

Metrology

From Reactive to Real-Time and Predictive: A New Era of In-Situ Semiconductor Metrology

Acquiring in-situ, real-time data at the molecular level offers true process observability, delivering rich, actionable, and impactful data with high potential for business impact.

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WHILE IN-LINE SEMICONDUCTOR metrology is very good at imaging and identifying problems in processes, it's actually very bad at helping to address those problems before they have significant financial impact.

Beyond identification, what semiconductor processes need more of is *in-situ*, real-time quantitative analysis, to mitigate issues before they turn up as defects or excursions in electrical

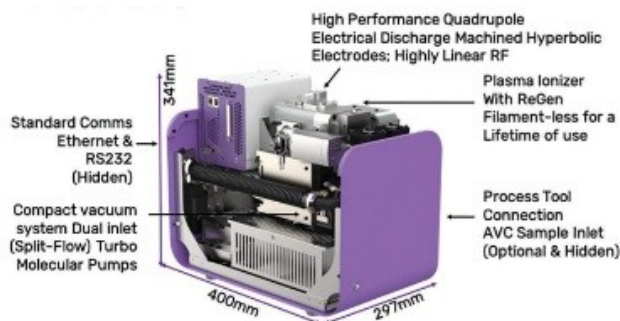


Figure 1. The Aston features a plasma ionization source that does not get attacked by corrosive gases, and a self-cleaning ReGen mode.

performance or line yield.

In other words, semiconductor process control needs to move from *in-line* monitoring to *in-situ* process measurement and control. Metrology needs to move from 'we've found a processing problem, what do we do about it?' to 'we *know* our process is running *right now* within optimal limits and at the highest throughput efficiency'.

But how can this change be achieved in practice?

Challenges for in-situ metrology

In-situ measurement and control are challenging. Effective process control requires real-time measurement with high sensitivity and repeatability, yet many process and chamber cleaning gases are

corrosive, and CVD deposition blankets everything in condensate particles.

Complexity in metrology and control not only comes from the harsh measurement environment, but also from the processes themselves. Ever-smaller open area etch requires increasingly high sensitivity to byproducts to detect end points. Also, binary gas ALD and ALE processes require efficient absorption and purge monitoring in the process chambers to maximize throughput and consistency.

Furthermore, many processes are using remote, weak, or no plasma, thus rendering traditional optical emission spectroscopy (OES) solutions ineffective. These challenges are growing increasingly difficult, and the costs of process excursions are growing exponentially.

Limitations of real-time metrology today

Some metrology solutions that provide *in-situ* real-time data do exist today, but they each have inherent limitations.

OES is the most widely used solution, but does not work in an increasing number of process applications. In OES metrology, chemically-specific and multivariate analysis are challenging, as spectral data from multiple molecules and sub species often overlap, and quantification of species is very difficult. Additionally, as plasma solutions become remote, pulsed, or absent, and concentrations of critical end-point by-product molecules diminish (especially in small open area etch), there is insufficient OES signal-to-noise to determine accurate end-point transitions. The lack of specificity and sensitivity is increasingly marginalizing OES as an effective *in-situ* metrology solution.

Residual gas analysis (RGA) mass spectrometry has been used selectively in fabs to detect and diagnose problems. However, RGA solutions are notoriously susceptible to harsh semiconductor processing conditions, and many lack either atomic mass unit range (amu) or the

sensitivity needed for advanced process monitoring at parts per million (ppm) or lower levels. In RGA systems, the electron ionization (EI) filament is used to create positively charged ions for the mass spec sensor (m/z) spectrum. The EI filament is easily corroded and will fail, or be covered in condensates, after mere hours of operation.

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A new approach to real-time, in-situ metrology

For mass spectrometry to become a powerful workhorse, a rethink was needed to address the current limitations. With this goal in mind, our team at Atonarp has developed a new approach to provide a robust in-situ metrology solution. We are already seeing evidence that this new approach delivered by the Aston system (FIGURE 1) provides superior analytical and operational performance.

Great emphasis is placed on low maintenance, long-term signal stability, and repeatability to enable the stringent requirements for 'copy exact' process control and matching of tools across production corridors, both within a fab and across the enterprise.

The new approach uses two innovations to address harsh process chemicals, process byproduct gases such as NF_3 , HF , HCl , and CF_4 , and deposition particles from processes using TEOS and SiH_4 .

Firstly, for ionization a plasma ionization source was developed that does not get attacked by corrosive gases, like a classic electron ionizer does. This means that the plasma ionizer can work several hundred RF hours before maintenance. This robust ionization solution

is key to ensuring long term stability and repeatability in Aston chemically-specific measurement data, to ensure consistent run-to-run measurements.

Secondly, to withstand particulate build-up found in deposition processes, Aston has a self-cleaning ReGen mode. This enables the instrument to clean itself, either using process gases or by

using energetic plasma ions to remove deposits on the sensor and plasma ionization chamber walls that can build up during CVD. ReGen mode can be synchronized with regular chamber clean cycles and tool preventive maintenance events.

One platform, many applications

There are many applications for this new approach to *in-situ* metrology within semiconductor processing, but here is a partial list:

- 1. EUV light source management and cleaning.** Aston is used to detect and monitor the end-point of SnH_4 (Stannane gas) during mirror cleaning. A hydrogen plasma is used to remove a thin film of tin from the mirror surface inside of the light source. The tin film is a by-product of the plasma used to generate the EUV light source (13.5nm) when molten tin is vaporized into a plasma with a laser. Aston is used for end point detection for that removal process, to prevent over-etch of the internal mirrors. Failure to remove the tin coating results in longer exposure times and inconsistent photolithography results.
- 2. Processes using WF_6 (tungsten hexafluoride).** WF_6 gas in the presence of hydrogen creates tungsten

