Application of advanced data processing techniques for single process parameters and electrical data for product engineering purposes

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Outline

- APC in high volume production
- Data compression - an essential need
- Data Mining Techniques
- Application of model based data processing on gate conductor (GC) etch at LAM TCP
  - Correlation between plasma parameters and tool parameters
  - Correlation between plasma parameters and product parameters
  - Correlation between tool parameters and product parameters
  - Calculation of control charts
- Summary
APC in high volume production
Why do we need APC in high volume production for PE purposes?

- In semiconductor manufacturing the ratio of electrical data to inline data is appr. 30 : 1.
  - Extension of data sources is urgently needed - improvement of the effectivity of PE-Analysis can be achieved.
- Sophisticated yield analysis methodology vs. data processing of unit process mastering.
  - More successfully evaluation of new data analysis methods w/ sensitive tool or process data than with highly compressed product data - application both for PE- and for APC-data.
- Tool alarms and test methods are not sensitive enough, problems are detected often too late \(\Rightarrow\) scrap lots.
  - Data bridging - determination of alarm limits w/ correlation between tool-, process- and product data.
Basic APC aspects: Offline analysis and real time process control including alarms

- Tool Parameters
- Process Parameters
- Product Parameters
- Logistic Data (Wafer, Recipe)
- Offline Analysis Model
- Data Base
- Real Time Monitoring
- Online Alarm

APC in high volume production
Data compression
Data compression - an essential need for APC in high volume production

- The broad measurement of process and tool parameters creates very large amounts of data additionally - no implementation of APC w/o data compression

- How to compress large amounts of data?
  - Using of smart „Intelligent“ sensors - calculation of relevant process parameters using raw data in real time based on physical models (e.g. Hercules based on SEERS).
  - Try to identify complex process parameters which depend on tool- and wafer impacts - better to monitor 2 than 20 parameters per chamber daily.
  - Calculation of statistical key numbers - per wafer and per process step.
  - Model based data analysis using high sophisticated modelling methods – the focus of this presentation.
Data compression by measurement of complex process parameters

- Monitoring of complex process parameters, indicating tool and wafer conditions (e.g. endpoint time or plasma parameters) reduce the number of parameters, checked regularly.
- Stable values of these complex process parameters indicate stable process condition.
- In case of process variations additional analysis of tool and wafer parameters is needed to identify the reasons in detail.
Data compression by use of process models

**Usualy measurable**
- RF power generator output
- Cooling temperature
- Pressure
- Gas flow
- ...

**Usualy not measurable**
- RF power chamber input
- Surface temperatures
- Polymer gas adsorption
- ...

**Input**

**Output (Responses)**

**Process Behaviour (Black Box)**

**Input (perturbation)**

**Yield**

**Electrical Parameter**

Usualy measurable
- RF power generator output
- Cooling temperature
- Pressure
- Gas flow
- ...

Usualy not measurable
- RF power chamber input
- Surface temperatures
- Polymer gas adsorption
- ...

Data compression
Data compression by use of process models, cont.

- The description of process behavior w/ simple statistics (e.g. correlations etc.) is not sufficient; it requires the evaluation of empirical process models, which are able
  - to find the main impacts from a big variety of inputs and calculate the influence of each one.
  - to use a quasilinear approach to describe highly correlated inputs.
  - to discover contrary interactions between two inputs.
  - to find the global optimum for the investigated process.

- The evaluation of empirical process models on the base of historical data - data, which are collected at normal process conditions, the only reason of variation is random - requires complex data processing methods - Data Mining.
Data Mining
Data Mining workflow

1. Data Source
2. Filter Outlier
3. Over-sampling
4. Data Partition

- Regression Tree
- Variable Selection
- Transform Variables

- Assessment and selection of the best model
- Regression

Data mining techniques
Data Mining – high sophisticated methods for evaluation of process models

- **Data Mining**
  - Advanced methods for exploring, selecting and modeling relationships in large amounts of historical „dirty“ data.
  - Passive process analysis.
  - „Fishing“ for p-values.
  - Find previously unknown pattern.

- **Data Mining work flows includes:**
  - Exploring data (filter outlier, data transforming, variable selection, elimination of redundancies e.g.).
  - Fitting a predictive model using regression / decision trees / neural networks.
  - Assessment and selection of the best.
Application of model based data processing on gate conductor (GC) etch at LAM TCP
Application of model based data analysis on GC etch at LAM TCP

- GC etch at LAM TCP:
  - Main etch - Cl, HCl, NF₃ - chemistry.
  - Over etch - HBr, He/O₂ - chemistry.

- Data obtained by collecting of tool data and measurement with the Hercules-sensor at one chamber:
  - Of DRAM and several logic products.
  - More than 6500 wafers.

- Model based data analysis to find correlations between
  - Plasma parameters and tool parameters.
  - Plasma parameters, electrical data and yield.
GC etch at LAM TCP – Correlation between plasma parameters and tool parameters
GC main etch: Correlation between plasma parameters and tool parameters

- The model allows to calculate the impact of each of the tool parameter inputs on the plasma parameters.
GC main etch: Correlation between plasma parameters and tool parameters, cont.

The model also allows to find the most important input tool parameters and to build an effects Pareto.
GC main etch: Discussion of correlation results

- The data were sampled keeping all tool parameters constant. The tool tries to compensate random variations - drifts of measurable tool parameters occur.

- A quasilinear model approach was taken - main effects and two-way interactions - in cause of highly correlated inputs.

- Model goodness of fit - 79% (e.coll.rate), 51% (e.dens.).

- At gate conductor etch in LAM TCP the main impacts on electron collision rate and electron density are:
  - TCP MatchTuneCap and TCP MatchLoadCap
  - RF timer and ThrottleValvePosition
  - BiasMatchTuneCap
  - ForelinePressure and ChamberPressure.
GC over etch: Correlation between plasma parameters and tool parameters

The model allows to calculate the impact of each of the tool parameter inputs on the plasma parameters.
GC over etch: Correlation between plasma parameters and tool parameters

The model also allows to find the most important input tool parameters and to build an effects Pareto.
GC over etch:
Discussion of correlation results

- The model evaluation was done similar to the main etch step with data mining methods.
- Model goodness of fit - 85% (el.coll.rate), 24% (e.dens.)
- At gate stack over etch the main impacts on electron collision rate and electron density are
  - TCP MatchTuneCap and TCP MatchLoadCap
  - RF timer, ChamberPressure and ForelinePressure
  - RF PowerRefl and ForwBottom
- Missing measurements during a determined period of time explains to two states of RF timer, a dirty chamber seems to lead to more stable process.
- One setting of BiasMatchTuneCap correlates to more stable conditions.
Summary of the correlations between plasma parameters and tool parameters

- The correlation results between plasma parameters and tool parameters at GC etch in LAM TCP show, that both plasma parameters, electron collision rate and electron density depend on
  - Tool impacts.
  - Process and wafer impacts.
- As a result they can be used to monitor tool and wafer conditions together.
- They are suitable as complex process parameters for data compression at daily process monitoring for APC.
- These results are similar with earlier modeling on a comparable chamber.
GC etch at LAM TCP – Correlation between plasma parameters and electrical product parameters
Correlation between plasma parameters and electrical product parameters

- Correlations between plasma parameters and tool parameters show, that plasma parameters can be used for tool monitoring. But from the product engineering and the process engineering point of view it is important to find out possible correlations between plasma parameters and electrical data or yield.

- **Data mining software and other available product engineering standard software tools are suitable for these calculations.**

- The following application demonstrates, that these correlations must be done separately for:
  - Various products (DRAM, logic products).
  - Various process steps (main etch, over etch).
Product interaction between DRAM and logic product at GC etch

- According to electrical tests on product level an interaction between DRAM and logic products was found at GC etch.
- Depending on the product mix in the chamber we observed
  - A drift of electrical parameters of a logic product.
  - And stable electrical parameters of DRAM at the same time.
- The problem was solved temporarily by chamber dedication.
- The target was to find out
  - If these impact of product mix on electrical parameters of logic product can be observed by plasma parameter measurement.
  - If the chamber dedication could be removed by definition of an acceptable process mix and real time monitoring of that conditions.
DRAM, GC over etch: No correlation between electron collision rate & gate contact width

Electron collision rate [median] vs. gate conductor width

DRAM product: no correlation

Plasma- and product parameters
Logic, GC over etch: Correlation between electron collision rate & gate contact width

Logic product: good correlation

Electron collision rate [median] vs. gate conductor width

Plasma- and product parameters
Logic, GC over etch: Correlation between electron collision rate & gate contact width

At gate conductor over etch of logic product the electron collision rate correlates with gate contact width.

Electron collision rate vs. time

Gate contact width vs. time

$t_0$ - introduction of process mix change (soft chamber dedication)
GC over etch: Discussion of correlation results

- At DRAM, showing stable electrical results
  - As expected, no correlation between plasma parameters and electrical results was found.
  - The process window is large, the process runs well.

- At the logic product, showing electrical parameter drift
  - A pretty good correlation was found between electron collision rate of the GC over etch and the gate contact width.
  - The over etch was identified as the problematic etch step.

- It's remarkable, that the good correlation was found at product parameter variations inside of the specification.

- At serious process problems we can expect a very significant response of electron collision rate at over etch.
GC etch at LAM TCP –
Correlation between
tool parameters and
electrical product parameters
Logic, GC over etch: Correlation between tool parameters & electrical parameters

Tool- and product parameters
Logic, over etch: Discussion of correlation plasma, tool & electrical parameters

- Good correlation between electron collision rate and gate conductor width was found (goodness of fit 56%).
- Weak correlations between tool parameters and electrical product parameters were found (goodness of fit 24% to 38%).
- Tool parameter drifts are highly correlated due to the „efforts of the tool“ to compensate the random process variations. This results in the variation of electron collision rate and electron density too, which are physical process parameters.
- **Tool parameters** are suitable for **tool monitoring** mainly.
- **Process parameters** should be used for **process monitoring** - it’s better to monitor 1 or 2 sensitive process parameters, than 20 less sensitive tool parameters for this purpose.
Calculation of control charts for plasma parameters
Logic, GC over etch: Calculation of plasma parameter control charts

Due to unstable mean an extended Shewhart chart was calculated.

Calculation of control charts
Summary

- Data compression for APC in high volume production is demonstrated on a product interaction problem between DRAM and logic products at GC etch in LAM TCP:
  - By measurement of plasma parameters with SEERS.
  - By calculation of statistical key numbers.
  - By model based analysis with data mining techniques.

- Due to highly correlated inputs a quasilinear approach is used, which considers main effects and two-way interactions.

- This method delivers to our opinion a better interpretability of results, than other statistical methods, e.g. simple correlations a.o.

- Data, recorded for more than 6500 product wafers show correlations between tool, plasma and product parameters.
Summary, cont.

- The electrical parameter drift of logic product
  - Is caused by a process interaction with the DRAM product at the GC over etch step.
  - And can be monitored by electron collision rate in real time.

- Electron collision rate control chart of the over etch step
  - Supplies an alarm level for real time monitoring of GC etch at LAM TCP.
  - Can be used to define and monitor an acceptable mix of DRAM and logic products in the same chamber.

- This is a way to remove the chamber dedication.