Data Mining in Manufacturing:
5 Years Experience
at ALTIS Semiconductor
Jean-Luc GROLIER

SAS FORUM GENEVA 2006
Agenda

- Altis Semiconductor
- Manufacturing Context
- Yield Monitoring with Data Mining
- Yield Improvement with Data Mining
- Conclusion
Altis Semiconductor

- Join Venture IBM & Infineon Technologies

- The largest advanced logic fab in Europe:
  - A capacity of 7,000 silicon wafers per week
  - 60% Copper - 40% Aluminum

- A major S/C Campus (60 ha - 40 km south of Paris):
  - A multicultural team of 2000 people from > 15 nations
  - European centers of 15 industry leaders

Partners: IBM, Air Liquide, TOPPAN, KLA-Tencor, Infineon, IGS, BOC Edwards, GEODIS
Altis ID Card

- **Products:**
  - Advanced CMOS logic, Embedded DRAM, mixed-signal technologies
  - **SOC Concept:** Integration on a chip of Logic, Memory & Analog devices
  - Minimum pattern size: 0.25 µm down to 0.11 µm

- **Markets:**
  - 40% Europe, 30% US, 30% AP

- **Total revenue 2005:** ~ 450 millions €

- **R&D investment 2005:** ~ 10% of total revenue

- **Certifications:** ISO 9002, ISO 14001, ISO 16949
System On a Chip

Source: TI
Integration scale

Board: 10 cm

Chip: 0.3 - 1 cm

Transistor: 0.13 µm
Number: 80 Millions

Copper Interconnections
5 to 8 levels
Our Market segments

Wide Range Of Applications

- Telecom
- Computer Peripherals
- Computer Graphics
- Computer Servers
- Internet & Networking
- Security
- Consumer
- Automotive & Industry
- Wide Range Of Applications
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**Manufacturing Context**

- **Manufacturing Clean Rooms:**
  - Surface: 35,000 m²
  - Specifications: < 1 particle/liter
  - Paris: 350,000 particles/liter

- **Manufacturing Steps:**
  - 300 steps / 800 Equipments
  - Cycle time: 1 to 2 months
  - Multiple Technologies / Products

- **Manufacturing Lots:**
  - 40 Lots / day
  - 25 Wafers / Lot
  - 100 to 3000 Chips / Wafer
  - 1000 Parameters / Chip
Manufacturing Context

- **Quality Controls**:  
  - Log = Logistic Flow of Manufacturing Lots  
  - Phy = Physical Measurements  
  - Def = Defects Detection

- **Electrical Yield**:  
  - Each Chip is electrically Tested  
  - Yield = # Good Chips / # Good & Bad Chips  
  - Yield = f (Log, Phy, Def)

- **Yield Improvement**:  
  - Focus on Yield Detractors (Log, Phy, Def)  
  - High Yield = Reduced Manufacturing Costs  
  - Rapid Yield Ramp-up = New Products Startup
Data Management System

- **Data Collection in DB2 DWH:**
  - **Multiple Data Sources:** raw material, equipment data & history, metrology, defect inspection, electrical data ...
  - **Different Data Aggregation Levels:** lot, wafer, chip
  - Large amount of Data to handle and retrieve
  - High level of Data Integrity to maintain in relational DB

- **Data Analysis on Centralised SAS server:**

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<th>Client/Server</th>
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<tr>
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Data Management System

- **Process**
  - OPR-1
  - OPR-2
  - MES-1
  - OPR-3
  - DEF-1
  - OPR-4
  - TEST

- **Operational DB**
  - Logistic Measurements
  - Contamination Test

- **Relational DB** (MVS or Unix)

- **Back Office** (Unix)
  - SAS

- **Front Office** (Windows)
  - SAS JMP
  - Emulation
  - SAS EM
Challenges of Data Analysis Solutions:

- Complexity of Data relationships ⇔ Specific analysis packages
- Diversity of Data ⇔ Flexibility and ease of Data access
- Specific user developments ⇔ Integrated Data Analysis Tool

In-House Development Capabilities:

- Expensive commercial solutions / not fully integrated
- SAS Programming Competence : Data Analysis Team
# Data Analysis Solutions

| **Specific ETL** | - Test calculator  
|                 | - Wafer Tracking loader  
| **Data Reporting** | - Automated Reporting  
|                  | - User defined profiles  
|                  | ~ 10000 graphics /week  
| **Wafer Map Reporting** | - Display of Yield Detractors  
|                      | - Web access  
|                      | ~ 1000 maps / day  
| **Interactive Data Analysis** | - Interactive Queries (GUI)  
|                        | - Data Restitution  
|                        | - Specific Analysis Modules  
|                        | - Deployment ~ 150 Engineers  

![TOP CRITICAL PARAMS](image)

![AG FONC](image)

![tools](image)
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**General Definition:**
- Data Mining is "the nontrivial extraction of implicit previously unknown and potentially useful information from data."
  (G. Piatetsky-Shapiro, W. J. Frawley)

**Altis Definition:**
- Specific Data Mining Approaches driven by Expertise
- Exhaustive Data coverage & fully automated Treatment
- Alerting & Decision made on Statistical Tests
- Results highlighted through easy visible representations
Yield Evolution

- Yield ramp up:
  - Different phases: development, ramp up & manufacturing
  - Different shapes: depending on technology & process complexity
Zoom on Yield trends:
- Drift detection ⇔ Yield Monitoring
- Baseline enhancement ⇔ Yield Improvement
Yield & Data Mining Objectives

**Yield Monitoring:**
- Reaction to unexpected Yield drift
- Unknown Root Cause mechanisms

  ➤ How to minimize and prevent any escape?
  ➤ How to find rapidly root cause mechanism?

**Yield Improvement:**
- Action for an expected Yield enhancement
- Process Change implementation

  ➤ How to perform exhaustive analysis?
  ➤ How to prevent any unexpected impact?
(1) “Bad Equipment” Detection:
- Yield = f (Operations-Equipments)
  - Tree decision
  - ANOVA

(2) “Bad Operation” Detection:
- Yield = f (Operations)
  - Proprietary algorithm

(3) Major Yield Detractors:
- Yield = f (Physical Measurements)
  - Mono/Multivariate regression
(1) “Bad Equipment” Detection

- EQ-B is “guilty”? 
  - 0 x EQ-B : Lot-X = 70% 
  - 1 x EQ-B : Lot-Z = 60% 
  - 2 x EQ-B : Lot-Y = 50%
(1) Tree Decision

**Wet Opération:**
- Known problem already detected
- Capacity Bottleneck
- Technical fixes on going.

**Anneal Operation:**
- Unknown problem!!
- Unknown mechanism to Experts!!
- High Yield Impact!!
- Stop Order of EQ-A & EQ-B
(1) ANOVA

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(2) « Bad Operation » Detection

● Objective :

- Explain: \( \text{Yield} = f(\text{Operations}) \)
- Slight «lot speed» variation at each operation
- Process Drift Factor calculated for each operation
- The smallest PDF -> the sharpest process drift

● Results :

- Emphasis of the drifting operation
- Additional investigations necessary to find the root cause
- Some clear findings of process degradation (recipe change or raw material quality problems)
(2) « Bad Operation » Detection

PDF
(Process Drift Factor)
(3) Major Yield Detractors

Objective:
- Explain: \( \text{Yield} = f(\text{Physical Measurements}) \)
- Univariate regressions preferred to multivariate
- Ranking of explanatory variables by correlation coefficients

Results:
- Fast, exhaustive review of all possible measurements
- Decision help to focus on major detractors (+ Data reduction interest)
- Unknown or unexpected relations found on many cases
(3) Major Yield Detractors

### Analyse de Corréléation

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**Yield Improvement Approaches**

- **Process Change Qualification**:
  - Old Process on EQ-A (reference)
  - New Process on EQ-B

- **Expectations**:
  - Yield or Performance improvement:
    - Yield(EQ-B) > Yield(EQ-A)
  - Productivity enhancement:
    - Yield(EQ-B) = Yield(EQ-A)

- **Different Phases**:
  - Evaluation: experimentation on a few wafers
  - Qualification: confirmation on more wafers and lots
  - Pre-Manufacturing: validation on many lots
    - After each phase: comparison EQ-B % EQ-A
Process Qualification: split Lot

Equipment variability minimized

Equipment Variability EQ-A ≠ EQ-B?
Yield Improvement Approaches

● Actual Limitations:
  - Manual Analysis on a limited set of parameters
  - Decision rules not unified and analyst dependant
  - Risk of escape on some parameters

● «SAFE» project for Process Qualification:
  - Exhaustive & automated analysis of all electrical parameters
  - ETL for data and results
  - Decision made on statistical test results (ANOVA)
  - HTML output (intranet)

● Results:
  - Most of Qualification analysed via SAFE
  - Efforts to «manage the change» and promote statistical analysis
  - ~700 à 1000 Parameters analysed by qualification
  - Increase in analysis throughput (+100%)
SYNTHESE SPLIT 6313.00 LEVEL : _PREFUSE

CLASSE CERTIF ELECTRODE 20°F

A = PORL03C
B = EWRL03A

PARAM GROUP DESCRIBE N.WAF MEAN
7228 V.C.10691 Allgood A=PORL03C 24 74.11
7228 V.C.10691 Allgood B=EWRL03A 25 74.48

YLD

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Essai 6313.00 PNP= 7228—C Value: YLD Alpha= 0.05
HBIN2 = 10002

Data analysis: 59/100 = 59.00%
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Strength of an “In-House” SAS Data Analysis Team:
- High Reactivity to Customer needs
- Deeper expertise and promotion of Statistics
- Strategical benefits in a very competitive industry

“Data Mining Success Story at Altis Semiconductor”:
- Fast, Exhaustive & Systematic Analysis of all possible Root Causes
- Key for Yield Monitoring & Yield Improvement
- Significant help for experts in decision making

The Human Expertise is key for Data mining:
- Definitions of the relevant parameters for analysis
- Validation of Root Causes & Corrective Actions
- Learning and Deployment of the Knowledge Discovery found in Database (KDD)
Thanks

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