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

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Ute Nehring ute.nehring@infineon.com
Product Engineering
Andreas Steinbach andreas.steinbach@infineon.com
Center for Development and Innovation
Infineon Technologies Dresden www.infineon.com

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

01.03.2001
Page 2

Acknowledgement

- The autors of this poster would like to thank:

  Lars Christoph | Mohammed Radwan
  Siegfried Bernhard | Jörg Bullmann

  - Infineon Technologies Dresden, Germany

  Thomas Dittkrist | Thomas Werner
  Harald Wendel | Sören Mothes

  - University of Technology Dresden, Germany

- The work for this paper was supported
  - by the EFRE fund of the **European Community**
  - and by funding of the **State Saxony** of the Federal Republic of Germany, project **PULSAR,** project number 5706.

- The authors are responsible for the content of the paper.

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

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

01.03.2001

APC in high volume production

Why do we need APC in high volume production for PE purposes?

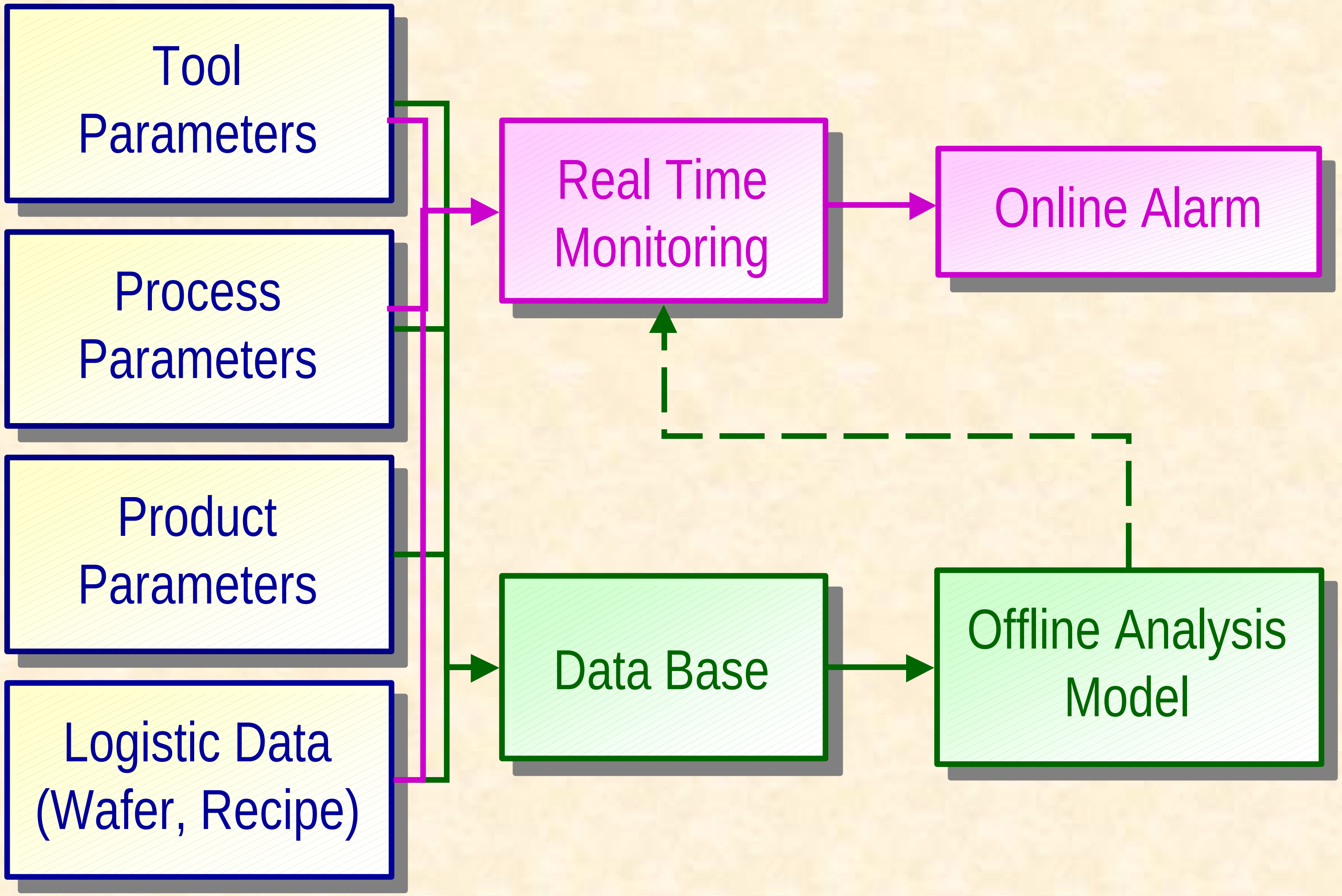
- In semiconductor manufacturing the ratio of electrical data to inline data is appr. 30 : 1.
  - Extension of data sources is urgently needed - improvement of the effectivity of PE-Analysis can be achieved.
- Sophisticated yield analysis methodology vs. data processing of unit process mastering.
  - 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 ➔ scrap lots.
  - Data bridging - determination of alarm limits w/ correlation between tool-, process- and product data .

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

Basic APC aspects: Offline analysis and real time process control including alarms



Ute Nehring
Product Engineering

Andreas Steinbach
Center for Development and Innovation

Infineon Technologies Dresden

APC

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

Data compression

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

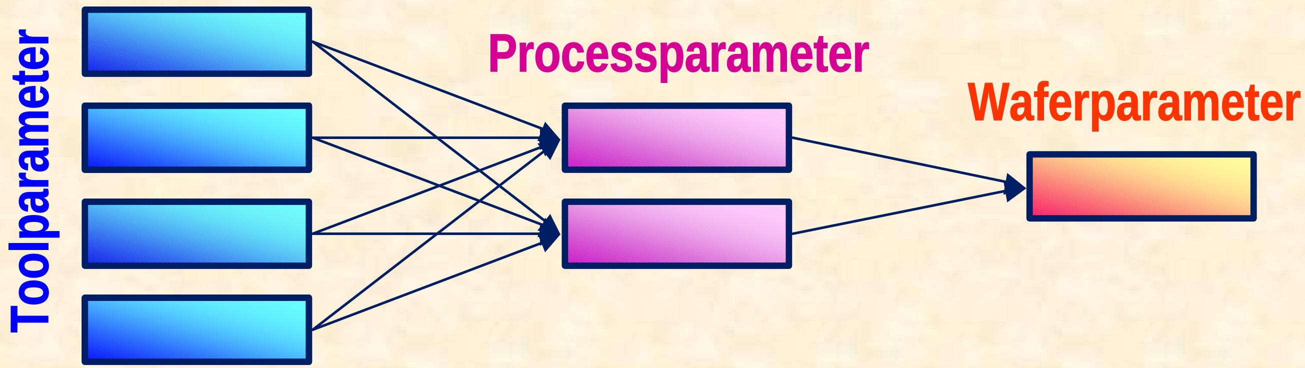
- The broad measurement of process and tool parameters creates very large amounts of data additionally - no implementation of APC w/o data compression
- How to compress large amounts of data ?
  - Using of smart „Intelligent“ sensors - calculation of relevant process parameters using raw data in real 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.**

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

01.03.2001
Page 10

Data compression by use of process models

Input

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

Input (perturbation)

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

Process Behaviour (Black Box)

Output (Responses)

- Yield
- Electrical Parameter

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

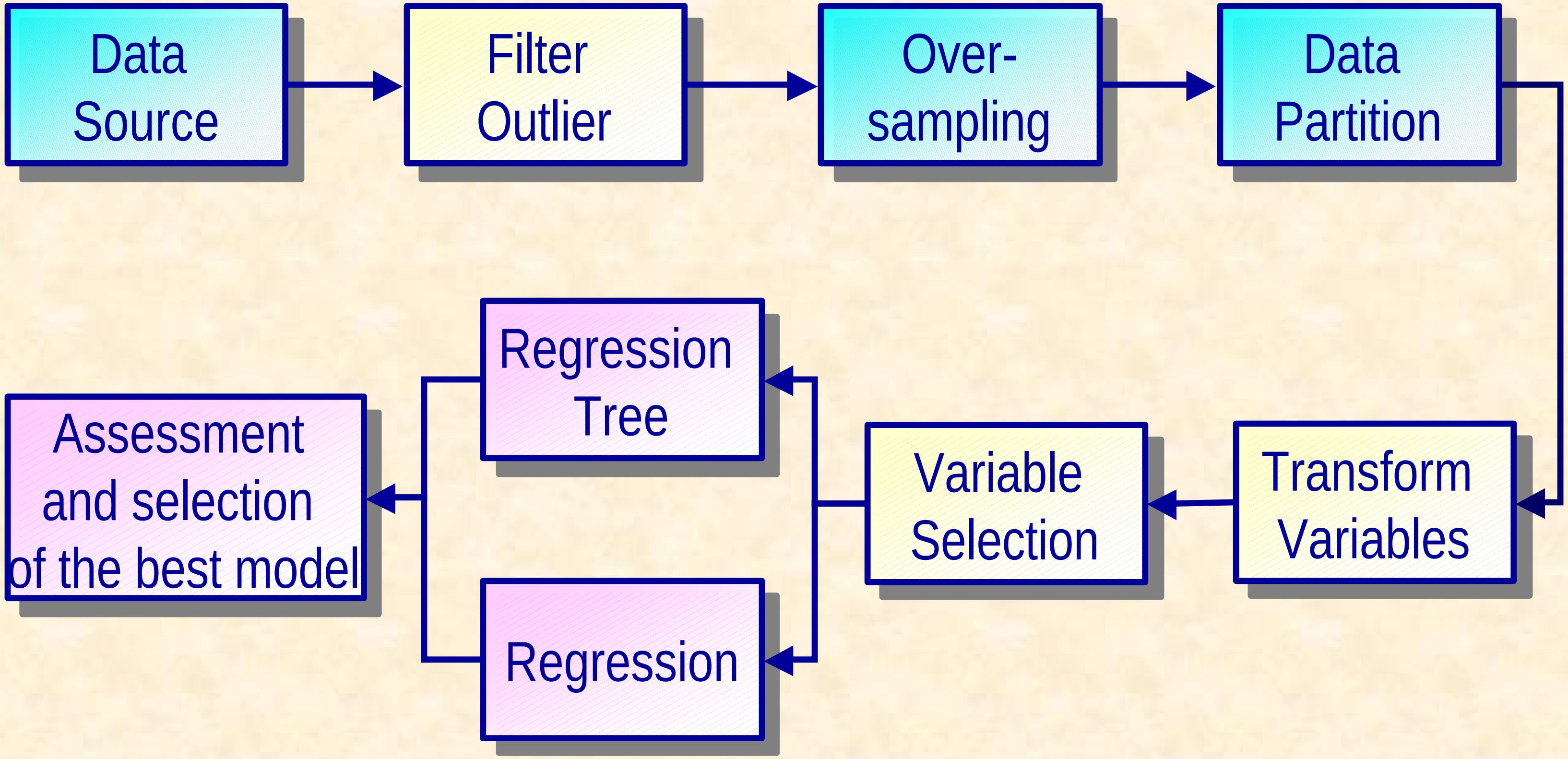
Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

Data Mining

Data Mining workflow



Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

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, NF_3 - chemistry.
  - Over etch - HBr, He/O_2 - chemistry.
- Data obtained by collecting of tool data and measurement w/ 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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies
Dresden

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

01.03.2001

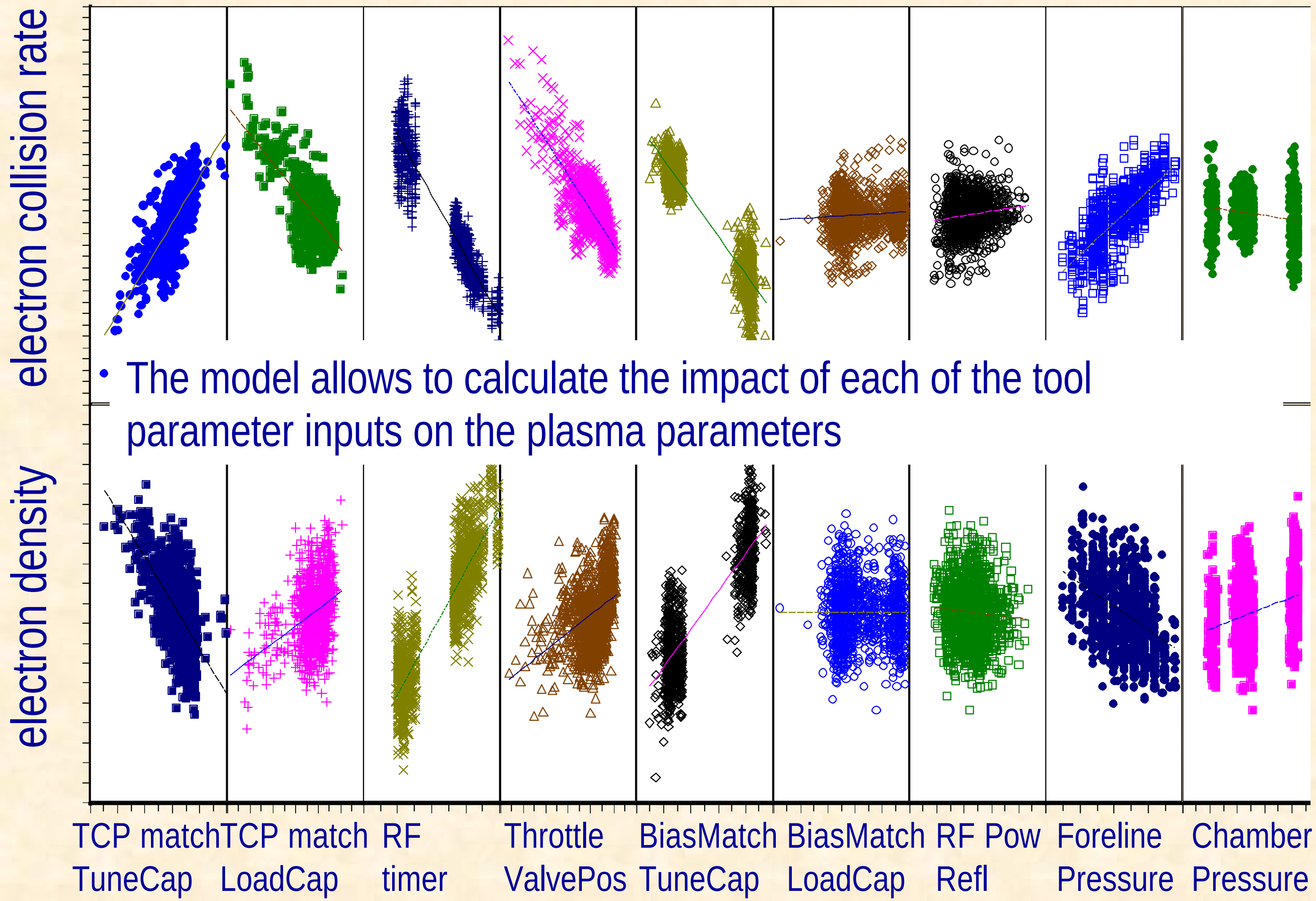
GC etch at LAM TCP – Correlation between plasma parameters and tool parameters

GC main etch: Correlation between plasma parameters and tool parameters

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies
Dresden

Project PULSAR

01.03.2001
Page 18



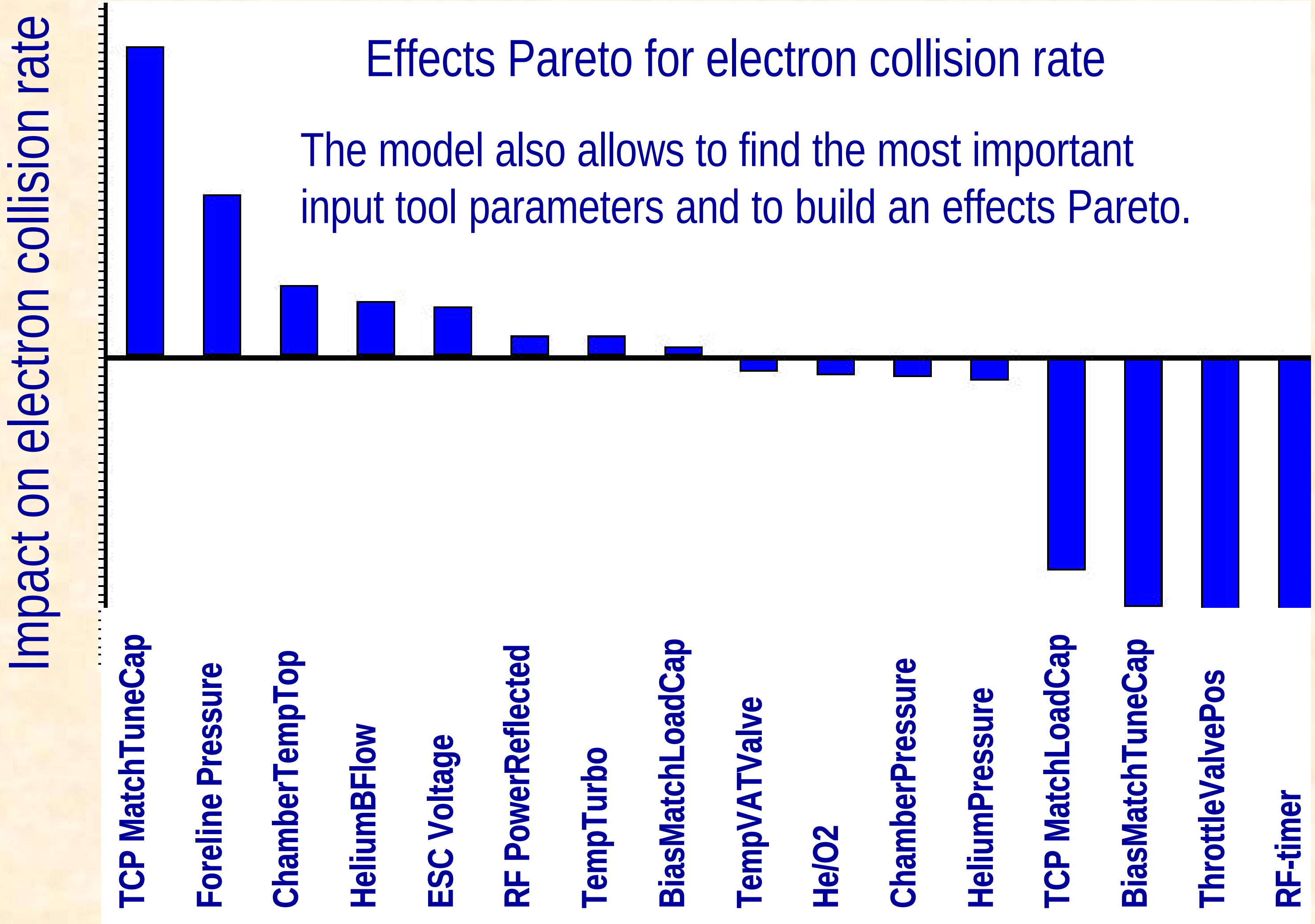
- The model allows to calculate the impact of each of the tool parameter inputs on the plasma parameters

GC main etch: Correlation between plasma parameters and tool parameters, cont.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR



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.

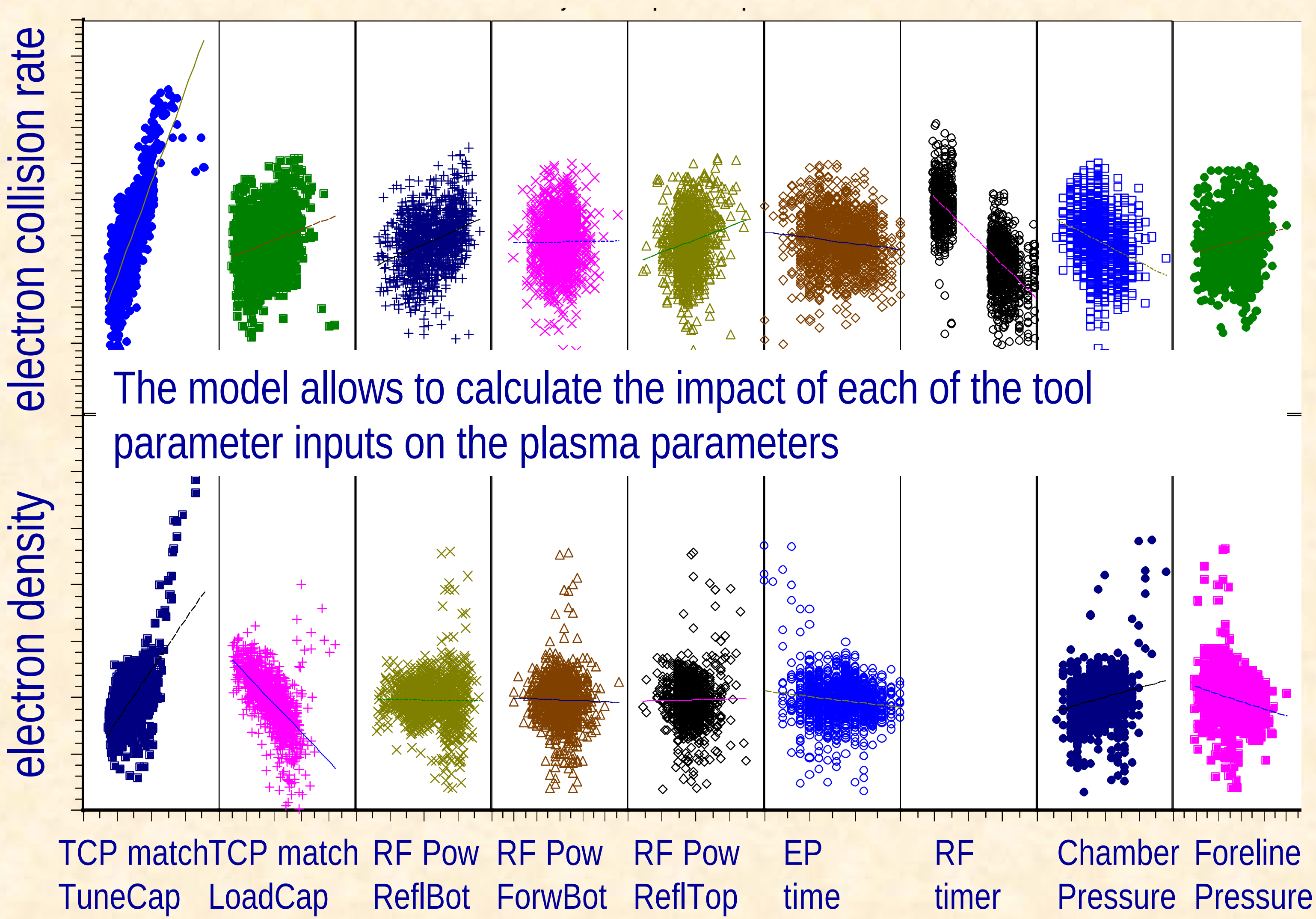
Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

GC over etch: Correlation between plasma parameters and tool parameters

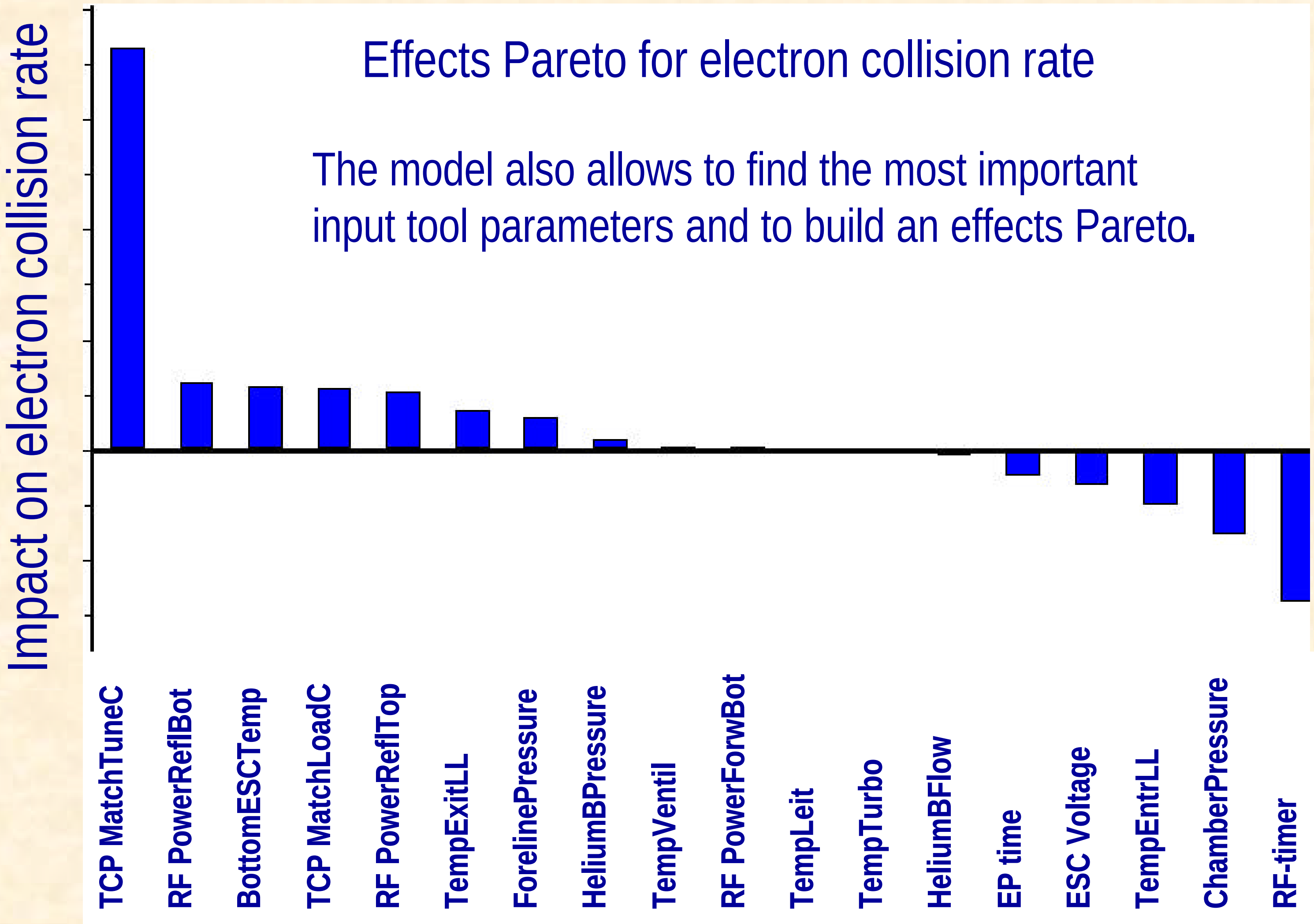
Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies
Dresden

Project PULSAR



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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

GC etch at LAM TCP – Correlation between plasma parameters and electrical product parameters

Project PULSAR

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).

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

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.

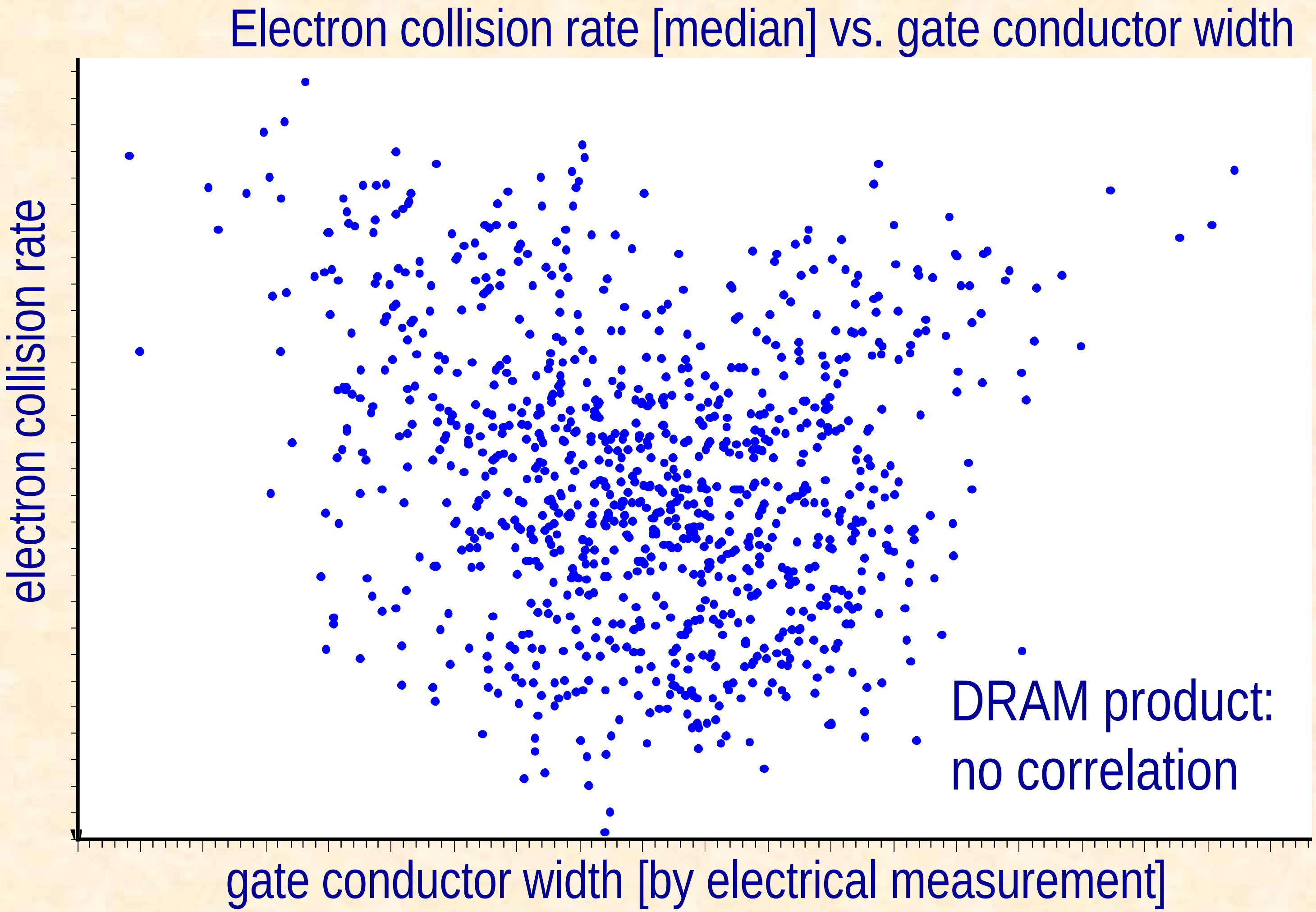
Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

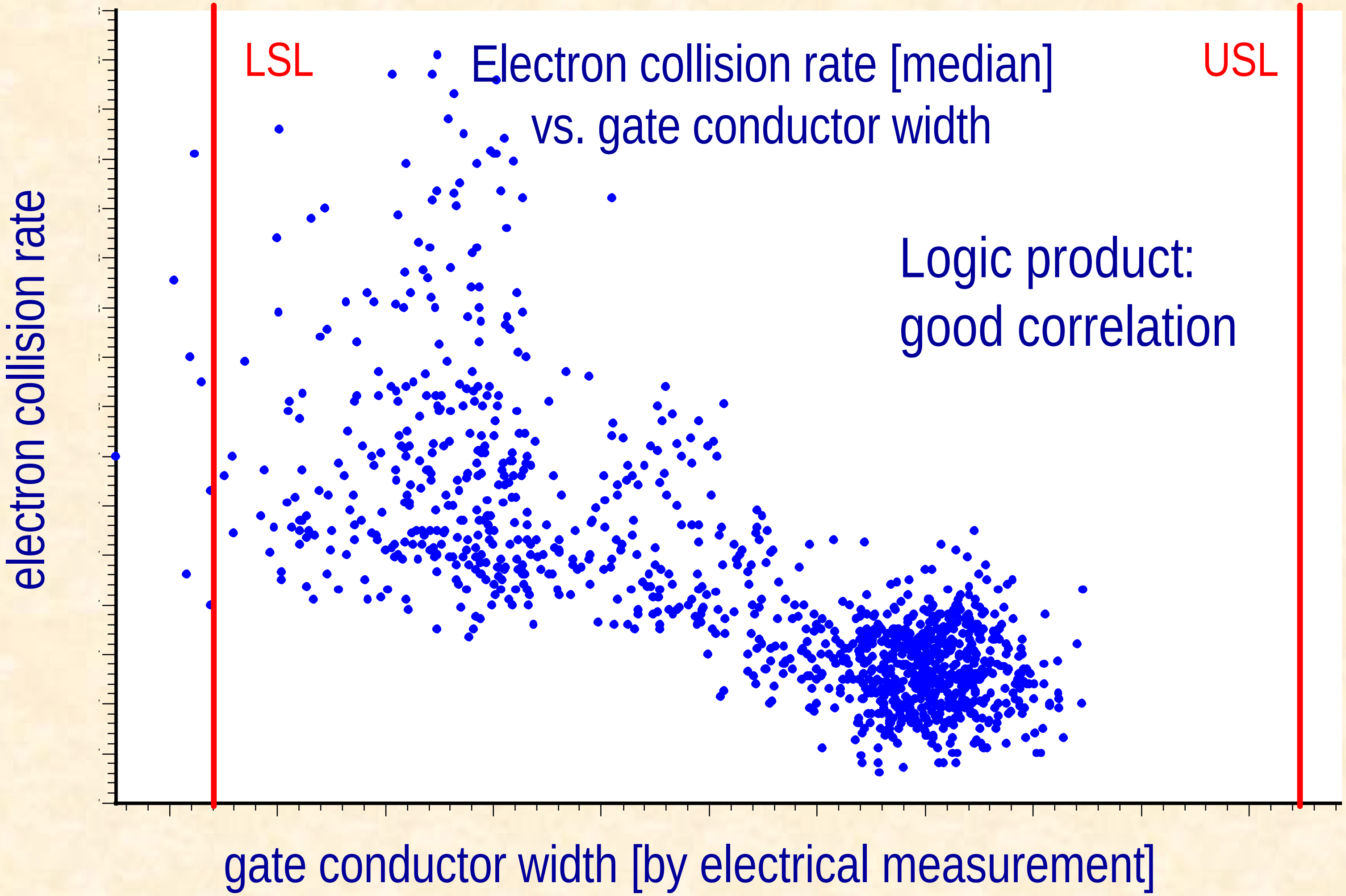
DRAM, GC over etch: No correlation between electron collision rate & gate contact width

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR



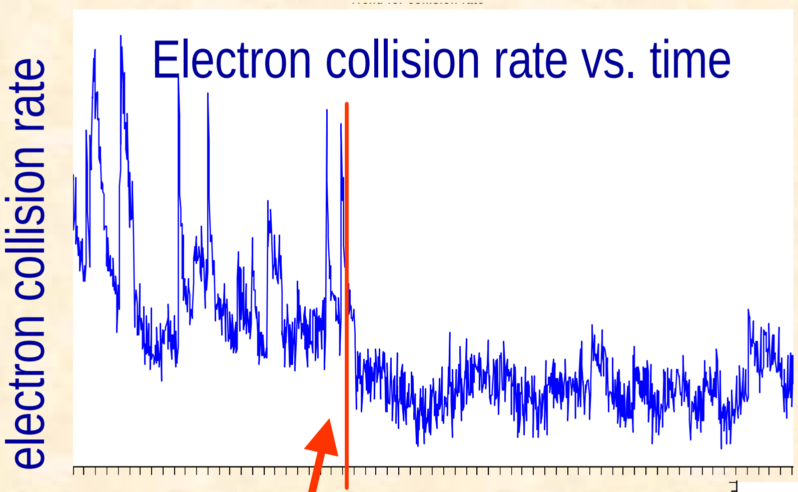
Logic, GC over etch: Correlation between electron collision rate & gate contact width



Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

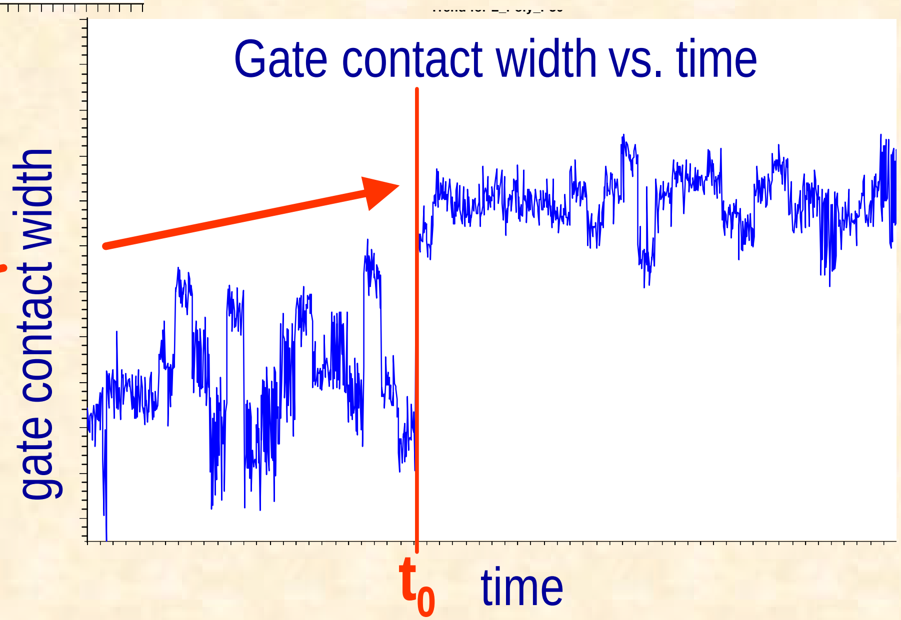
Project PULSAR

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.

t_0 - introduction of process mix change (soft chamber dedication)



Ute Nehring
Product Engineering

Andreas Steinbach
Center for Development and Innovation

Infineon Technologies Dresden

APC

Project PULSAR

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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

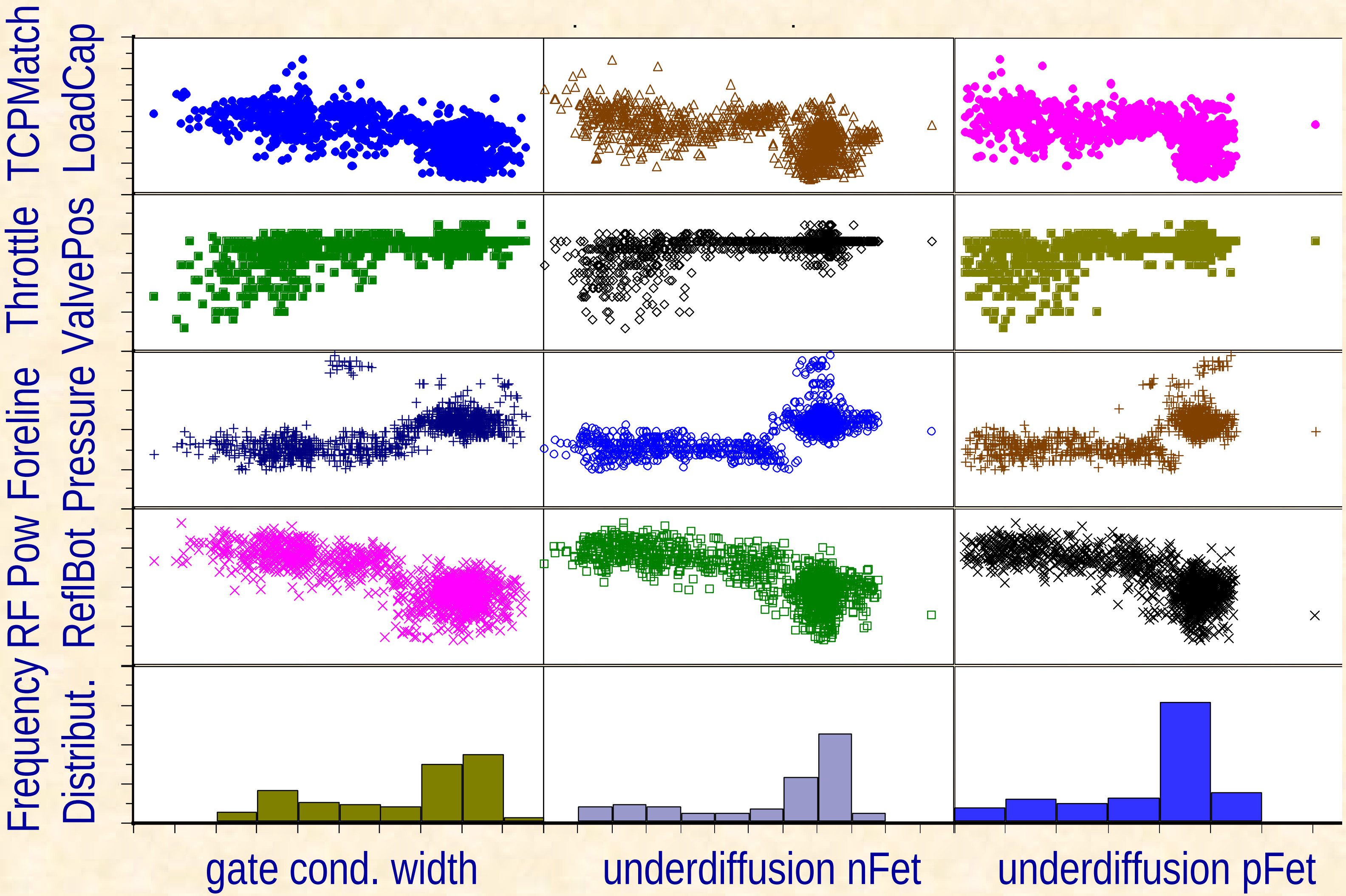
Project PULSAR

GC etch at LAM TCP – Correlation between tool parameters and electrical product parameters

Logic, GC over etch: Correlation between tool parameters & electrical parameters

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies
Dresden

Project PULSAR



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.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project PULSAR

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

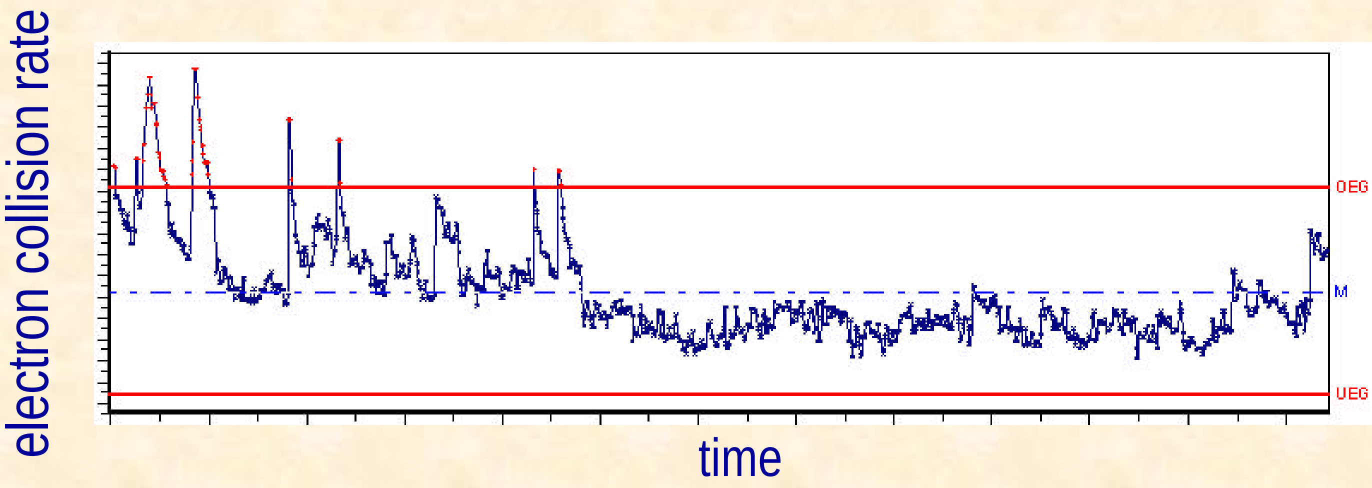
Project PULSAR

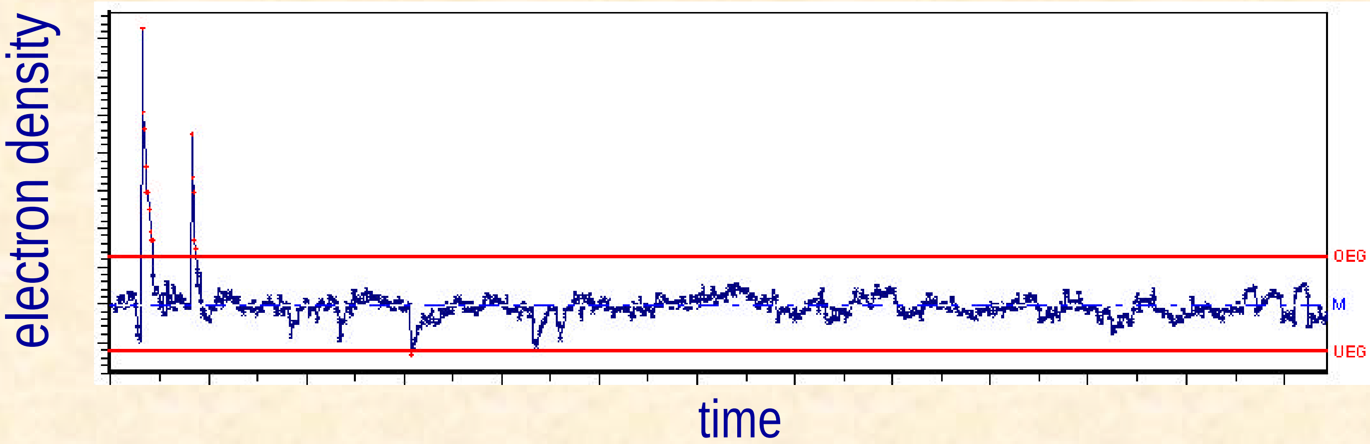
Calculation of control charts for plasma parameters

Logic, GC over etch: Calculation of plasma parameter control charts

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR





Due to unstable mean an extended Shewhart chart was calculated.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR

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 a acceptable mix of DRAM and logic products in the same chamber.
- This is a way to remove the chamber dedication.

Ute Nehring
Product Engineering
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Project PULSAR