AccuStrata

AtOMS:

FREQUENTLY ASKED QUESTIONS

Short Glossary:

AtOMS: *AccuStrata's Atomic Optical Monitoring System for in situ thin film deposition and etching control.*

Atomic Spectroscopy: *This analytical technique utilizes the effects of atomic absorption and emission for identifying chemical elements and their concentration. Atomic Spectroscopy requires the analyzed material to be in an atomized state. Physical vapor deposition (PVD) processes are ideal for Atomic Spectroscopy, including all variety of reactive, ion-, laser- or arc-based PVD processes. They can be classified as plasma processes as most particles are in excited states.*

Atomic absorption (AA): The process when an electron in the atom absorbs a specific photon and transitions to a higher energy level. The absorbed photon has the exact energy of the difference between the two energy levels.

Measuring AA: To measure AA one needs a light source emitting the wavelength required for the energy transition. By measuring the energy of the light source (or number of photons) that enters and exits from the material one can measure the atomic concentration of the absorbing element, as per the Beer-Lambert Law.

AA spectral range: While generally AA can be in any spectral range, most metals, metalloids and semiconductors have AA in the deep UV spectrum, where quartz optics is used. The width of the absorption spectral lines is very small and special technique is required. Example: Cobalt absorbs at 240.73 nm and 346.58 nm.

Atomic Emission (AE): It is a process exactly reverse to AA. When electrons transition from a higher energy level to a lower energy level they emit photons with energy equal to the energy difference. Cobalt emits at the same 240.73nm and 346.58 nm. Therefore, a single element has AE in a very narrow spectral band ~ ±5 pm.

Optical Emission (OE): Also called Plasma Emission, it is the compound emission in the broad UV-vis-NIR spectrum. It consists of the AE of the individual elements in the plasma, but also molecular emission of gas molecules and radicals. OE is natural in the PVD process as all particles absorb plasma energy and emit photons in a spontaneous fashion.

Measuring AE/OE: The emitted light in a broadband spectral range is collected and analyzed. By analyzing OE we extract the AE of the individual elements, the inert gases such as Ar and Ne, and the molecular emission of gases such as O_2^*, N_2O^*, CF_x^*, etc. Since OE contains many narrow and overlapping peaks, having a light source emitting the exact elemental line is important to measure not only AA but also AE of the element of interest.

Deposition Rate: The amount of material condensing on the substrate per unit time (Angstrom/sec). It can be described as the atomic flux (number of atoms falling on the substrate per unit time per unit area), multiplied by the area of the substrate and the atomic radius of the element (for a single element film) or molecular radius (for a compound film).

Deposition Uniformity: The uniformity of the plasma plum in the area below the substrate holder. Different substrate motion and rotation configurations can be devised to minimize the effect of the non-uniformity in the deposition plum and achieve better coating uniformity.

Hollow Cathode Light (HCL) source: The light sources used to perform AA. They are special glass lamps where the cathode of certain material is sputtered in vacuum and emits the specific wavelength line of the cathode element.

11900 Parklawn Drive, Suite 203, Rockville, MD 20852 Tel: (240) 399 4192 www.accustrata.com

For which deposition techniques is AtOMS best suited?

AtOMS works best for all types of PVD processes, where the material is atomized by the process. Reactive E-Beam, magnetron & ion sputtering, ion implantation, laser pulse deposition and ablation and plasma etching are ideal for AtOMS.

What process parameters does AtOMS monitor?

AtOMS monitors momentary deposition rate, attained physical thickness, film quality and chemical composition or bandgap of the films.

What materials does AtOMS monitor?

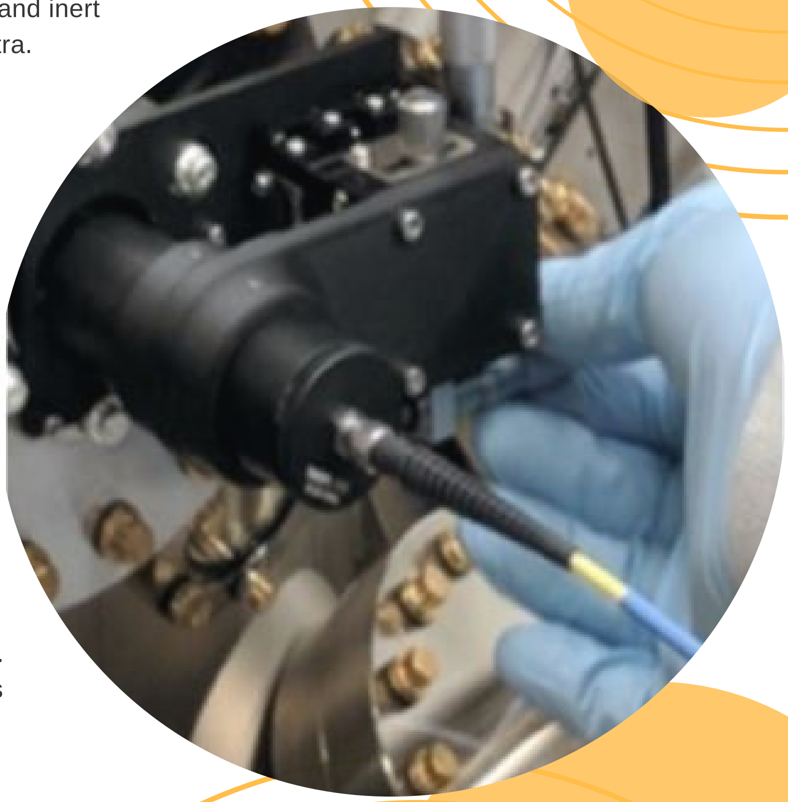
AtOMS is agnostic to the type of material, deposited on the substrate. AtOMS monitors metals, alloys, opaque materials, semiconductors and dielectrics.

How does AtOMS monitor my process?

AtOMS measures the AA, AE and OE and in the range 190 – 800 nm. 4 quantities in each single duty cycle are measured multiple times per second: 1) 100% reference of the HCL source, 2) 0% (dark) reference, 3) AA of the element, 4) OE of all other elements and gases in the plasma including AE of the monitored element. The sum of AA and AE of the element provides for determination of atomic concentration and atomic flux towards the substrate (deposition rate) without additional calibration.

Which elements can be monitored by AtOMS?

About 70 chemical elements absorb in the convenient DUV-UV-VIS region, where quartz optics is transparent and suitable HCL sources are available. In case when no HCL is installed for certain element, AtOMS detects the element in the same way as a legacy OE Spectroscopy system. For instance, the reactive and inert gases in the plasma are characterized by analyzing the OE spectra.



Why combination of AA and AE together is better than AE or OE alone?

- AA is 10-20 times stronger effect than AE for majority of metals.
- For each element, AA is more stable and repeatable compared to AE.
- AA allows continuous 100% and dark references for quantitative measurement.
- By measuring both AA and AE, AtOMS directly calculates the elemental concentration and the atomic flux (deposition rate) without calibration factors.
- Combination of AA, AE and OE takes advantage of the broadband spectrometers, which detect all AA, AE and the broad OE from 190 nm to NIR.
- AE and OE can provide 0% (dark) reference only. This is sufficient for end-point etching processes but not for deposition. 100% reference cannot be taken. Thus, quantifying AE requires continuous calibration with another device such as quartz crystal monitor (QCM).
- Being a weak effect, AE is detected by use of photomultipliers with bandpass filters, which prevents seeing other element and radicals in the plum.
- OE/AE strongly fluctuates with process, temperature, target wear, material preparation and chamber cleanness. Example: pre-cleaned target may have 2x the AE of not well cleaned.

Will AtOMS work for any substrate type, shape, holder, or rotation?

Yes. AtOMS is agnostic to the substrate type, shape, rotation, or the type of the film deposited or etched on the substrate. AtOMS measurement beams do not intersect with the substrate as the they pass just few mm below the substrate and parallel to the substrate plane.

What is the typical accuracy of AtOMS for deposition rate?

AtOMS accuracy is very much element dependent as elements have different AA and AE capacities. All metals such as Al, Cu, Co, Ni, Cr provide very high accuracy down to 0.005A/sec. Semiconductors Si, B and Se have much stronger AE in comparison to metals. Because AE fluctuates much more with the process, the total accuracy is 0.01-0.05A/sec.

What is the typical accuracy of AtOMS for chemical composition of compounds and superalloys?

To measure the composition AtOMS measures the deposition rates of all elements of the compound simultaneously and separately. Depending on the coater geometry, AtOMS achieves chemical composition accuracy for materials such as ITO, InGaAs, CIGS, YBCO, Inconel, MoSi2 better than 0.01 atomic %.

Is my deposition system retrofittable?

As a fiber-based solutions, AtOMS is flexible, allowing installation outside or inside of chambers. Installation outside chambers uses the already available chamber flanges, which we exchange with our optical viewports with already pre-installed sensors. This is done during routine maintenance and takes several hours. Installation inside chambers uses metal coated fibers run through a pre-designed flange, which we install on the equipment replacing one of the existing flanges. This is extremely flexible and reconfigurable solution but requires some customization and installation plan.

What installation is better – outside or inside the chamber?

They both have advantages and shortcomings. Installation outside is low cost, simple and does not require equipment down time. It is very suitable for high temperature deposition processes as well as suits for instant demo. Installation inside chambers is more complex, but achieves higher accuracy, as sensors are custom installed where it matters most. It also provides for installation of multiple probe beams to monitor the plasma plum in different directions and detect deposition non-uniformity.

How many elements can AtOMS monitor simultaneously?

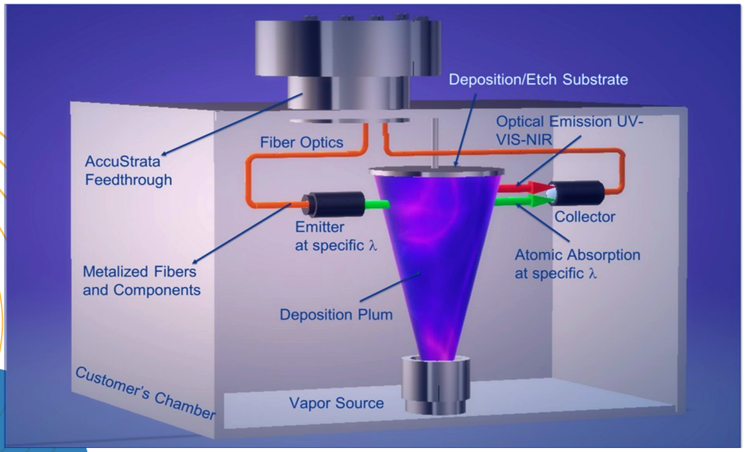
Providing the suitable HCL are installed, AtOMS measures AA and AE of up to 4 elements simultaneously with high accuracy. More than 4 (up to 6) elements require special customization.

Can AtOMS monitor deposition uniformity?

Yes. Monitoring deposition uniformity typically requires installation of 3 pairs of sensors inside the chamber configured to launch 3 probe beams. The 3 beams can be arranged to monitor 3 separate areas in the same chamber, 3 different compartments in the same chamber, or different chambers. When arranged to monitor under the same substrate holder, they provide information about the uniformity of the vapor plum by taking the differential signal between the individual beams.

Can AtOMS detect failures and drifts of the individual vapor sources?

Yes. AtOMS is extremely sensitive to minimal fluctuations, glitches or drifts of the individual evaporators or magnetrons, or the process conditions. Any change such as a shutter movement, pressure change, gas inlet, target wear, change in the material in the crucible or any motion inside the chamber is detected, displayed and warning messages is issued.



Can AtOMS be used in control mode?

AtOMS is offered as a stand-alone monitoring system, but protocols and interface are suitable for integration into a variety of control systems. As vacuum equipment is very diverse, our team works with the customer team to integrate AtOMS into the controls of the equipment.

How AtOMS optical components are protected against coating?

Our optical components are uniquely designed to prevent coating on critical optical parts during deposition. AtOMS uses several protection methods simultaneously and can operate for weeks w/o maintenance. As HCL sources operate in Neon inert gas, AtOMS measures the Ne spectral line directly from the HCL and compares it with the line measured through the chamber. Any attenuation of the Ne line is attributed to contamination of the optics. Periodically, a quartz protection chip at the aperture of the sensor has to be replaced with a new one as well. We also use a variety of other methods to protect optics.

How much does AtOMS cost?

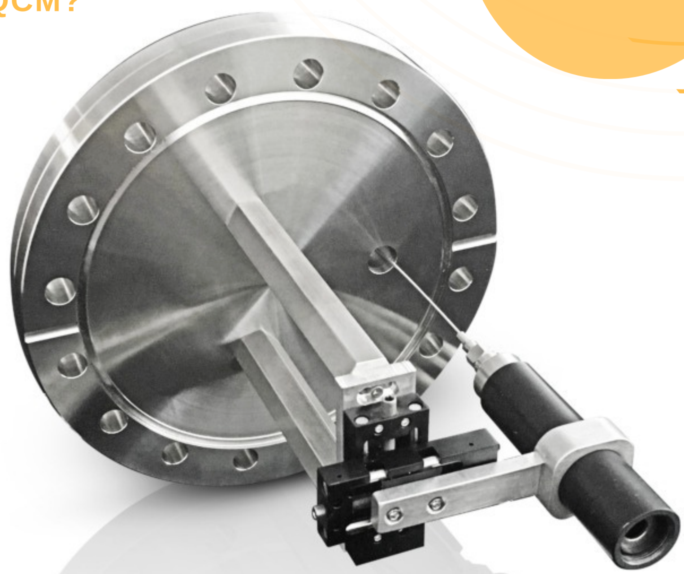
Depending on configuration, the list price for AtOMS is between $100,000 and $160,000. Currently, 4 configurations are offered: 1) 11- One element, one probe beam, 2) M1- Multiple elements, one probe beam, 3) 1M-One element, multiple probe beams, and 4) MM- Multiple elements, multiple probe beams.

How is AtOMS IP protected?

AtOMS' system and method are covered by several USA and EU patents, which belong to AccuStrata with USA Department of Energy having some special rights over some of them.

How AtOMS compares to quartz crystal monitoring QCM?

- AtOMS measures the deposition rate of the element based on atomic concentration directly under the substrate. QCM detects the mass of the deposited material and calculates thickness using tooling factors.
- AtOMS measures film quality based on the energetics of the atoms and presence of other elements and radicals. QCM does not provide information about the film quality.
- AtOMS displays the deposition rate of each element separately. QCM shows compound dep. rate and does not distinguish between different elements.
- AtOMS accuracy is 0.005A/s for dep. rate and 0.01 atom% for composition. QCM achieves 0.05A/s accuracy and does not measure composition.
- AtOMS is agnostic to film thickness. It measures with high accuracy very thick coatings (>100s of microns) and extremely thin films and interface layers (<2 nm). QCM is limited to ~2m film thickness only.
- AtOMS is seamless and does not affect the deposition. QCM is positioned over the vapor source and shadows the deposition plum.
- AtOMS can be more expensive than typical QCM.



11900 Parklawn Drive, Suite 203, Rockville, MD 20852
Tel: (240) 399 4192
www.accustrata.com

How AtOMS compares to direct optical spectroscopy of the substrate OMS?

- AtOMS monitors the area few mm below the substrate using FO collimators. OMS monitors the substrate directly in R or T mode.
- OMS is not applicable to opaque materials. AtOMS is agnostic to type of material to be monitored.
- OMS monitors the optical thickness by the R or T interference oscillations. This is not applicable to small film thickness <15-20 nm. AtOMS monitors extremely thin films and engineered interfaces.
- AtOMS monitors chemical composition directly. OMS does not monitor it or calculates it based on the measured optical thickness envelopes.
- AtOMS is agnostic to the type, shape and rotation of the substrate. OMS strongly depends on the substrate and its motion.
- OMS requires substantial chamber retrofitting and changes of chamber geometry. AtOMS can be installed on any chamber configuration.
- OMS can achieve very high accuracy for multilayer coatings, but not for single or few layers. AtOMS can achieve very high accuracy for each layer separately.
- OMS can be equal, or substantially more expensive than AtOMS.

For more information please visit https://accustrata.com/our-technology/atoms/

AccuStrata

11900 Parklawn Drive, Suite 203, Rockville, MD 20852
Tel: (240) 399 4192
www.accustrata.com