ATONARP

Atonarp Aston™

Molecular Sensor

Real Time Molecular Process Control for Semiconductor Applications

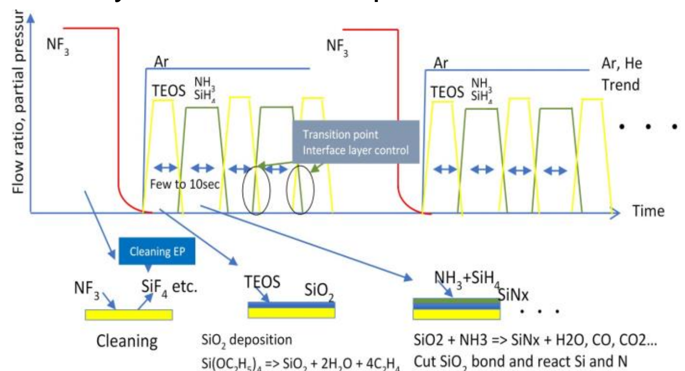
Robustness
Reliability
Repeatability
Accuracy
Sensitivity

Cloud Ready

Mass Spectrometry for Metrology

Atonarp Aston™ robust compact mass spectrometer is designed from the bottom up to be the workhorse metrology tool for gas monitoring and control in semiconductor manufacturing. High quantitative accuracy and real-time performance are combined with production ready robustness and dependability; increasing process chamber throughput and maximizing yields of precision multi-layer material deposition and etch processes in production environments. Additionally, the rich dataset from the complex process chamber chemistry provided during analysis enables advanced artificial intelligence or machine learning with a level of detail not possible with traditional metrology instruments. The small footprint, integrated process logic controller (PLC) and industry standard communication interfaces allow for on-chamber installation and full integration into the process equipment control system. Aston™ is a versatile, total chamber solution, for real time *in-situ* monitoring of precursors, reactants and byproducts during various process steps allowing for baseline fingerprinting, chamber clean and process monitoring end point detection in the presence of corrosive gases, excessive particle deposition and gaseous contaminant condensation. Aston™ represents a major evolution in metrology for semiconductor gas analysis by addressing the challenges of sensor durability, matching and ease of use.

Today's *in-situ* process control requires increasingly precise process management. Atomic-level tolerances of a few angstroms (10^{-10} meters) are increasingly common. A silicon atom size is ~2Å, critical tunneling barriers and oxide layers in advance semiconductor logic and memories made from Silicon Oxide (SiO_2) or Silicon Nitride (Si_3N_4) may be less than 100 molecules thick. Controlling the deposition and etch of these layers has faced growing metrology complexity. NAND Flash memories, emerging embedded memories like MRAM and RRAM and even simple logic devices now require 3D structures using atomic processes such as Atomic Level Etch (ALE) using Reactive Ion Etch (RIE) and Atomic Level Deposition (ALD) using Physical Vapor Deposition (PVD). Gate-All-Around (GAA) transistors and stacked memories are continuing to push the boundaries of semiconductor material deposition and etch tolerances. Critical metrology requirements for these processes demand fast, quantitative analysis of multiple molecules



concurrently. Monitoring gas chemistries including reactants and byproducts is critical to process matching, layer-by-layer deposition transition, and etch endpoint detections. Existing endpoint detection, OES (optical emission spectrometer) devices are not adequate as they require line of sight and lack the sensitivity and quantification required to manage process features a few nm across.

Mass spectrometry is the gold standard for quantitative molecular chemical analysis, however conventional mass spectrometers using *filament-based* ionizers to generate charge ions and are not suited for semiconductor applications. The reactivity of the filament based ionizer with corrosive fluorine based etch gases like CF_4, SF_6, CHF_3, C_4F_8, and chlorine-based gases Cl_2, BCl_3, CCl_4, severely limit the filaments lifetime. Additionally deposition of particles and vapor contaminants (PVD) can also affect the sensor performance. Filament ionizers are therefore both impractical on a production tool intended for high volume manufacturing.

Atonarp Aston™ enables a critical paradigm shift in the way process is controlled; moving from crude time-based control to precise measurement-based, real time, reliable, and accurate control even in harsh chemical environments. Having metrology information is critical to controlling low contact density (< 0.5%) open area and high aspect ratio (HAR) features (> 50:1) prevalent in the 3D process structures that are increasingly demanded. The figure below illustrates a typical deposition intensive 3D NAND process cycle where Silicon oxide and Nitride layers are alternated at high speed followed by chamber clean following each wafer. In this case Atonarp Aston™ can precisely detect the endpoint in both the oxide-nitride transition and chamber clean this saves processing time relative to time based or less precise OES metrology.

Typical 3D NAND SONOS Deposition Process

Embedded into the architecture of Aston™ are patented technologies enabling 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 within a fab and enterprise wide for similar processes across different fab locations.

μPlasma Ionizer & Self-Cleaning

To withstand the harsh environment of etch and deposition processes, Aston™ introduces two unique patented features to a semiconductor mass spectrometry solution: μPlasma ionization and self-cleaning (ReGen™ mode).
Aston eliminates the ionizing filament and replaces it with micro plasma

ionization, removing the problems of filament degradation due to filament reactivity with corrosive process gases (e.g. NF_3, CF_4, Cl_2).

The ReGen™ mode enables the instrument to clean itself, using energetic plasma ions, to remove deposits on the sensor and Aston chamber walls that can build up during CVD. Aston sensitivity is therefore maintained over a thousand RF hours of operation. ReGen™ mode can be synchronized with regular tool preventive maintenance events. Astons' µPlasma ionization, combined with ReGen™ for the removal of particles such as tetraethyl orthosilicate (TEOS) and vapor contaminant deposits, gives Aston a lifetime of operation comparable with other production semiconductor tools.

AVC™ Sampler (optional)

Process gases are efficiently sampled by the Aston™ via a fast response pressure controller module: Automatic Vacuum Controller (AVC™). The intelligent sampler ensures a constant small inlet flow even if the process chamber experiences pressure excursions.
The pressure in both the µPlasma and HyperQuad sensor chambers is maintained at a constant level using a commercial dual inlet turbomolecular pump.

HyperQuad Sensor

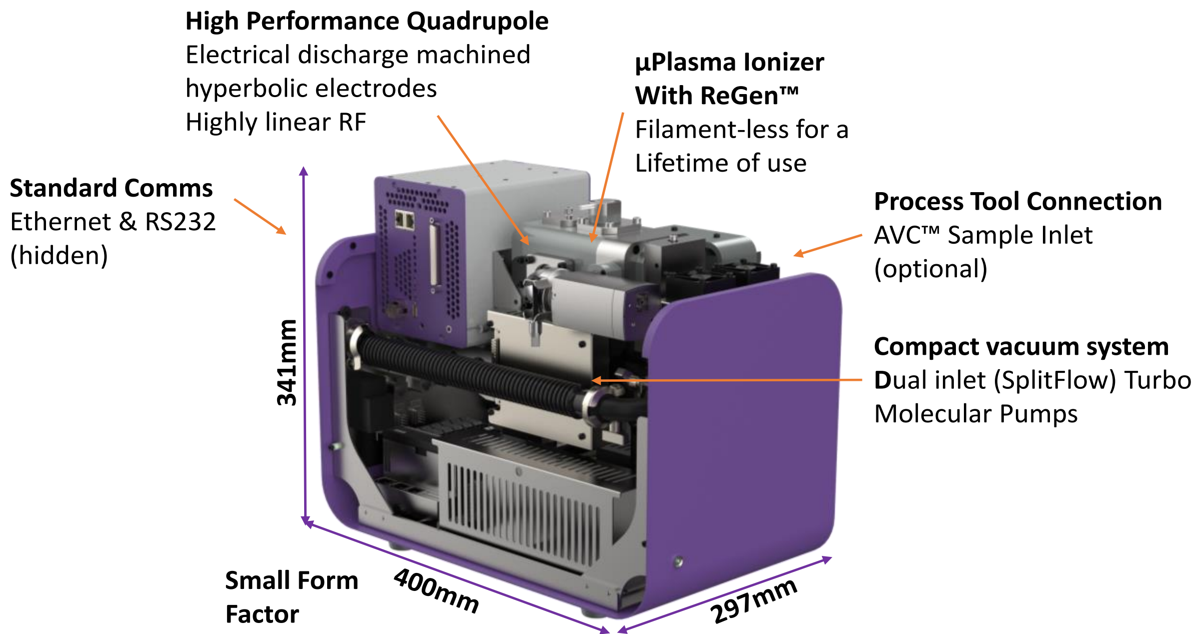
Molecules ionized in the µPlasma ionizer are efficiently transported to the sensor for analysis using a network of electrostatic lenses. The HyperQuad sensor is also outfitted with conventional electron impact (EI) ionizer intended for operation at baseline pressures and calibration.

The analytical stage of the HyperQuad sensor is a quadrupole using µm-level accurate hyperbolic electrodes. Driven by a highly linear RF (Radio Frequency) circuitry and utilizing a dual Faraday/SEM detector, Aston's HyperQuad sensor produces high analytical performance over a mass range of up to 350 amu (see specifications table below).

Software, Tool Integration & Communications

AtonLab™ is the primary graphical user interface (GUI) for control, data acquisition, analysis, and quantification. It is web browser-based and each Aston™ unit has a unique IP address. Atonarp also has a published web service application programming interface API to allow the user to directly control and acquire data from Aston™. High speed communications with the device are established using Ethernet and/or RS232 ports built into the controller module. Protocol interface options include Ethercat, Modbus, and CLI (Command Line Interface). Aston™ is interfaced to the process tool via a PLC (programmable logic controller) peripheral module featuring a network of digital and analog inputs and outputs (ADIOs). Process parameter

collection is accomplished over Ethercat to enable correlating chemistry data with the production run data (e.g. wafer ID), as well as providing advanced alarm capabilities that protect the process from “out of specification” process events.



Specifications

Parameter	Condition	Min	Typical	Max	Units
Mass Range		2		350	u
Mass resolution	Full Width at 10% Valley for N_2	0.6	0.8	1.0	u
Mass number stability		0.1	0.1	0.3	u
Sensitivity (FC/SEM)	Nitrogen-equivalent		$5x10^{-6}/5x10^{-4}$		A/Torr
Minimum detectable partial pressure (FC/SEM)	Nitrogen-equivalent		$10^{-9}/10^{-11}$		Torr
Limit of Detection	Nitrogen-equivalent		10		ppb
Maximum operating pressure			10^{-3}		Torr
Dwell time per u		1	40	200	ms
Scan update rate per u			37		ms
Sampling pressure range		$1x10^{-5}$		$1x10^{3}$	Torr
Operating temperature	80% relative humidity non-condensing	5		35	^{o}C
Emission current		0.1	0.4	1	mA
Emission current accuracy		0.03	0.05	0.1	%
Start-up time			5		mins
Ion Current Stability	Over 24 hrs at constant ambient & pressure		< +/-1		%
Concentration Accuracy			< 1		%
Concentration Stability		±0.5	±0.5	±1	%
Power consumption	24VDC		350		W
Weight			13.7		Kg
Size	Length x Width x Height		400 x 297 x 341		mm

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