Supervision of Plasma Processes using Multi-Way Principal Component Analysis

Dirk Knobloch
Ferdinand H. Bell
Infineon Technologies AG
Munich, Germany

Jan Zimpel
Knut Voigtländer
Fraunhofer IVI Dresden

Outline

- Introduction - Supervision of plasma processes
- Experimental - Features of OES spectrometer
- Advanced data processing methods
  - Standard methods (mean value, PCA, etc.)
  - Multi-Way Principle Component Analysis (MPCA)
- Multi Way PCA for contact hole etch
  - Interpretation of MPCA scores for process and tool phenomena
  - Monitoring of thermal and chemical chamber condition
  - Analysis of OES- Endpoint Signals
- Conclusion

Dirk Knobloch
Ferdinand H. Bell
Infineon
Technologies
Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
IVI Dresden

Introduction

Equipment Data

int. & ext. sensors

data processing

Information

relevant key numbers per wafer, recipe, tool

actions

Improvement

equipment and process stability, productivity, quality

- Data collection in high volume production creates large amount of data

➜ Data compression for key number extraction is essential

Dirk Knobloch
Ferdinand H. Bell
Infineon Technologies
Jan Zimpel
Knut Voigtländer
Fraunhofer Institut IVI Dresden

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- Focus:

Optical Emission Spectroscopy

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Dirk Knobloch
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Infineon Technologies
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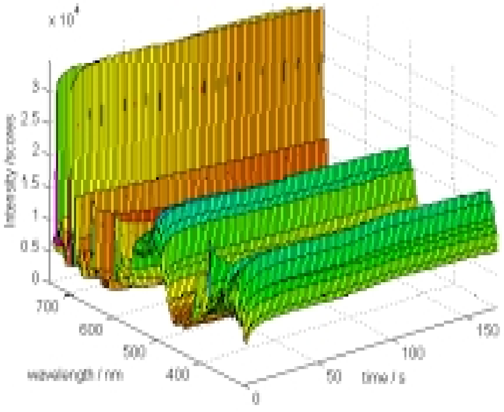
Knut Voigtländer
Fraunhofer Institut IVI Dresden

Features of Hamamatsu Spectrometer MPM



- spectral range: 200 - 950 nm
- resolution: < 2 nm
- CCD line channels: 1024
- connection to Host PC via TCP-IP, RS 232
- internal data processing for endpoint detection; up to 100 endpoint scripts are available
- digital/analog ports for connection to etch tool

All experiments conducted on an AMAT MxP+ etch chamber (200mm)

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Infineon
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Knut Voigtländer
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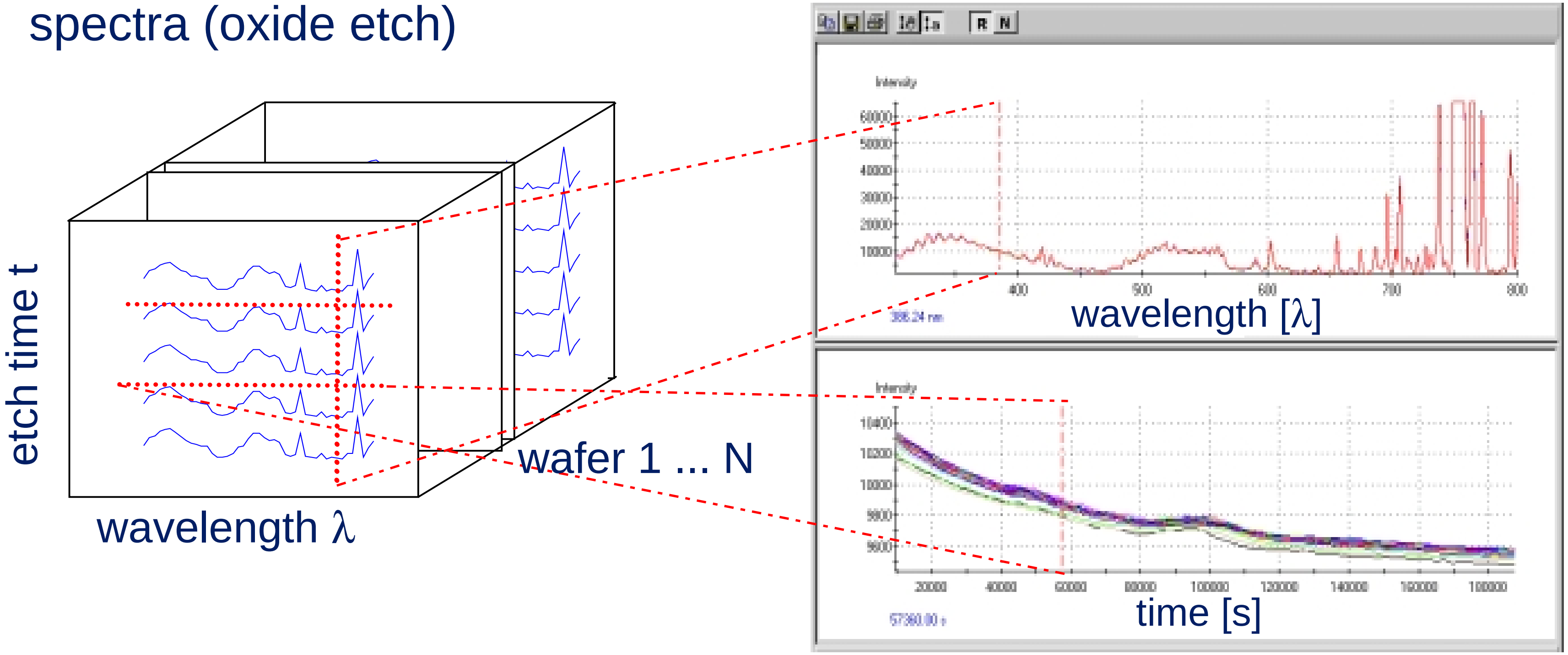
Optical spectra visualized as a „Data cube“

3 dimensional data cube containing OES spectra (oxide etch)

Vertical and horizontal cut through data cube



Challenge: to obtain methods for extraction of key-numbers for long-term process monitoring, process diagnostics and fault detection

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Ferdinand H. Bell
Infineon Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut IVI Dresden

Advanced data processing methods

<u>Standard: *univariate* key number extraction</u>

- 1. Simple key-numbers
  - mean value
  - standard deviation
  - time duration of process steps
- 2. Extraction of key-numbers using signal decomposition
  - application of Tschebyscheff functions
  - adjusted signal base decomposition (PCA) →
- 3. Adaption for a nonlinear parametric signal model

<u>*multivariate* key number extraction</u>

⋮

- 2. Extraction of key-numbers using signal decomposition

⋮

  - Multi-Way PCA (MPCA)

⋮

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Dirk Knobloch
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Infineon
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Knut Voigtländer
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Multi-Way Principle Component Analysis (MPCA)

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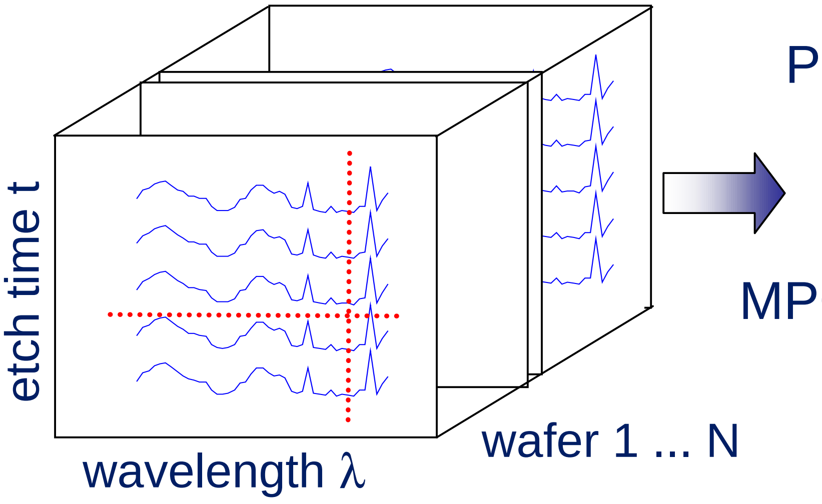

PCA: $$\mathop{}_{i} M(i,n)\cdot u_i(\lambda)$$

MPCA: $$\mathop{}_{j}\ \mathop{}_{i} M(i,j,n)\cdot u_i(\lambda)v'_j(t)$$

$$\text{for } n=1,\ldots,N$$

- "standard PCA": use of <u>one mean spectrum</u> per wafer
  - wavelength but no time dependency per wafer
- Multi Way PCA: Calculation of orthogonal wave pattern u_i and orthogonal base time signals v_i by unfolding the original data cube in <u>time and wave</u> direction
  - wavelength and time dependency per wafer

Dirk Knobloch
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Infineon Technologies
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Fraunhofer Institut
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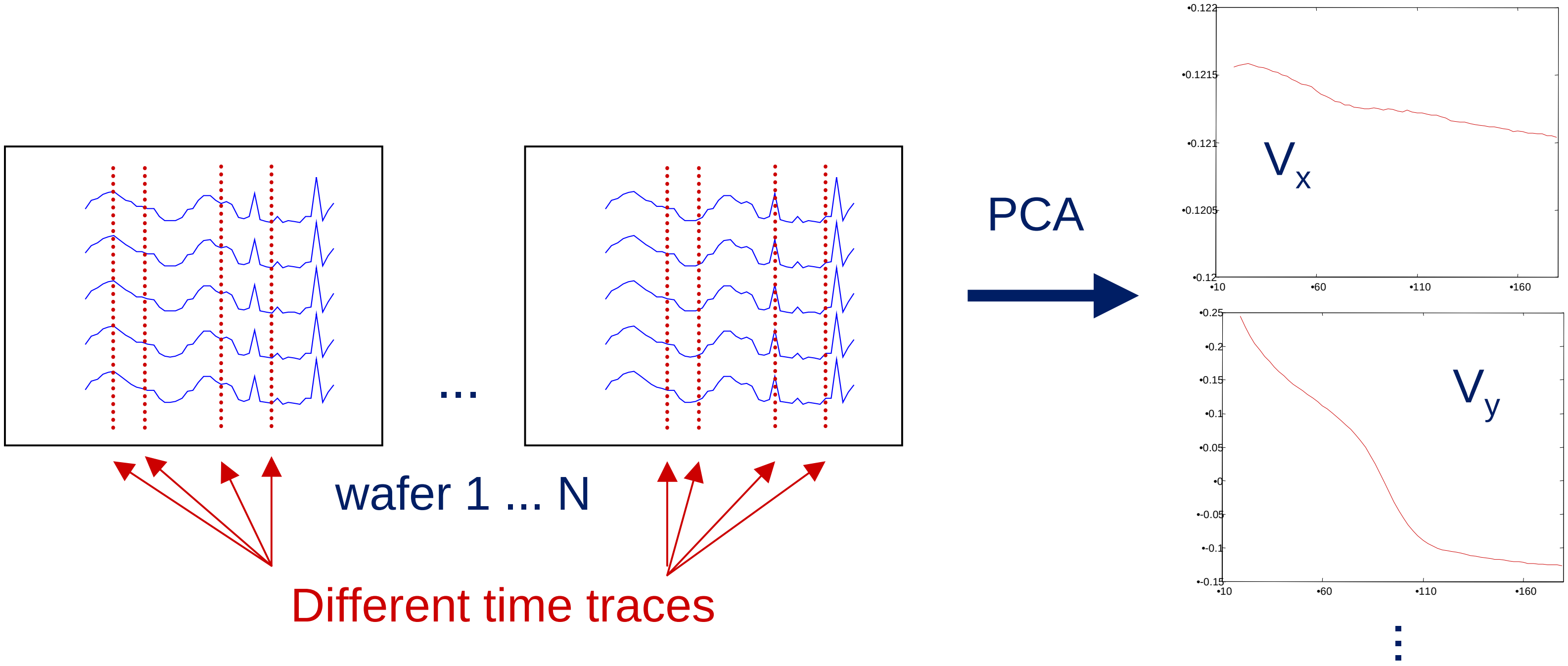
Multi-Way Principle Component Analysis (MPCA)

- 1^{st} step: PCA of all time signals
  - calculation of the time signal pattern $\mathbf{v}_j$
  - in the calculation included 1024 (number of channels) x N* time traces
  - result: 1024 x N time signal patterns $\mathbf{v}_j$

*N = number of wafers



PCA

wafer 1 ... N

Different time traces

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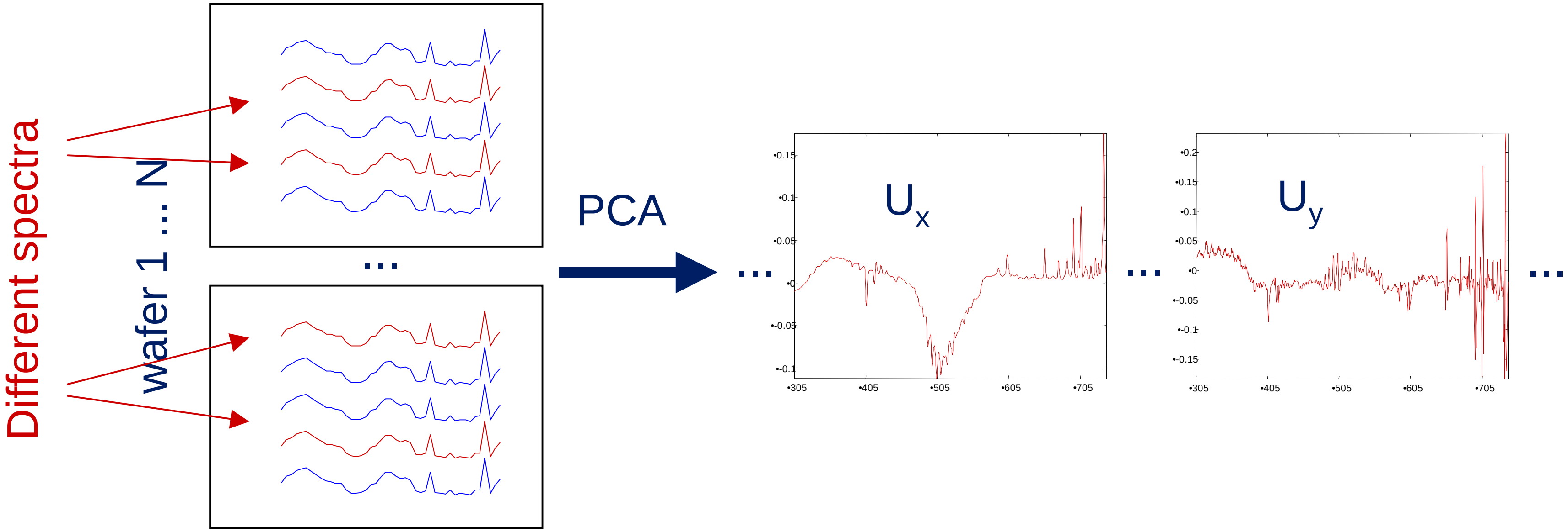
Dirk Knobloch
Ferdinand H. Bell
Infineon Technologies
Jan Zimpel
Knut Voigtländer
Fraunhofer Institut IVI Dresden

Multi-Way Principle Component Analysis (MPCA)

- 2^{nd} step: PCA of all wavelength spectra
  - calculation of the wavelength pattern $\mathbf{u}_i$
  - in the calculation included Y (=number of spectra for each wafer) x N
  - result: Y x N wavelength patterns $\mathbf{u}_i$



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Ferdinand H. Bell
Infineon
Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
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Multi-Way Principle Component Analysis (MPCA)

- 3rd step: calculation of the scores $M(u_i,v_j,n)$, n=1...N
  - orthogonal patterns for time signal (v_j) and wavelength (u_i)
  - apply patterns on raw data of the optical emission spectra for each wafer
  - results in the scores $M(u_i,v_j,n)$
  - reconstruction of the raw data of optical emission spectra:

$$\underset{j}{}\;\underset{i}{}\; M(i,j,n)\cdot u_i(\lambda)v'_j(t)$$

$$\text{for } n = 1,\dots,N$$

  - number of useable patterns depends on information content of process data

Dirk Knobloch
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Infineon Technologies
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Fraunhofer Institut
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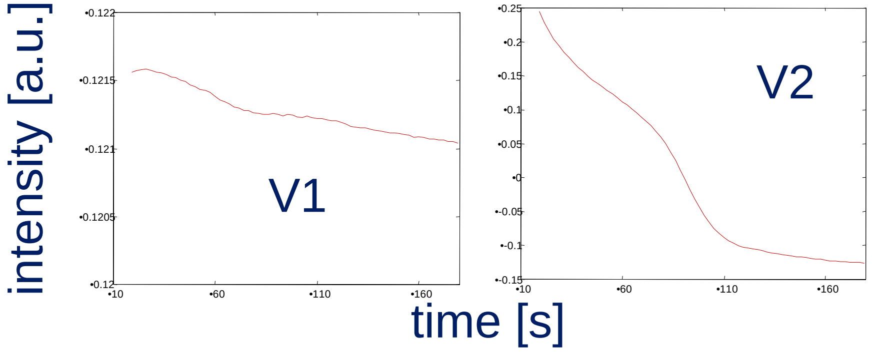
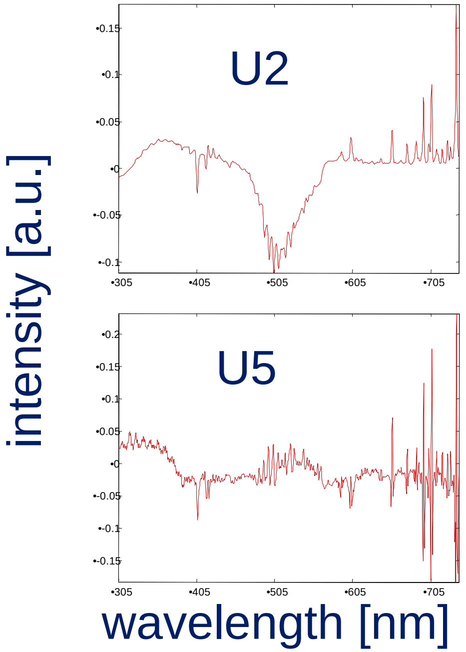
Example: Multi Way PCA for contact hole etch

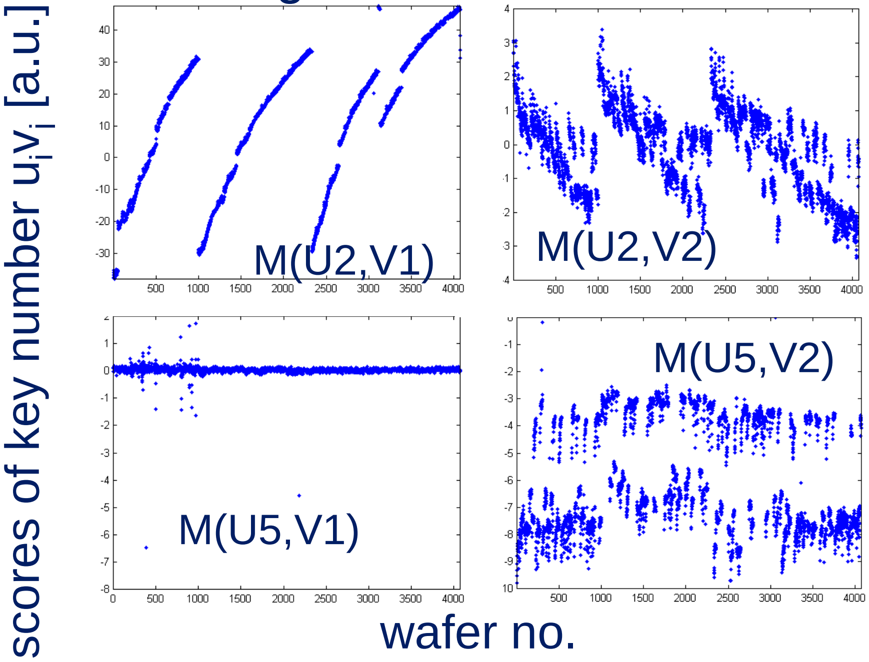
extracted time signals v_j →

extracted wave pattern u_i ↓





resulting MPCA scores vs. wafer



Dirk Knobloch
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Infineon
Technologies
Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
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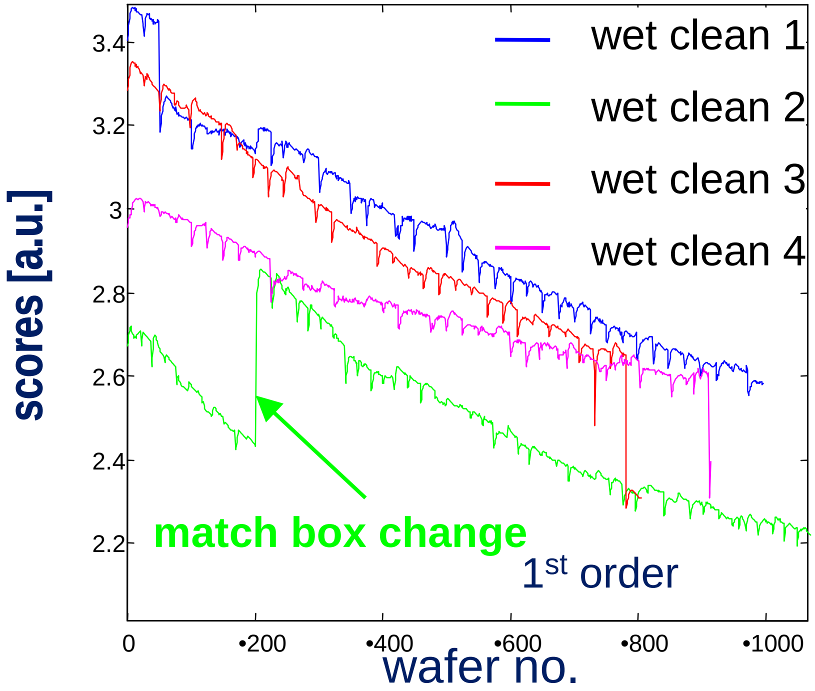
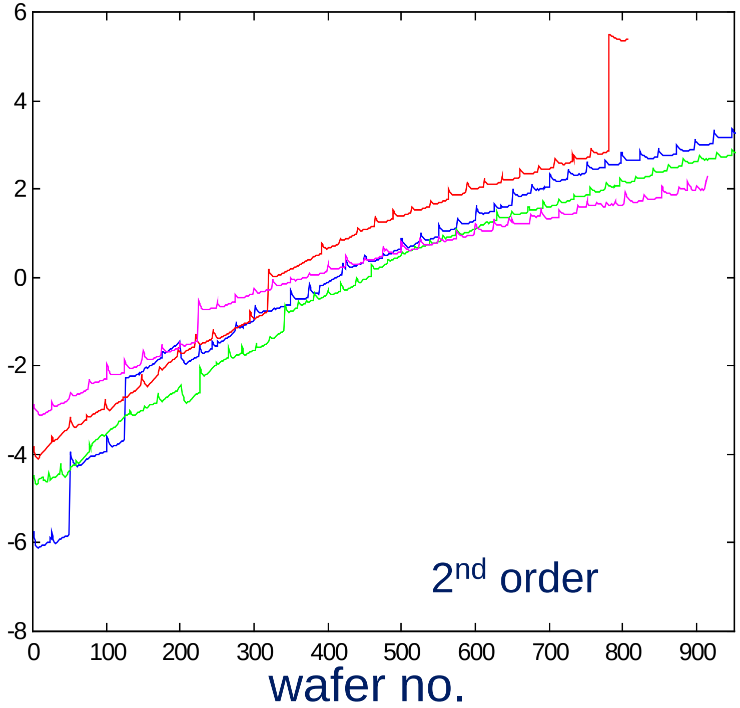
MPCA scores - no process mix

scores of 1st and 2nd order of wet clean cycles (1..4) [time signal of 1st order]





Score correlations:

- 1st order score: - match box change
  - decrease of scores through decreasing light transmission caused by polymer coating during wet clean
- 2nd order score: - increase of scores caused by interaction between chamber wall and plasma

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Ferdinand H. Bell
Infineon
Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
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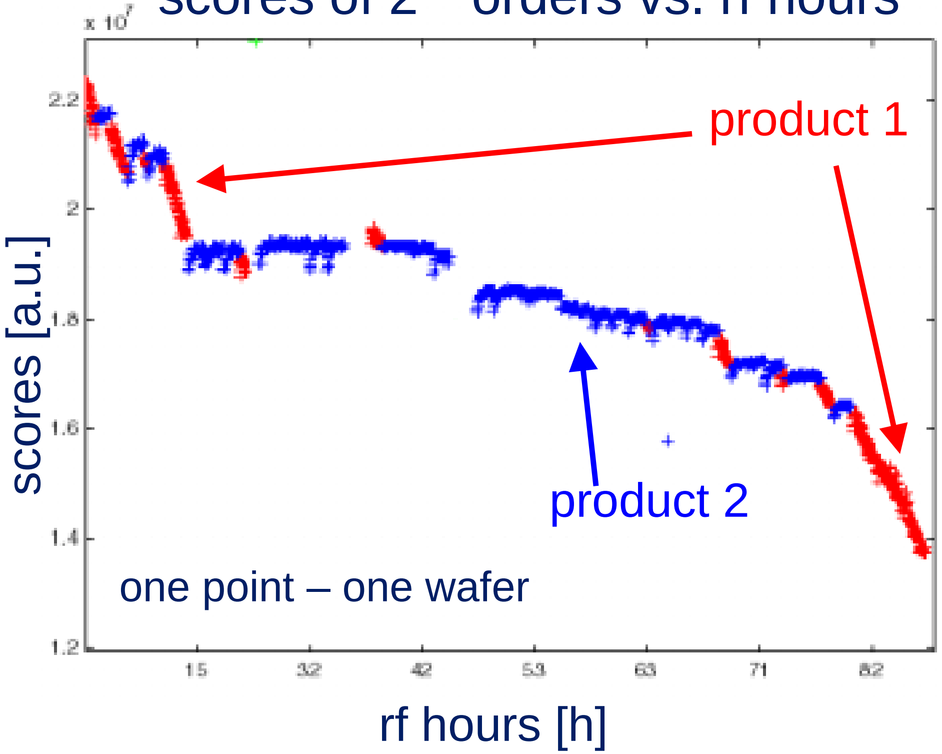
MPCA scores - process mix

- two products with high (product 1) and low (product 2) polymerizing gas chemistries
- scores of 2nd order [time signal of 1st order] during 1 wet clean cycle

scores of 2nd orders vs. rf hours



one point – one wafer

- scores of product 1 decrease significant more than scores of product 2
- caused by different behaviour of chamber polymerization
- results in varying duration of wet clean cycle

↓

- scores are used to determine optimum wet clean cycles as a function of process mix

Dirk Knobloch
Ferdinand H. Bell
Infineon Technologies
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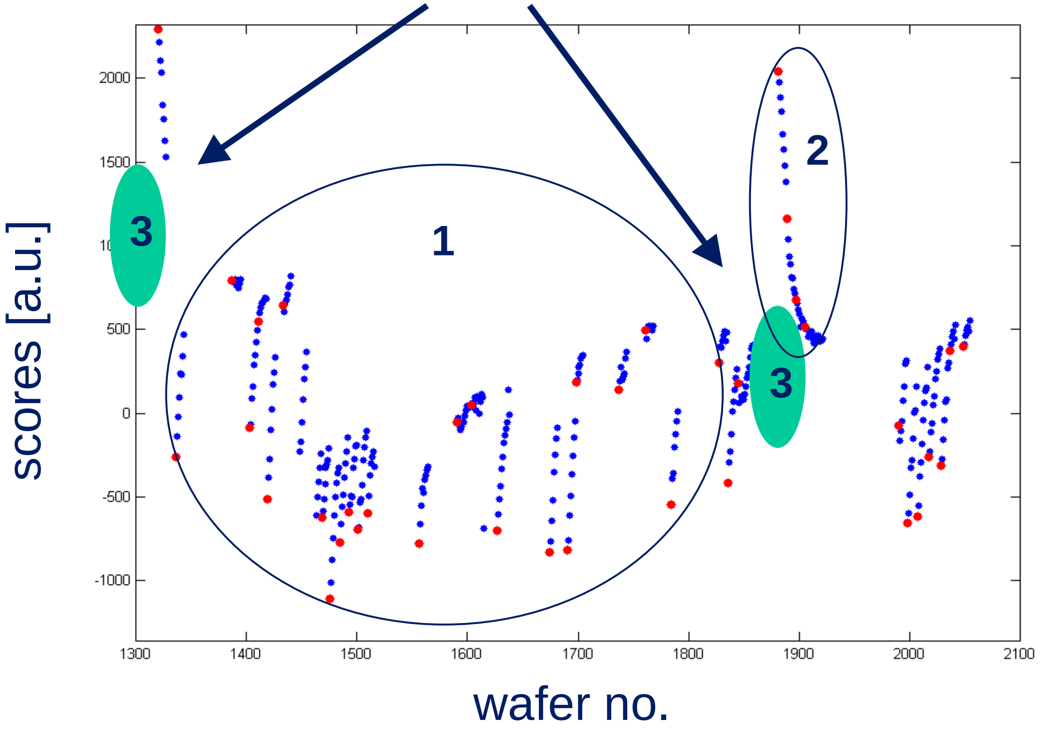
Knut Voigtländer
Fraunhofer Institut IVI Dresden

MPCA scores - thermal and chemical variations caused by process mix

- scores of 4th order [time signal of 1st order] during 1 wet clean cycle

Process with different gas chemistries



- different conditioning effects caused by product mix
  - **(1)** typical behavior for 1st wafer effect
  - **(2)** inverse 1st wafer effect caused by de-conditioning of the chamber through different pre-process **(3)**

↓

- scores are used to characterize memory effects

Dirk Knobloch
Ferdinand H. Bell
Infineon
Technologies
Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
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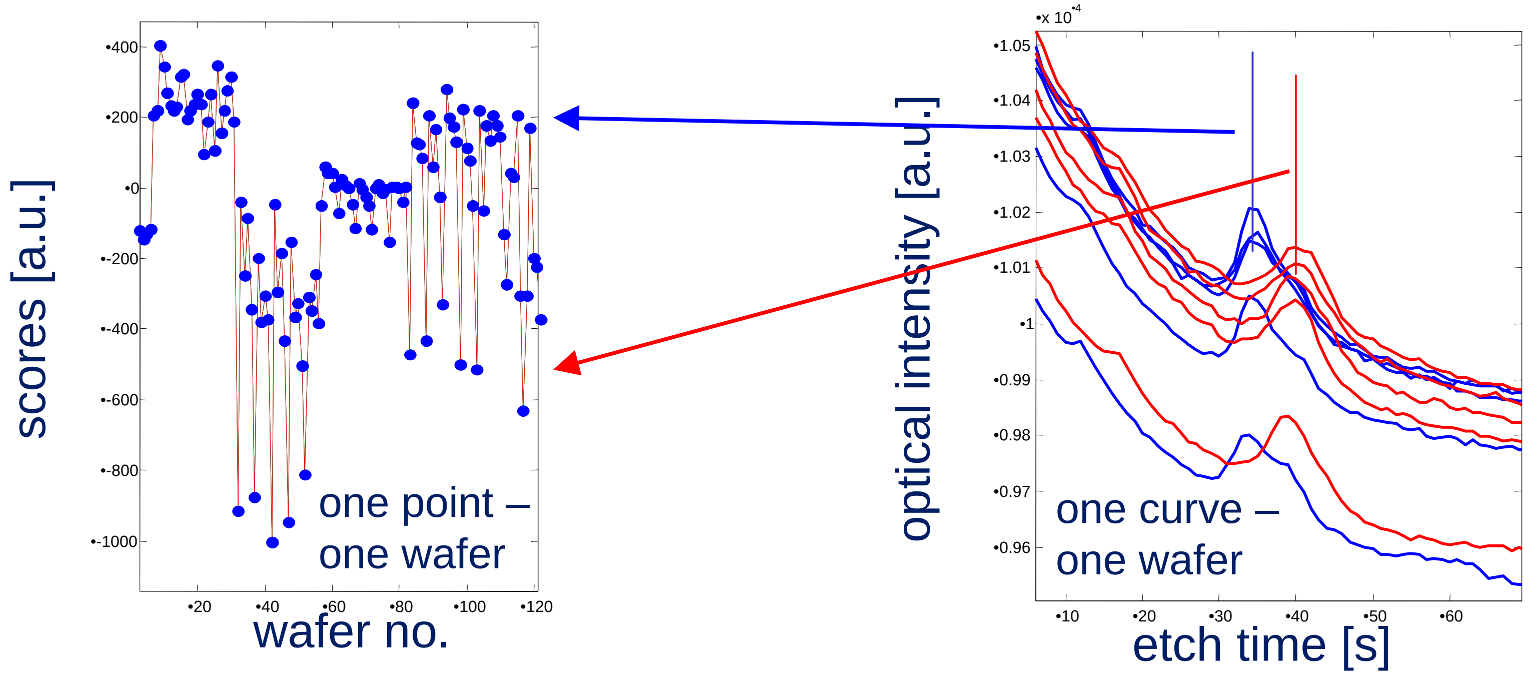
MPCA scores - correlation with variations in endpoint behavoiur

- scores of 5th order [time signal of 6th order]

scores vs. wafer

optical endpoint signal vs. etch time



- endpoint signal depends on previous process step variations (e.g. CMP, CVD, etc.)
- scores characterize variatons in endpoint signal behaviour
- scores are used to determine stability of previous process steps

Dirk Knobloch

Ferdinand H. Bell
Infineon
Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
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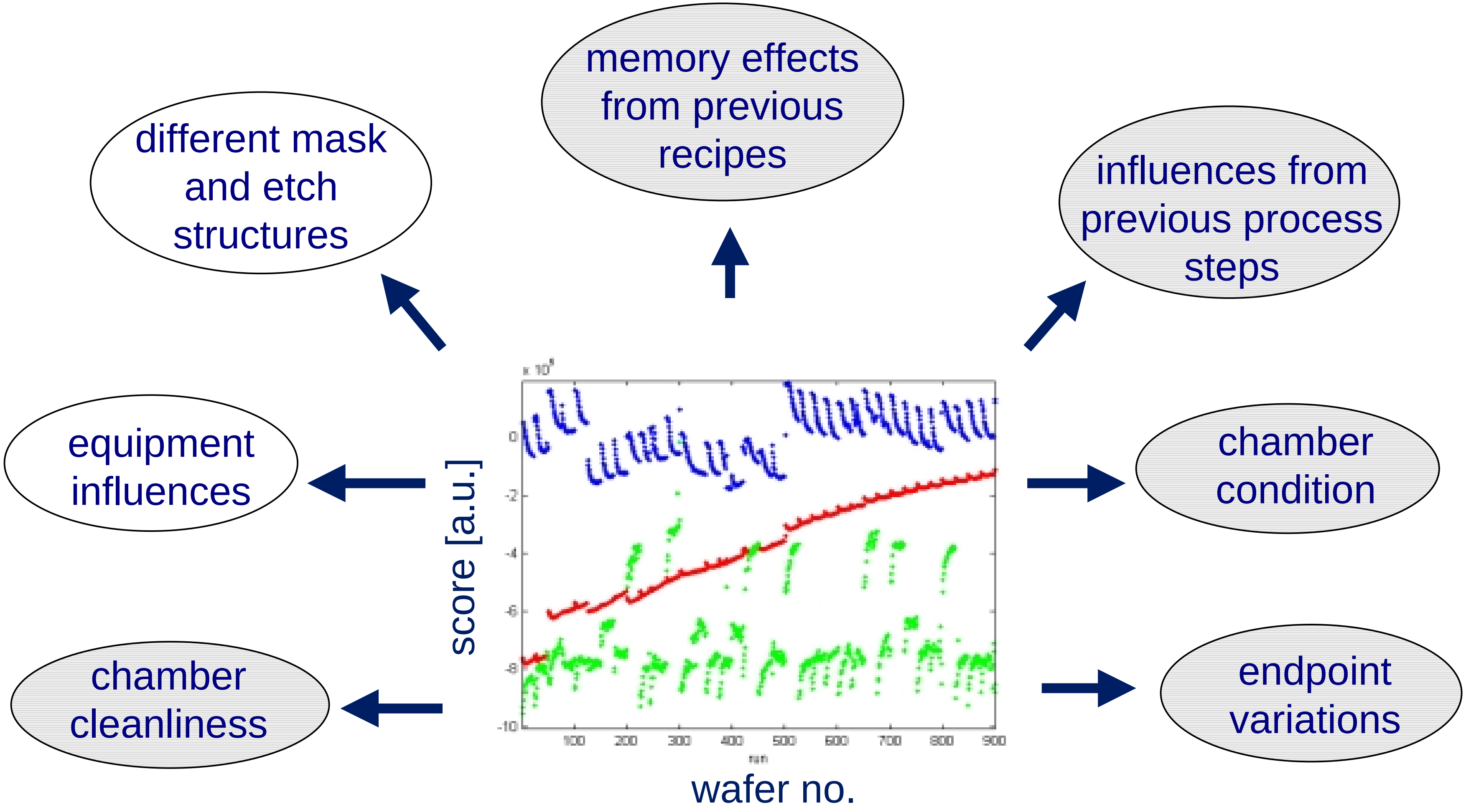
Summary of process and tool phenomena as characterized using Multi Way PCA



different mask and etch structures

memory effects from previous recipes

influences from previous process steps

equipment influences

chamber condition

chamber cleanliness

endpoint variations

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Infineon
Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
IVI Dresden

Conclusion

The supervision of plasma processes using Multi-Way Principal Component Analysis (MPCA) has been demonstrated for an oxide contact hole etch process

- The MPCA decomposition technique pinpoints **significant** process and equipment key numbers
- The MPCA analyses allows process and equipment monitoring, such as characterization of
  - first wafer effect, chamber cleanliness, process mix
- The MPCA is powerful in qualitative analysis of endpoint traces
  - robust endpoint analysis of endpoint traces as a function of previous processes

Dirk Knobloch

Ferdinand H. Bell
Infineon
Technologies

Jan Zimpel
Knut Voigtländer
Fraunhofer Institut
IVI Dresden