New Methods to Reduce Variation in Bare Wafer Particle Inspection Results

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Agenda

- Background
- tpM2M (Tighter Pre-scan Map-2-Map) Method
- DIOO (Dual Incidence Oblique Oblique) Method
- Applying tpM2M + DIOO to Filter Evaluations

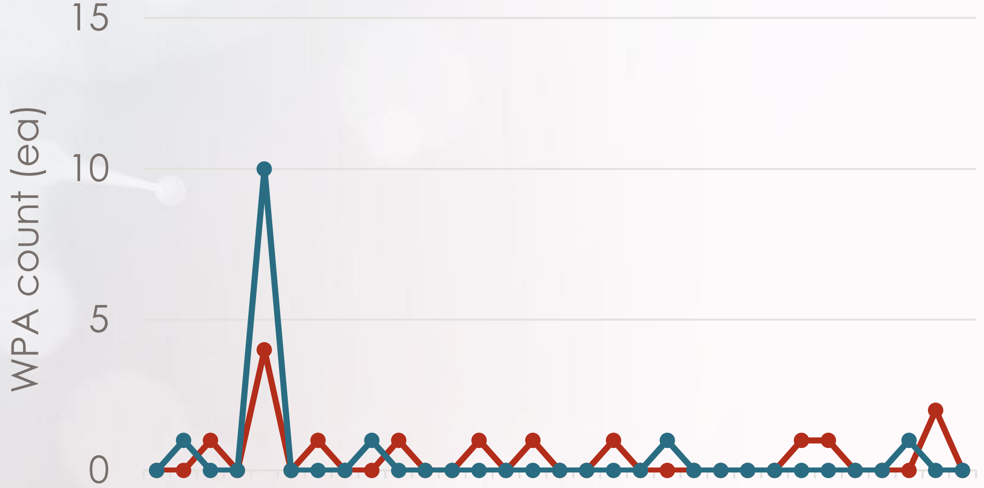
Background

Background

As contaminant concentration reduces in advanced wafer processes, there is a higher likelihood to see significant variation in on-wafer defectivity as there are fewer defects to compare from pre-inspection to post-inspection

It is increasingly difficult to compare processes, materials or equipment when they produce low baseline particle counts

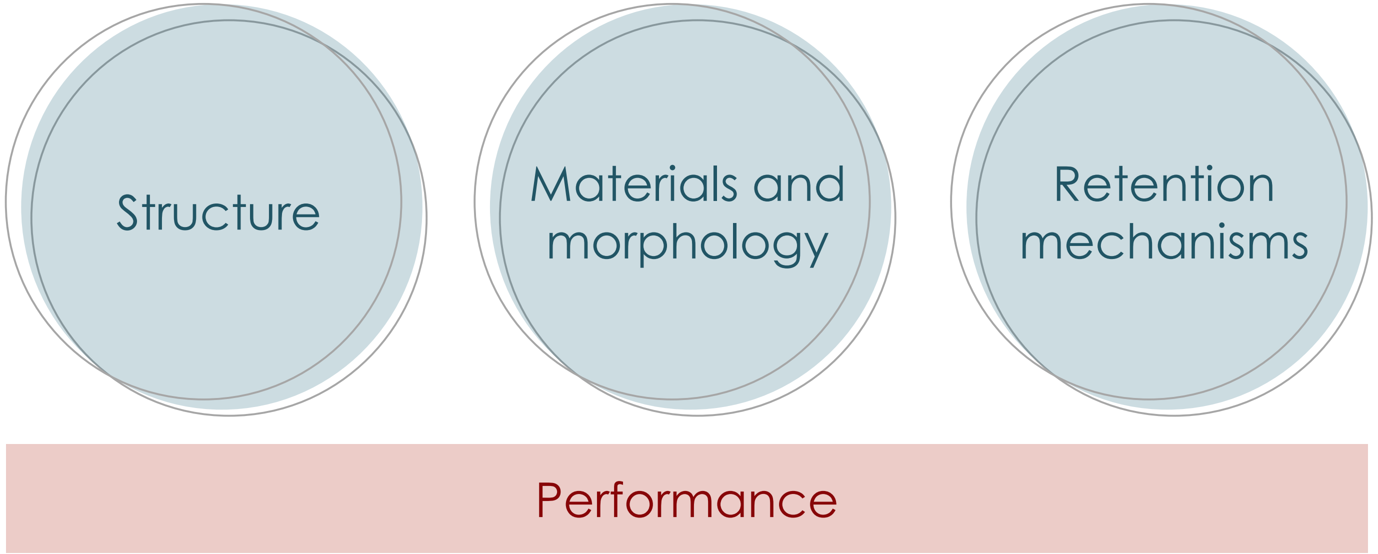
Particle Adders for Processes A and B



Process A: Average WPA: 0.45 ea
Touch-ground rate: 68%

Process B: Average WPA: 0.45 ea
Touch-ground rate: 84%

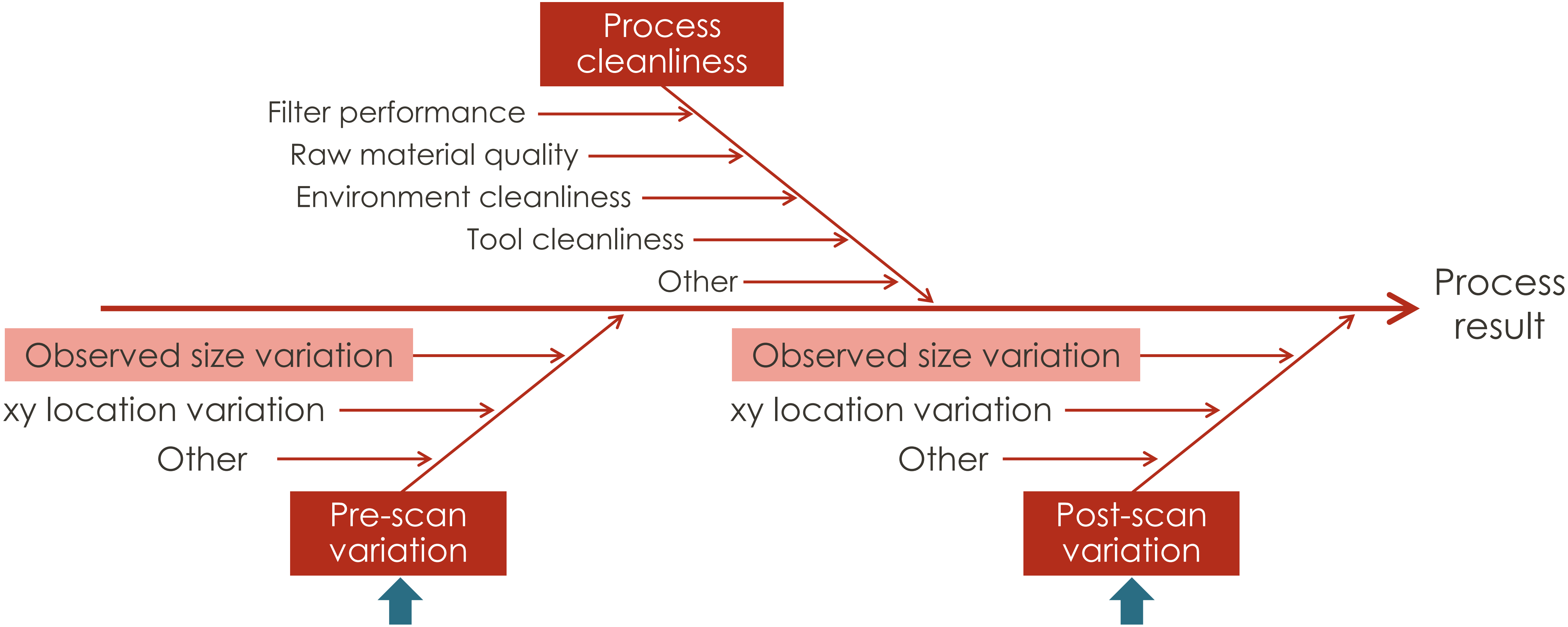
Many factors influence filter choice and defectivity performance



Compatibility
+
Morphology and flow path
+
Retention mechanisms
=
Total performance

In order to best characterize filter performance in an application, metrology results need to provide meaningful, actionable results.

Fishbone diagram for process result



Process cleanliness

Filter performance

Raw material quality

Environment cleanliness

Tool cleanliness

Other

Process result

Observed size variation

xy location variation

Other

Pre-scan variation

Observed size variation

xy location variation

Other

Post-scan variation

Reduced variation by "**tpM2M**"
(tighter pre-scan Map-to-Map)

Reduced variation by "**DIOO**"
(Dual Incidence Oblique Oblique)

Metrology variation (pre-scan and post-scan) of a Surfscan SP3

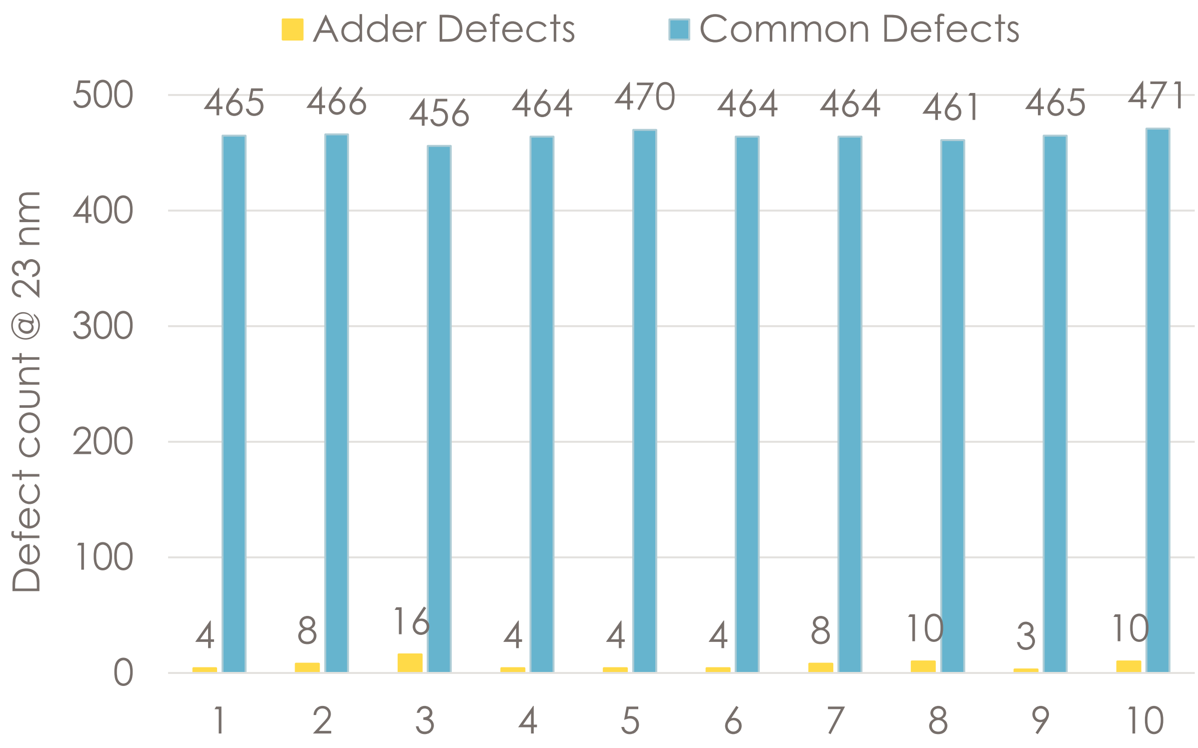
#1 Wafer
(processed DIW before)


23 nm pre-scan → No process → 23 nm post-scan

Overlap 2 maps and calculate adder

Ideally, there should be no adder

Standard Map-2-Map Adder
w/o wafer processing @ 23 nm
(10 repeat scan on same wafer)



Ideally, we would expect 0 adders in result, but some adders showed at sensitivity threshold

Metrology variation (pre-scan and post-scan) of a Surfscan SP3

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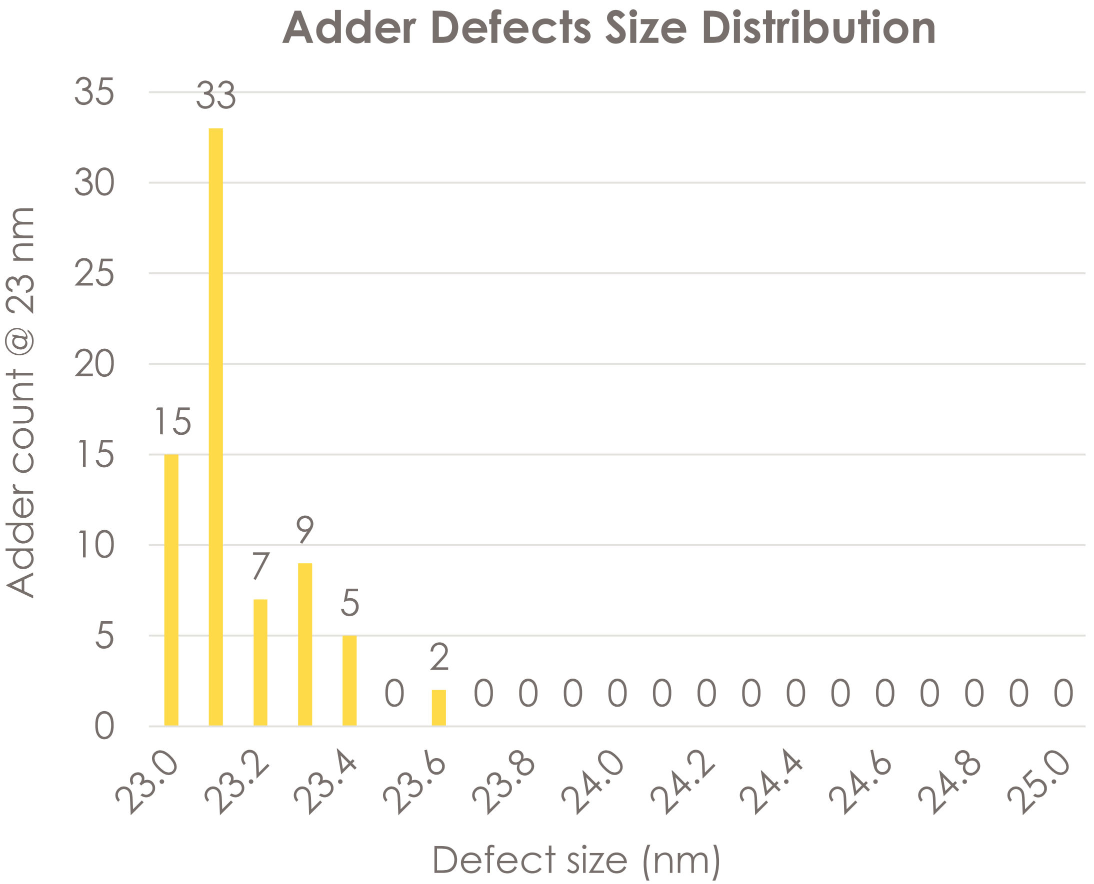

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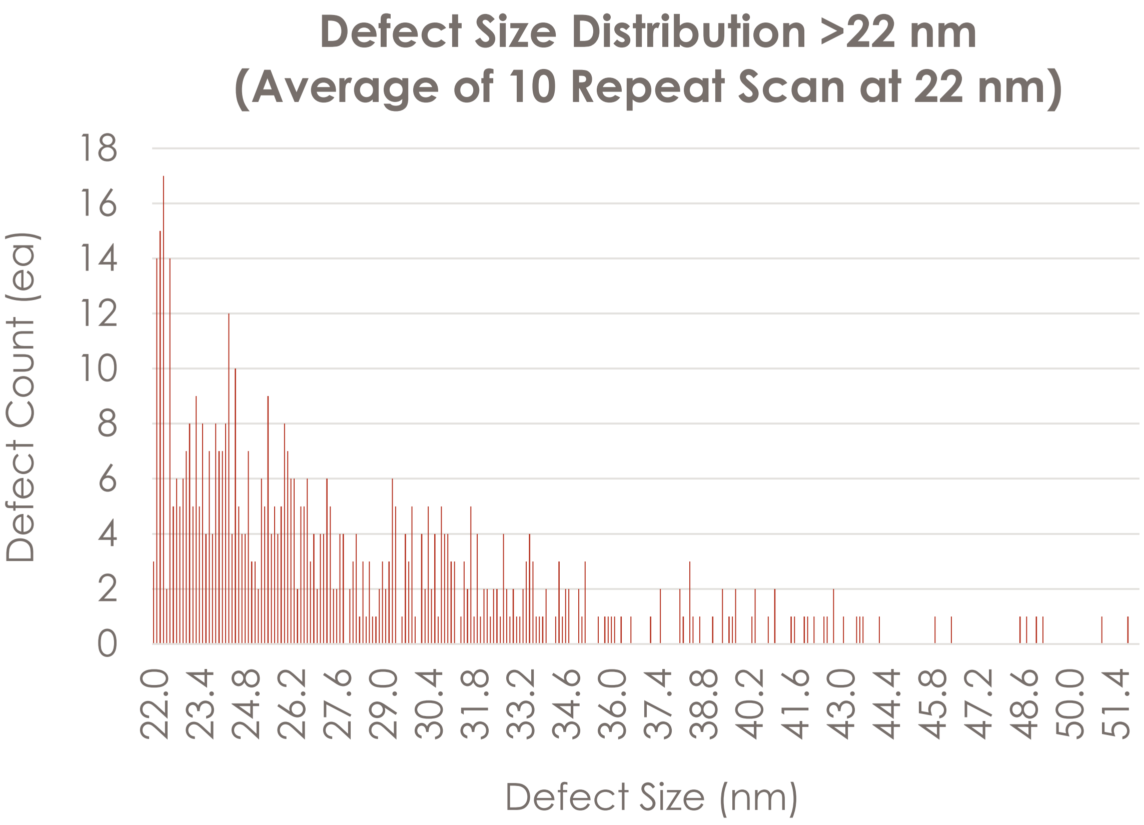
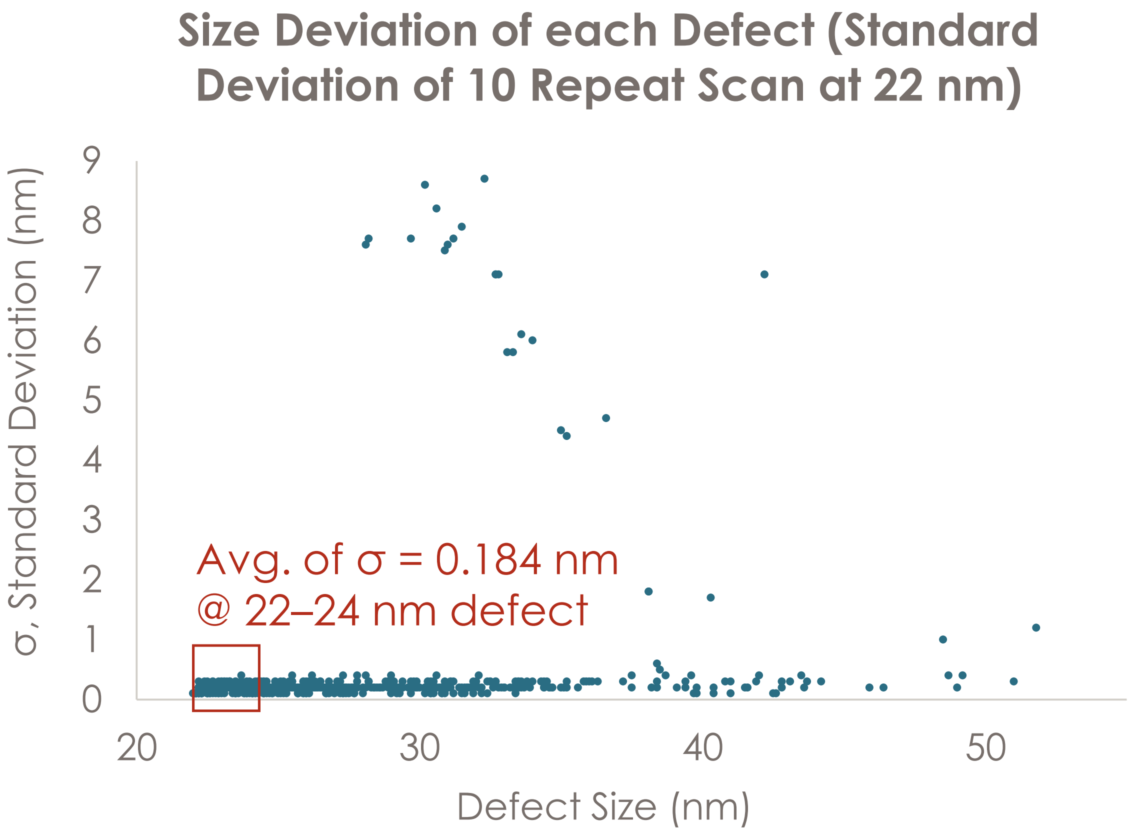
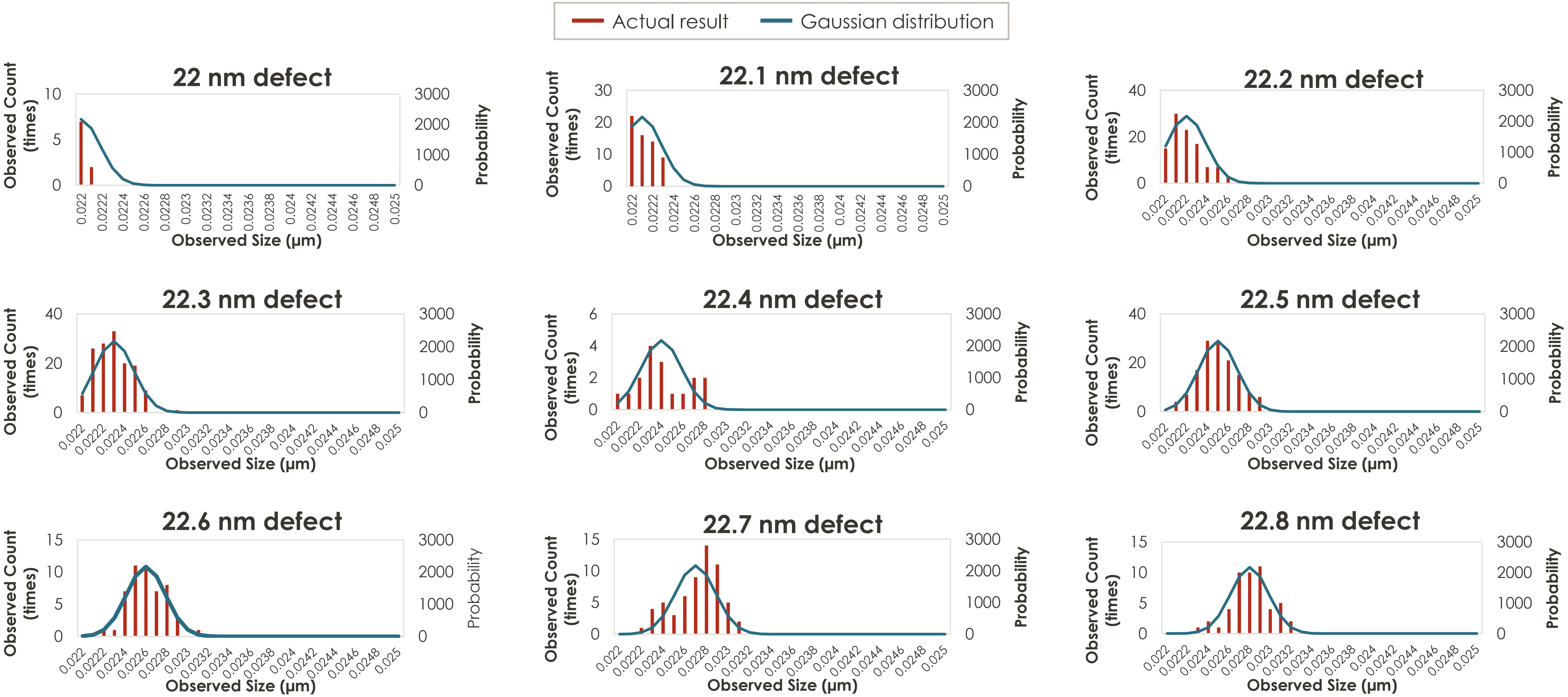
Size deviation in a bare wafer inspection system





Standard deviation of the observed size is a constant, and equals 0.184nm

Observed size follows Gaussian distribution



The observed size in the 10 scans followed Gaussian distribution

*Defects uncaptured in certain scans are not included into the plot

Probability for a defect to be captured

After showing the result from a bare wafer inspection system follow Gaussian distribution, the probability for a defect to be captured can be calculated.

$$\text{Probability} = 1- 0.5*(1 + \text{erf}[(\text{Threshold Size} - \text{Actual Size})/(\sigma *\sqrt{2})]$$

For example, a recipe threshold of 23nm is used to capture a 23nm defect.

$$\text{Probability} = 1- 0.5*(1 + \text{erf}[(\mathbf{23} - \mathbf{23})/(\mathbf{0.184} *\sqrt{2})] = 50\%$$

Probability of seeing this defect is 50%

tpM2M Method and Model

(Tighter Pre-scan Map-2-Map)

tpM2M (tighter pre-scan Map-2-Map) method and model

Entegris

tpM2M method

sM2M Adder
(Standard Map-2-Map)

tpM2M Adder

Fewer defects were missed
in pre-scans by tpM2M method
(fewer false adders)

tpM2M modeling

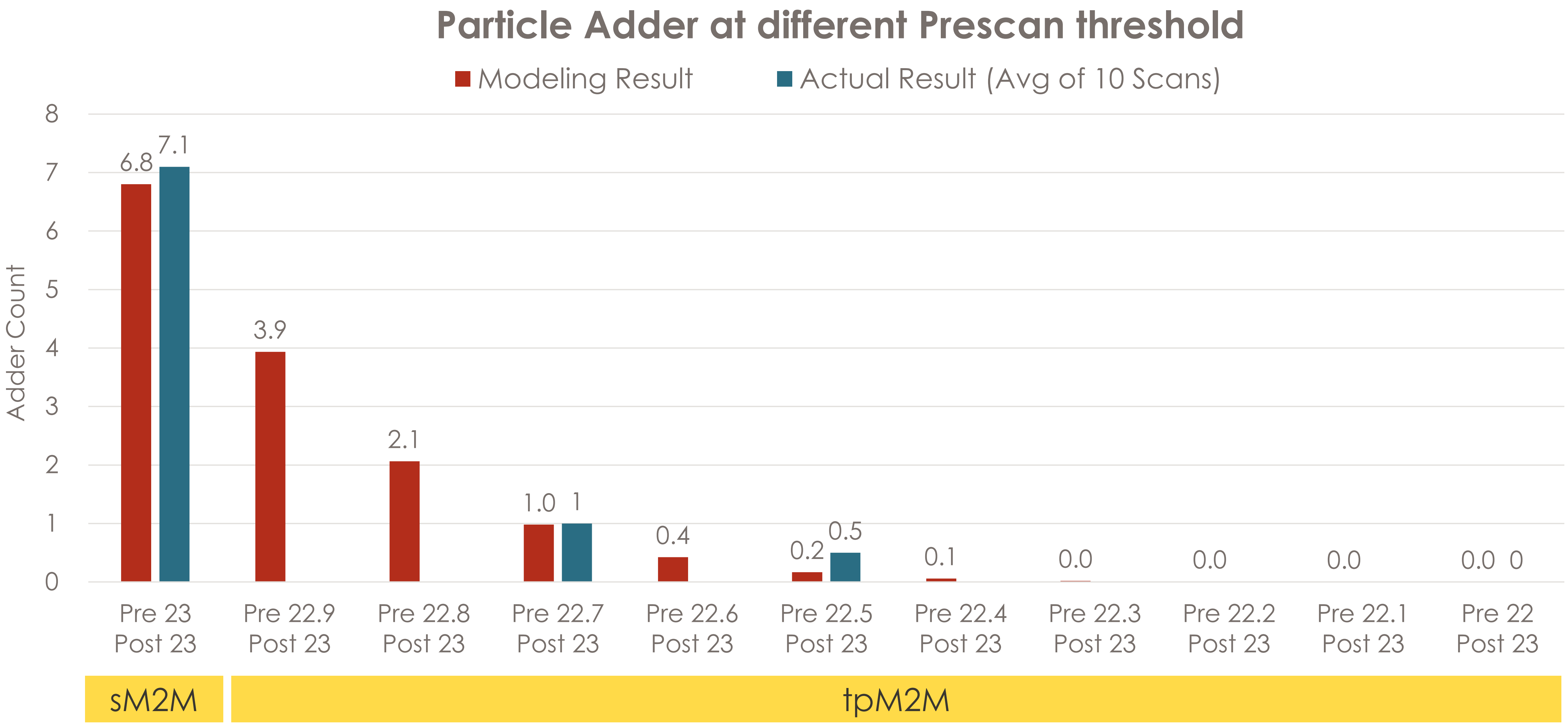
$$f(x) = \sum_{D=22.0}^{24.0} \underbrace{\left(\frac{1}{2} + \frac{1}{2}\mathrm{erf}\left(\frac{T_{pre} - D}{\sigma\sqrt{2}}\right)\right)}_{\text{Probability that a size=D defect CANNOT be seen in pre-scan}} * \overbrace{\left(\frac{1}{2} - \frac{1}{2}\mathrm{erf}\left(\frac{T_{post} - D}{\sigma\sqrt{2}}\right)\right)}^{\text{Probability that a size=D defect CAN be seen post-scan}} * \underbrace{ND}_{\text{Count of size=D defect}}$$

T_{pre} = Recipe Threshold at pre-scan (22.0–23.0)
D = Diameter of the defect
σ = Standard deviation in size (Assume = 0.184 = constant)
N_D = Count of size = D defect

Assumptions made:

1. All false adder defects came from observed size deviation (e.g. adder caused by x-y deviation is neglected)
2. Observed size follows Gaussian distribution
3. Standard deviation of the observed size is constant and equals 0.184 nm

tpM2M result



DIOO Method and Model

(Dual Incidence Oblique Oblique)

DIOO method and model

DIOO method

23 nm scan → 23 nm result

Standard

23 nm scan → 23 nm scan —Compositing→ 23 nm DIOO result

DIOO Method

More true defects were captured in post-scans by DIOO method

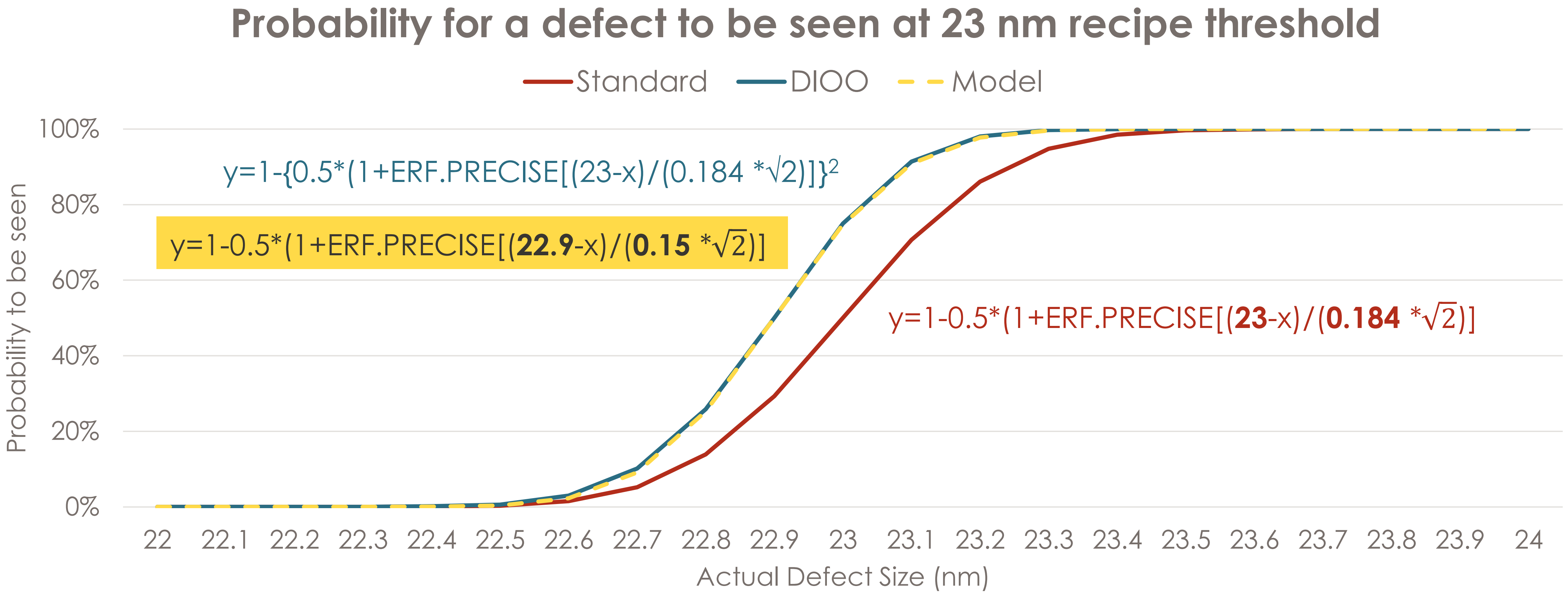
Probability for a defect to be seen at different recipe threshold

	Recipe Threshold 23	
Actual Defect Size	**Standard**	**DIOO**
22.0	0.0%	0.0%
22.1	0.0%	0.0%
22.2	0.0%	0.0%
22.3	0.0%	0.0%
22.4	0.1%	0.20%
22.5	0.3%	0.60%
22.6	1.5%	2.98%
22.7	5.2%	10.13%
22.8	13.9%	25.87%
22.9	29.3%	50.02%
23.0	50.0%	75.00%
23.1	70.7%	91.42%
23.2	86.1%	98.07%
23.3	94.8%	99.73%
23.4	98.5%	99.98%
23.5	99.7%	100.0%
23.6	99.9%	100.0%
23.7	100.0%	100.0%
23.8	100.0%	100.0%
23.9	100.0%	100.0%
24.0	100.0%	100.0%

Standard = 1 - 0.5*(1+ERF.PRECISE[(Threshold Size–Actual Size)/(σ *$\sqrt{2}$)]

DIOO = 1 – {0.5*(1+ERF.PRECISE[(Threshold Size–Actual Size)/(σ *$\sqrt{2}$)]}^{2}

DIOO method and model



DIOO probability curve fit the normal distribution curve with u = 22.9 and σ = 0.15

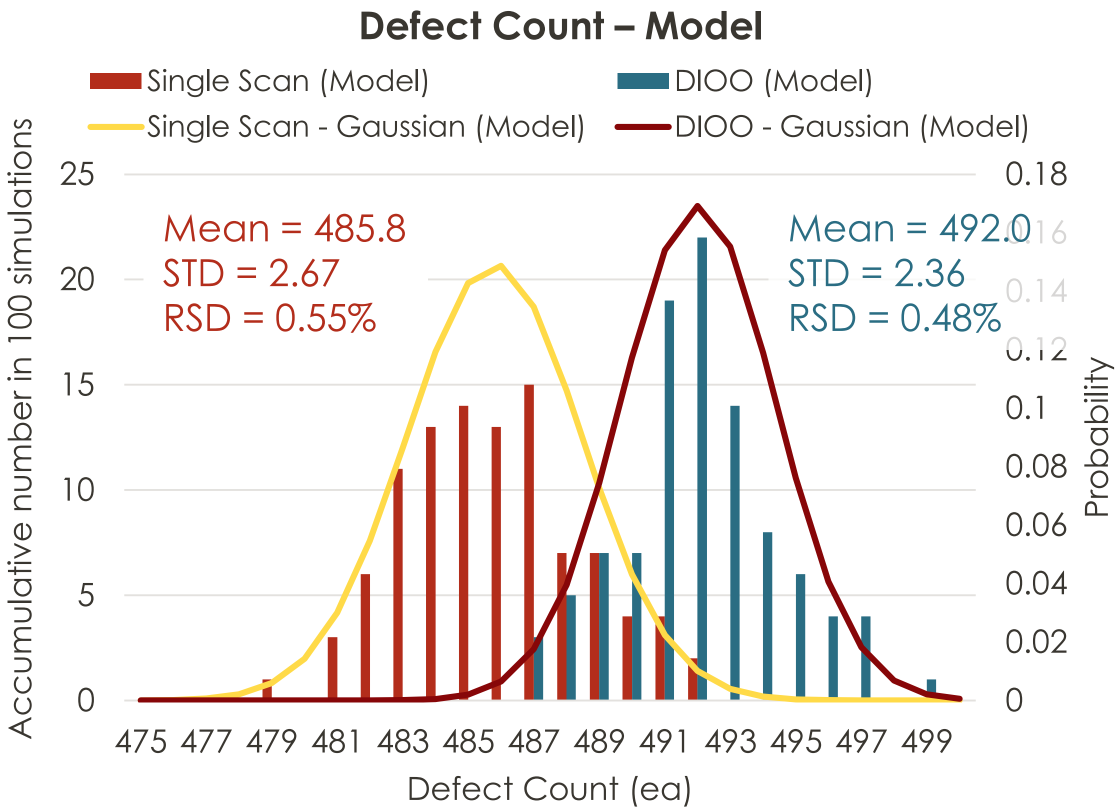
We can consider the standard deviation of observed size is reduced from 0.184 nm to 0.15 nm

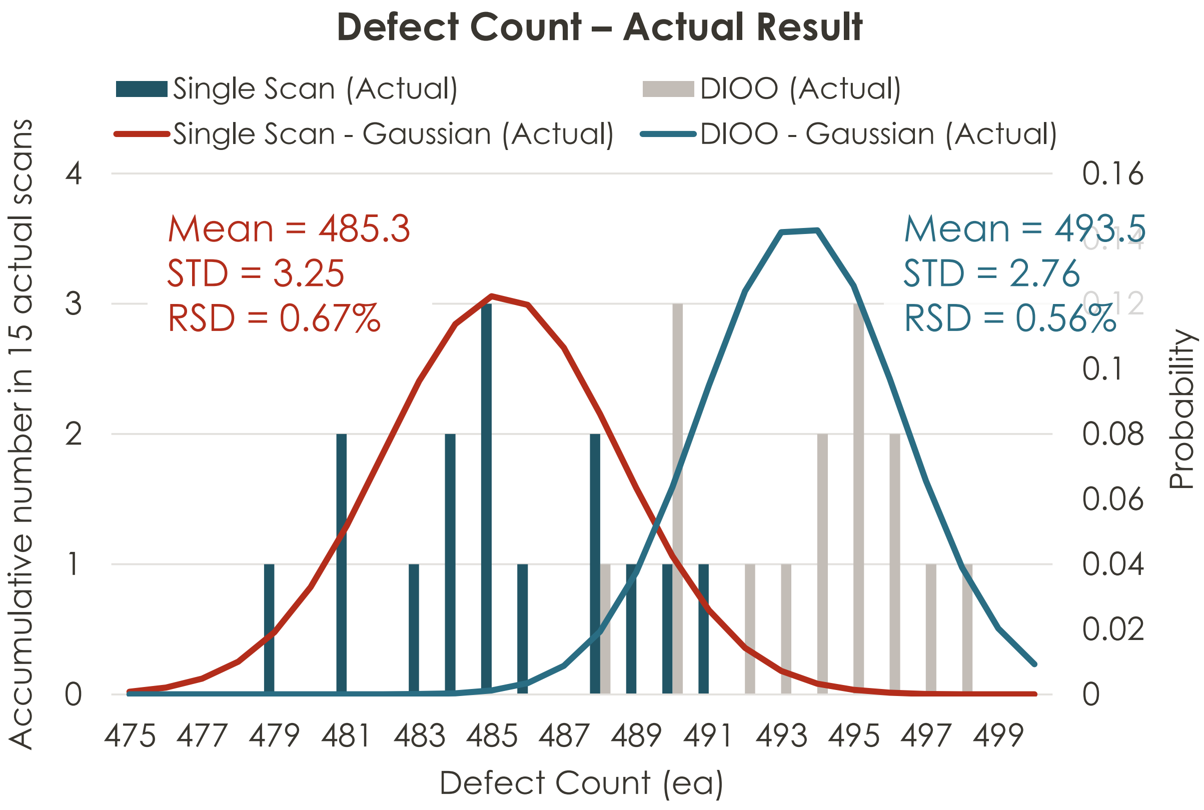
DIOO method and model

Wafer #2 was scanned 10 times at 22 nm recipe threshold

The average and standard deviation in size of each defect were used to calculate the theoretical count of 100 scans (left) at 23 nm recipe threshold

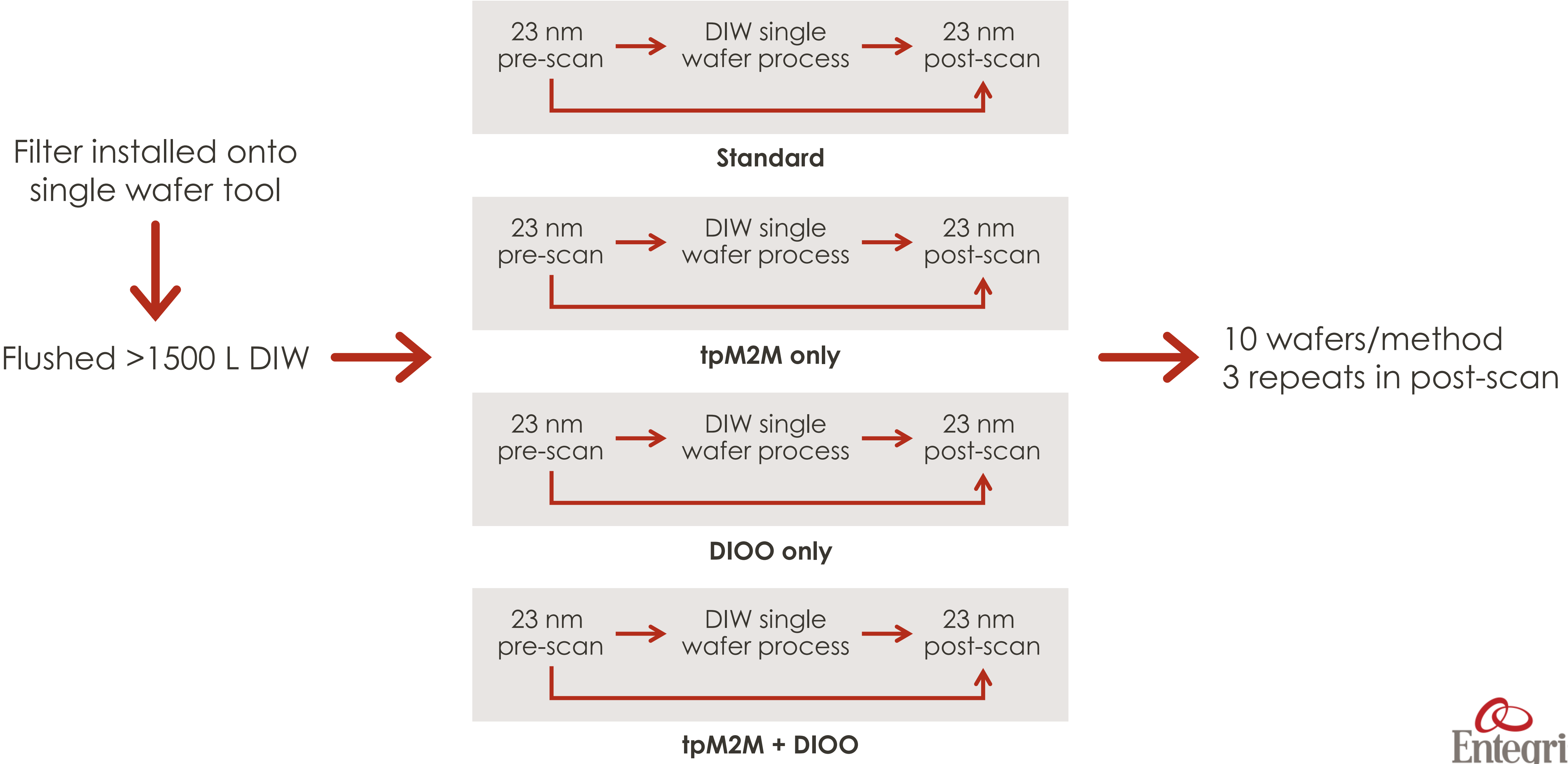
The actual wafer result of 15 scans at 23 nm (right) pretty much aligned with the prediction





Example of applying tpM2M plus DIOO method in Wet Process Monitor

Applying tpM2M + DIOO on filter evaluation



Filter installed onto single wafer tool

Flushed >1500 L DIW

23 nm pre-scan → DIW single wafer process → 23 nm post-scan

Standard

23 nm pre-scan → DIW single wafer process → 23 nm post-scan

tpM2M only

23 nm pre-scan → DIW single wafer process → 23 nm post-scan

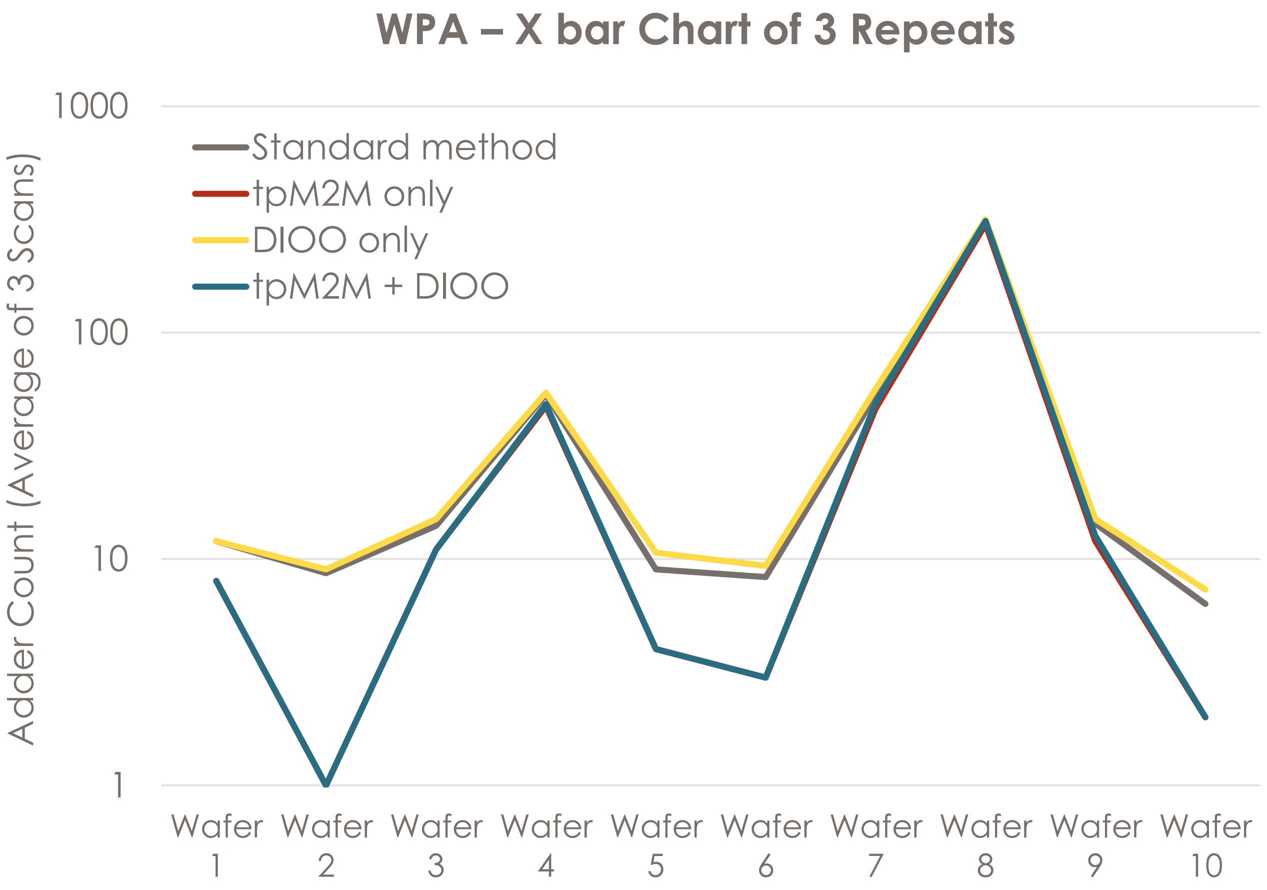
DIOO only

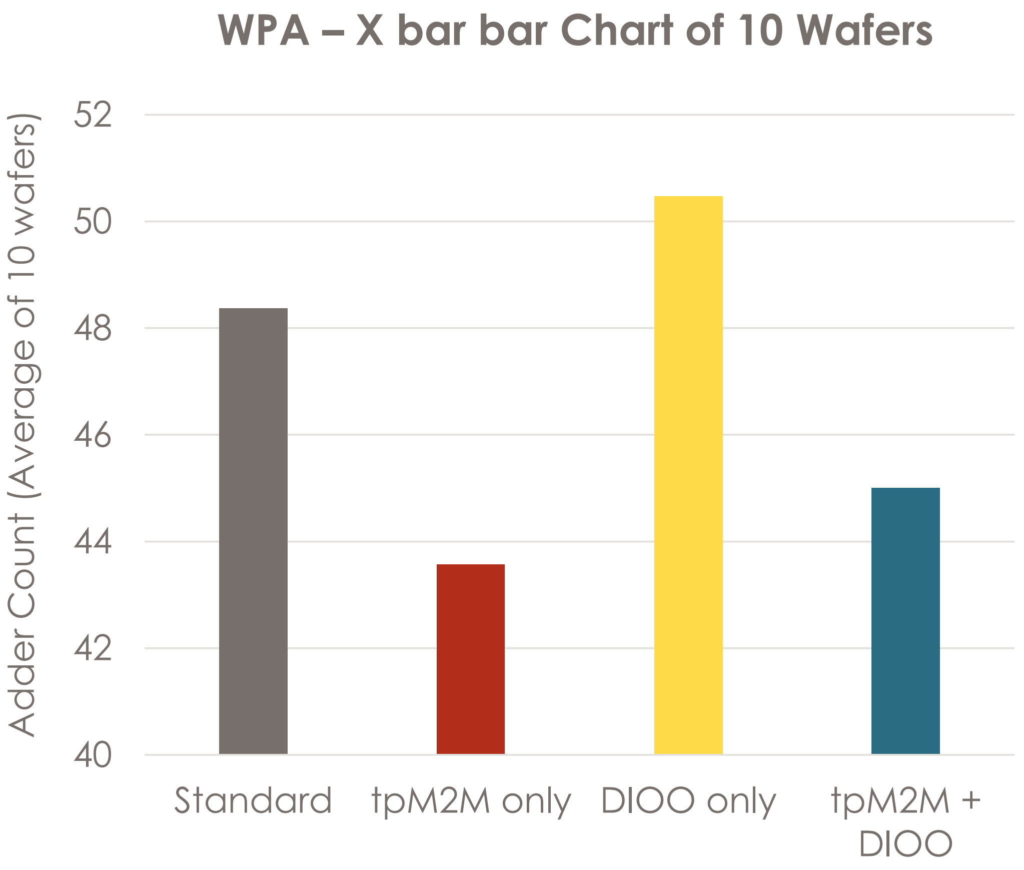
23 nm pre-scan → DIW single wafer process → 23 nm post-scan

tpM2M + DIOO

10 wafers/method
3 repeats in post-scan

Results of applying tpM2M and DIOO – average

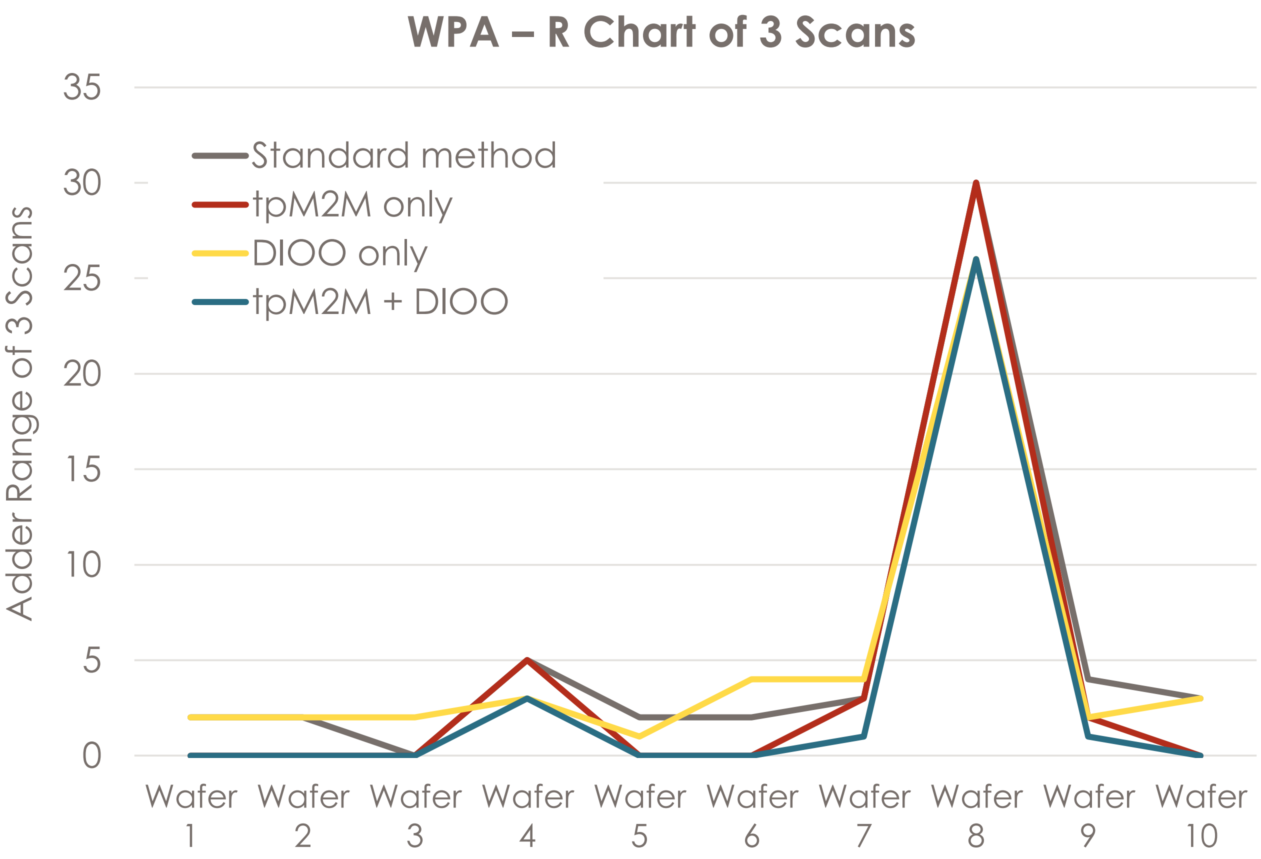


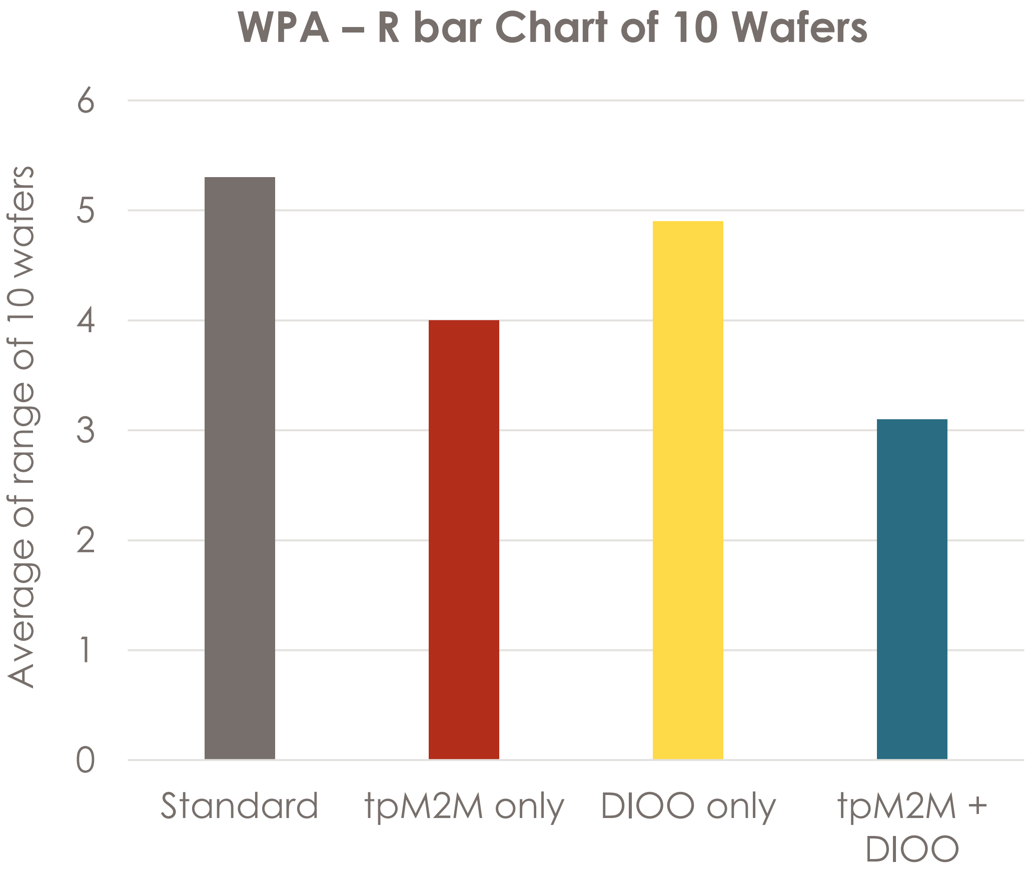


tpM2M reduced false adder and gives a lower count

DIOO slightly increased sensitivity and gives a higher count

Results of applying tpM2M and DIOO – range





tpM2M and DIOO method both reduced the WPA count variation of this DIW process (tpM2M more than DIOO)

A combination of applying both tpM2M and DIOO gives the best result

Summary

Reducing variation generated by on-wafer inspections is essential, so we can make better decisions regarding equipment/material

Results from an unpatterned wafer defect inspection system (e.g. Surfscan) follows Gaussian distribution

tpM2M and DIOO methods were introduced with a model to reduce the variation

A combination of tpM2M and DIOO methods is suggested to give the best result when evaluating a process/ equipment/material

Thank you!

Q&A