Feature Article

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EV-140 P, New Emission Spectroscopic Product for Semiconductor Endpoint, Cleaning and Plasma Chambers Control.

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To address new requirements in semiconductor Dry Etch and PECVD (Plasma Enhanced Chemical Vapor Deposition) industry, HORIBA Semiconductor has introduced a unique generation of (Multi) Sensor dedicated to Fault detection, Chamber health monitoring and Advanced Process Control. Hardware and Software issues are developed so that EV-140 P may be adapted to all etchers (clusters and single chambers) and to help researchers, engineers and Fab's to manage actual but also future products and technologies. Based on innovative technologies like smart sensors, unique software architecture, including analytical methodology and sophisticated signal processing, this platform allows satisfying all the needs of in-situ plasma process control. Our paper describes, first, Recipe Designer engineering flow and then results obtained in Fab's for Endpoint and chamber health monitoring applications, like immediate Misprocessing detection, Preventive maintenance setting, Statistics and Multi-run Viewer for quality control in order to secure wafers during critical process.

Introduction

Plasma etching is a widely used technique in the semiconductor industry and the need for in-situ process monitoring is becoming greater as the technology advances. Extremely tight control of key process parameters must be maintained to increase throughput and reproducibility. The greatest need for plasma process monitoring arises in the determination of EndPoint (EPD) for critical ETCH process, which reduces the degree of over/under etching, but also now to control cleaning step and process stability.

For Endpoint detection and plasma reactor diagnosis, Optical Emission Spectroscopy (OES) is the most commonly used method in the industry today. As the open area becomes smaller and the device density becomes greater, select the relevant wavelengths with sufficient robustness in manufacturing environment represents a big challenge for process engineers: even if a new process development often means complex plasma spectra analysis, Process Engineer needs to setup "immediately" a production recipe.

The OES tool we present, EV-140 P, handles this complexity and allows to develop/optimize quickly and quite automatically any process:

- Selection of the relevant wavelengths that carry the information about the transition with the engineering software, Recipe Designer.
- Real-time data filtering (in the broad sense) and construction of an ENDPOINT indicator with the real-time software, Sigma_P.
- Series of tests to confront the algorithm to the reality of production fluctuations.

In this paper, after a short introduction about methods of analysis, two complementary types of OES in-situ metrology are presented: Endpoint detection and Health Monitoring based on real production applications.

With the help of Altis, historically IBM-Infineon Company, we present a method to monitor plasma during contact etch with low open area and high Polymerizing chemistry. This method uses Optical Emission Spectroscopy to improve plasma monitoring using wavelengths emission intensity of different species. When EPD is too much difficult to find or not a key parameter, Health monitoring on specific wavelengths ratio between polymer depositions and etch can be a good alternative. As a complement, typical characteristic wavelengths can be used to catch any equipment failure.

In this experiment it was shown that the optical spectrometer can be used for EPD and Health monitoring to enhance etch process monitoring and secure wafers etching.

Method for Endpoint Detection and Health Monitoring

Optical emission spectroscopy

Optical emission spectroscopy is a spectral analysis of the light emanating from plasma. For EPD and plasma diagnosis measurements, Optical Emission Spectroscopy is the most commonly used method in the industry today. Plasma emission results from the excited species relaxation in plasma. The direct electronic impact is the main excitation source. The spectral domain, 200 to 800 nm, is the main region being able to be observed by OES. And OES has the big advantage of being an external diagnosis from the reactor. So, plasma is not disturbed by this system. As we can see on Figure 1, EV-140 P gives access to many spectra (down to every 20 ms) and then to huge data along process. The question now is: how to select relevant process wavelengths from spectra?

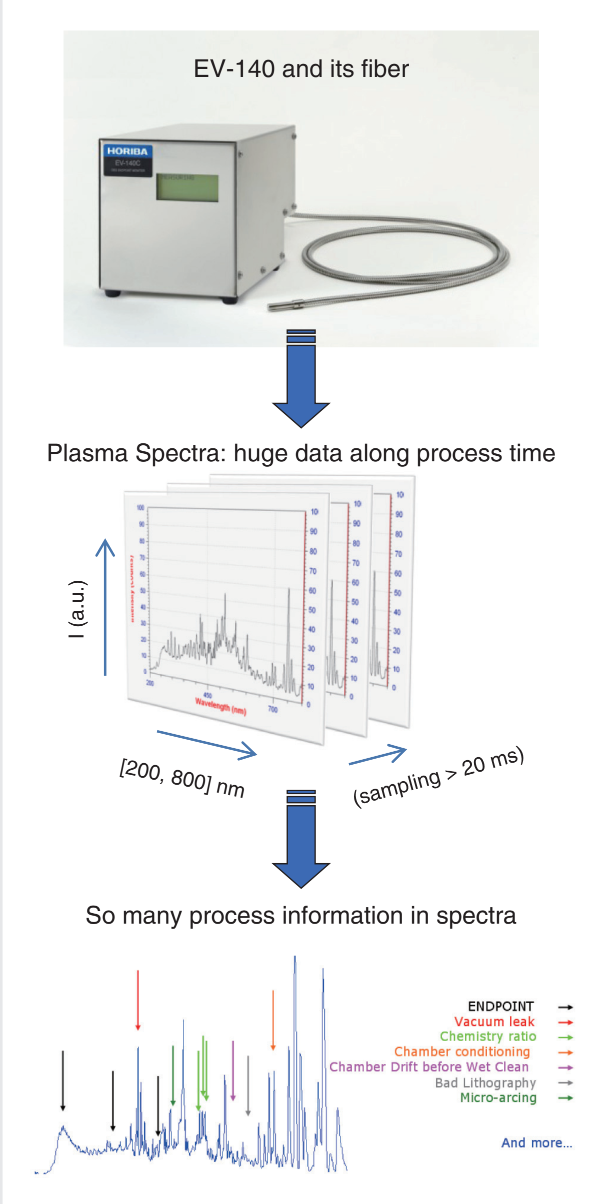


Figure 1 Ev-140 P spectra acquisition

Endpoint detection

By monitoring the emission intensity of selected wavelengths, the system tracks the amount/loss of material in the plasma, as when a particular material has been completely removed from the etch surface. Thus, based on the changes in the spectrum of radiation emitted by the plasma, the Endpoint is detected: due to non-uniformity on wafers, EPD is characterized by two ruptures as described Figure 2.

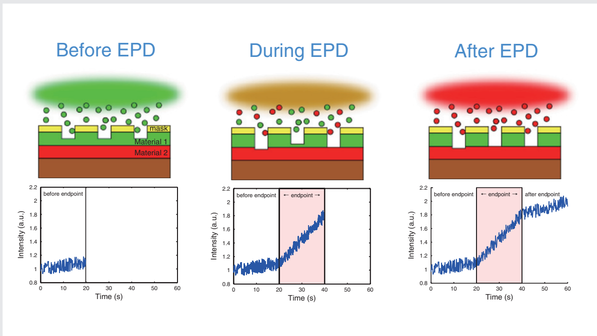


Figure 2 Principle of Endpoint detection

From endpoint to health monitoring

Sigma_P contains a large SQL database to allow:
- General monitoring for plasma dry Etch and PECVD: Spectra Data collection (using Fab's logistics information), analysis, comparison using internal emission library and spectra reference, process

identification, uniformity control. Various functions like trends, ratios, differences, average, standard deviation.... can be used.

- Advanced Endpoint Process Control:
  Fully Automated Endpoint/Run to run control/Fault Detection Classification to improve yield and increase productivity in semiconductor manufacturing.
- Chamber Health Monitoring:
  • Chamber qualification and cleaning.
  • Chamber conditioning to avoid first wafer effect.
  • Matching and troubleshooting.
  • Chamber gas leak detection or gas purity control.
  • Preventive maintenance.
  • Failure analysis.

Hardware and fab's logistics

The HORIBA cluster system is used to collect the plasma emission during any etching or PECVD process. This system is equipped with a sturdy optical fiber which can be easily mounted on the side window of the plasma chamber. It uses 2048 CCD sensors. EV-140 P provides process automation for in-line integration in a production environment. It offers RFon, PIO remote, stop etch management, RS232 with the tool, TCP/IP/SECS/HSMS with network...

Softwares

Endpoint detection and Health Monitoring are available thanks to Recipe Designer and Sigma_P software.

Recipe designer, engineering flow

Based on new advanced mathematical treatment like wavelet and rupture probability, including analytical methodology and sophisticated signal processing, **Recipe Designer** allows satisfying all the needs of in-situ plasma process control.

On the Figure 3, the principle of Endpoint detection using Recipe Designer is illustrated. This software permits to extract *semi-automatically* relevant wavelengths contained on raw spectra, characteristic of

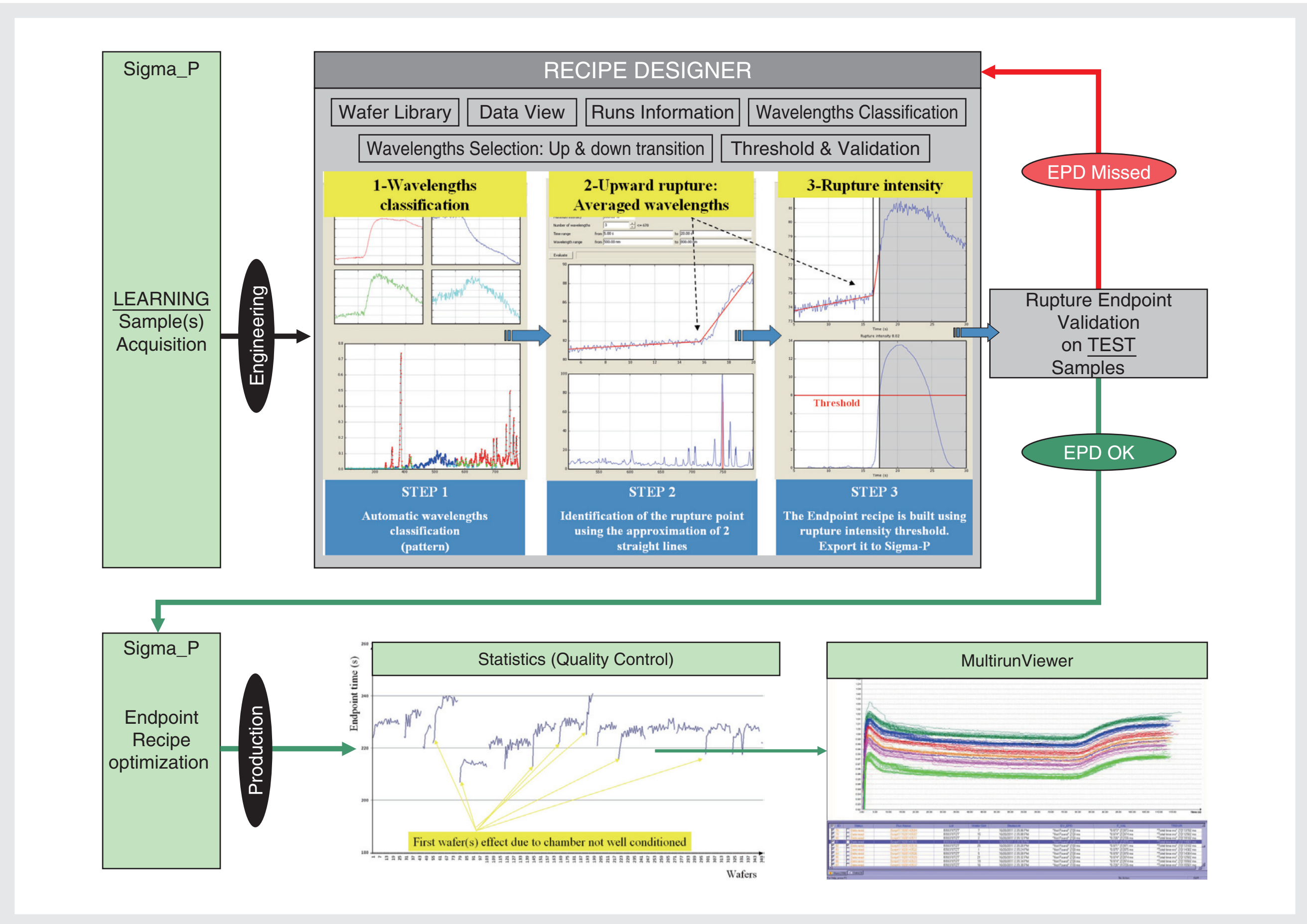


Figure 3 Recipe designer engineering flow: From spectra acquisition to Endpoint on Production

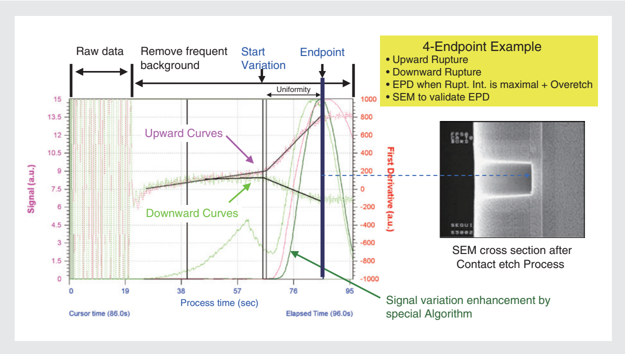


Figure 4 Sigma_P endpoint with SEM confirmation

plasma change like interface achieved, impurities detection, and Endpoint found...

Rupture slope may be "upward" or "downward". Working simultaneously on several runs result, Recipe Designer defines a threshold on the best rupture intensity and then check validity over those samples, as shown on Figure 3.

Real –time acquisition & EPD

Recipe Designer creates an Endpoint recipe directly exported to Sigma_P. Exposing the algorithm to the reality of production environment, this recipe is enhanced with reprocessing, optimizing parameters like derivative, filtering, conditions/decisions.

Then, EPD has to be confirmed using, for example:
- Scanning Electron Microscope (SEM cross section) measurement (Figure 4).
- Prepared wafers with varying thickness to show the correlation versus endpoint time.

As Endpoint management is done, it remains now to be sure that chamber and process stay on a safe mode to protect samples, wafers, masks, flat panel display...

Engineering tools to help process engineer to develop health monitoring algorithms

To achieve preventive and comparative actions, Sigma_P contains a Health Monitoring Toolbox:
- Statistics (Figure 3): EPD stability, EPD missed, 1st wafer effect…
- Spectrum and kinetics comparator with pattern envelop models, trends, Process Tags.
- Fingerprinting using references.
- Multi-runs Viewer (Figure 3): 1 color = 1 batch of 25 wafers.
- Real time action: Health Warning, Health Stop, continuation until Default time to avoid under etch, Emails...

Experiment

In this study, Dual damascene etch process, MXVX, is performed in a TEL (Tokyo Electron Ltd) SCCM (Super Capacitively Coupled Module) etch chamber (dual source) while Contact Etch, CA, is done on Applied Materials.

MXVX process has many etch steps with:
- ARC open (Anti reflective Coating) and Nitride etch (SiN) with endpoint detection possibility (ARC to Oxide (SiO) and SiN to Copper interface).
- VIA etch which uses a very high selective chemistry oxide to SiN with low open area (less than 2%), and over etch is minimum on actual production wafers, so endpoint detection is very difficult.
- Trench etch which has no stop layer, so the goal is to control these two steps using Health Monitoring.

First we decide to evaluate:
- EPD on the Arc open step which has low open area but with a low polymerizing effect.
- Health monitoring on the Partial VIA step with same open area (2%) but with a high polymerizing effect.

EPD on MxVx etch process

On this process, we want to detect one endpoint at the ARC/SiO interface (Figure 5). This step exists with two types of integrations. One with a 193 nm resist and one with a 248 nm resist. With a 193 nm resist, ARC is less thick than ARC with a 248 nm resist. This difference of thickness is visible with endpoint time on the Figure 5. With a 193 nm resist, we found an endpoint earlier than with a 248 nm resist. For both types of resist, statistic results show a good reproducibility on endpoint time.

Then, this endpoint has been validated with a SEM cross section:

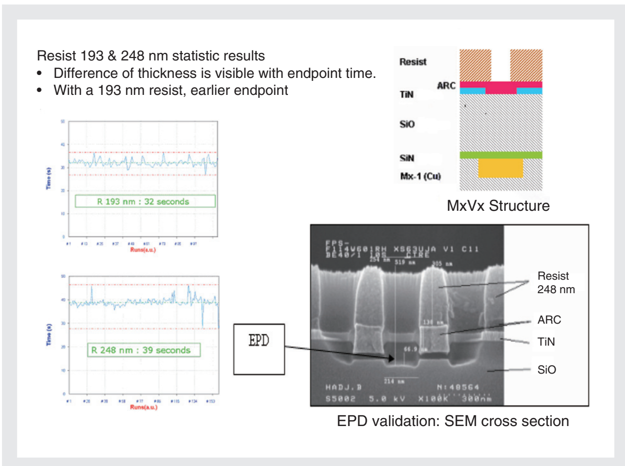


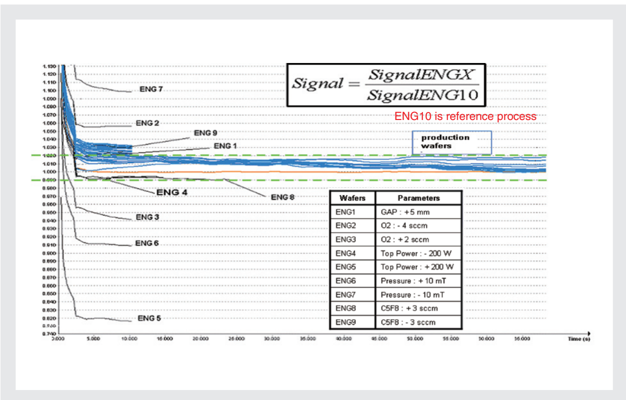
Figure 5 Arc open structure: EPD validation

ARC is open in 45 seconds with 248 nm resist (with an overetch).

Health monitoring on MxVx etch (Partial VIA step)

In this part, we want to detect all wafers considered as abnormal on the Partial VIA (2% open area) step from MxVx process. Thus, various defects into production recipes have been simulated. These defects are resumed below (Figure 6). The wafer ENG1 simulates a GAP (inter electrodes) problem, the ENG2 and ENG3 simulate an abnormal quantity of O_2 gas, the ENG4 and ENG5 feign a power problem, the ENG6 and ENG7 simulate a pressure problem, and the last ENG8 and ENG9 simulate an abnormal quantity of C_5F_8 gas.
Depending on equipment capability, these parameter's drifts are chosen for their sensitivity to the process (etch stop or less selectivity):
- Etch stop: too much polymers, ratio CF2/SiF4 increases
- Loss selectivity: less polymers, ratio CF2/SiF4 decreases

The aim was to develop an algorithm able to detect all these misprocessing. The algorithm integrates a superior and an inferior threshold in order to constitute an envelope (Figure 6: green dotted). When the signal characteristic of these wafers crossed the envelope, the signal has to be stopped. Monitored signals are the ratio between ENGX intensity and reference intensity (so reference is at 1). This reference, ENG10, was realized from a standard wafer during a standard process. On the Figure 6, there are the results. In x-axis, the time in second, and in y-axis, the ratio intensity. All the signals characteristics of these wafers (ENG 1 to 9) are stopped. Hence, Health Monitoring algorithms are able to discriminate Misprocessing even without managing endpoint.



Wafers	Parameters
ENG1	GAP : +5 mm
ENG2	O2 : - 4 sccm
ENG3	O2 : +2 sccm
ENG4	Top Power : - 200 W
ENG5	Top Power : + 200 W
ENG6	Pressure : + 10 mT
ENG7	Pressure : - 10 mT
ENG8	C5F8 : + 3 sccm
ENG9	C5F8 : - 3 sccm

Figure 6 Multi Runs Viewer, Health Monitoring on MxVx

Furthermore, in order to give more realism to this study, several batches from production (Figure 6: the long blue curves) are inserted to check if Health Monitoring algorithm is strong enough to deal with classical wafers. But some lots are rejected due to Health Monitoring reason. After analysis, result is that wafers with too different open area cannot be monitored with this recipe.
To go further, each technology has to be monitored with a dedicated recipe containing a relevant reference.

Health monitoring on CA etch process

On contact etch (CA), Health Monitoring (HM) target is to fit tool evolution (polymerization) between two wet cleans and monitor the tool drifts (Figure 7).
On this picture, the N_2 leak causes the instability of the electric signal. HM action wanted is to stop before the first abnormal wafer of the batch.

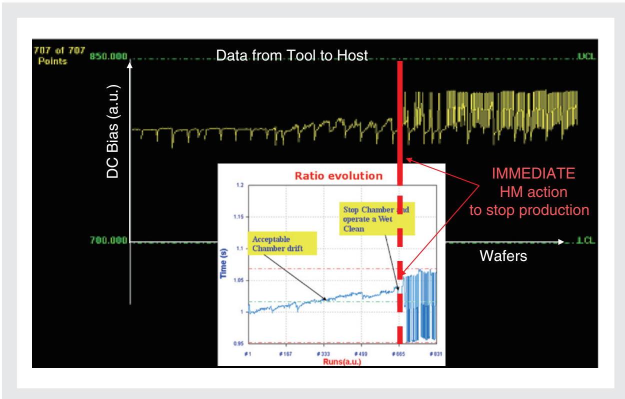


Figure 7 Tool drift and stop at the batch

This process is very sensitive at N_2 gas leaks which change the plasma composition and destroy the wafers. The aim is to detect the leaks before wafers degradation. Before the use of EV-140 P system, these leaks were detected too late because the time between the tool drift and the warning mail sent to the engineer is about 3 hours. And with this system we are able to detect very quickly these leaks and act on the tool during the production. So, the destruction of several batches is avoided. The engineers are able to act immediately after the drift because the system is configured to warn engineers at the first signs of drift (Email sent by EV-140 P from the clean room) and/or stop immediately the tool.

Health monitoring on wet clean recovery

Another application of Health Monitoring is the analysis of the production. On the Figure 8, there are the statistic results on about 7500 wafers (over 6 wet cleans). In x-axis there is the number of wafers and in y-axis there is the signal intensity (real time spectra/reference spectra ratio).

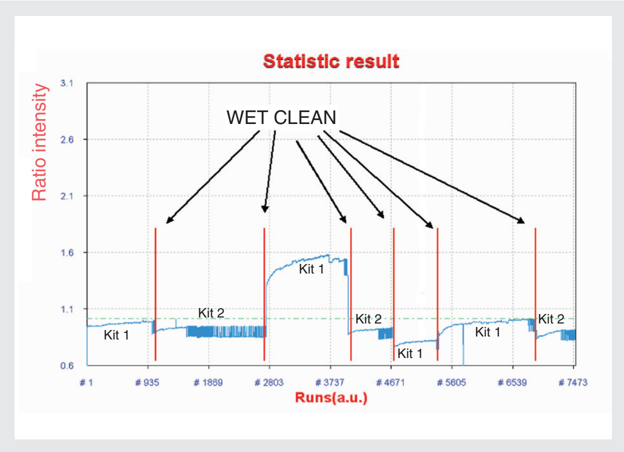


Figure 8 Health Monitoring on CA etch process

The Figure 8 gives us two important results:
- After each Wet Clean, the signal doesn't start with the same intensity, so Wet Clean procedure must be modified to obtain better reproducibility.
- Depending on Kits used, chamber life duration is different. We can see that Kit 2 is not adapted to this production.

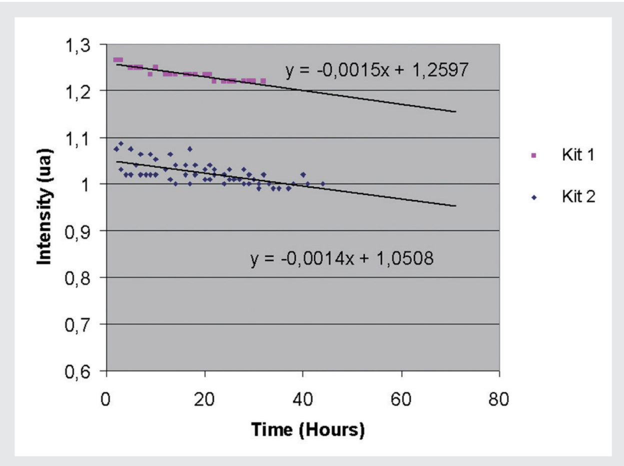


Figure 9 Chamber evolution with two different Tool Kits

On Figure 9, two Tool Kits have been emphasized with two groups of points. We note there are two similar trends (same slope) for two different Tool Kits.

Analyzing CF2/SiF4 ratio, we see that the polymerization (the equipment's clogging) is linear. Thus, we can follow the tool's clogging, and predict the wet clean depending on Tool Kit installed.

Conclusion

Monitoring the MxVx and CA process was extremely challenging due to low open area (2%), high selectivity chemistry, wet clean management and polymerization.

Endpoint detection using OES method proves to be a powerful technique that meets the plasma etching needs of the next generation of logic chips. Even if endpoint cannot be raised (especially for PECVD), Health Monitoring permits to manage chamber life duration and process drift to avoid Misprocessing and also raise alarm if necessary. But to do that on production environment, optical setup from chamber to OES system must be well known and reproducible chamber to chamber and Wet Clean after Wet Clean. It is so important for process engineer to have an up-to-date toolbox to enter into plasma information that a new version of Recipe Designer, RD7, will be soon out.

Besides EV-140 P, as soon as a top window exists on tool chamber, LEM-CT permits with Interferometric camera to obtain Etch rate, thickness Etched/deposited, Endpoint.

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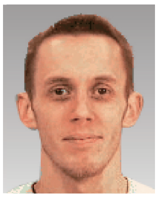

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