Low Yield and Dynamic Equipment Fault Analysis

*Using Machine Learning and Big Data*

with Application to High-Tech Manufacturing

2018-3-29
1. 4th Industrial Evolution Trend & What is happening in High-Tech

2. Analytics in High-Tech Manufacturing

3. Examples of Analytic Applications in High-Tech

4. Summary
1. 4th Industrial Evolution Trend & What is happening in High-Tech
4th Industrial Revolution and Hyper Connected Era

- Computer (~2000)
- Internet (2000 ~ 2010)
- Mobile (2010 ~ 2020)
- Hyper Connected (2020 ~)

4th Industrial Revolution

- Communicative
- Autonomous
- Self-Predicting
- Self Learning
- Self Prescribing
- Secure
Recent IT Game Changers in Industry 4.0 enabled Smart Manufacturing

**Internet of Things**
- Smart Sensors
- IoT and Platform
- Edge Computing

**Artificial Intelligence**
- Machine Learning
- Deep Learning
- Multi-dimensional Visualization
- Real-Time insights
- Voice/Text/Image recognition

**Big Data**
- Volume, Velocity, and Variety
- Parallel Computing
- Unstructured Data
- In-memory

**Cloud Computing**
- User Applications
- IaaS, PaaS, SaaS
- Virtual Machine
- Open or Built-In Services

Smart Factory powered by Big Data & AI in Hyper-Connected Era
Challenges in fast-evolving High-Tech manufacturing

1. More Data
2. New product introduction & ramp up
3. Complexity & Cost
4. Test & Debugging
5. No Traceability
6. Assembly and functional testing
   - System integration and after-sales
   - End of Life
   - Product design, process development, and factory setup
   - Supply Chain Management
   - Product Management

High-Tech Manufacturing
What Should be Considered in Smart Manufacturing?

Maximum Production?  
Highest or Golden Yield?  
Fully Automated?  
No human?  
Cyber Physical Systems?  
Intelligent Operation in Manufacturing?  
AI based cognitive?  
IoT Sensor based?  
Digital Twin?

Production with consistent *High Yield of Product and Fully Automated Cognitive Analysis* is one of critical smart manufacturing objectives.
Vision for Next-Gen Smart Manufacturing Platform in High-Tech

- Flexible, Scalable, Agile
- Horizontal Integration of Systems
- Continuous Optimization
- Fundamental of Factory Automation
- Data-Driven Operation & Decision Makings Enterprise-Wide
- Vertical Integrations of IT & OT
- Enables AI / Machine Learning
- Big-Data & Cloud Based

Next-Generation Smart Manufacturing Platform

- Data Lake – supporting high-speed data collection & integration with full scalability
- Full integration with utility (safety, health, environmental) systems and other legacy systems
- Transformation of business operation to be data-driven
- Transforms from Multi Factory – Multi System to Multi Factory – One System
- Enabler of latest technology into manufacturing
2. Analytics in Manufacturing
Four Major Characteristics of Data Analytics in High-Tech Manufacturing

1. **Majority to Minority → No Missing Data**
   - **Sampling (Majority)**
   - **Manufacturing (Minority)**

2. **Real-Time Analytics & Detection**
   - **Batch Analytics**
   - **Real-Time Analytics**
   - Delays in Monitoring: Not able to monitor actual status and events.
   - Real-Time Monitoring: All events & status are detected.

3. **Very Complex & Difficult for Analytics**
   - **Complex Process (200+ Process Step)**
   - More challenges for Analytics (e.g. Trace Analytics)

4. **Predictive Analytics**
   - **Analytics**
   - **Prediction**

**Real-time Sensor Predictive Analytics**
Requirements for Real-Time Advanced Predictive Analytics in High-Tech Manufacturing

<table>
<thead>
<tr>
<th>Automatic and Dynamic Classification</th>
<th>Root Cause Analysis using AI</th>
<th>Micro Level (Trace) Data Analysis</th>
<th>Engineering Decision Support System</th>
</tr>
</thead>
</table>
| • Auto recognition of quality/yield patterns using data with coordinates  
  • Classification of quality/yield patterns  
  • Analyze hundred thousands of substrates within minutes |
| • Analyze huge volume of data and diverse variety of data fast  
  • Accurate root cause analysis without in-depth statistical knowledge  
  • Incorporation of domain knowledge into root cause analysis |
| • Use of micro (raw sensor level) data for deep down analysis  
  • Analyze and solve previously unsolvable problems  
  • Integrate analysis result to real-time detection for future prevention |
| • Data & feature integration to support engineering decision  
  • Automated data gathering, analysis, deploy, and report  
  • Use of Knowledge Base  
  • Daily & Hourly auto summary dashboard |
History of Analytics in High-Tech Manufacturing

~ 2000

Remote Site Tool

Manual Inspector
Desktop Computer
Metrology

2000 ~ 2010

Internet

Remote Inspector
Server
Desktop Computer
Metrology

2010 ~ 2020

Mobile

Remote Inspector
Server
Desktop Computer
Metrology

2020 ~

Hyper Connected

AI Hyper-Connected

Cloud
Edge Computing
Mobile

Metrology
3. Examples of Analytic Applications in High-Tech
Real-time Monitoring – Difference in Approach

Existing FDC/SPC

- Domain Knowledge
- Experience
- Static Model
- Feedback
- Fine-tuning

Dynamic Fault Detection

- Artificial Intelligence
  - Dynamic Modeling
  - Trace Analytics
  - Machine Learning
  - Auto Signal Processing

FDC system deployment in **MONTHS**

FDC system deployment in **1 less than WEEK**
Advancement of Yield Analysis in High-Tech Manufacturing

**Standalone Yield Analysis**

1. Input Data (Bare Item)
2. Step #1: PROC Data, MET Data
3. Step #2: PROC Data, MET Data
4. Step #n: PROC Data, MET Data
5. Material + Equipment Data
6. Final Test

**Integrated Yield Analysis**

1. Tested Items with Yield parameter
2. Identify causally process steps (Tracking Data)
3. Root-Cause Analysis (Trace Summary Data)
4. Raw Trace Data Analysis

**Steps**

- **Input Data**
- **PROC Data**
- **MET Data**
- **Material + Equipment Data**
- **Final Test**
- **Automated**
- **Integrated**
AI based Linear Wafer Pattern Recognition in Semiconductor Mfg.

- Using CNN or customized AI model for detecting linear failure pattern of wafer map.
- Create final model through the repetitive & reinforced training and testing process of Deep Learning.

Workflow of Deep-Learning Training

1. **Extract data**
2. **Image file conversion**
3. **Class Labeling**
4. **Database**

- **Deep Learning Model Training**
  - Failure wafer map image (generated data)
  - CNN models
  - Learning rate
  - NVIDIA DIGITS: Interactive Deep Learning GPU training
  - Tuning the Deep Learning model
    - Training Set
    - CNN architecture
    - Learning rate

- **Deep Learning Model Testing**
  - Performance of classification results (Accuracy)
  - CNN models

- **Final model**
  - Pass
  - NG
# Big Data Usage in Analytics of Low Yield Issue

## Root-Cause Analysis for Low Yield
- For 1 months data (>30K wafers)
- For all process steps (>0.5K steps)
- For all parameters (>2M parameters)

<table>
<thead>
<tr>
<th>Items</th>
<th>Before (Traditional Systems)</th>
<th>After (with Big Data Systems)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Source for Root Cause Analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking Data</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Event Summary Data</td>
<td>Δ (Limited, 1 step per 1 analysis)</td>
<td>O (All step &amp; all parameter used)</td>
</tr>
<tr>
<td>Trace Summary Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trace Raw Data</td>
<td>Δ</td>
<td>Planned</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Size (Tested)</td>
<td>1 GB</td>
<td>&gt; 300 GB</td>
</tr>
<tr>
<td>Algorithm Performance</td>
<td>~1K minutes</td>
<td>Within half hour</td>
</tr>
<tr>
<td>(Appr. 8GB for 30K wafers) concurrent up to x users</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Clustering</strong></td>
<td>Need to register User Maps</td>
<td>Dynamic Clustering</td>
</tr>
<tr>
<td>Drill Down Analysis</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>Scheduling Job</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td><strong>Analysis time to find Root Cause</strong></td>
<td>A Week</td>
<td>&lt; One hour</td>
</tr>
<tr>
<td><strong>Analysis time to find Root Cause</strong></td>
<td>X</td>
<td>Planned</td>
</tr>
<tr>
<td><strong>Near real time analysis</strong></td>
<td>X</td>
<td>Planned</td>
</tr>
</tbody>
</table>

Diagram showing the comparison between before and after with Big Data Systems.

*Algorithm Performance *

- Before: ~1K minutes
- After: Within half hour

*97% saving*

BISTel Confidential
Integrated Sequential Low Yield Drill-down Analysis in FPD MFG.

01 Defect Map Clustering: High defect rate at the 4 corners of a glass

Use of Machine Learning to Automatically classify defect pattern
Dominant defect cluster

02 Data Mining with MES Data: 2nd dry etch tool

Drill down to this tool

03 Time Series Tool Sensor Raw Data Analysis: RF Vpp High @ RCP Step 5
Defect Pattern Auto Classification

Using various wafer defect images, classify defect map pattern automatically

CNN (Convolution Neural Network)

Advanced Trace Data Analysis

Using parameter trace data, analyze sequential data patterns of the tool and extract various hidden features

RNN (Recurrent Neural Network)

PdM & Quality Prediction

Using all kind of data and stored knowledge, analyze data behavior and predict process quality and equipment maintenance

Reinforcement Learning

Integration with Existing Application

Value added by AI

Map Analytic (Defect Classification)

Root Cause Analysis (Data Mining)

PdM & Quality Prediction

Data Analysis and Prediction using Existing Application on Big Data
4. Wrap up
Summary: Transition Status from High-Tech to Industrial Mfg. in Advanced Analytics

- Data Collection
- Data Standardization & Integration
- Data Mining & Analysis
- Process Improvement
- Big Data Implementation

- System Integration (Vertical + Horizontal)
- Advanced Data Analytics (Trace + Predictive Analysis)
- Machine + Deep Learning
- New platform + Cloud
- Process + Factory Optimization

- AI + Cognitive Analytics
- Complete Data-Driven operation
- Enterprise-wide Optimization
- Factory Automation + Autonomous Control
- Continuous Optimization
Summary: Smart Manufacturing in High-Tech should be transferred to Industrial Manufacturing

Phase I
Application Intelligence
Application-specific solutions designed with advanced analytic and innovative capabilities to support and optimize various aspects of your operation lifecycle

Phase II
System-level Intelligence
Applications with built-in SMART engines to allow collaboration and autonomous intelligent decision making within a manufacturing system

Phase III
Enterprise-Level Intelligence
Expanded intelligence to allow autonomous Inter-system recommendations and intelligence decision making throughout the enterprise

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