather narrow, frequency band. The small amount of light that passes through the mirror at the far end of the measurement cell is captured by a detector, which measures its remaining intensity. The gas stream to be analyzed flows continuously through the measurement cell.

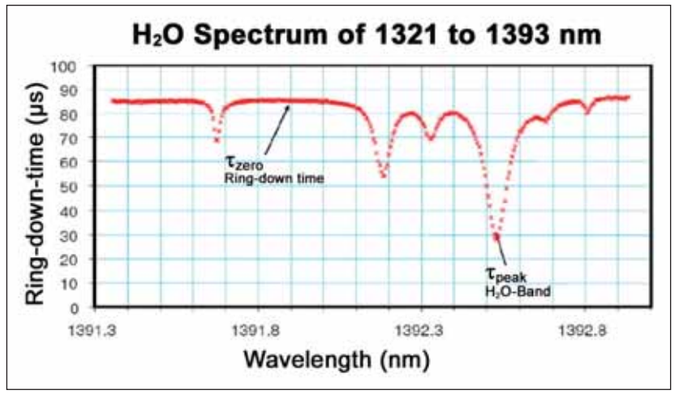
The measurement process starts with the continuous-wave (CW) laser energizing the cell until the light energy reaches a threshold value. The laser is then shut off for a fraction of a second. The laser beam travels back and forth between the mirrors within the measurement cell, for a total path length of close to 30 kilometers. The laser light's intensity level follows a decreasing exponential function until the energy is exhausted (a "ring down"). The determination of the concentration of moisture is based on the time required for the light to die.

CW CRDS provides an "absolute" measurement via the Beer-Lambert Law, so no zero gas is required. The zero portion of the measurement is determined by intentionally tuning the laser to a frequency at which moisture does not absorb light. Figure 2 shows the water vapor spectrum in the wavelength range of 1391 to 1393 nm. In the wide region marked "τZero – Abklingzeit/Ring-down time," there is no absorption of light by the moisture present in the gas stream. The associated ring-down time of 86 microseconds is solely caused by the loss of light from the measurement cell. The laser is then tuned to the wavelength of a known absorption peak of the water vapor spectrum (marked "τPeak H2O-Band" in Figure 2). The shorter measured ring-down time of 29 microseconds is due to moisture absorbing a portion of the light. When the τZero

and τPeak ring-down times are entered into the formula of the Beer-Lambert Law, the result is the moisture concentration. This time-based measurement contrasts with other laser-based measurement techniques relying on hard-to-control factors such as differences in light intensity, rendering them "relative" techniques, requiring external calibration.

While a true zero measurement is insured by capturing the ring-down time off-peak, the on-peak performance is verified via a reference cell. A small fraction of the laser light is diverted through a reference cell that contains a small amount of the analyte in question.

When the laser is exactly on peak, the amount of light reaching a detector at the far end of the reference cell is minimal. If the intensity begins to increase (indicating a drift from the correct wavelength), the laser is adjusted by changing the supplied current until the intensity is again at a minimum. This "laser locking" ensures that the proper τPeak wavelength is being used and eliminates any long-term drift that continues to plague other technologies. While the underlying science is relatively complex, the instruments are very simple to operate. All of the calculations are performed by the system's software and the concentration is continuously updated on the touch-screen display. Tiger analyzers are effortless to install and do not require the use of calibration gases or null gases. Once the system is taken out of the crate, measurements on a dry gas can be taken in just a matter of minutes.



	LaserTrace3		LaserTrace	
H2O	LDL	Sensitivity	LDL	Sensitivity
In Argon	150 ppt	75 ppt	300 ppt	150 ppt
In Helium	100 ppt	50 ppt	200 ppt	100 ppt
In Hydrogen	250 ppt	125 ppt	500 ppt	250 ppt
In Nitrogen	250 ppt	125 ppt	500 ppt	250 ppt
In Oxygen	300 ppt	150 ppt	300 ppt	150 ppt

Figure 2: LaserTrace3 vs LaserTrace Moisture Specifications

Tiger's Reach

Since 2001, Tiger's R&D team has developed a variety of analyzer versions from its CW-CRDS technology. These include the LaserTrace family, HALO family, Tiger-i (for ambient and environmental contaminants), ALOHA-H2O (for UHP ammonia), and Prismatic. Each platform addresses specific market needs. Foremost on Tiger's agenda: anticipating the requirements of the semiconductor industry, with its ever-decreasing line geometries coupled with increasing wafer sizes. No instrument maker is more attuned to a fabrication plant's constant need for gas purity analyzers with lower LDLs, reduced cost of ownership (COO), and increased uptime.

Accordingly, Tiger introduced its LaserTrace system in 2003. The platform provides users with a modular product line that allows for the monitoring of their bulk gases (Ar, He, H2, N2, O2) to sub-ppb levels for moisture, oxygen, methane, and other analytes. By 2008, the LaserTrace+ system was able to provide users with an LDL as low as 200 ppt (depending upon the gas matrix). The LaserTrace has become the company's most popular product family, with nearly 500 systems in use worldwide.

The EURAMET 1002 Study

The absolute nature of the CW-CRDS technology is heralded not only by industrial users, but by the scientific community as well. Throughout the world, national metrology institutes (NMIs) have established their own methods of generating precise levels of moisture to develop and compare standards and to perform vital calibration processes in their own country or region.

As each NMI's moisture generator is large and of complex design, it has not been feasible to ship these generators around the globe for comparison studies. The NMIs needed a portable, absolute measurement technique that could be shipped from one institute to another to perform the analysis. Enter Tiger Optics.

Using two Tiger instruments, the European Association of National Metrology Institutes (EURAMET) recently completed an international study of different moisture generating techniques from four (4) NMIsii. The participants included the National Institute of Standards and Technology

(NIST, USA), National Metrology Institute of Japan (NMIJ, Japan), National Physical Laboratory (NPL, UK), and Physikalisch-Technische Bundesanstalt (PTB, Germany). The multi-year, multinational study determined that the deviation of Tiger's LaserTrace analyzer was less than two percent (2%) over the three (3) year period in the entire range of 10 ppb – 2 ppm.

LaserTrace 3

While the semiconductor industry has long relied on the LaserTrace system for absolute measurements, shrinking geometries on the wafer have resulted in even tighter controls being placed on the purity of gases used in the semiconductor manufacturing process. As some fabs set alarm limits for moisture as low as 500 ppt, the semiconductor industry is now requiring even lower LDLs. Once again, Tiger Optics has responded to the industry's needs.

At Semicon West 2011, Tiger Optics introduced the LaserTrace 3, for which the LDLs of most contaminants and gas matrices have been cut in half. For moisture in helium, the LDL is now an astonishingly low 100 ppt (Figure 3). The achievement is one of the reasons that the Tiger Optics' LaserTrace 3 won the prestigious Golden Gas Award for 2012 from Gases and Instrumentation International Magazine in the Gas Analysis and Detection category.

In addition to the dramatic reduction in the LDL, the engineering team at Tiger Optics has increased the speed of response for a multi-channel LaserTrace 3 by a factor of more than 2.5x. The end user can be assured that the LaserTrace 3 will display updated moisture concentrations on each channel every two seconds. This dramatic improvement in the LDL and the speed of response is the result of a tremendous amount of work on both the hardware and the software of the system. In keeping with Tiger's philosophy of focusing on the needs of the customer, existing LaserTrace users are able to upgrade the hardware and the software of their systems to achieve the performance of the LaserTrace 3.

LaserTrace 3x

While the LaserTrace 3 (coupled with the associated moisture and/or oxygen, etc. measurement cells) is focused on measuring the contamination levels of the bulk gases as they enter the fab, the LaserTrace 3 platform is also utilized to monitor the moisture levels in the exhaust gases of low temperature epitaxial process tools from manufacturers such as Applied Materials, Inc., and ASM International N.V.

> I'm a great believer in particularly being alert to changes that change something, anything, by an order of magnitude
>
> Andrew Grove, former CEO, Intel Corporation

In order to perform the required moisture measurements at pressure levels down to 50 torr (or below), Tiger uses a reduced-pressure or Epi sensor. Initially, the industry needed only two Epi sensors to be coupled to a single LaserTrace 3 electronics module so that the exhausts from a two-chamber epi system could be monitored independently. Subsequent requests to also monitor the moisture levels within the transfer chamber required a redesign of the electronics module.

According, Tiger Optics developed its LaserTrace 3x, to permit monitoring the transfer chamber at reduced pressures while also monitoring each of the tool's epi exhausts. Tool owners can monitor for moisture in these critical areas after preventive maintenance is performed on the tool. The result is that the tool can now be brought back on-line when the moisture levels are low enough to insure that the product will not be impacted due to moisture contamination. The savings from the reduced downtime of the tool, along with a reduction in the number of wafers that might need to be scrapped due to moisture contamination, is sure to bring about a high return on investment (ROI).

Working in Tandem

The semiconductor industry, having set the goal to produce 14nm nodes and 450mm wafers by 2015, can only intensify its strenuous efforts to control the quality of the inputs and the manufacturing process itself. With the LaserTrace 3 insuring the quality of the input gases and the LaserTrace 3x insuring the quality of the process, the hard-working fabs may continue to score—by orders of magnitude—improvements upon previous generations of product.

Fig 3

References

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