Meeting the needs of EUV lithography

EUVL is a significant departure from the lithography used today, but reducing mask defects is key to its viability. **Fred Conroy,** Tiger Optics, describes a new AMC detector that could help in this aim

On-line analysis of airborne molecular contamination (AMC) in semiconductor manufacturing cleanrooms has taken on added significance of late. As the industry prepares to migrate to extreme ultraviolet (EUV) lithography to shrink the size of chip designs, the requirements to reduce airborne contamination and to monitor the contamination levels in real-time grow ever more stringent.

To that end, semiconductor manufacturers have shifted to new, more sensitive AMC detectors, reliant upon techniques such as Continuous Wave Cavity Ring-Down Spectroscopy (CW CRDS) and Ion Mobility Spectroscopy (IMS).

Notably, with previous generations of lithography tools, contamination issues have been well documented, based upon varying methods in place to monitor the contamination events. Airborne acid contamination results in corrosion issues and airborne contamination due to bases leads to "T-top" formations (a large, T-shaped insoluble head on a photoresist feature) as well as a haze that forms on the back of the reticle, known as reticle hazing.

Acids in the ambient air, specifically low concentrations of hydrogen fluoride (HF), can attack the HEPA filters and accelerate the release of boron, which can result in crystal salt formations, creating a reservoir for permanent low-level contamination. Another acid-induced wafer defect occurs when hydrochloric acid (HCl) makes the photoresist soluble, engendering hole-type defects on the photoresist.

But additional contamination challenges will arise with the transition to EUV lithography, which is regarded as "the most credible way for the industry to continue to print smaller features onto ever-more complex chips", according to ASML Holding, a leading supplier of lithography systems.

"EUV lithography is carried out in a vacuum using a plasma to produce EUV light using highly sophisticated mirrors instead of lenses to project the circuit patterns onto silicon wafers," the company explains. "Today's silicon chips have features as small as 40 nanometres (nm) – less than a few hundred atoms across. EUV lithography tools will be used to print features 22nm and smaller.

"Using EUV to print transistors this small is equivalent to printing an image the size of a human eye on the surface of the earth from a space shuttle... and then printing another image on top of the first one with perfect alignment..."

With EUV lithography, outgassing from various components within the chamber and from the resist itself, in addition to the contaminants found within the chamber environment, will result in hydrocarbons being absorbed onto the surface of the ►

Researchers at IMEC are operating an ASML EUV Lithography Tool
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◀ optics. When these are met with the high-energy photons from the EUV source, the result is the formation of a carbon deposit that greatly impairs the lifetime of the tool's costly mirrors.

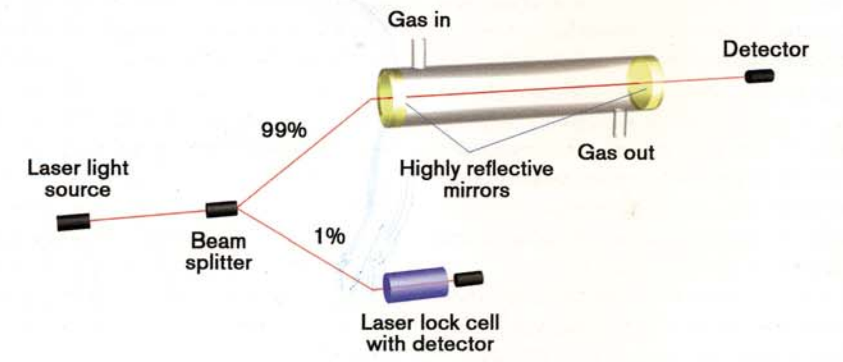
Until the advent of EUV, molecular analysis usually relied on traditional, off-line monitoring methods, using impingers or solvent traps. Samples were collected over a perod of two to 24 hours and the average concentration over that time period was reported. While these methods satisfied the provisions to maintain the tool warranty, the averaging of data over such a long time frame cannot identify spikes or the specific timing of a contamination event.

Alternately, a relatively recent method for measuring AMCs is Ion Mobility Spectrometry (IMS). Unfortunately, this technique calls for a radioactive source to ionise the molecules and then make the measurement via time-of-flight (TOF) spectroscopy. While this method allows for real-time analysis, it is affected by well-documented cross sensitivity to other species – such as ozone and isopropyl alcohol (IPA) – that are prevalent in cleanrooms. In addition, there are calibration protocols that add to maintenance cost, downtime and operational complexity.

By contrast, the Tiger-i platform of analysers from Tiger Optics eliminates the concerns arising from these other analytical techniques. By utilising Tiger's patented CW-CRDS technique, the company's instruments provide calibration-free, real-time analysis without the concerns of a radioactive source. The CW-CRDS technology is designed to measure a specific analyte, so there is no cross contamination or interference from other chemicals present in the ambient air. As the Tiger analysers produce an absolute measurement, they are used as transfer standards and even "travelling" standards by multiple national metrology institutes, including those of the UK, the US, Germany and Japan.

One of the most vexing AMCs plaguing cleanrooms is ammonia (NH_3). As ammonia is a base, it neutralises the acidic property of the photoresist, resulting in "T-topping" and wafer image defects. Ammonia contamination can result in wafer hazing, as well as corrosion of the metal surfaces of the wafer. The Tiger-i NH_3 analyser is capable of monitoring for ammonia down to 5 parts per billion (ppb). The small, portable system can be located anywhere within a cleanroom to provide continuous measurements of the most critical processes. The data-logging feature of the Tiger-i system offers additional time-based details to help determine the root cause of a spike in the NH_3 readings.

Cavity Ring-Down Spectroscopy (CDRS) – Principle of operation



Furthermore, hydrogen fluoride levels must be monitored to prevent the release of boron via degradation of the borosilicate glass that is used in cleanroom HEPA filters. The Tiger-i HF system can monitor HF in real-time down to 100 parts per thousand (ppt). The accuracy of the analysis is the greater of 4% of the reading or +/-0.1ppb. The recovery time for a wet-up or dry-down to a 1ppm intrusion is less than two minutes to 90% of the final value. Thus, by monitoring the HF levels, users can accurately predict the lifetime of the HEPA filters and schedule their replacement before boron contamination becomes a major issue.

Also, critical, real-time monitoring is required in cleanrooms where HCl levels might breach the critical 2.9ppb by volume (ppbv) threshold. The Tiger-i HCl analyser is able to monitor levels down to 500ppt, and takes a measurement roughly every second. Plus, users can set two different alarm levels to alert the cleanroom personnel that the concentration levels are nearing or have reached the 2.9ppb level.

Not only that, but to prevent the build-up of carbon deposits on the precision EUV optics, the methane levels in the ambient air will need to be monitored. In this instance, the Tiger-i CH_4 is able to monitor methane levels to points lower than 4ppb. While the concentration data is displayed on the touch-screen interface of the Tiger-i, the data can also be sent to a central monitoring system via RS232 or Ethernet (user selectable), ensuring that the real-time data provided by the analysers is actionable.

Patented technology

Worth noting is the Tiger-i analysers' utilisation of powerful, world renowned CW-CRDS technology. For AMC

Tiger-i 3000 NH_3 – trace ammonia monitor for ambient molecular contaminants applications, a small vacuum pump pulls the ambient cleanroom air through a measurement cell within the analyser at a continuous rate of ~1 standard litres per minute (slpm). A near-infrared laser beam enters the measurement cell, which has parallel, highly reflective mirrors at either end. These mirrors reflect more than 99.999% of the light. A small portion of the light passes through the mirror at the far end of the measurement cell and is captured by a detector.

Once its pre-determined threshold value is reached, the laser is shut off for a fraction of a second, and the light in the measurement cell continues to pass between the mirrors for a total path length of approximately 30 kilometres before extinction. This allows for great sensitivity within a compact cell, two of which nest comfortably in a standard rack.

The time to extinction of the laser light follows a decreasing exponential function. This is called a "ring down" and is completed in microseconds. The laser is locked to a specific wavelength that is predetermined, based on the spectroscopic profile of the target analyte. The greater the concentration, the faster a ring-down will occur as the analyte absorbs the laser's energy.

As CW-CRDS provides an "absolute" measurement via the Beer-Lambert Law, no zero gas is required. The zero portion of the measurement is determined by intentionally tuning the laser to a wavelength at which the analyte does not absorb light. The ring-down time at this point (called Tau Zero) is purely a function of the mirror reflectivity of the measurement cell and forms the basis for the instrument's zero measurement. The difference between the ring-down time at the measurement wavelength and at the zero-absorption wavelength provides an accurate immediate measurement of the analyte concentration in the analyser at that moment.

Countering long-term drift

The two variables in the application of the Beer-Lambert Law are the mirror reflectivity and the wavelength at which the laser operates. The true zero measurement is ensured by regularly capturing the ring-down time "off-peak" and verification that the laser is "on-peak" is performed by use of a reference cell.

A small fraction of the laser light is diverted through a permanently sealed reference cell that contains a tiny amount of the target analyte to a light detector. When the laser is exactly on peak, the amount of light reaching the detector is minimal. If the light signal at the detector begins to increase (indicating a drift from the correct wavelength), the laser is adjusted by changing the supplied current until the signal is again at a minimum. This "laser locking" ensures that the proper Tau Measure wavelength is applied and obviates potential long-term drift.

With the transition to EUV lithography, there will be a requirement for a better understanding and control of AMCs in the cleanroom environment. Older, traditional measurement technologies that either provide an off-line average of AMC concentrations or require frequent calibrations will not meet the needs of tool owners. With Tiger-i analysers, such obstacles are eliminated by the use of an absolute technology that provides low-level analysis of the conditions inside the fab in real time. **CT**

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