Robust and Interpretable Multivariate Process Control of Temporal Wafer Data

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Agenda

- Motivation
- Methodology
- Advantages
- Real data example
- Conclusion
Motivation

**Conventional process monitoring:**
Fault detection and classification system to monitor complex equipment operations using

- univariate process control schemes
- advanced process control with multivariate techniques
- condensed data (mean, min, max, …)

**BUT: Information on time variation is lost**
Motivation

Wafer processing typically records data in 3 dimensions:

- wafers
- process variables
- process time points
Motivation

Wafer processing typically records data in 3 dimensions

- wafers
- process variables
- process time points

→ multi-way array
Methodology

Suitable analysis method: multi-way principal component analysis

- decomposition of array into $C$ components
- one score value per wafer per component

Original Data = Score x Loading + Error

Error array
Methodology

Multi-way principal component analysis

- scores hold information of variation over process time
- monitor wafers via score values
- multivariate process control via Hotelling’s $T^2$
Methodology

A useful process control approach should be

• robust against noise / measurement errors / other outliers
• interpretable for engineers to determine root cause of problems
• capable of real-time production monitoring
A useful process control approach should be robust against outliers.

In model building phase use:

- robust estimation of mean and covariance
- robust decomposition of multi-way array
A useful process control approach should be interpretable and allow root cause analysis

- consolidate process variables into functional blocks
- use multiblock approach
- PCA scores become meaningful
- $T^2$ monitoring for each block
A useful process control approach should be capable of real-time production monitoring

- use time variation information for on-line monitoring
- on-line multivariate process control
- problem detection & diagnosis while wafer is processing
Advantages

- outliers do not influence model
- functional block building allows interpretation
- on-line multivariate process control of wafer
Advantages

Process control & root cause analysis of every data dimension

Which wafers are affected?

Which variables show problems?

In which process step do problems occur?
Case study
Magnetic field failure of plasma etch process (VIA etch on AMAT Centura)

- severe etch rate decrease
- no classical univariate alarms

Data from June 2011:
- 400 good wafers for model building
- 460 wafers for comparison (faults included)

16 variables in 5 functional groups:
- **Process Gas Flow Group** (Ar, CF4, CHF3, N2)
- **Endpoint Group** (Endpoint Time, Endpoint Trace)
- **Pressure Group** (Foreline Pressure, Chamber Pressure, Throttle Valve Step)
- **Helium Group** (Backside Cooling Parameters)
- **RF Group** (Load Position, Tune Position, Reflected Power)
Case study
Magnetic field failure of plasma etch process

Which wafers are affected?
→ Robust $T^2$ signal of score values over functional groups *Endpoint, Pressure, Helium & RF*
Case study
Magnetic field failure of plasma etch process

*Which variables show problems?*
Case study
Magnetic field failure of plasma etch process

In which process step do problems occur?

→ Real-time monitoring for fault detection every time a data point is recorded
Outlook

**Drawback:**
Approach assumes linearity in data

**BUT:**
Process variables often show *nonlinear characteristics*

**Improvement:**
use *kernel methods*

- transform input data via nonlinear function
- model transformed data to capture nonlinear characteristics
- use multi-way multi-block approach
Conclusion

- multi-way analysis utilizes full temporal data information of wafer
- multivariate process control
- robust against noise / measurement errors / other outliers
- supports fault diagnosis & root cause analysis
- on-line monitoring
Thank you

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