PROCESS MONITORING ON LOW OPEN AREA STEPS
BY
OPTICAL EMISSION SPECTROSCOPY
(Endpoint Detection & Health Monitoring)

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Abstract

This paper presents 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 endpoint detection is too much difficult to find, 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, equipment or gas line failure. In this experiment it was shown that the optics spectrometer can be used for endpoint detection and Health Monitoring to ameliorate monitoring etch 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 all process parameters must be maintained to increase throughput and reproducibility.

The greatest need for plasma process monitoring arises in the determination of the etch endpoint for a given process, which can reduce the degree of over/under etching. As the open area becomes smaller and the device density becomes greater, select the relevant wavelengths with sufficient robustness in manufacturing environment represent a big challenge for process engineers.

Biolsi et al. [1] demonstrate an advanced endpoint system for low open area etches by applying signal processing to a signal wavelength. Anderson [2] proposed to use evolving window factor analysis to detect endpoint. Yue and co-workers [3], present their work in using principal component analysis (PCA) to extract a reliable endpoint signal. White et al. [4] proposed to use T² and Q statistics for endpoint detection for low open area wafers. These methods are reliable for large open area (> 10%), but for very small open area the endpoint feature is severely corrupted with a drift that leads to missed endpoint detection.

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. Health Monitoring is introduced to characterize chambers/processes to secure wafers etching even if endpoint is difficult to reach. Using various applications on different Etch tools, we describe how to improve process monitoring to manage actual and future products and technologies.

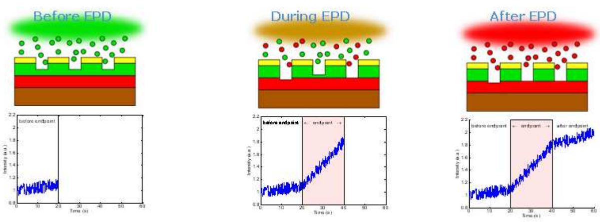
METHOD FOR ENDPOINT DETECTION AND HEALTH MONITORING [5]

Optical Emission Spectroscopy

Optical emission spectroscopy is a spectral analysis of the light emanating from plasma. For endpoint detection and plasma diagnostic measurements, Optical Emission Spectroscopy is the most commonly used method in the industry today. The plasma emission results from the excited species relaxation in plasma. The direct electronic impact is the main excitation source. The spectral domain, 190 to 850 nm, is the main region being able to be observed by OES which has the advantage of being an external diagnosis from the reactor. So, plasma is not disturbed by this system.

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 the endpoint is detected based on the changes in the spectrum of radiation emitted by the plasma: due to non-uniformity on wafers, EPD is characterized by two ruptures as described below:



<Fig. 1> Principle of endpoint detection

From Endpoint to Health Monitoring

Sigma_P software contains a large SQL database to allow:

- **General monitoring for plasma dry** Etch: Data collection, analysis, comparison using internal emission library and spectra reference, process identification, uniformity control. Various functions like trends, ratios, differences, average, standard deviation, etc. 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 Jobin Yvon cluster system is used to collect the plasma emission during the MxVx etching 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.

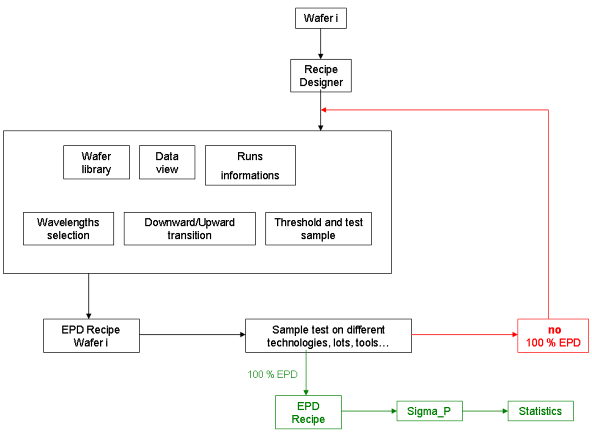
The MultiCPM provides process automation for in-line integration in a production environment. It offers RFon, PIO remote, stop etch management, RS232 with the tool, TCP/IP/SECS/HSMS with network…

Softwares

Endpoint detection and Health Monitoring are available thanks to Recipe Designer and Sigma_P software (from Horiba Jobin Yvon Company):

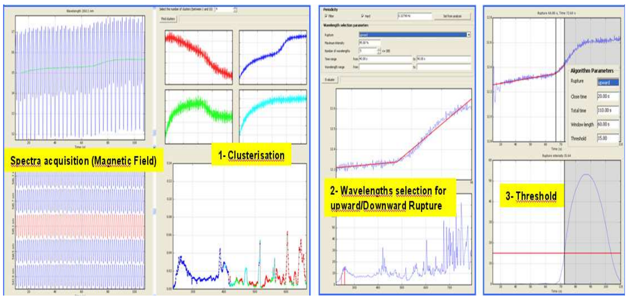
Recipe Designer, Engineering Flow

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 1, 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 plasma change like interface achieved, impurities detection, and endpoint found…



<Fig. 2> Recipe Designer principle for EPD

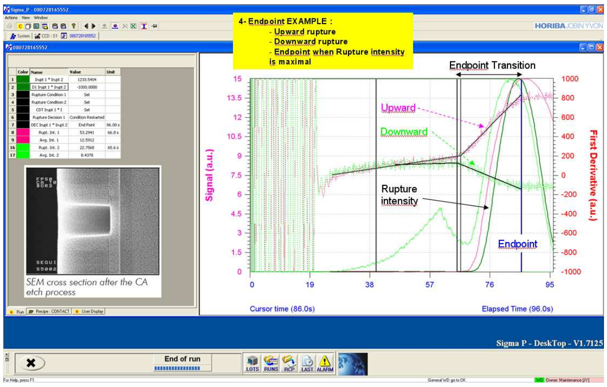
Rupture slope may be "upward" or "downward". Working simultaneously on several runs result, Recipe Designer defines a threshold on the best rupture intensity and then check validity over those samples (Fig 3).



<Fig. 3> Recipe Designer example

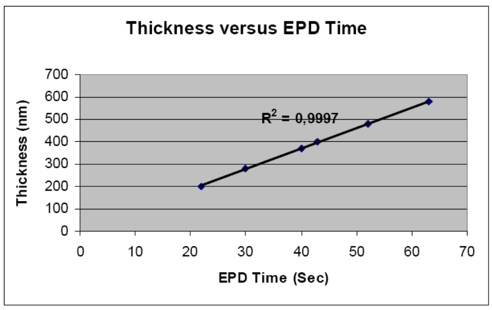
Real –Time acquisition & EPD

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



<Fig. 4> Sigma_P endpoint

Then, the endpoint has to be confirmed using, for example:
- Scanning Electron Microscope (SEM cross section) measurement (Fig. 4)
- Prepared wafers with varying thickness to show the correlation versus endpoint time (Fig. 5)



<Fig. 5> Endpoint algorithm validation

Engineering Tools to help process engineer to develop Health Monitoring algorithms [6]

To achieve preventive and comparative actions, Sigma_P contains a Health Monitoring Toolbox:
- Spectrum and kinetics comparator with pattern envelop models
- Process Tags
- Trends
- Fingerprinting using references

- Real time action: Health Warning, Health Stop, continuation until Default time to avoid under etch, Emails…

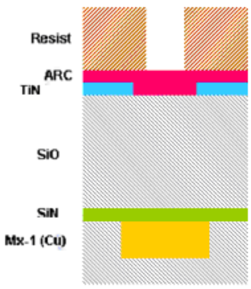
EXPERIMENT

In this study, Dual damascene etch process is performed in a TEL SCCM etch chamber (dual source). This process has many etch steps:
- ARC open and Nitride etch with endpoint detection possibility (Arc to Oxide and SiN to Copper interface)
- VIA etch which use 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, 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

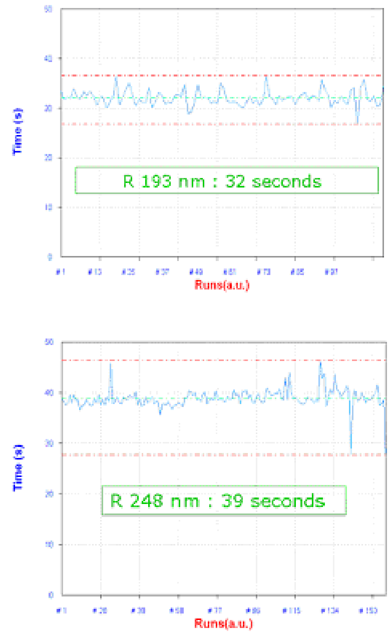
On this process, we want to detect endpoint at the Anti Reflective Coating / SiO interface (Fig. 6).



<Fig. 6> Step ARC open

This step exists with two types of integrations:
- One with a 193 nm resist
- One with a 248 nm resist

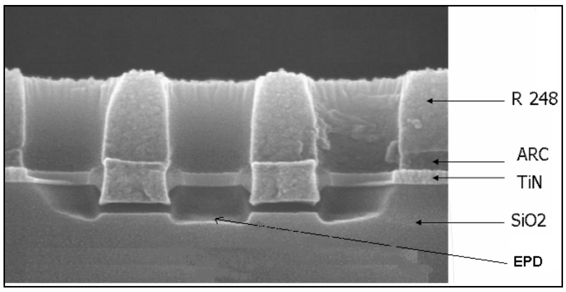
With a 193 nm resist, ARC is less thick than the ARC with a 248 nm resist.



<Fig. 7> Resist 193 & 248 nm statistic results

This difference of thickness is visible with endpoint time on the figure 7: 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:



<Fig. 8> SEM cross section on 248 nm resist

ARC is opened in 45 seconds with 248 nm resist (with an overetch), figure 8. A little overetch is already visible on SiO, as awaited.

Health Monitoring on MxVx etch process (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 (Fig. 9).

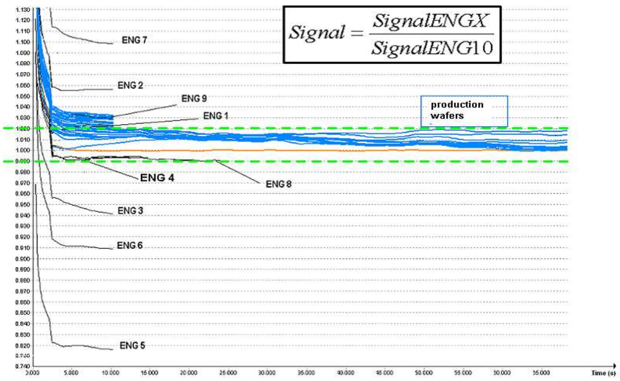
Wafers	Parameters
ENG1	GAP : +5 mm
ENG2	O2 : - 4 sccm
ENG3	O2 : +2 sccm
ENG4	Top Power : - 200 W
ENG5	Top Power : + 200 W
ENG6	Pressure : + 10 mT
ENG7	Pressure : - 10 mT
ENG8	C5F8 : +3 sccm
ENG9	C5F8 : - 3 sccm

<Fig. 9> Various modifications of recipe for HM

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 ENG (ENG 8 and ENG 9) simulate an abnormal quantity of C_5F_8 gas. These parameter's drifts are chosen for their sensitivity to the process (etch stop or less selectivity) or equipment capability.

- 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. The algorithm integrates a superior and an inferior threshold in order to constitute an envelope (Figure 10: 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 was realized from a standard wafer during a standard process. On the figure 10, there are the results. In x-axis, the time in second, and in y-axis, the intensity. All the signals characteristics of these wafers are stopped. Hence, Health Monitoring algorithms are able to discriminate miss-process even without managing endpoint.

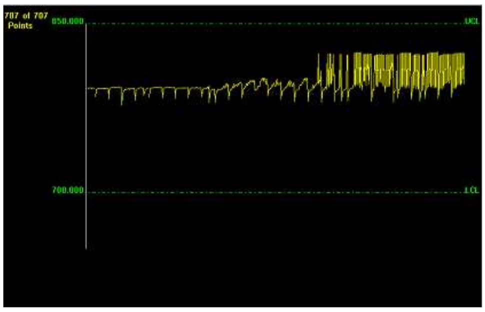


<Fig. 10> Results concerning Health Monitoring on MxVx

Furthermore, in order to give more realism to this study, several batches from production (Figure 10: the blue curves) are inserted to check if Health Monitoring algorithm is strong enough to deal with classical wafers. And some of these production lots are rejected due to Health Monitoring reason. After analysis, result is that wafers with too different open area cannot be monitored with a single 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 target is to fit tool evolution (polymerization) between two wet cleans and monitor the tool drifts (Figure 11). On this picture, the N_2 leak causes the instability of the electric signal. HM action wanted is to detect the leaks before the first abnormal wafer of the batch to avoid any degradation.



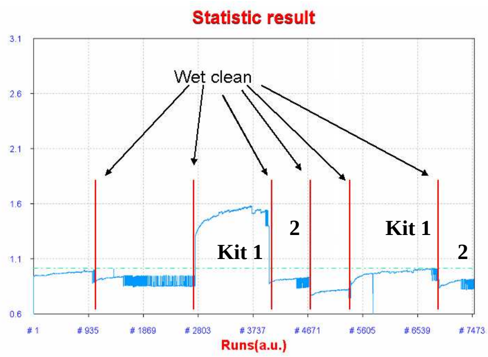
<Fig. 11> Tool drift and stop at the batch

This process is very sensitive at N_2 gas leaks which change the plasma composition and destroy the wafers. Before the use of HORIBA Jobin Yvon 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. Now 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 during the drift because the system is configured to warn the engineers at the first signs of drift and/or stop immediately the tool.

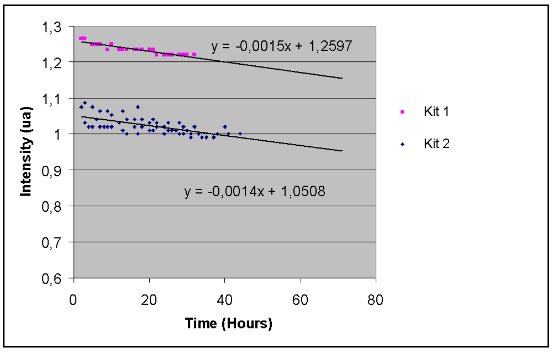
Health Monitoring on Wet Clean recovery

Another application of Health Monitoring is the analysis of the production. On the figure 12, there are the statistic results on about 7500 wafers (with 6 wet cleans). In x-axis there is the number of wafers and in y-axis there is the signal intensity. The figure 12 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



<Fig. 12> Health Monitoring on CA etch process



<Fig. 13> Two different Tool Kits

On this picture, 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. We see that the polymerization (the equipment's clogging) is linear. Thus, we can follow the tool's clogging, and predict the wet clean as a function of Tool Kit installed.

CONCLUSION

Monitoring the MxVx and CA process was extremely challenging due to low open area (2%), high selective 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, Health Monitoring permits to manage chamber life duration and process drift to avoid miss-processing and raise alarm if necessary. But to do Health Monitoring 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.

REFERENCE

Endpoint detection and Health Monitoring: cf AEC/APC (Advanced Equipment Control/Advanced Process Control)

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