Fab automation – Artificial Intelligence
Questions I get asked

1. What is this “AI” all about and why now?

2. Now, how does it apply to a fab?

3. How do we get out of pilot purgatory?
The essence of artificial intelligence (AI) is learning

Artificial intelligence (AI)

Intelligence exhibited by machines, with machines mimicking functions typically associated with human cognition

AI functions including all aspects of perception, learning, knowledge representation, reasoning, planning, and decision making

Strong AI differentiated from weak AI by, e.g., ability of these functions to adapt to new contexts, i.e., situations an AI system was not previously trained to deal with
Technology is no longer a limitation and data as well as funding becomes increasingly available for AI and machine learning

Artificial Intelligence research and technology exists for several decades …

… but only now its capabilities have improved dramatically to allow wide application

Improved algorithms & training methods
Better & specialized hardware
Growth of data availability
Expansion of cloud services
Increased investment activity

Artificial Intelligence is no new topic
1 Proof of concepts

1950s
1970s
1980s
1990s
2000s

Artificial Intelligence is no new topic
In the 1970s capabilities were limited
Commercial applications emerged
AI began to be used somewhat behind the scenes
Extending applications and more POCs

1950s
1970s
1980s
1990s
2000s
Real impact being achieved across sectors

Manufacturing: ~6%
Supply chain & procurement: ~16%
R&D / Engineering: ~15%
Customer: ~10%
Talent: ~4%
Semiconductor sector has a lot to gain

**Example opportunities**

- **Segmenting customer groups to improve sales**
  e.g. real time micro-segmentation of customers to target promotions and advertising

- **Measuring performance in new ways**
  e.g. Comparative R&D effectiveness studies to determine optimal team performance

- **Innovation in business models, products, and services**
  e.g. using product sensor data to create innovative after-sales service offerings

- **Optimizing asset utilization**
  e.g. using predictive maintenance to increase machine availability

- **Automated algorithms to replace/support human decision-making**
  e.g. machine learning for yield acceleration

**Semiconductor industry is tough**

- Increasing time-to-market for new products
- Slow growth, cyclical demand
- Rising complexity of equipment and system parameters
- Rising capex and R&D investment at leading-edge
- Rising pressure on margins
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Advanced fabs already with ‘high intensity’ data environments

**Fab planning and construction**
- **Advanced fab planning:** Accelerate construction & tool hookup
- **Project management:** Develop overarching plan & drive implementation

**Digital thread:** powered by powerful data lake and cloud computing to ensure real time connectivity and analytics between all functions

**Manufacturing with real time analytics and control**
- **Smart FDC:** Optimize tool condition & matching
- **Next gen APC/R2R control:** Optimize wafer processing
- **Automated AMHS/MCS:** Increase automation of delivery system
- **Real time dispatching:** Optimize tool utilization

**Design and process development center**
- **Design for manufacturability:** Ensure manufacturability and yield

**Customer co-creation:** involve customer early in development and ensure design-to-value

**Remote control center**
- **Line control/scheduling:** Enhance line flow, balance, flexibility
- **Real time capacity simulation:** Increase fab capacity
- **Predictive maintenance:** Avoid failure and unplanned downtime
Leading edge APC systems employ big data solutions to accelerate yield ramp

<table>
<thead>
<tr>
<th>Approach</th>
<th>Description</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Infrastructure</td>
<td><strong>Comprehensive tool data</strong> is stored across Hadoop’s HDFS¹</td>
<td>Production yield improved</td>
</tr>
<tr>
<td></td>
<td><strong>Data normalized, classified, analyzed</strong> (at a preliminary level), and insights visualized automatically with Log Analyzer</td>
<td>3-5% through improvements in lithography alone</td>
</tr>
<tr>
<td>Advanced Analytics</td>
<td><strong>In-depth correlation analysis</strong> on comprehensive tool and metrology data enable the identification of ‘golden-rules’ to set pre-configured algorithms</td>
<td>Root-cause identification shortened</td>
</tr>
<tr>
<td></td>
<td><strong>Rapid analysis of tool and metrology data</strong> based on pre-configured algorithms identify yield detractors within tools</td>
<td>99% ~1 day to ~10 min</td>
</tr>
<tr>
<td>Reaction Mechanism</td>
<td><strong>Finer R2R process control including within-wafer and within-field adjustment</strong> (e.g., dosage mapping in lithography for reticle and laser uniformity)</td>
<td></td>
</tr>
</tbody>
</table>

¹ APC: Advanced Process Control; R2R: Run-2-Run; FDC: Fault Detection and Classification; SPC: Statistical Processing Control; HDFS: Hadoop Distributed File System,
Leading edge predictive and dynamic RTD increases automation and accelerates cycle time

**Approach**

**Architecture**

- ** MES**
- ** Dispatch repository**
- ** Analysis & prediction**
- ** Iterative Scheduling**
- ** Predictive, schedule-aware dispatching**

**Description**

- ** Data gathered real-time including:**
  - New lot routing plans
  - WIP lot status and priorities
  - Tool condition and failures

- ** Schedules developed, simulated, and optimized iteratively real-time** by forecasting WIP lot arrival at tools and identifying key bottleneck
- ** Zero human** intervention

- ** AMHS/MCS¹ completely** services fab
- ** OHVs¹ with decentralized computing capable** of individually optimizing the specific lot’s schedule and dispatching
- ** Zero human** intervention

**Impact**

- ** Cycle time accelerated**
  - ~20%

- ** Reduced material delivery time**
  - ~30%

- ** Accelerated fab production ramp up**
  - 30-50%
  - 6 to 3-4 months

- ** Reduced operators on fab floor**
  - ~90%
  - >300 to ~30 FTEs

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¹ RTD: Real-Time Dispatching; AMHS/MCS: Automated Material Handling System/Material Control System; OHV: Overhead Vehicle
Questions I get asked

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The data is out there …

Fab Operations Example – Data collection and usage for ETCH tool

<table>
<thead>
<tr>
<th>Tags used for tactical decisions</th>
<th>Typical findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>People &amp; processes</td>
<td>Maintenance schedule not-driven by cost consideration</td>
</tr>
<tr>
<td>Deployment</td>
<td>No interface in place to enable near real time analytics to effect action on failure modes explored (data and insights integrated after lot is processed)</td>
</tr>
<tr>
<td>Analytics</td>
<td>Reporting limited to a few KPIs which are monitored retrospectively</td>
</tr>
<tr>
<td>Data Management</td>
<td>Hard to access &amp; investigate full breadth of recorded data due to non-integrated systems</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Only 6 months of trace data kept before down-sampled to 1%</td>
</tr>
<tr>
<td>Data capture</td>
<td>22 of 45 parameters measured not available to user and some critical parameter not measured</td>
</tr>
</tbody>
</table>

~45 parameters
... yet typically several issues are holding companies back

<table>
<thead>
<tr>
<th>Issues</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quality not suitable for purpose</td>
<td>Fragmented data</td>
</tr>
<tr>
<td>Data definitions missing</td>
<td>Poor data accuracy and consistency</td>
</tr>
<tr>
<td>Data Access issues and data delivery issues</td>
<td>Latency and timing problems</td>
</tr>
<tr>
<td>Inconsistent systems of record</td>
<td>Silo solutions</td>
</tr>
<tr>
<td>Too many sources</td>
<td>Poor synchronization</td>
</tr>
<tr>
<td>Lost or disorganized data</td>
<td>Non-scalable IT infrastructure</td>
</tr>
<tr>
<td>Restrictive access and usage policies stifling innovation</td>
<td>Complex infrastructure</td>
</tr>
<tr>
<td>Too difficult/slow to get innovation data onto an acceptable platform</td>
<td>Lack of self-sufficiency (in business)</td>
</tr>
<tr>
<td>Internal risk management organisations are significantly out of alignment with business</td>
<td>Security and privacy violations</td>
</tr>
<tr>
<td>Inconsistent reference values</td>
<td>Lack of audit, balance and control</td>
</tr>
</tbody>
</table>
A solid foundation is a prerequisite for impact at scale

Industry 4.0 enhancement

Enhancement details

- Additional front end applications supporting the workflow e.g., yield learning
- Introduction of analytics engine to leverage advanced analytics and machine learning
- One comprehensive data lake, real time linked to all sensors/data systems
- Enhancement to enable advanced analytics and big data analytics
- Consistent leverage and readout of sensor data

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1 Artificial Intelligence  2 Advanced Analytics  3 Product lifecycle management  4 Computer integrated manufacturing  5 Enterprise Resource planning  6 Manufacturing execution system  7 run to run  8 Failure Detection and Classification
Nurturing a robust ecosystem of established and emerging partners becomes key

<table>
<thead>
<tr>
<th>Potential partners</th>
<th>Established</th>
<th>Emerging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-end/ visualization</td>
<td><strong>Tableau</strong>, <strong>Qlik</strong></td>
<td><strong>Quantum Black</strong>, <strong>SparkBeyond</strong></td>
</tr>
<tr>
<td>Analytics engine (Big data simulation, Machine learning, AI, AA etc.)</td>
<td><strong>Alteryx</strong>, <strong>Optimal</strong>, <strong>Simulia</strong>, <strong>Synopsys</strong>, <strong>Teamcenter</strong></td>
<td><strong>Motivo</strong>, <strong>Clarizen</strong></td>
</tr>
<tr>
<td>Data layer (big data)</td>
<td><strong>SAP</strong>, <strong>BIM 360</strong></td>
<td><strong>Cloudera</strong></td>
</tr>
<tr>
<td>ERP/MES</td>
<td><strong>SAP</strong>, <strong>IBM</strong>, <strong>Siemens</strong></td>
<td><strong>APPLIED MATERIALS</strong>, <strong>PDF/SOLUTIONS</strong>, <strong>Nanotronics IMAGING</strong></td>
</tr>
<tr>
<td>Automation/ quality system (R2R,FDC)</td>
<td><strong>Applied Materials</strong>, <strong>PDF/Solutions</strong></td>
<td><strong>Muratec</strong>, <strong>ASML</strong></td>
</tr>
<tr>
<td>Tools</td>
<td><strong>Lam</strong>, <strong>Muratec</strong>, <strong>ASML</strong></td>
<td><strong>Nanotronics IMAGING</strong></td>
</tr>
</tbody>
</table>

Industry 4.0 enhancements
New roles are required to fully leverage data and analytics

- **Analyze Big Data** through advanced analytics to get strategic/business insights
- **Drive the design and execution of the overall Big Data and analytic strategy**
- **Provide link across IT, analytics, and business**
- **Support the design, development and main-tenance of the data architecture**

- **Head of analytics**
  - Responsible to develop the software to program with Big Data
  - “Translate” business needs into advanced analytics language (e.g., define data requirements)
  - Ensure future data requirements and delivery roadmap is robust and complete
  - Define the content of the data they own and are responsible for data quality

- **Analytics developers**
  - Analyze Big Data

- **Data Scientists**

- **Solution Architects**

- **Data Owners**

- **IT data specialists**
Thank you

ondrej_burkacky@mckinsey.com