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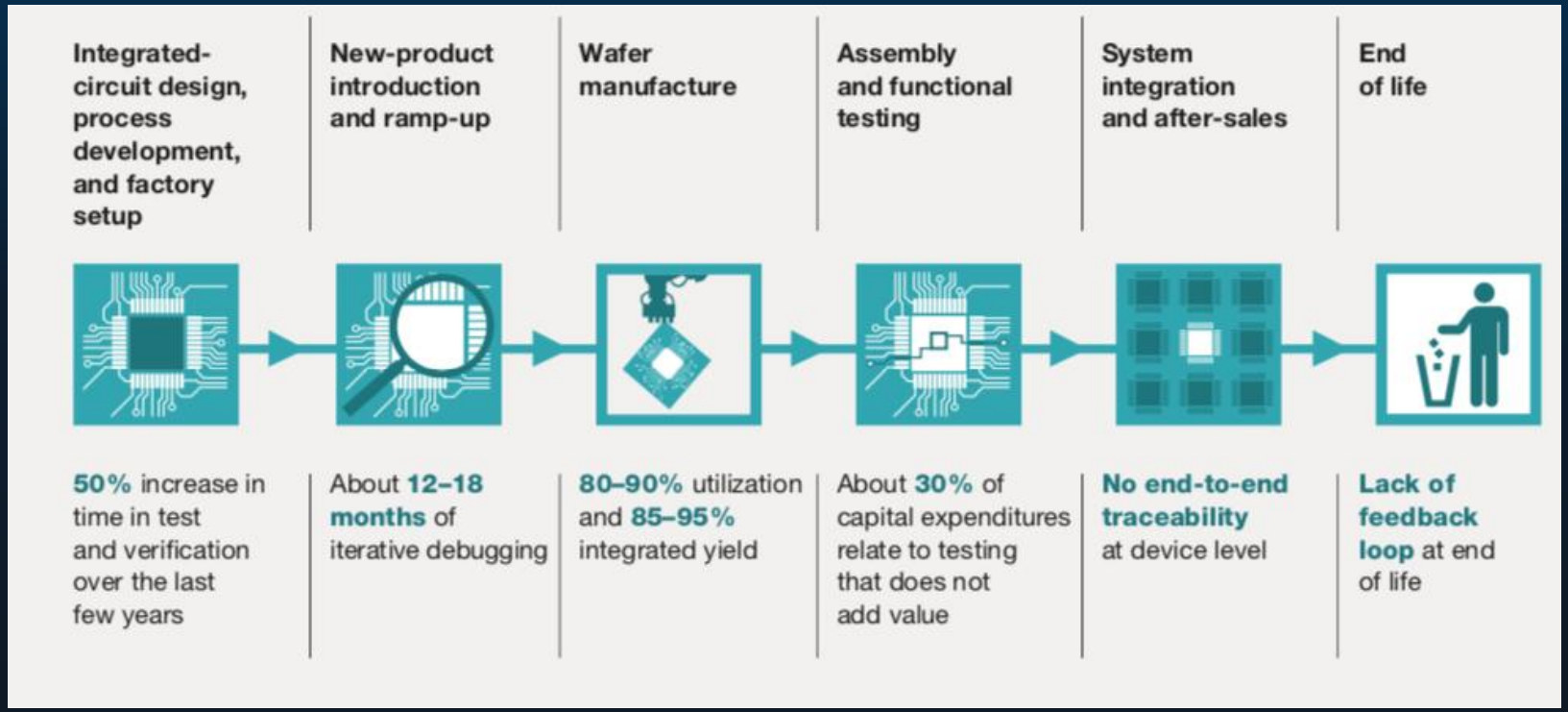
Applying Machine Learning to Improve Production & Yield for Semiconductor Fabrication

Increased Complexity in Fabs Needs New Approaches



Source: McKinsey - Advanced Analytics in semiconductor manufacturing, October 2017

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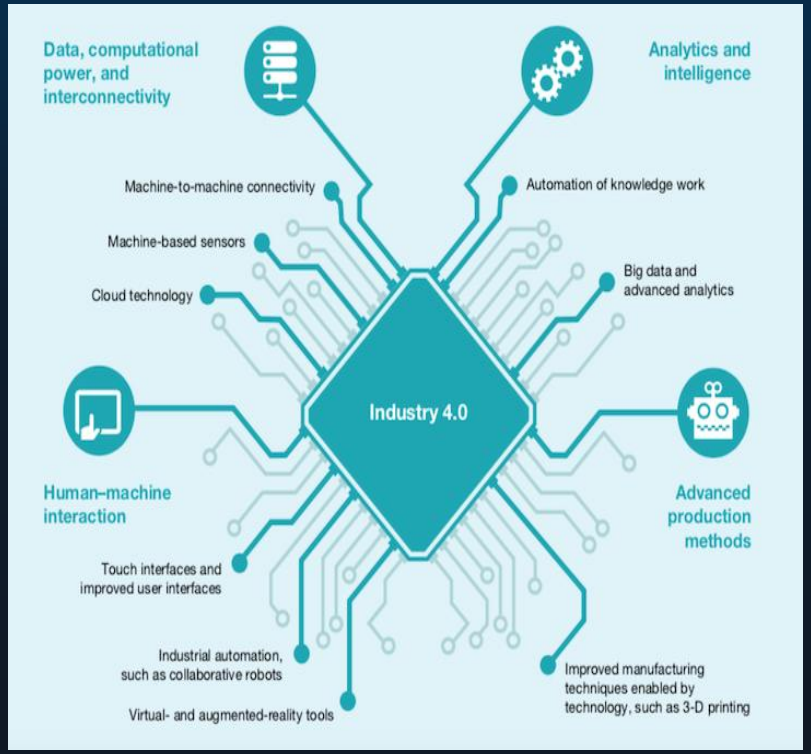
Machine Learning Transforming Semiconductor Manufacturing

Impact of Machine Learning

- 1-5% improvement in yield
- 10-20% gains for maintenance productivity
- 20% reduction in equipment downtime
- 25% reduction in inspection costs



Source: McKinsey - Optimizing semiconductor manufacturing

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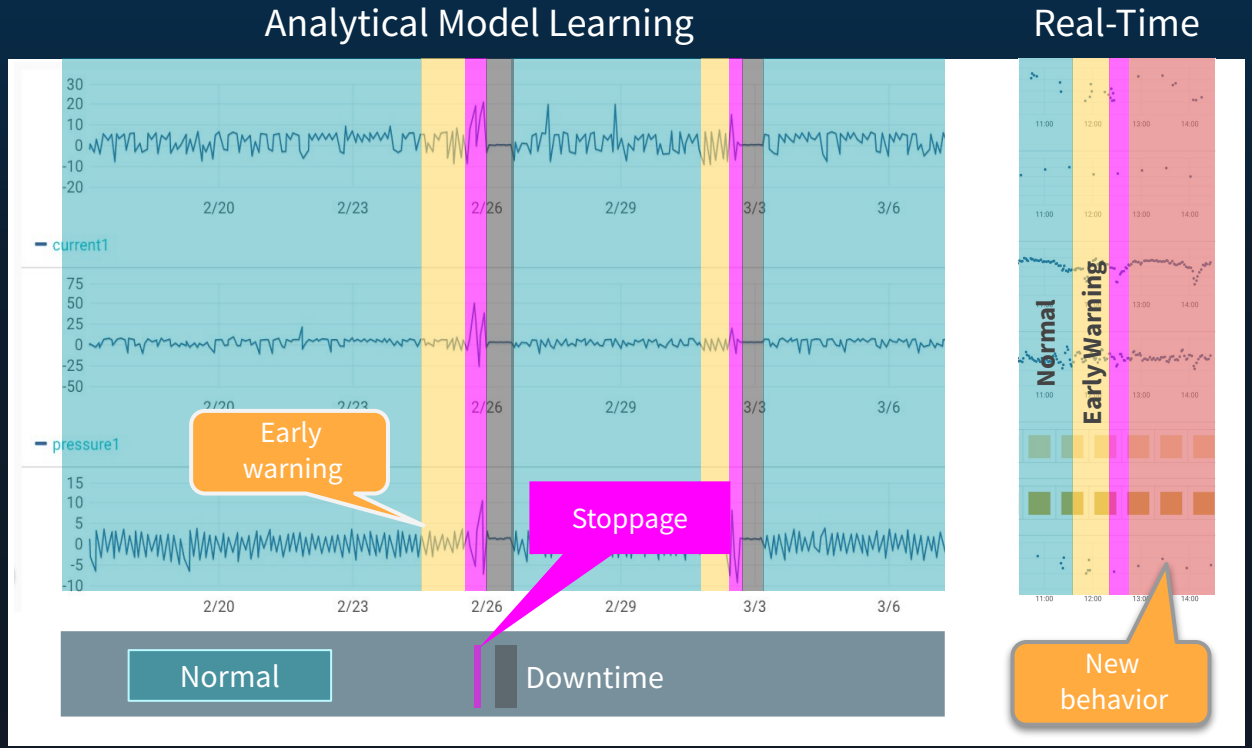
Machine Learning Enables Predictive Operations

Enable time series pattern discovery and early warning



Predictive Operations Use Cases

Yield & Quality Improvement

Improve yield by identifying process variables that affect defect density and other on-wafer outcomes

Identify excursions by classifying known events as they recur

Predictive Maintenance

Identify early lifetime failures to avoid unscheduled downs

Identify early periodic failures to schedule proactive maintenance

Optimize preventative maintenance schedule to reduce consumables costs and minimize lost production

Root Cause Analysis

Signal contribution indicates subsystems involved

Signal clustering allows efficient investigation of new phenomena

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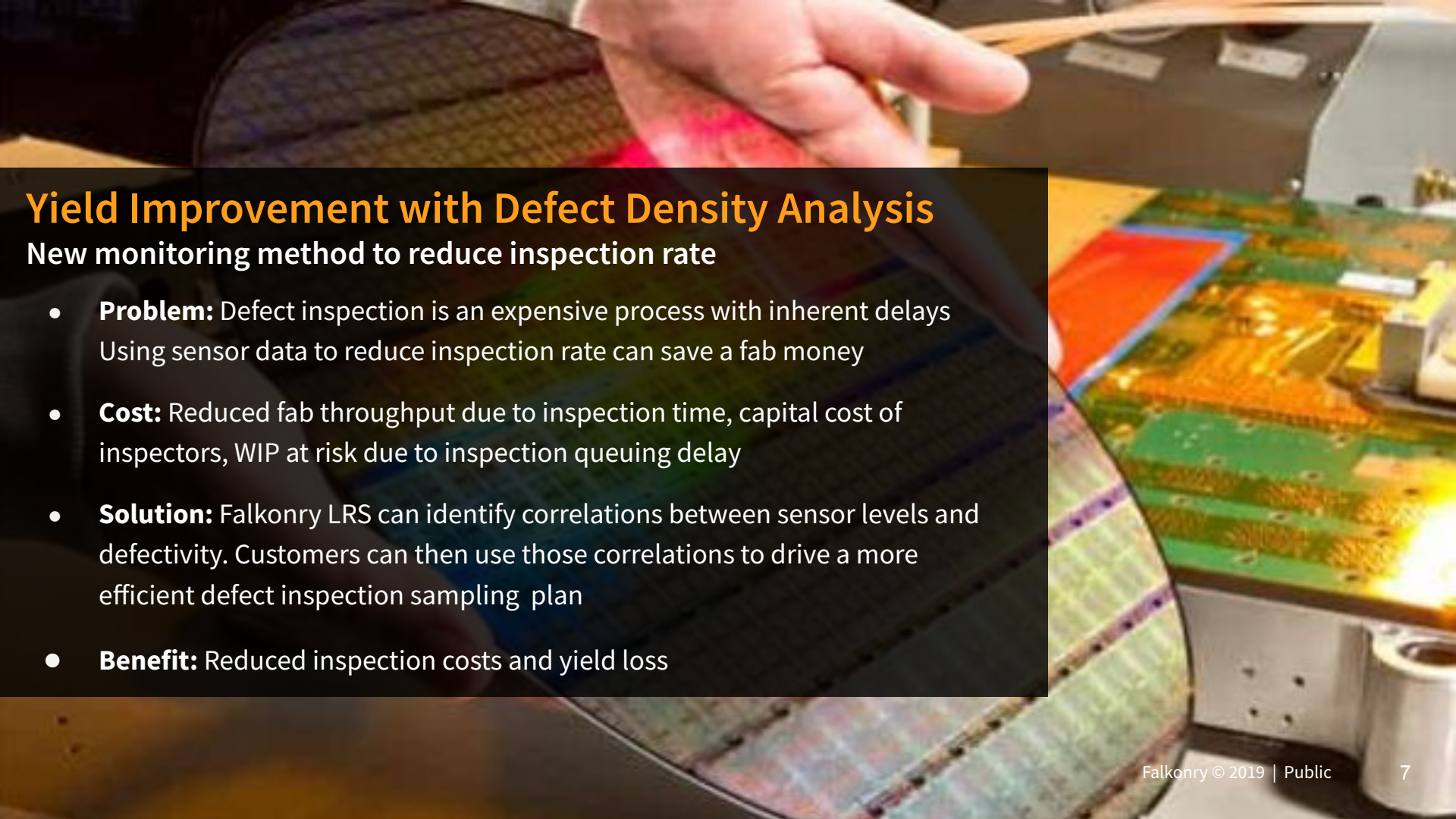
Quality Improvement / Yield Improvement



Yield Improvement with Defect Density Analysis

New monitoring method to reduce inspection rate

- **Problem:** Defect inspection is an expensive process with inherent delays Using sensor data to reduce inspection rate can save a fab money
- **Cost:** Reduced fab throughput due to inspection time, capital cost of inspectors, WIP at risk due to inspection queuing delay
- **Solution:** Falkonry LRS can identify correlations between sensor levels and defectivity. Customers can then use those correlations to drive a more efficient defect inspection sampling plan
- **Benefit:** Reduced inspection costs and yield loss

Defectivity Analysis

- Wafers are etched and then cleaned
- Signal data from a number of high and low defectivity lots measured post-etch were analyzed by Falkonry
- Falkonry performed unsupervised modeling using ~75 signals and found correlation between cluster groups and defect density
    - Bias/clamp voltage, coolant flow, current, gas flow, pressure, temperature, throttle valve position, pump speed, ring position
- Falkonry's predictive analytics helps customer understand which wafers are likely to have a high defect density
- Those wafers can be preferentially sampled thereby decreasing total inspection sampling rate and cost while maintaining low risk of missed defect excursions.

Pattern Discovery: Two Chambers From The Same Equipment

Note:

- Each batch comprises of a single wafer that undergoes etch followed by a wash cycle
- Lower % occurrence of a pattern suggests lower quality/yield and higher defect density

Discovering Important Signals For “Low Defect Density”

75 chamber signals

Operational Machine Learning

Top 10 signals

1. IB2 Valve
2. Foreline Manometer Adjusted Pressure
3. ESC Coolant Flow
4. Gas 11 Flow
5. RF 2 MHz PA Dissiptaion
6. RF 27 MHz PA Dissipation
7. Top Plate Heater Temperature Output Value
8. Gas 1 Flow
9. Gas 3 Flow
10. RF 2 MHz Gen Forward Power

Run-to-run Comparison of Discovered Patterns

Wafers have process signatures not easily discernible to the human eye

Higher impact signals for LOW defect density wafer batches

Higher impact signals for HIGH defect density wafer batches

Predictive Maintenance

Detect Impending Mass Flow Controller (MFC) failures

Preventative maintenance for production efficiency (Dry Etching)

- **Problem:** An imbalance in gas flow can result in too many reactive species in the chamber and loss of anisotropy in the etch process
- **Cost:** Unscheduled maintenance and yield degradation
- **Solution:** Detect etchant MFC anomalies days in advance of potential failure
- **Benefit:** Convert unscheduled downtime into scheduled downtime for more efficient fab operations

Predicting Malfunction of MFC in Etch Chamber

- Dry etchers used to fabricate wafers have several MFCs that control the release of gas etchants with precise measure
- These MFCs may start malfunctioning and eventually fail
    - In the meantime, they also impact the quality of the wafers being etched
- **Cost of undetected failure:**
    - Reduced yield
    - Unscheduled downtime waiting for maintenance team slot to open or for long lead time parts to be obtained
- Customer used LRS to detect patterns of MFC behavior which indicated failure of the MFC up to a week in advance
- This allowed the customer to schedule equipment maintenance, minimize the time equipment was running in poor state and avoid an unplanned system down

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Detecting Gas Valve Malfunction

Failure detection one week in advance

Model trained on one etch chamber

Actual failure

Failure identified by Falkonry (Early Warning)

Same model applied on another etch chamber with no facts provided

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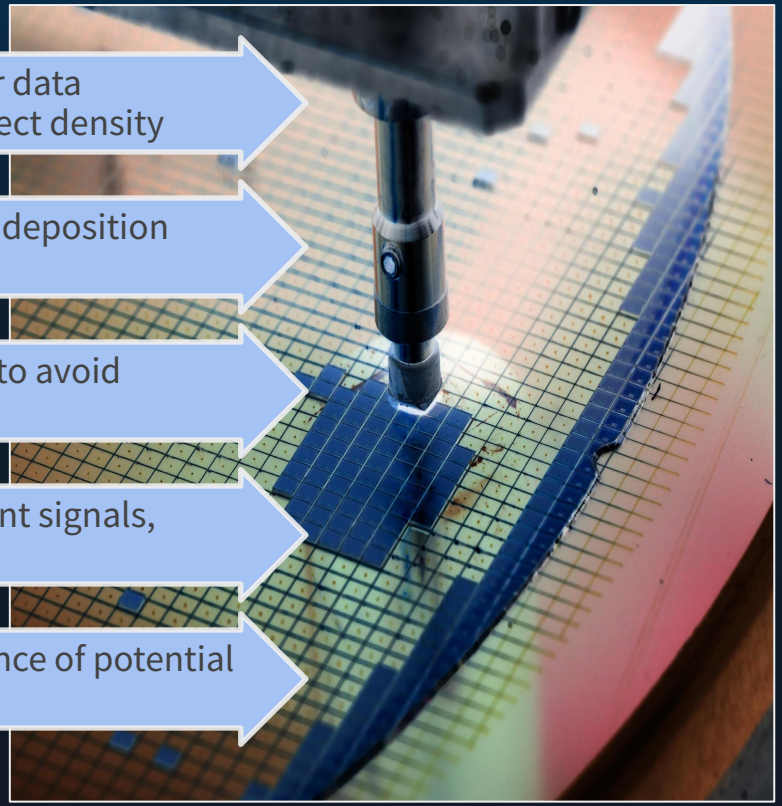
Summary of Use Cases

Applying machine learning to optimize semiconductor manufacturing

Yield & Quality	Reduce inspection rate using sensor data Identify sensor signals affecting defect density
Throughput	Detect misprocessed wafers, adjust deposition process to reduce defects
Scrap	Identify bad wafers and scrap early to avoid wasted processing cost
Root Cause Analysis	Explanation scores identify important signals, investigate new phenomena
Maintenance	Detect MFC anomalies days in advance of potential failure



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