Practical Applications of "Measurement Systems Analysis" (MSA) for Semiconductor Process Control

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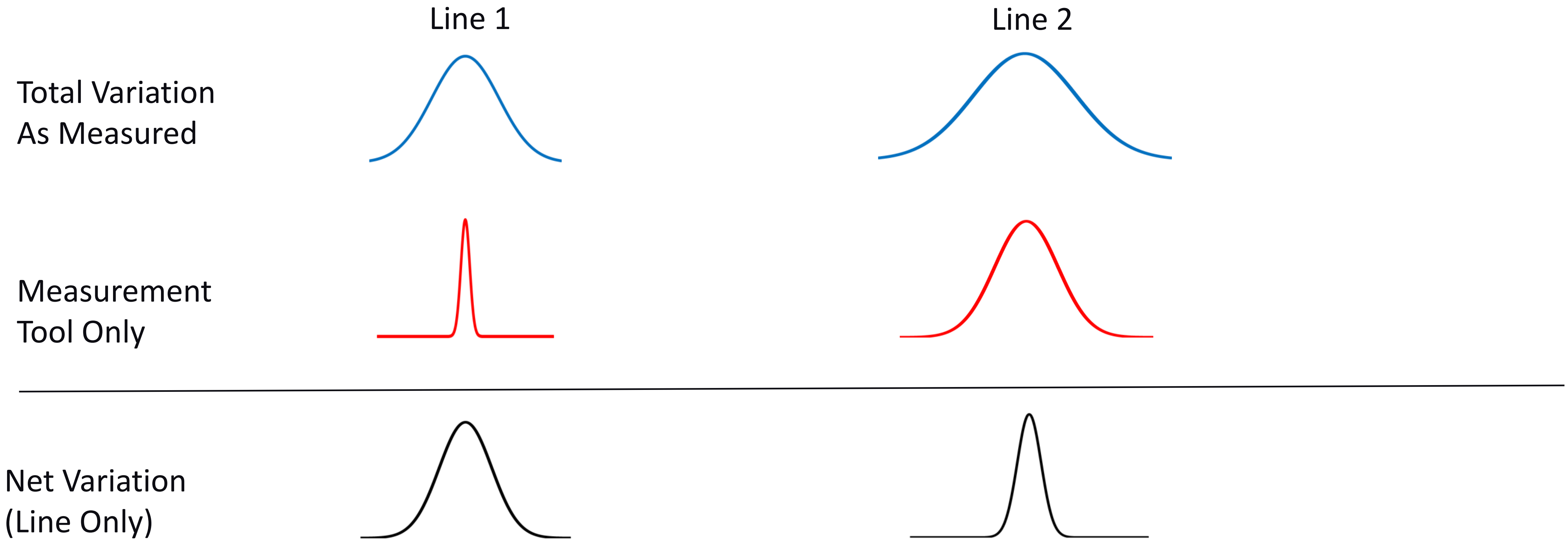
Agenda

1. Introduction
2. Metrology Measurement Systems
3. Defect Inspection Measurement Systems
4. Maintenance Considerations
5. Summary

Why We Care About Measurement Systems Analysis (MSA)

Which process has less variability?



Decisions are only as good as the measurements we use to make them

MSA and The Semiconductor Industry

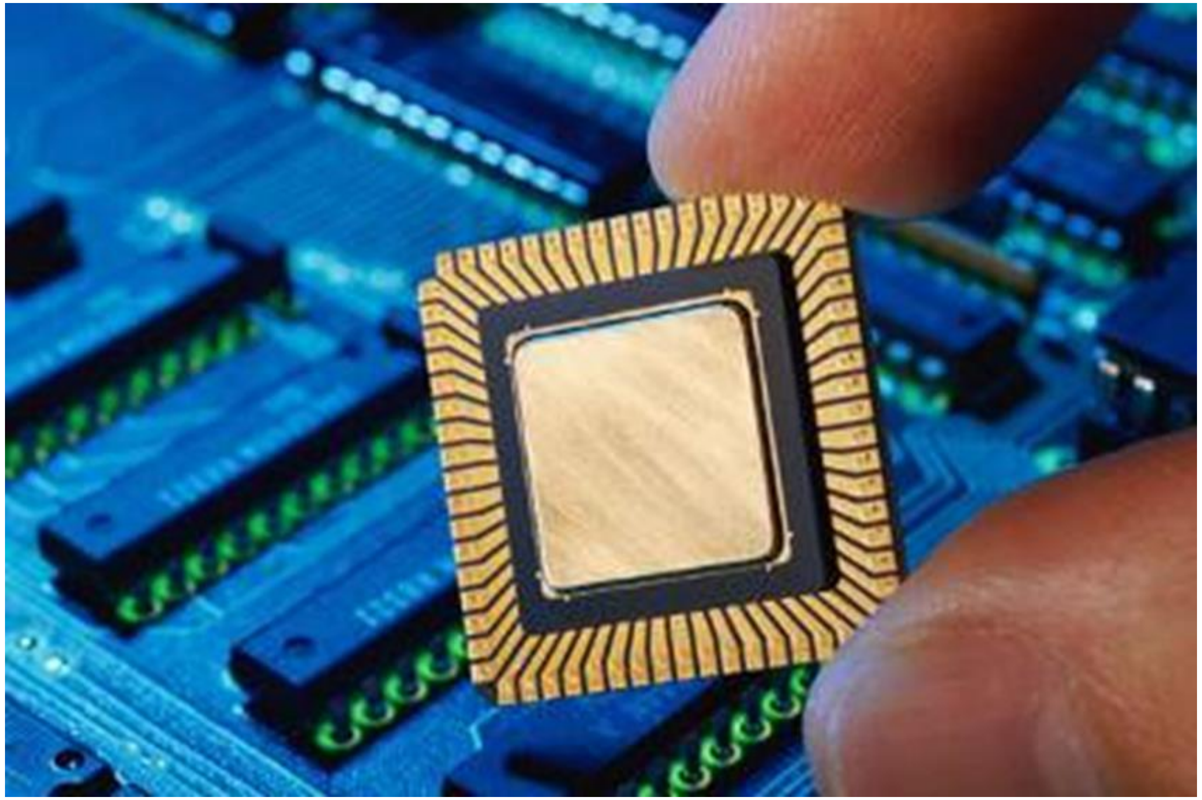
- Ensures integrity
- 200+ Pages
- Thorough
- Comprehensive

- GR&R
- Linearity
- Matching
- Maintenance
- Traceability
- Etc.

<u>Semiconductor Process Control</u>

- For MSA adherence there must be:
  - Agreement
  - Capability
  - Compliance
- Some Semi practices aren't covered

Manufacturing Semiconductors



- 100 to 1000 process steps
- Billions of transistors
- Miles of wire
- Same size as a postage stamp

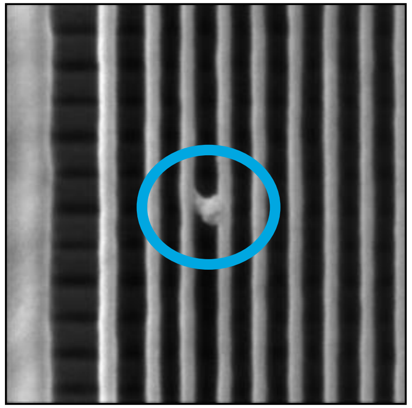
Near perfection required at every process step.

KLA

Semiconductor Process Control

Process control consists of two primary functions …

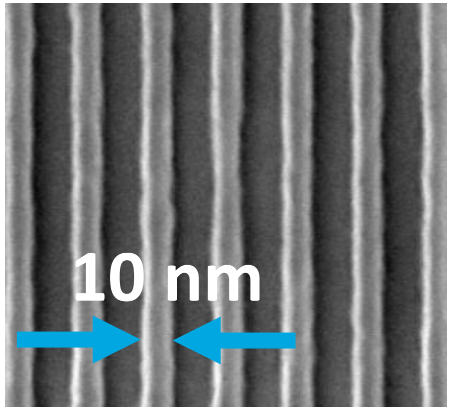
Inspection



Find the stuff that's not supposed to be there

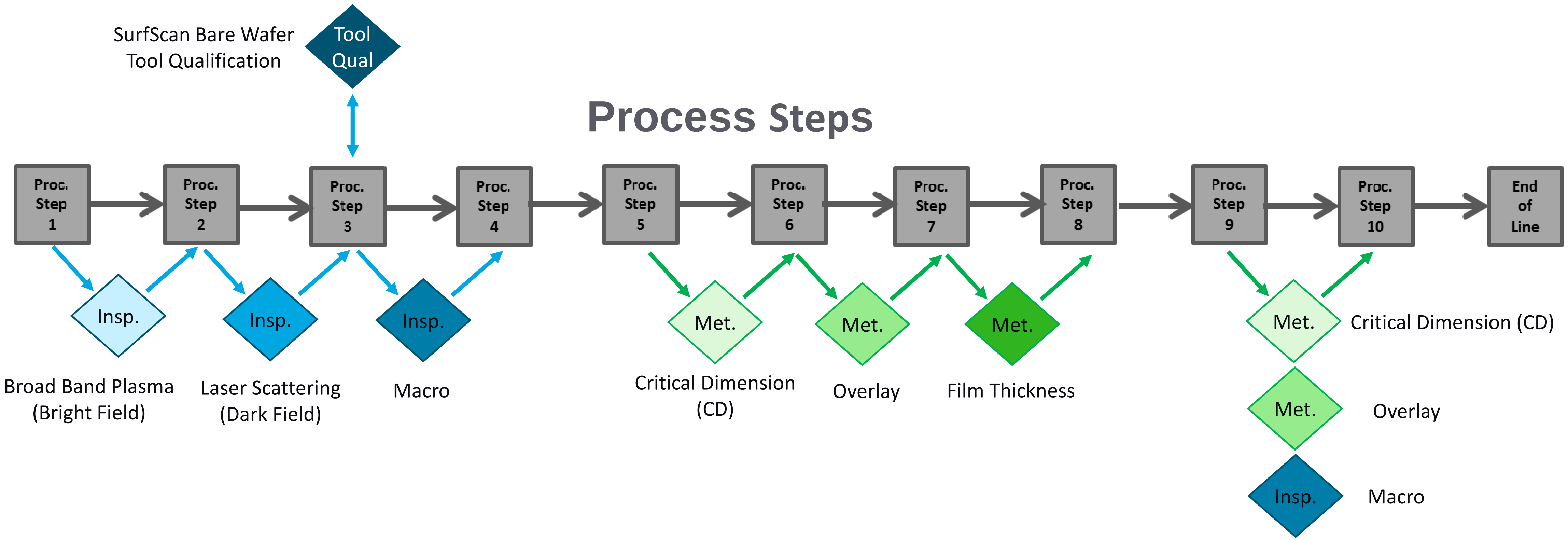
And

Metrology



Measure the stuff that is!

Process Control Steps



Different Types of Defect Inspection

- Typically 10% to 33% of lots
- Typically 1-5 wafers per lot

Different Types of Metrology

- Typically 100% of lots
- Typically 2-5 wafers per lot

Combinations

Most process steps have some metrology and/or defect inspection

Process Control Decisions

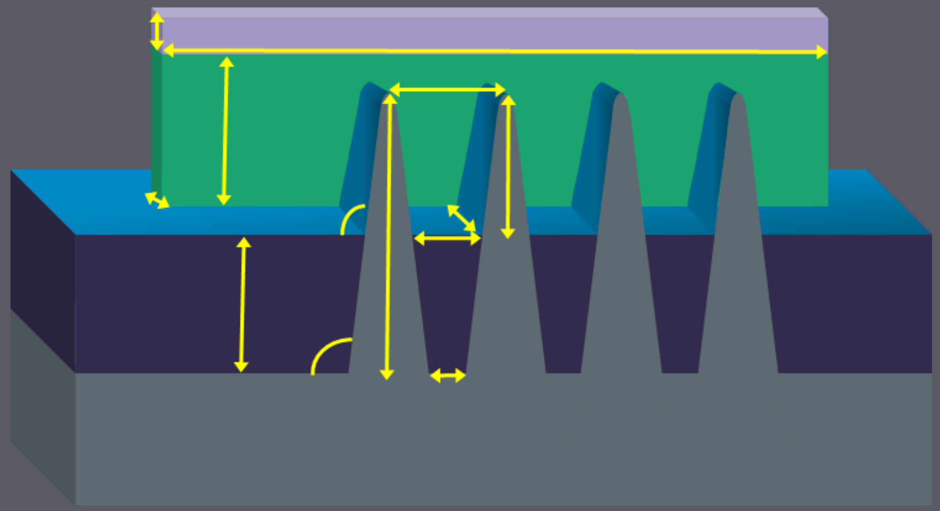
Every process Control step creates two questions AND two types of risk:

1. What do I do with this lot?
   a) Everything OK? – Send it on
   b) Questionable? – Hold for disposition
   c) Obviously wrong? - Scrap

2. What do I do with this process?
   a) Continue?
      - If you get the measurement wrong this is VERY expensive (Beta risk – aka “Consumer Risk”)
   b) Stop the line?
      - If you get the measurement wrong this is VERY annoying (Alpha risk – aka “Producer Risk”)

Actual \ Measurement	In Spec	Out of Spec
In Spec	✓	Alpha Risk (False Alarm)
Out of Spec	Beta Risk (False Positive)	✓

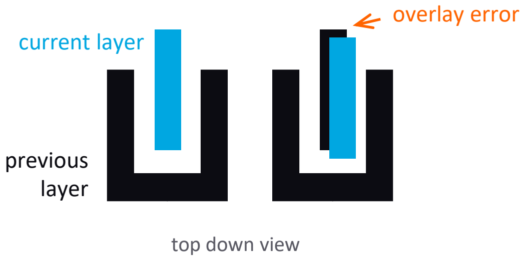
Metrology

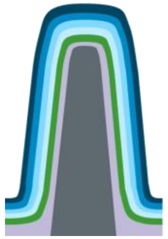


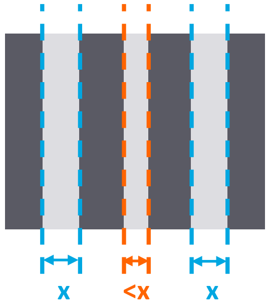
Metrology Tools

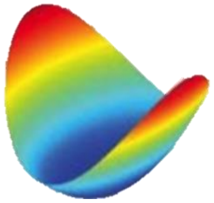
Four main types of metrology systems

Overlay	Film Thickness	Critical Dimension	Wafer Shape









Tool Type	Function	Fab Area
Overlay	Measures alignment between successive layers	Litho
Film Thickness	Thickness in the vertical plane	Deposition and CMP
Critical Dimension	Lines, spaces, diameter in the horizontal plane	Litho and Etch
Wafer Shape	Warping, dishing bowing	Anneal and Litho

MSA Requirements vs Semiconductor Requirements: GR&R vs Precision

MSA

GRR	Decision	Comments
Under 10 percent	Generally considered to be an acceptable measurement system.	Recommended, especially useful when trying to sort or classify parts or when tightened process control is required.
10 percent to 30 percent	May be acceptable for some applications	Decision should be based upon, for example, importance of application measurement, cost of measurement device, cost of rework or repair. Should be approved by the customer.
Over 30 percent	Considered to be unacceptable	Every effort should be made to improve the measurement system. This condition may be addressed by the use of an appropriate measurement strategy; for example, using the average result of several readings of the same part characteristic in order to reduce final measurement variation.

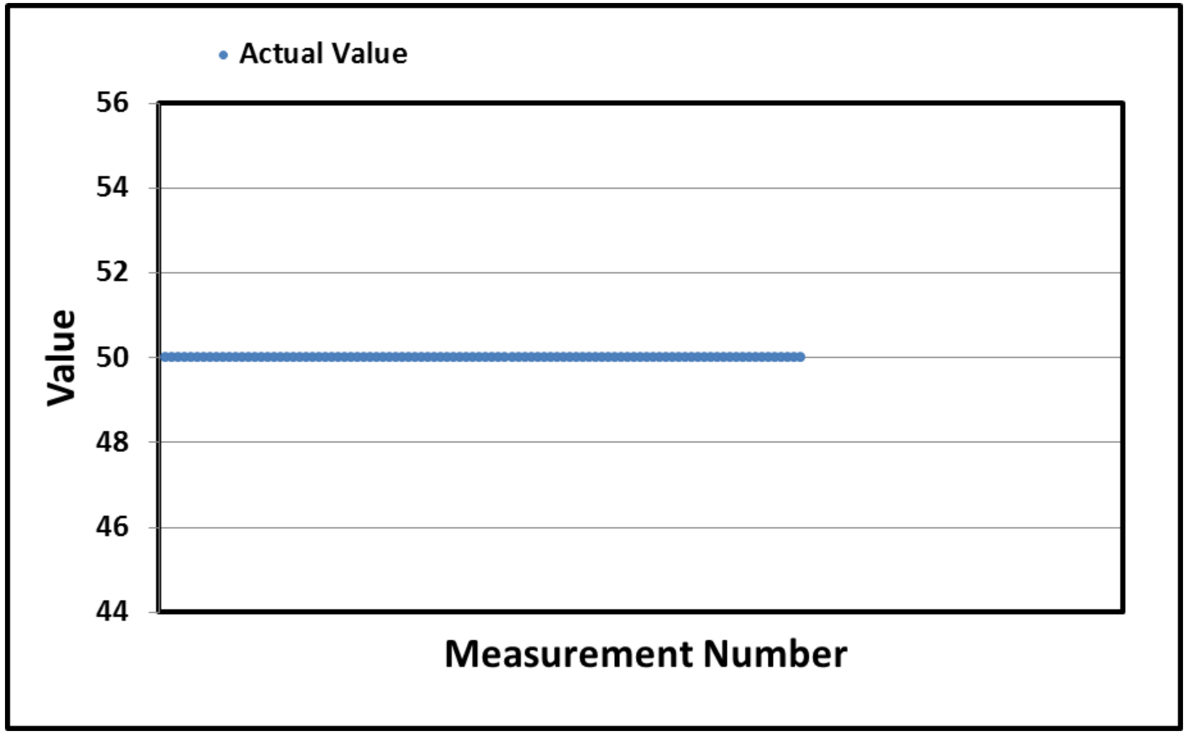
Pg 78, Measurement Systems Analysis, 4th Edition
GRR = "Gauge Repeatability & Reproducibility"

Semi Industry

Precision / Tolerance <10%

Precision to Tolerance Ratio

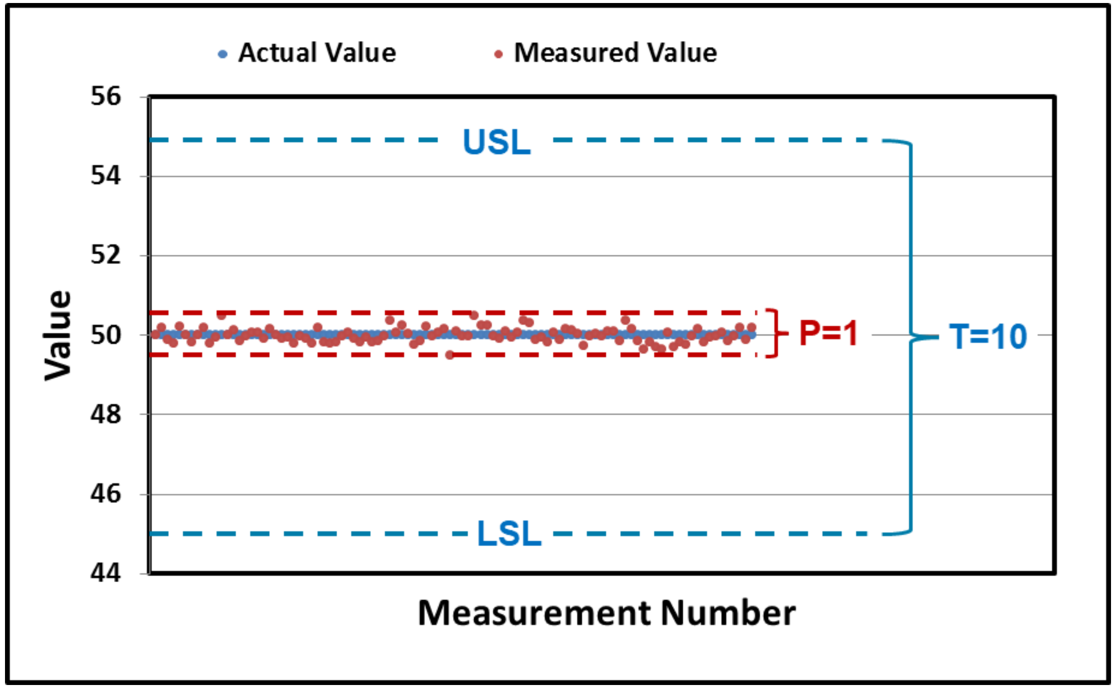
Imagine a process where every feature on the wafer has exactly the same value



Precision to Tolerance Ratio

Agreement
Capability
Compliance

The act of measuring always introduces "some amount" of error



Semi Industry Terminology

P / T < 10%

T = USL – LSL and

P = 6σ_{Tool}

MSA Terminology

%GRR < 10%

%GRR = GRR / TV*

TV = USL – LSL*

GRR = 6σ_{Tool}

*Pg 122, MSA 4th Edition

Same method. Different terminology.

KLA

Instrument (Tool) Matching

MSA

Potential sources of reproducibility error include:

- *Between*-parts (samples): average difference when measuring types of parts A, B, C, etc, using the same instrument, operators, and method.
- *Between*-instruments: average difference using instruments A, B, C, etc., for the same parts, operators and environment. Note: in this study reproducibility error is often confounded with the method and/or operator.
- *Between*-standards: average influence of different setting standards in the measurement process.

Pg 56, Measurement Systems Analysis, 4th Edition

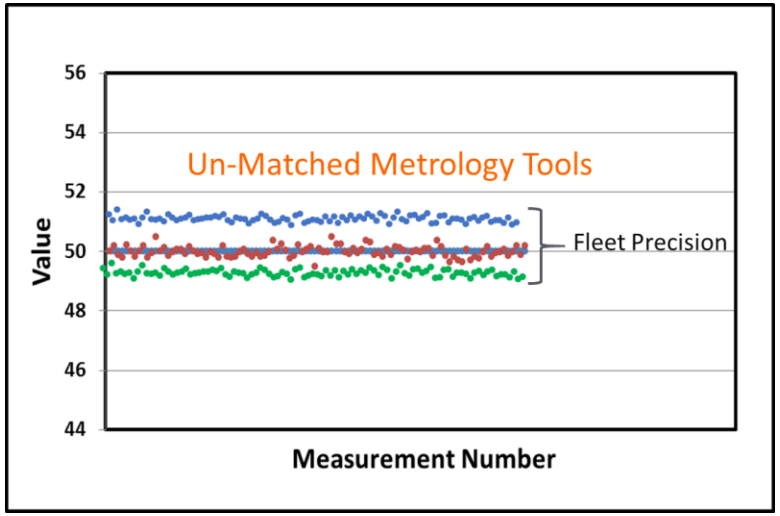
Semi Industry

Tool matching included in precision measurement

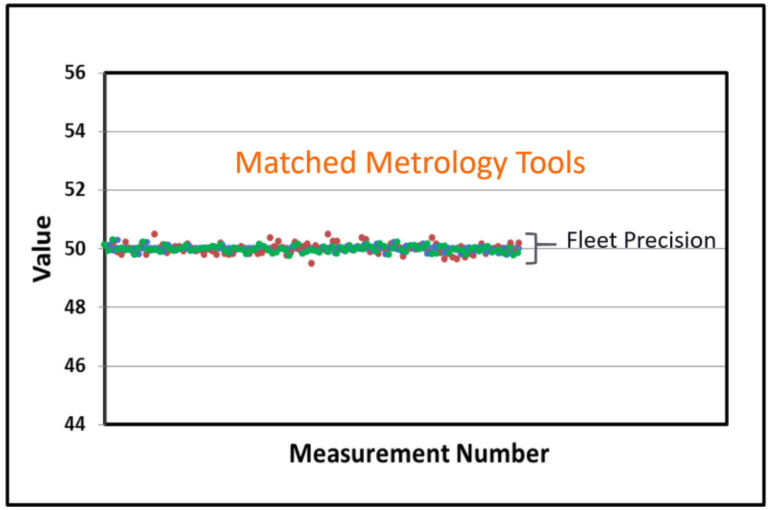
Same method. Different terminology.

Metrology Tool Matching

Un-Matched



Matched



Metrology Tools

Agreement
Capability
Compliance

Matching can be the biggest source of measurement variation

Sampling

Measurement Systems Analysis, 4th Edition, Page 27:

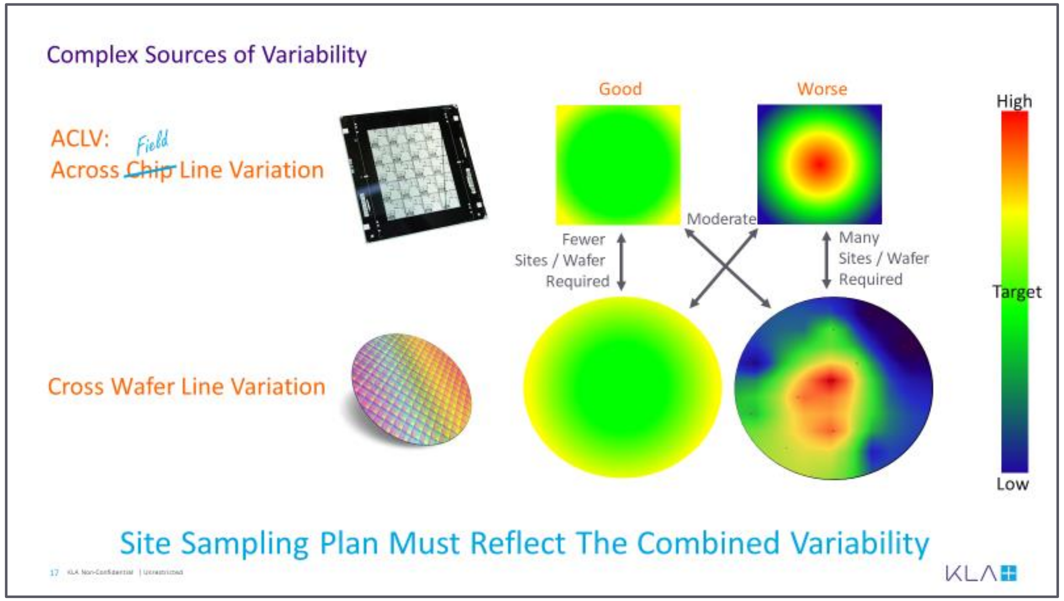
- How are measurements taken? Will it be done manually, on a moving conveyor, off-line, automatically, etc? Are the part location and fixturing possible sources of variation? Contact or non-contact?

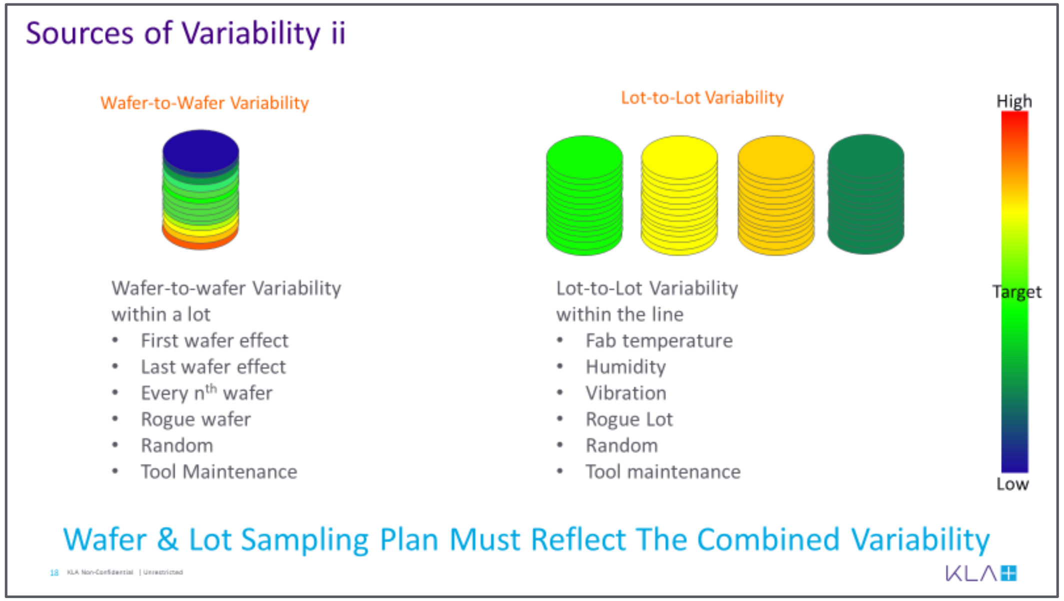
Yes!

The sampling plan is as important as the measurement itself

Sources of Variability

Agreement
Capability
Compliance



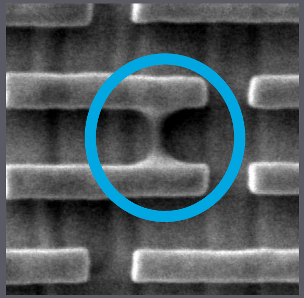


Covered in previous presentation by John Robinson

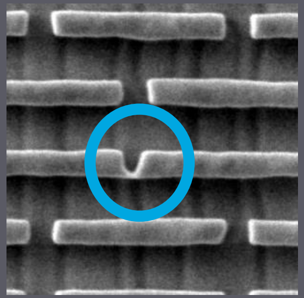
Sampling plan must include all sources of variability

- This is well known but not always practiced
- There is no specification for this

Defect Inspection



Yield
Killer



Potential
Reliability
Failure

Defect Inspection

Pg 4, Measurement Systems Analysis, 4th Edition

Purpose

The purpose of this document is to present guidelines for assessing the quality of a measurement system. Although the guidelines are general enough to be used for any measurement system, they are intended primarily for the measurement systems used in the industrial world. This document is not intended to be a compendium of analyses for all measurement systems. Its primary focus is measurement systems where the readings can be replicated on each part. Many of the analyses are useful with other types of measurement systems and the manual does contain references and suggestions. It is recommended that competent statistical resources be consulted for more complex or unusual situations not discussed here. Customer approval is required for measurement systems analysis methods not covered in this manual.

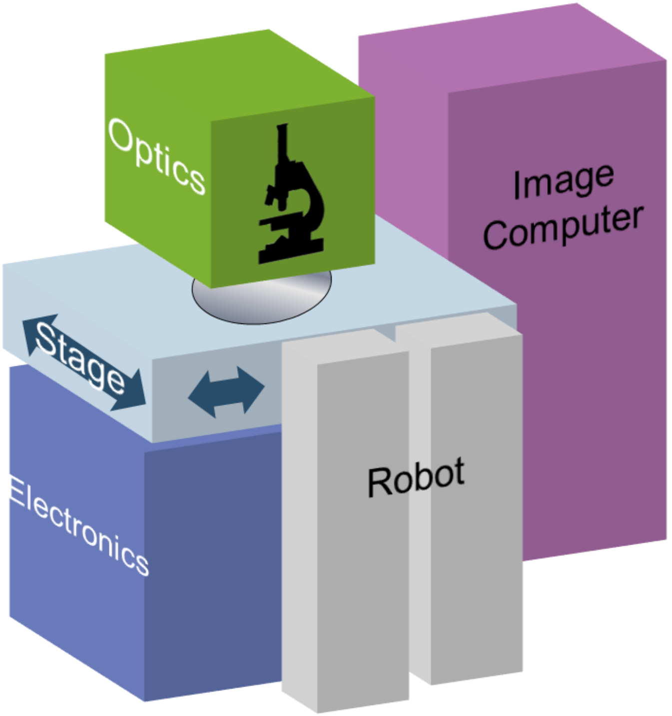
complex or unusual situations

Defect Inspection

- Not a parametric measurement
- No objective specifications
- No absolute standards
- No absolute correct answer
- Target is always Zero

Most aspects of defect inspection are not covered in the MSA

Defect Inspection



4 Main types of optical defect inspector

- Functional blocks are the same
- Underlying technology is different

Tool Name	AKA	Use Case	Sensitivity	Throughput
Broad Band Plasma	Brightfield	Defect Discovery; R&D; Ramp; HVM	High	Low
Laser Scattering	Darkfield	Excursion Monitoring; Ramp; HVM	Medium	Medium
Macro		Litho excursions; I-PAT	Low	High
SurfScan	Bare Wafer	Process Tool Monitor	Medium	Medium

Capability

The tool must be capable for the job at hand

Defect Discovery (Tool: Broad Band Plasma)

- Find all relevant defect types in their relative abundances
- Sensitivity to find defects significantly smaller than the DR

Excursion Monitoring (Tool: Laser Scattering)

- Sufficient sensitivity to find all defects of interest (high signal)
- Sufficient filtering of non-relevant defects (low noise)

I-PAT (Tool: Macro)

- Sensitivity is less important
- But must be able to identify outlier die (higher defectivity)

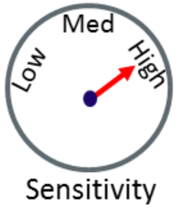
Process Tool Qualification (Tool: SurfScan / Bare Wafer)

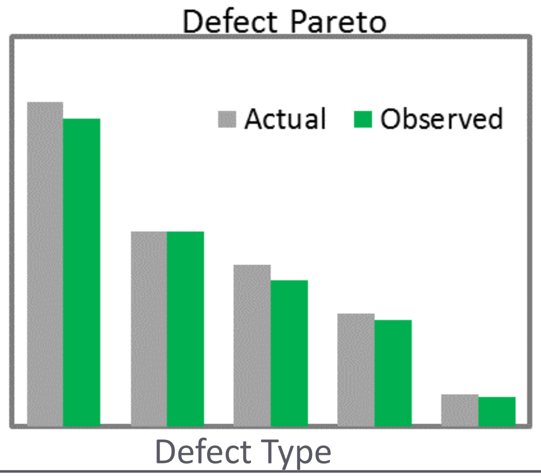
- Sensitive to defects that impact reliability
- Usually a full design rule smaller than those that impact yield

Capability and Sensitivity – Broad Band Plasma (Brightfield)

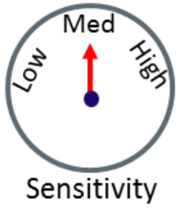
Tool: Broad Band Plasma, Use Case: Defect discovery

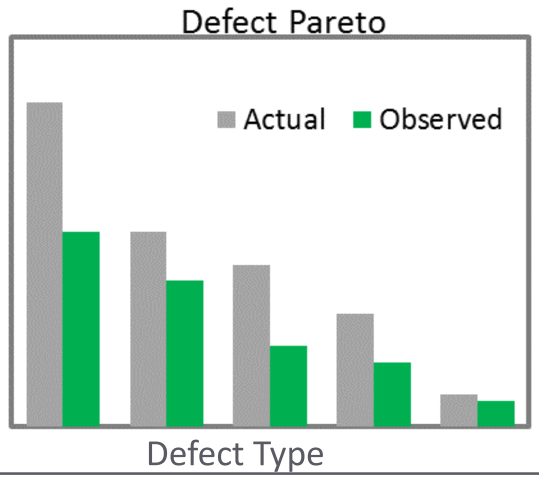
High Sensitivity:
- Good match between actual and observed



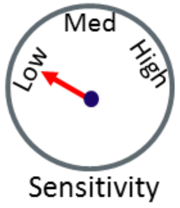


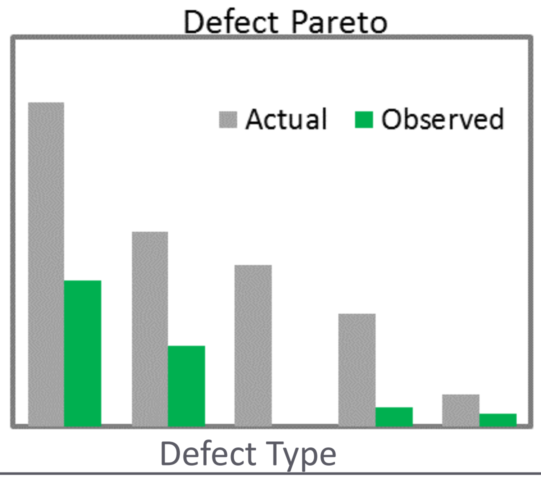
Medium Sensitivity:
- Loss of fidelity in actual vs observed defect count





Low Sensitivity:
- Some defect types are missing completely



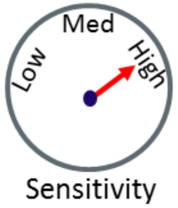


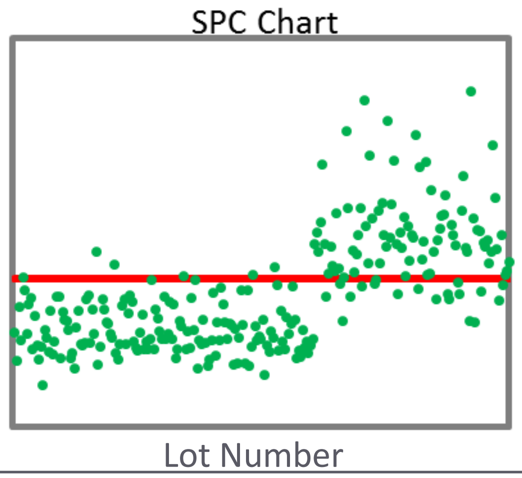
Capability and Sensitivity – Laser Scattering (Darkfield)

Tool: Laser Scattering, Use Case: Excursion Monitoring

High Sensitivity:

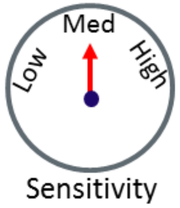
- High signal-to-noise
- Good excursion detection

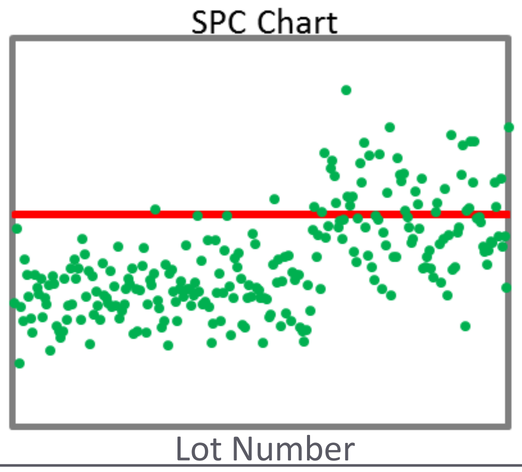




Medium Sensitivity:

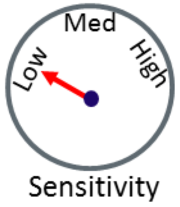
- Takes longer to detect excursion
- More exposed lots

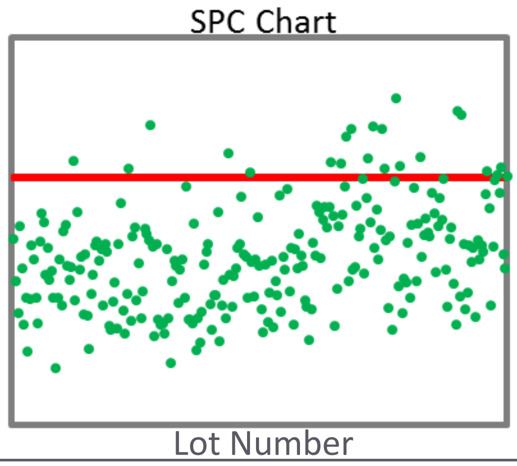




Low Sensitivity:

- Some excursions completely missed



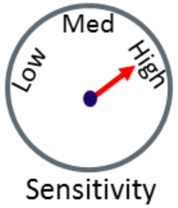


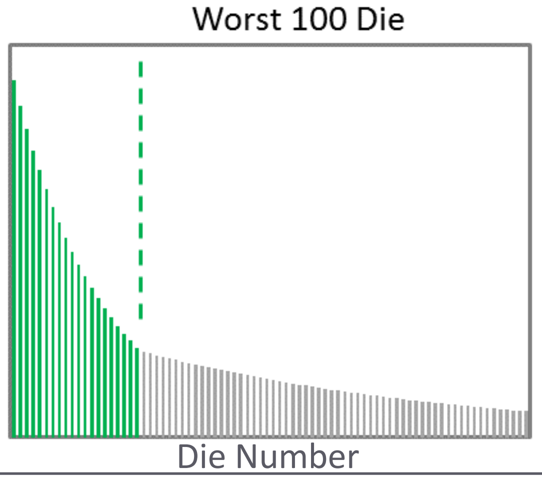
Capability and Sensitivity - Macro

Tool: Macro, Use Case: I-PAT

High Sensitivity:

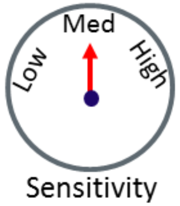
- Good identification of outlier die

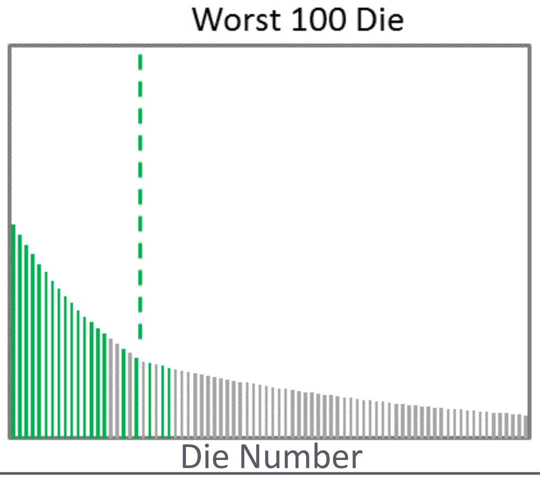




Medium Sensitivity:

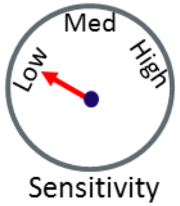
- Some outliers will be mis-classified

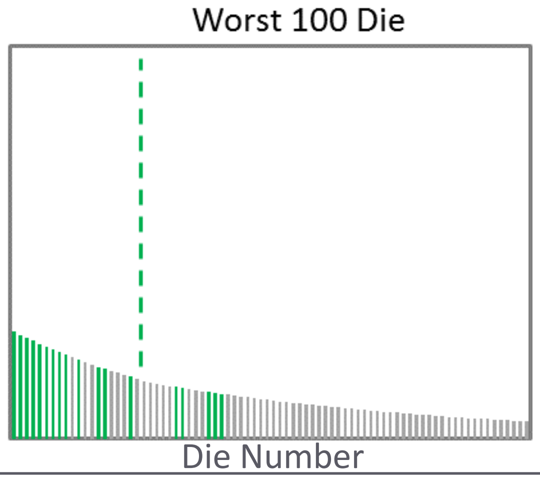




Low Sensitivity:

- More outliers mis-classified but still useful





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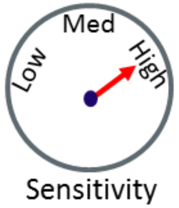
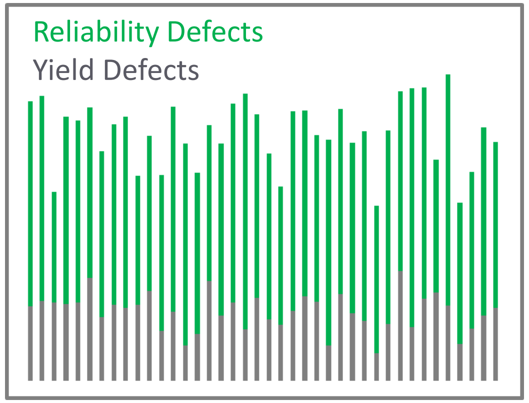
Capability and Sensitivity – SurfScan (Bare Wafer Inspection)

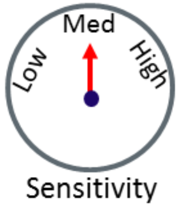
Tool: SurfScan, Use Case: Process Tool Qualification

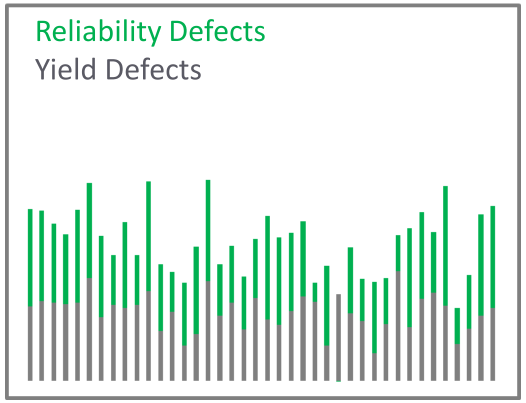
High Sensitivity:
- Finds all defects that are a full DR smaller than spec.



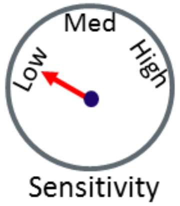


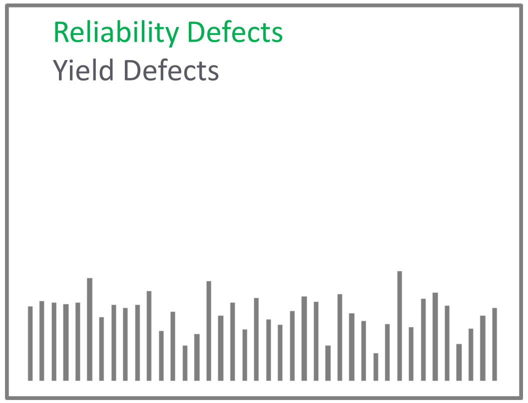
Medium Sensitivity:
- Misses some small (reliability) defects



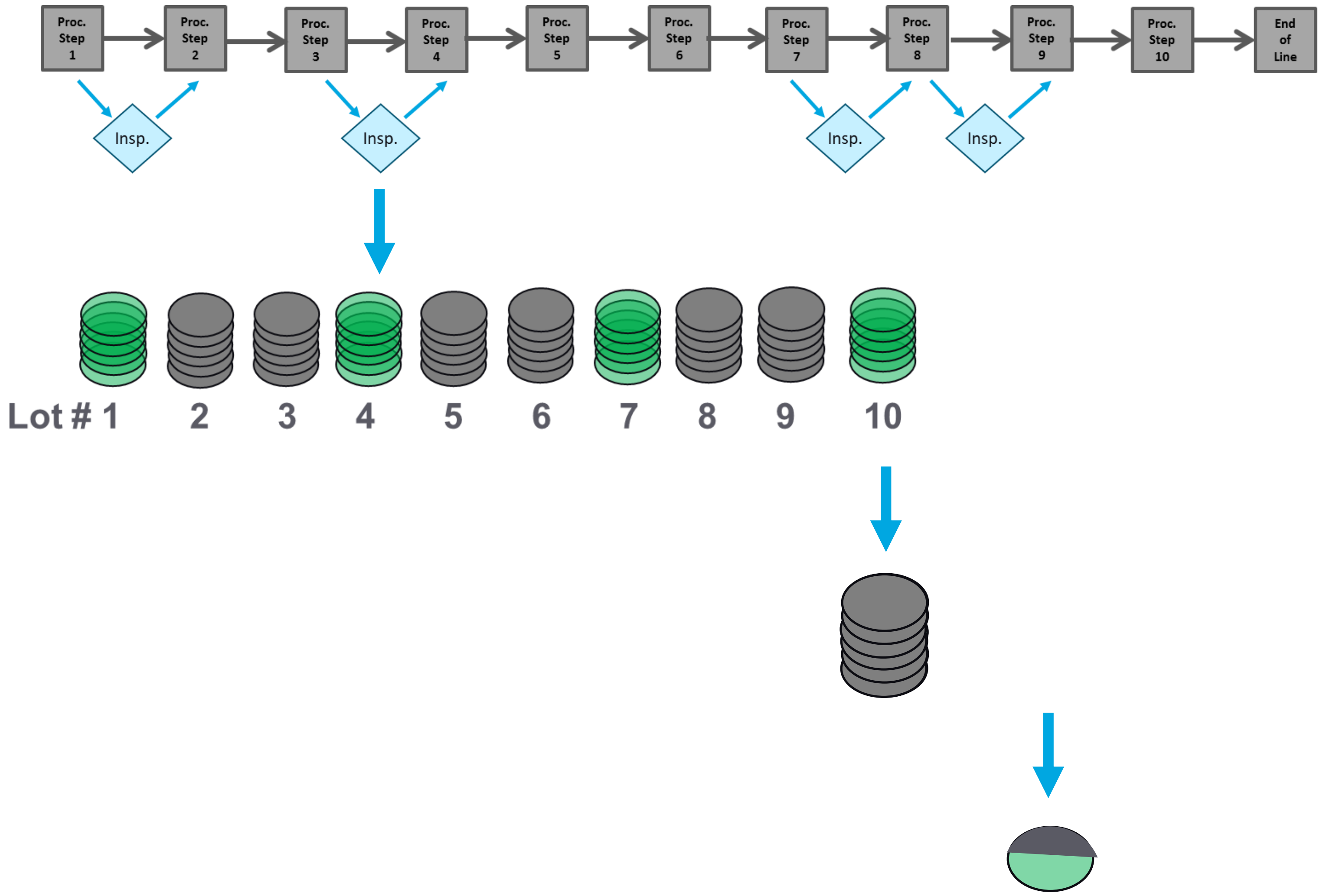


Low Sensitivity:
- Misses all reliability defects and some yield killers





Capability and Sampling



a) Number of defect inspection steps in the line

b) Average percent of lots inspected

c) Average wafers per lot

d) Average area per wafer

You will only find problems in the places that you actually look for them!

KLA

Maintenance Considerations

Preventative Maintenance

MSA

What activities should be scheduled for preventive maintenance (e.g., lubrication, vibration analysis, probe integrity, parts replacement, etc.)? Much of these activities will depend on the complexity of the measurement system, device or apparatus. Simpler gages may require only an inspection at regular intervals, whereas more complex systems may require ongoing detailed statistical analyses and a team of engineers to maintain in a predictive fashion.

Pg 32, Measurement Systems Analysis, 4th Edition

Semi Industry

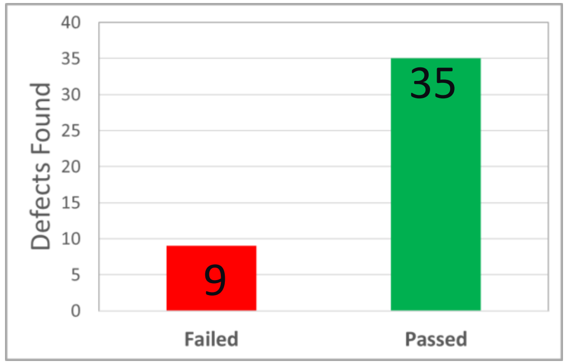
more complex systems

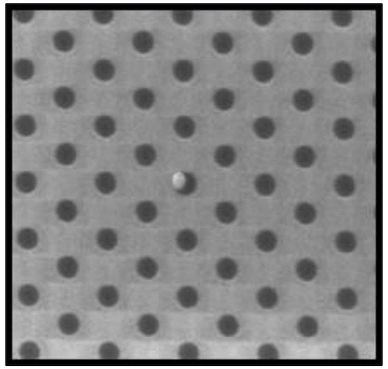
Unambiguous maintenance guidelines exist, but are not always followed in practice.

Maintenance Test: Conformance to OEM Specs

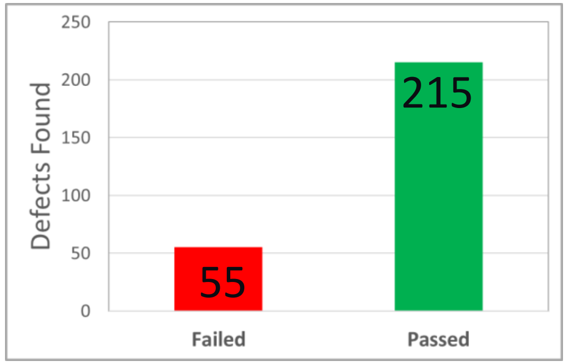
Agreement
Capability
Compliance

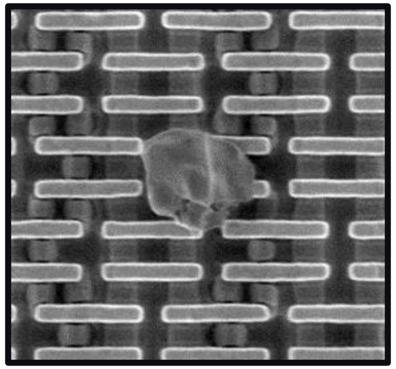
Small Particles



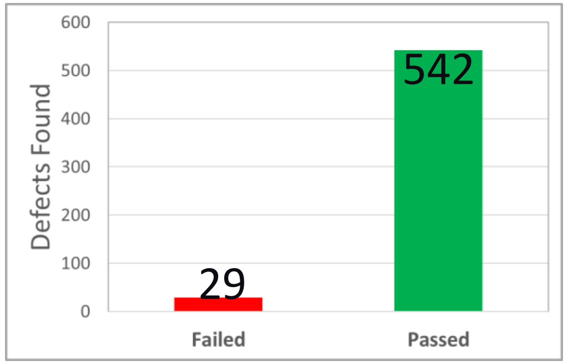


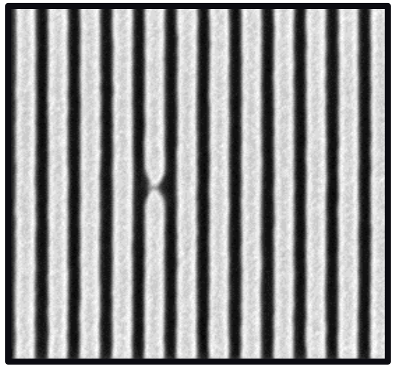
Large Particles





Broken Lines





- Same wafers
- Same tool make & model
- Same tool recipe
- Different tool maintenance

Finding fewer defects is only better … if you're finding all of them!

(You can't fix what you can't find)

Fab Audits

[Fab Audit Process]()

[Service Conformance App]()

- Develop the industry BKM for demonstrating compliance to OEM specs
- Facilitate a frictionless transaction between Auditor & Fab

Coming Soon!

Summary

- The Semi industry is in full compliance with many aspects of the MSA document.
- Some aspects of MSA fall into the “Knowing / Doing Gap”
  - Everyone knows what to do
  - Everyone knows how to do it
  - But, there is a lot of variability in the way (or if) it actually gets done.
- Defect Inspection is unique to the semiconductor industry
  - The MSA document is usually not directly applicable
  - Modifications and/or additions are probably required

Thank you!