## Introduction

There is a revolution in ALD processing taking place; Spatial ALD is emerging as a critical technology for advanced selective processing of memory and logic process. As process nodes shrink the need for precisely controlled and conformal thin films *increases* as process tolerances get tighter. Spatial ALD has several distinct advantages over other deposition solutions: Highly conformal coatings, high deposition rates (10-100x other ALD processes), low temperature processing and low or no vacuum requirements. Combined these features provide the benefits of a cost effective, high throughput, high yield and high precision material deposition process technology that is being broadly adopted in the manufacture of advanced semiconductors.


## The Problem

Optimizing spatial ALD to realize its full potential is challenging to deliver on the key metrics that the semiconductor industry values in thin films:

First is depositing a highly uniform or conformal coating. Desired is a uniform thin film without voids, pinholes, bird-beaks, uneven thickness or drifting when the film is deposited. Uniform or conformal coverage on all surfaces (including sidewalls and on overhang 'shadow areas') is critical for consistent and uniform mechanical and electrical specifications.

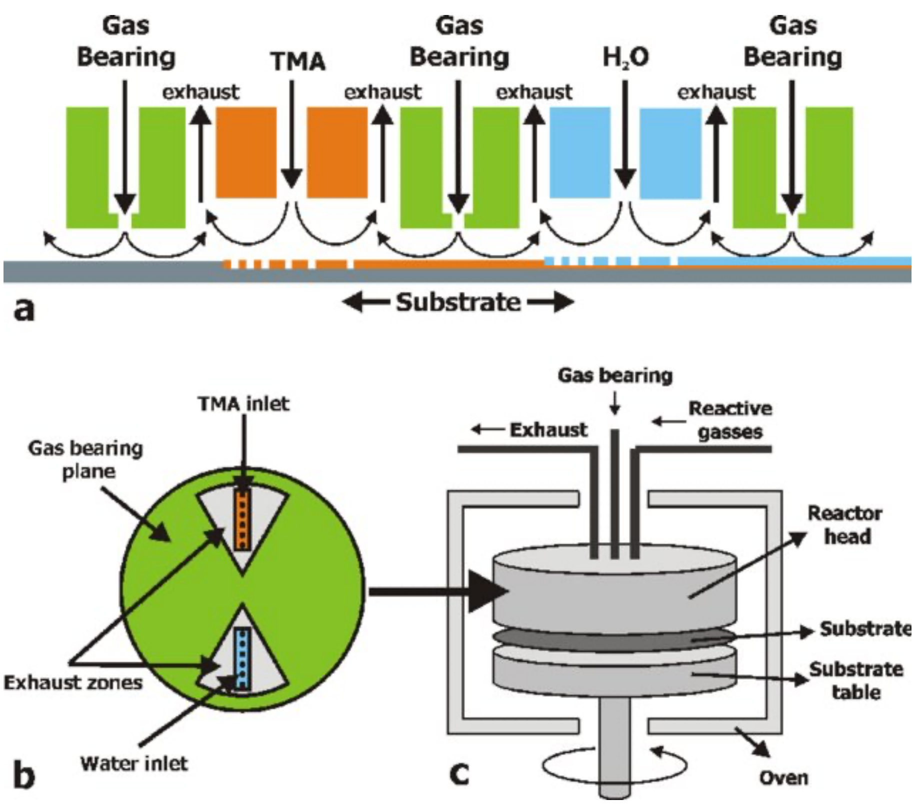
Secondly the rate of conformal coating deposition determines the throughput and efficiency of the ALD process. ALD are surface area self-limiting processes and deposit only one atomic layer (or mono-layer) during each multi-second ALD unit process cycle. ALD processes are notoriously slow and the increased throughput achieved with spatial ALD without compromising conformity is highly desirable.

Finally, limiting thin film contamination will determine its electrical properties and product yield. It is important that the reaction between precursor and reactant gases ONLY happen on the wafer surface. Mixing of these gases in the chamber (not on the wafer surface) effectively creates an *uncontrolled* bulk deposition chemical vapor deposition (CVD) process and not the desired ALD process, which can result in spot defects from particulates, material clumping and uneven material depositions.

In spatial ALD (see figure 1 for Aluminum deposition), the wafers rotate under the gas sources in the processing chamber, instead of other ALD applications where the gases are sequentially injected into a processing chamber where the wafers are static.  In spatial ALD, by rotating the wafers under the pre-cursor and then the reactant gases in turn, high conformal coatings with high throughput (up to x100 other ALD processes) can be achieved. In spatial ALD establishing purge gas regions between pre-cursor and reactant gas using purge gas curtains is difficult. Wafer table rotation speeds and gas flows need to be optimized to prevent unwanted 'vortex' gas mixing (making the process CVD, not ALD) while maximizing throughput. Management of reactant gas delivery and in chamber concentration variations further complicate the process.

To control and optimize the spatial ALD process a new approach to in-situ metrology is required. Spatial ALD has unique metrology requirements:

- Metrology sample speed with sensitivity is key to track rapidly changing gas concentrations and by-product endpoints. PPM level sensitivity with 100Hz sample rate requirements is typical.
- No plasma or remote plasma is used during ALD processing and renders optical emission spectroscopy unusable
- Corrosive gasses (e.g. HCl, HF) are common ALD process byproducts and corrosive $NF_3$ and $SF_6$ are frequently used for chamber cleans
- Relative quantification of gasses is desired for gas concentration management




Source: Fred Roozeboom Professor Emeritus at University of Twente

**FIGURE 1**

a) Schematic drawing of the spatial ALD reactor concept, where the precursor TMA (Trimethylaluminum which is an organo-aluminium compound $Al_2(CH_3)_6$) and reactant gas (water) reaction zones are separated by gas bearings/purge zones.

b) Schematic drawing of the bottom side of the spatial ALD reactor head, where the precursor (TMA) and reactant (water) reaction zones are integrated into inlets surrounded by exhaust zones and gas bearing/purge planes.

c) Schematic drawing of the reactor. The reactor head and rotating substrate table with the substrate in between are placed in a convection oven. The substrate table is rotated by a servo motor, connected by a drive shaft.

## The Solution

Aston Impact and Aston Plasma from Atonarp are being used successfully on several spatial ALD original equipment manufacturers' (OEMs) equipment to manage the Spatial ALD process on production tools. The Aston family of in-situ metrology solutions offer unique features to enable actionable spatial ALD process control:

- Aston's hyperbolic quadrupole sensor that gives 2x-3x the sensitivity at faster sample rates of competing legacy RGAs.

- Aston's optional integrated plasma ionization source allows for high pressure ALD processes with corrosive gases to be identified and quantified. The robust plasma ionization source provides extended periods between routine maintenance and mitigates the need for frequent electron impact ionization filament replacement.
- Highly integrated unit with split flow pumping capability, integrated control electronics including digital and analog I/O and optional dual (plasma and electron impact) ionization sources in an industry leading form factor.

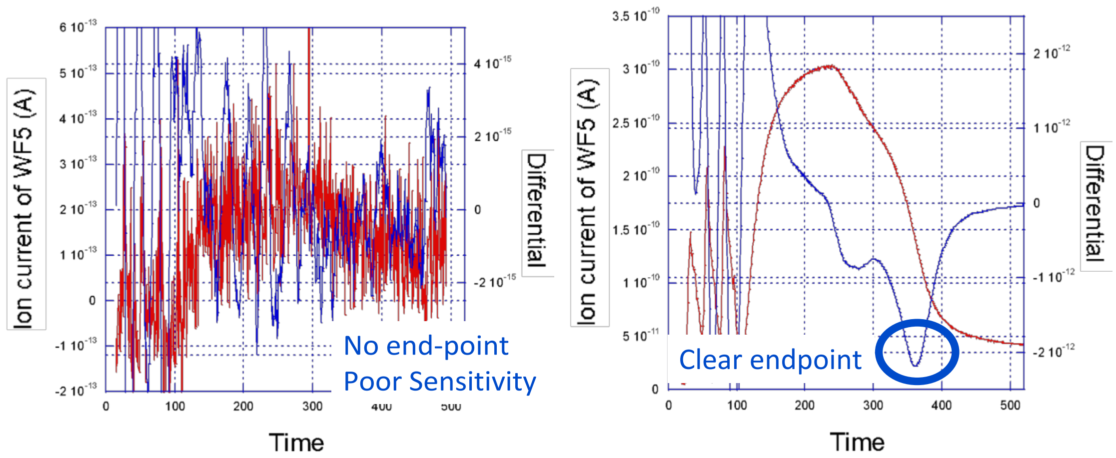
**FIGURE 2.**

Comparison of side-by-side in-situ metrology sensitivity.

Legacy RGA (top) Vs Atonarp Aston (bottom) in End Point Detection (EPD)

Aston is up to 20x more sensitive in higher-speed sampling applications in detecting end point. Even with low signal to noise applications (i.e., looking at low level byproduct gases)

Red = Ion current, Blue = Differential (1st derivative) for EPD




**Other RGAs** **Aston From Atonarp**