Effluent Stream Monitoring Of An Al_2O_3 Atomic Layer Deposition Process Using Optical Emission Spectroscopy

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Abstract. The formation of Al_2O_3 by Atomic Layer Deposition poses new challenges to process control. Traditional process metrics have proven not to be the most reliable indicators of process performance and in some cases not responsive at all to process excursions. As with any batch reaction, by-products and excess reactants are natural consequences. Process quality and performance can be gauged by monitoring these "reaction leftovers" downstream of the processing chamber. This paper will describe the use of Optical Emission Spectroscopy to trend and monitor process specific, effluent stream constituents. Where traditional methodologies fail to detect process excursions, monitoring of effluent stream wavelengths has proven to be a valuable process control tool.

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INTRODUCTION

As DRAM designers enter the nanoscale realm, memory cell dielectrics are requiring finite control deposition methods. To meet this need, diverse approaches such as Atomic Layer Deposition, have been introduced to the semiconductor manufacturing environment[1]. Atomic Layer Deposition is a relative newcomer to the world of large scale DRAM manufacturing[1,2]. Traditional "feedback" process control methodologies, such as post processing thickness and equipment output monitoring, have been limited in their ability to provide adequate, "real-time" indicators, of process quality[3].

The *Lightwind Corporation L3* Optical Emission Spectroscopy sensor provides a robust approach to monitor reaction chamber gas stream effluents. Process specific wavelengths were monitored "real-time" using the *Triant Technologies Inc. ModelWare* software. Setpoint limits were placed around the tool average trend for a given wavelength. Changes in the behavior of the process specific wavelengths indicated a change in reaction chemistry. Excursions beyond the setpoint limits trigger a real-time alarm, which can then be quickly addressed and investigated.

OPTICAL EMMISION SPECTROSCOPY

Optical emission spectroscopy (OES) has long been used to monitor and control plasma etch and some PECVD processes. This technique relies on the plasma glow of the process, i.e. optical emissions from chemically active process species[4]. OES is a preferred sensor because of cost and reliability, and is frequently found in the manufacturing environment. Typical process control applications include end point and fault detection, and in both cases, lower cost and reduced wafer misprocessing are the likely result.

However, thermally driven processes, such as ALD, have no built-in source of optical emissions, so traditional OES cannot be used. In this work a new type of optical emission system was used. It is comprised of a secondary plasma generator downstream of the ALD process chamber. (The downstream location assures that the ALD process itself is unperturbed.) Optical emissions from this inductively coupled plasma (ICP) source are treated in the same manner as traditional OES. Changes in the OES spectra can be used for fault detection and other means of process control. The downstream OES system used in this work was an *L3* from *Lightwind Corporation*, a schematic diagram of which is shown in Figure 1.

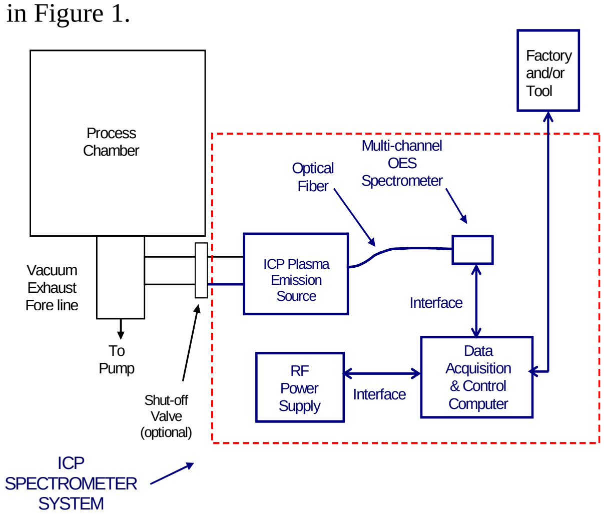

FIGURE 1. Block Diagram of a Downstream OES Process Monitoring System

Process Specific Wavelength Determination

A series of initial experiments were performed with selected process parameters varied. The intent was to mimic known high risk events. The *L3* sensor was able to identify wavelengths specific to the current AL2O3 process of record. These identified wavelengths exhibited a measurable response to the experimental conditions. Figure 2 displays the full spectrum as recorded by the *L3*. Based on experimental conditions, responsive wavelengths were identified for monitoring with the ModelWare software.

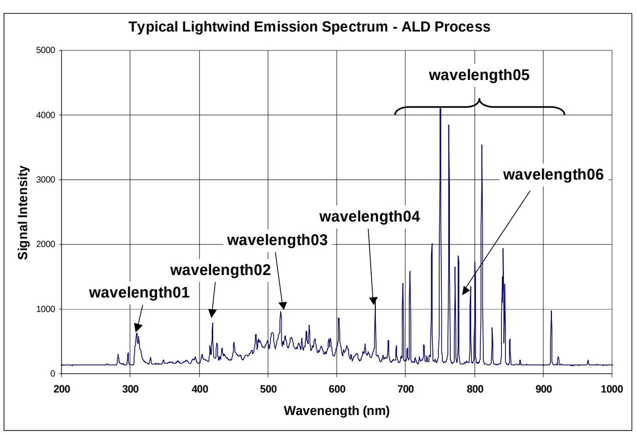

FIGURE 2. Full Spectrum for the Al_2O_3 ALD process

Figure 3 displays a wavelength response to the experimental conditions in a time series format. Note that relative to the standard group, the response was observed in the average wavelength intensity and standard deviation.

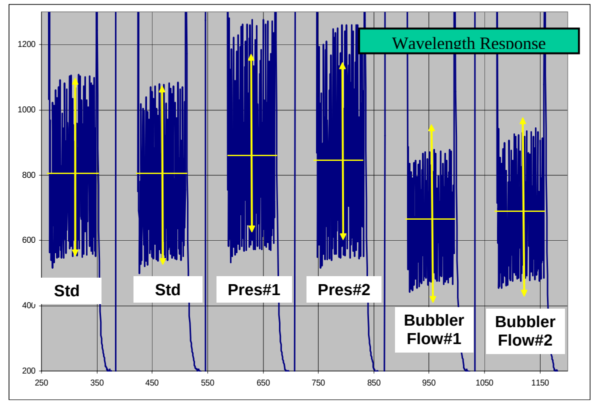

FIGURE 3. Wavelength response to experimental conditions.

The results from this initial experiment show that the *Lightwind Corporation L3* OES sensor is capable of discerning differences in the effluent stream wavelengths.

Bare Si (P Type, 100) monitors were also processed with each experimental condition to evaluate the thickness response. Figure 4 displays the monitor wafers average thickness and range normalized against the standard group results. Average and range results based on 5 site measurements (t,l,c,r,f) as measured on a KLA ASET-F5X. The results in figure 4 indicate that the monitor wafer thickness changes were small in degree with the largest response being slightly over .6Å.

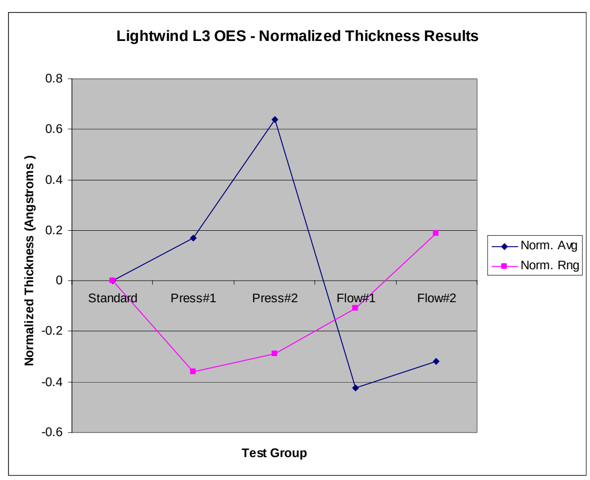

FIGURE 4. Normalized Bare Si Monitor Wafer Results

Based on the monitor wafer results, it can be concluded that should one of these high risk events occur, changes in thickness may be indiscernible. As a result, if dependent on thickness monitoring alone, a fault condition may continue without notice.

In general, for this particular Al_2O_3 Atomic Layer Deposition Process, effluent stream monitoring by OES appears credible. Known fault conditions were evaluated with favorable wavelength responses while traditional thickness monitoring proved to lack the anticipated degree of response.

Process Monitoring

The initial experimental test provided a process specific fingerprint which displayed the most responsive wavelengths. Figure 5 displays an example of a real-time process monitoring via the *Triant Technologies ModelWare* software. The green band represents the setpoint window employed by the process model. The setpoint window was established based on the historical trend exhibited by the process tool.

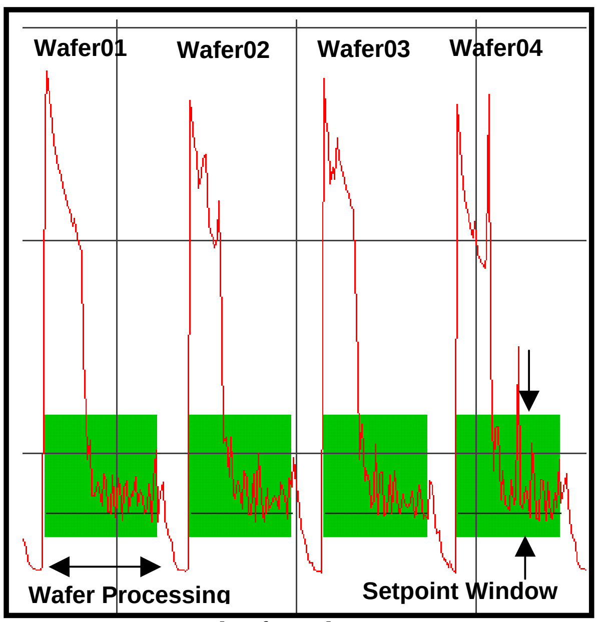

FIGURE 5. Example of a real time process monitor.

One of the strengths of effluent stream monitoring by OES, is early fault detection. Effluent stream monitoring by OES has proven itself effective in responding to process changes that other metrics fail to detect. Figure 5 exhibits a wavelength process shift as a consequence of an atmospheric leak. This excursion triggered an alarm event.

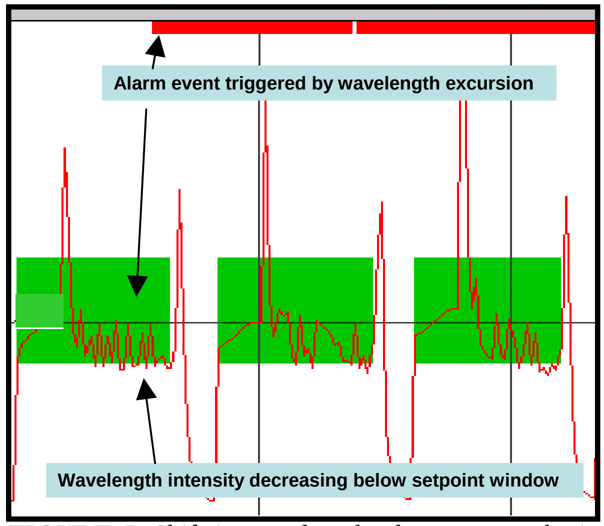

FIGURE 5. Shift in wavelength due to atmospheric leak.

As a result the leak was detected, contained, and repaired with minimal impact. In contrast to the OES monitored wavelength, the tool average thickness trend in figure 6 did not exhibit a change great enough to solicit a response.

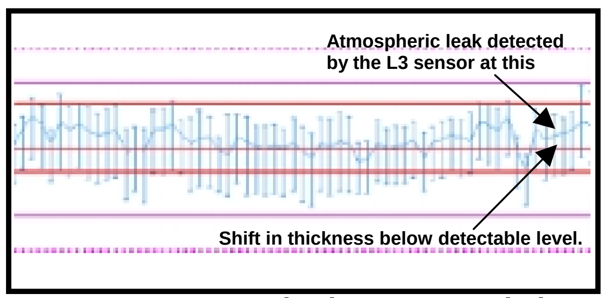

FIGURE 6. Process Chamber Average Thickness Trend.

CONCLUSION

In the scope of this paper it has been demonstrated that effluent stream monitoring by OES is capable of detecting excursions in this Al_2O_3 ALD process. Wavelength intensity can be monitored and used to supplement other process metrics and serve as a touchstone for process quality. In addition, OES does not limit itself solely to process monitoring. Potential uses also include process optimization, tool matching, and improving maintenance procedures. Since the wavelength intensity has shown to be sensitive to subtle changes in the process chemistry, OES may also be used to monitor equipment upgrades.

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