Verification of Probing Accuracy

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Agenda

- Background
- Definition of Terms
- Experimental Design
- Results and Analysis
- Summary and Future Evaluations

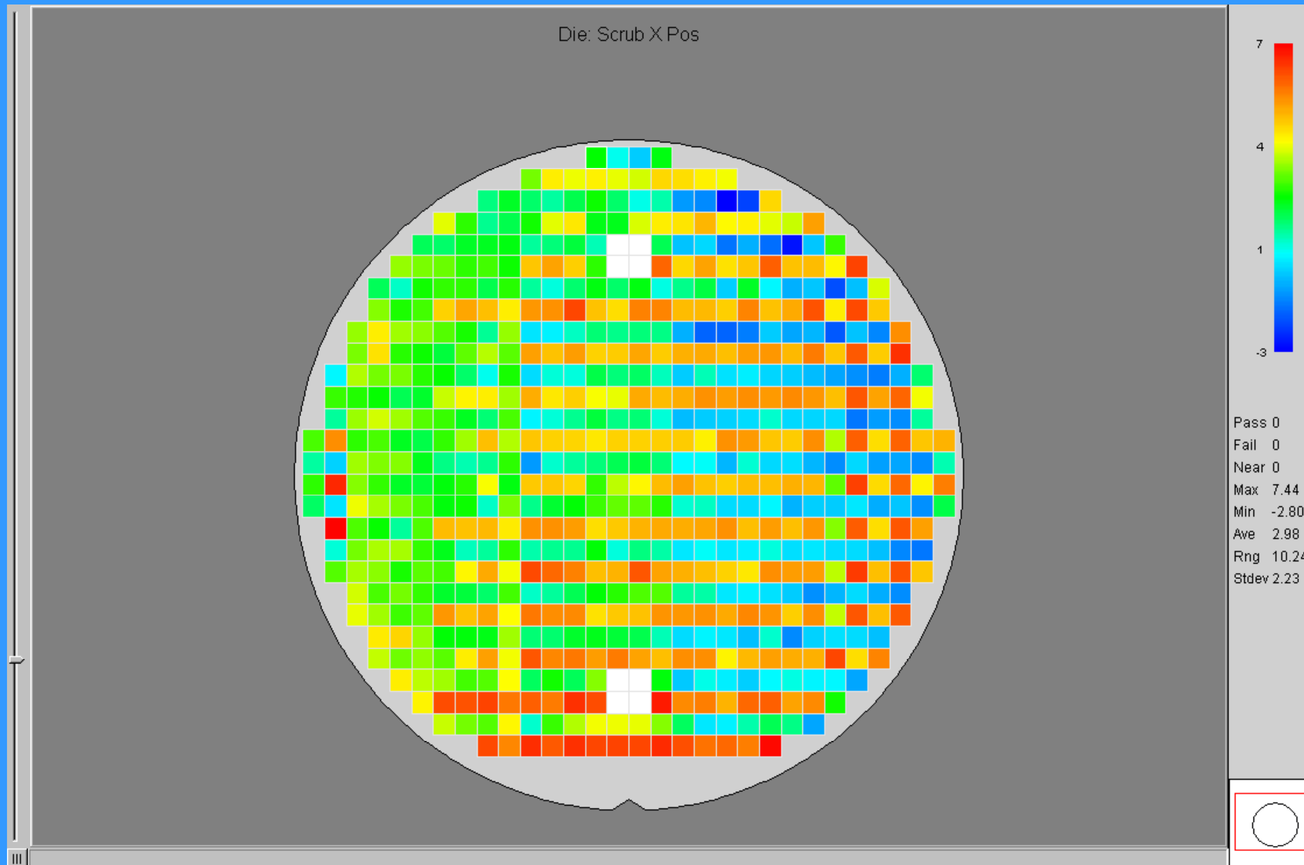
Verification of Probing Accuracy

Background

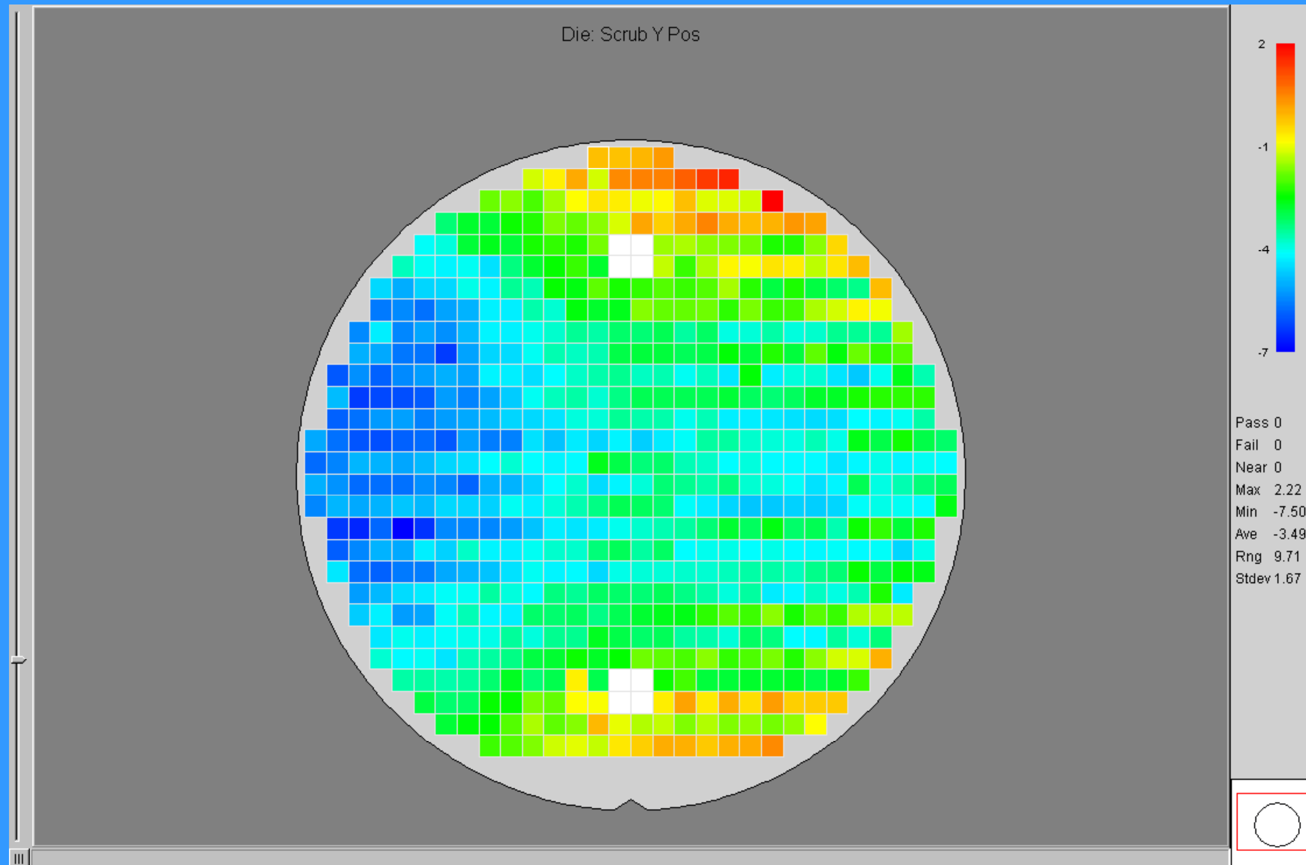
Prober Accuracy

- EG 5|300 specifies probing accuracy of ±4 µm
- Prober accuracy commonly refers to stepping accuracy only
- Wafers probed on an EG 5|300 beta prober measured by waferWoRx™ showed probing accuracy of ± 4.5 µm
- Are the waferWoRx results real or an artifact of the measurement?

Die: Scrub x Position



Die: Scrub y Position



Verification of Prober Accuracy

Definition of Terms

Repeatability and Reproducibility

- Repeatability is variation of multiple measurements
- Reproducibility is the variation of means of multiple iterations of multiple measurements

Repeatability and Reproducibility

Iteration					
measurement	1	2	3	…	k
1 2 3 . . . n	$x_{1,1}$ $x_{1,2}$ $x_{1,3}$ . . . $x_{1,n}$	$x_{2,1}$ $x_{2,2}$ $x_{2,3}$ . . . $x_{2,n}$	$x_{3,1}$ $x_{3,2}$ $x_{3,3}$ . . . $x_{3,n}$	… … … …	$x_{k,1}$ $x_{k,2}$ $x_{k,3}$ . . . $x_{k,n}$
Mean	[illegible]	[illegible]	[illegible]	…	[illegible]
Std Dev	s_1	s_2	s_3	…	s_k

- Repeatability = average $(s_1, s_2, s_3, \ldots, s_k)$
- Reproducibility = std dev $(x_1, x_2, x_3, \ldots, x_k)$

Gage Capability

- Gage capability is related to measurement error

$$\sigma^2_{gage} = \sigma^2_{repeatability} + \sigma^2_{reproducibility}$$

- Precision to tolerance ratio

$$\frac{P}{T} = \frac{6\hat{\sigma}_{gage}}{USL - LSL}$$

Probing Accuracy

- The “standard” for accuracy is the pad
- Measure the probe mark position relative to pad center
- How accurate is the measurement tool?

Verification of Prober Accuracy

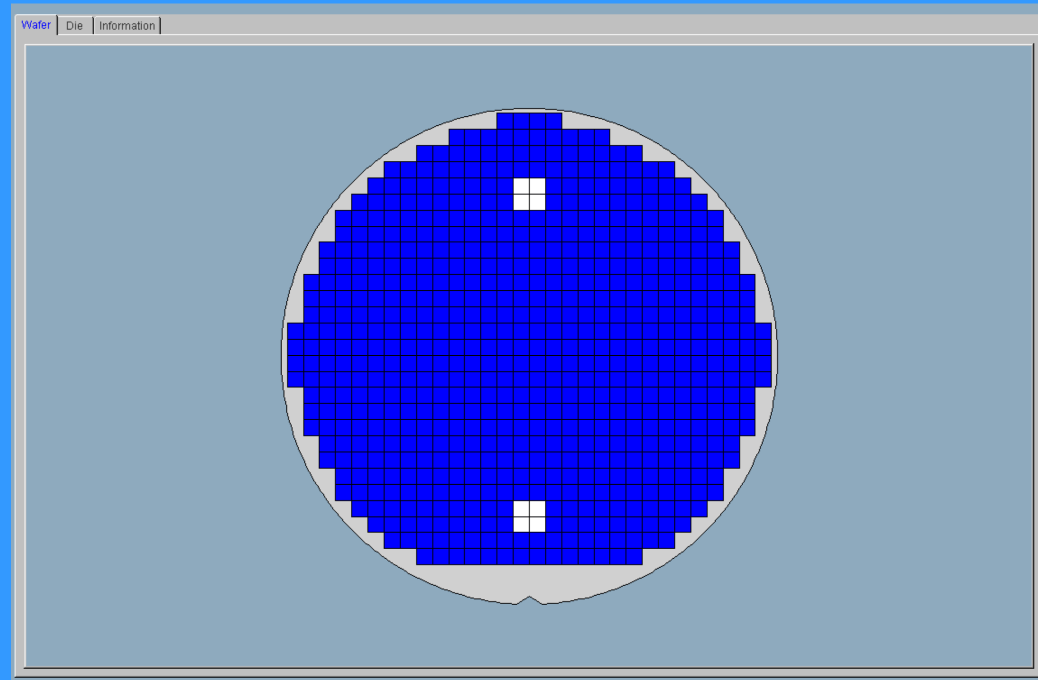
Experimental Design

Repeatability

- Using a single probed wafer - measure wafer 5 times

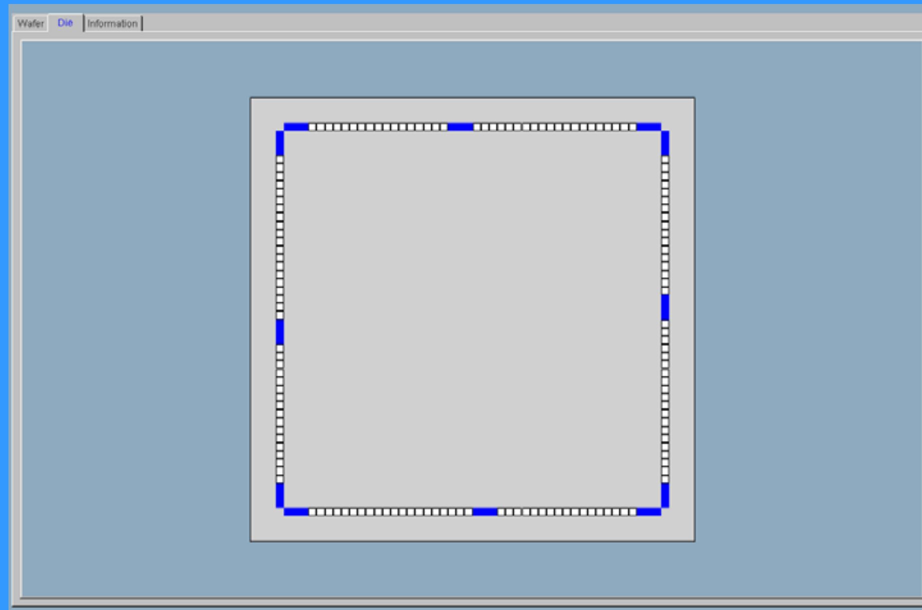
Wafer Layout

- Measurements made across entire wafer surface



Pad Layout

- 36 Pads, 6 at each corner, 3 in the middle of each row/column



Reproducibility

- Repeat repeatability measurement on 5 consecutive days

Accuracy

- Using 5 wafers with induced scaling error by changing die size (100 ppm = 20 μm)
  - 100 ppm scaling
  - 50 ppm scaling
  - nominal
  - -50 ppm scaling
  - -100 ppm scaling

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Results and Analysis

Normalization of data

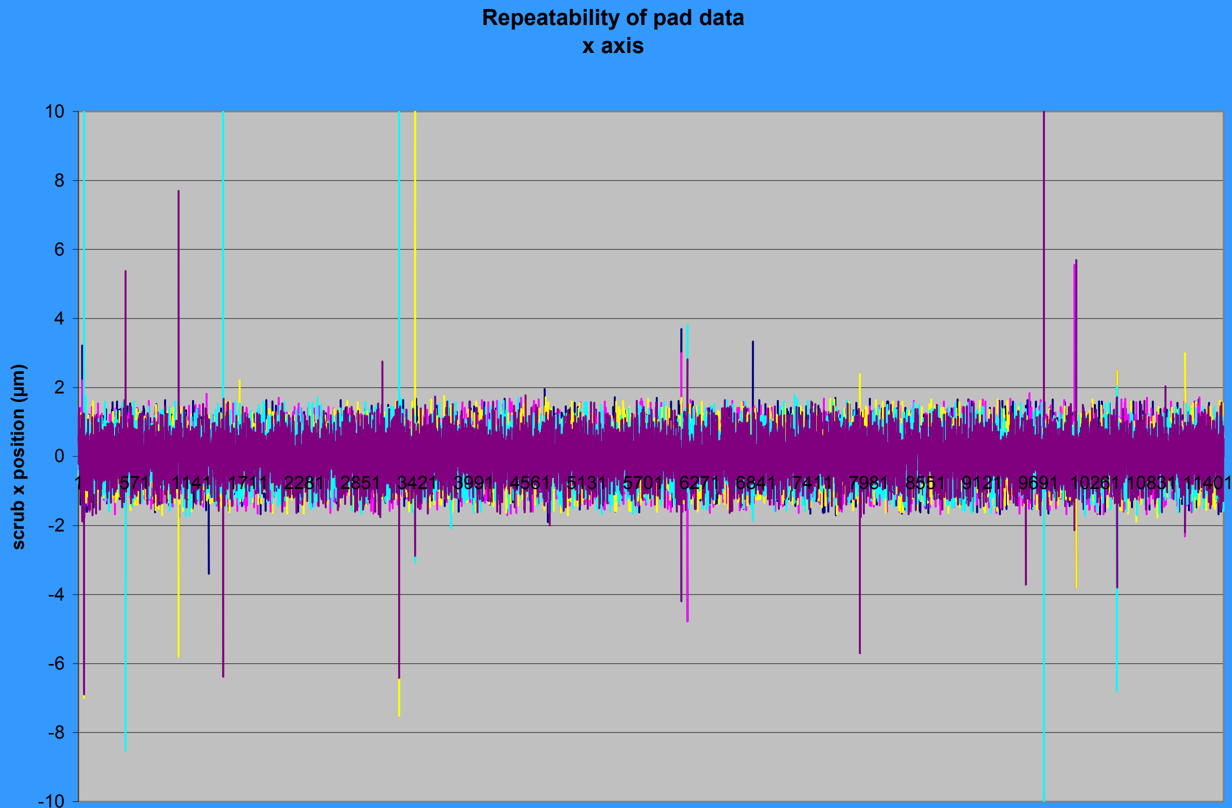
- Each pin is potentially different
- Data first needs to be normalized by pad

$$\hat{x}_{pad,i} = x_{pad,i} - \frac{\sum_{j=1}^{5} x_{pad,j}}{5}$$

- Repeatability is calculated from the standard deviation of the normalized pad data

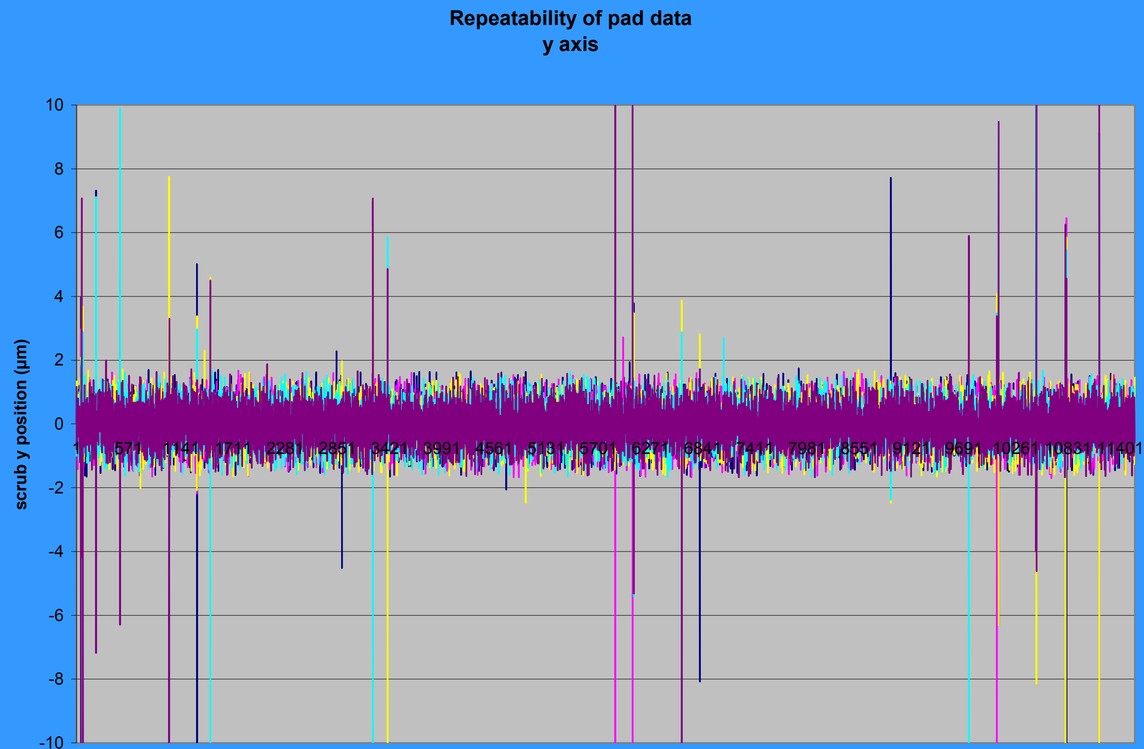
Repeatability of Pad Measurements - x axis

- 36 pads, 681 die, 5 repetitions

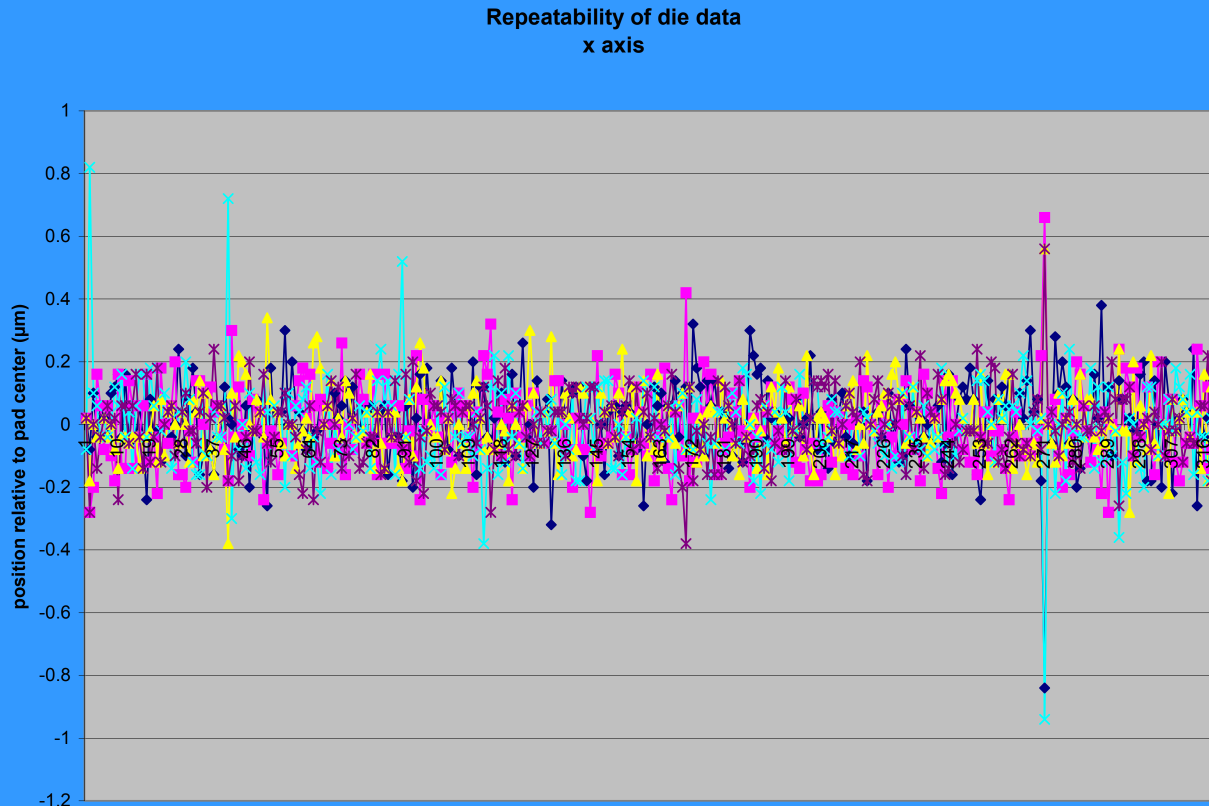


Repeatability of Pad Measurements - y axis

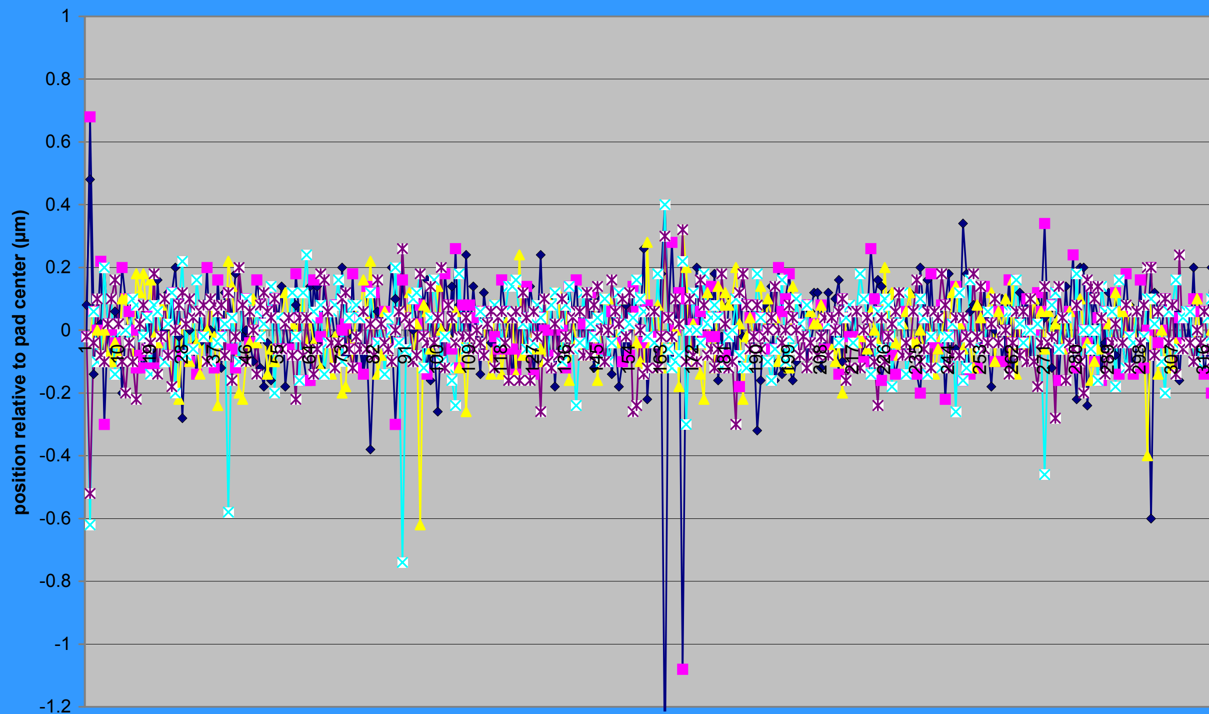
- 36 pads, 681 die, 5 repetitions



Repeatability of Die Measurements - x axis

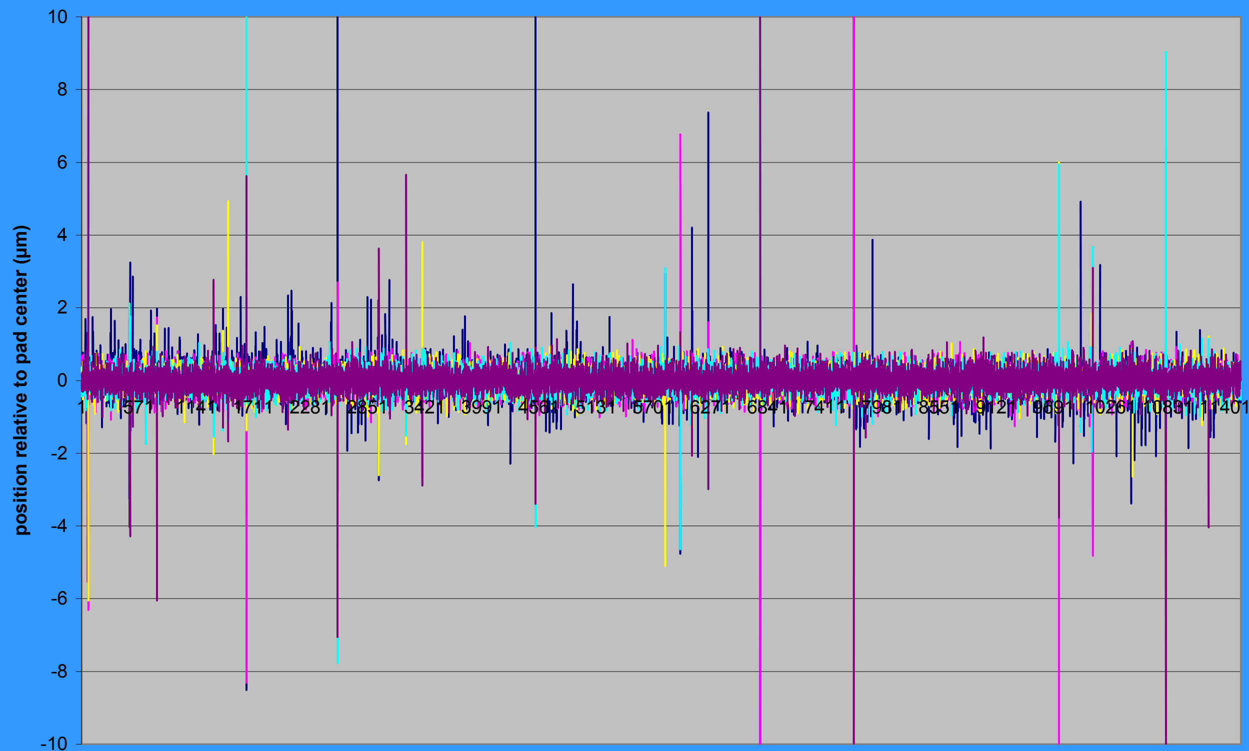


Repeatability of Die Measurements - y axis



Reproducibility of Pad Measurements - x axis

- Average the 5 repetitions, normalize the data by pad



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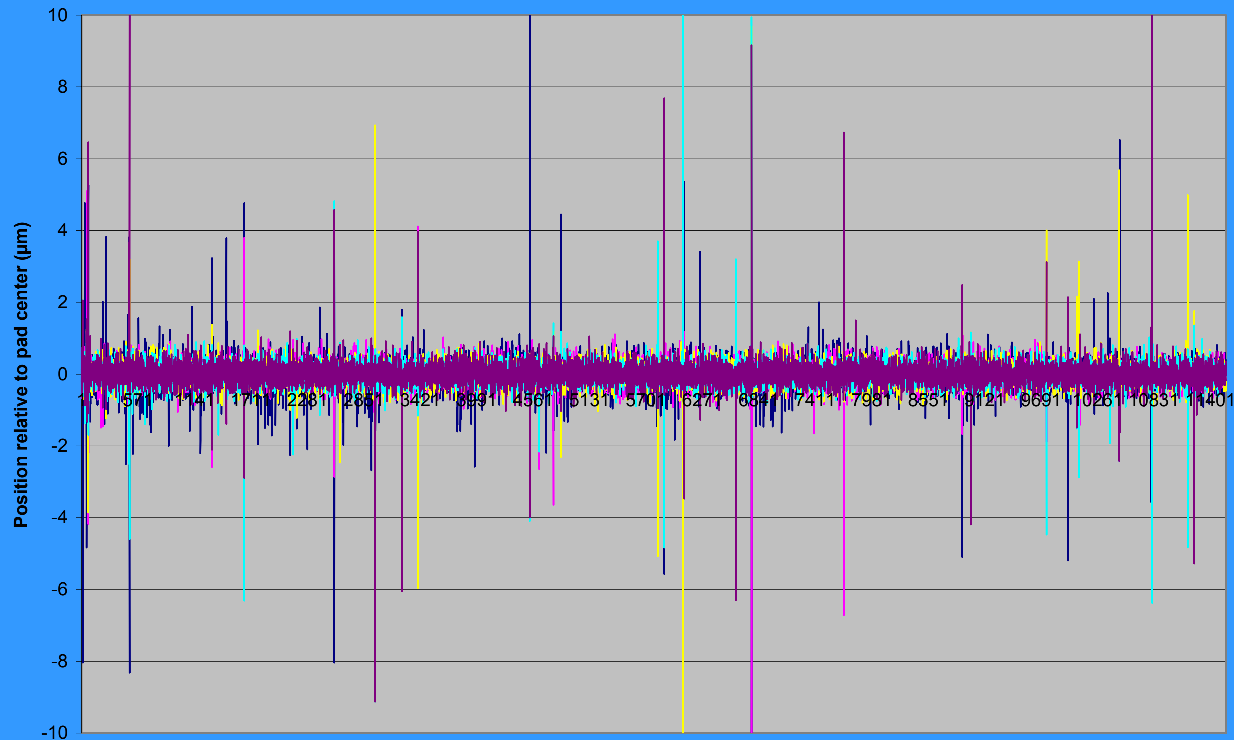
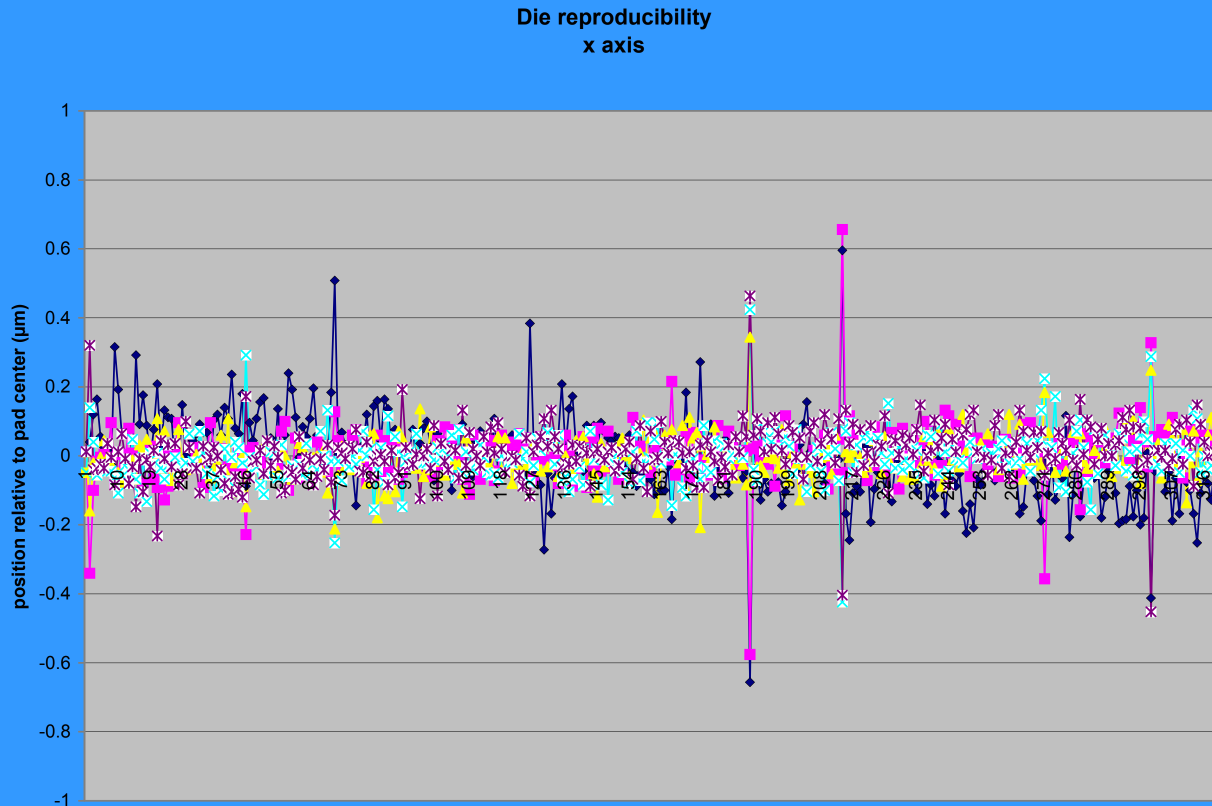
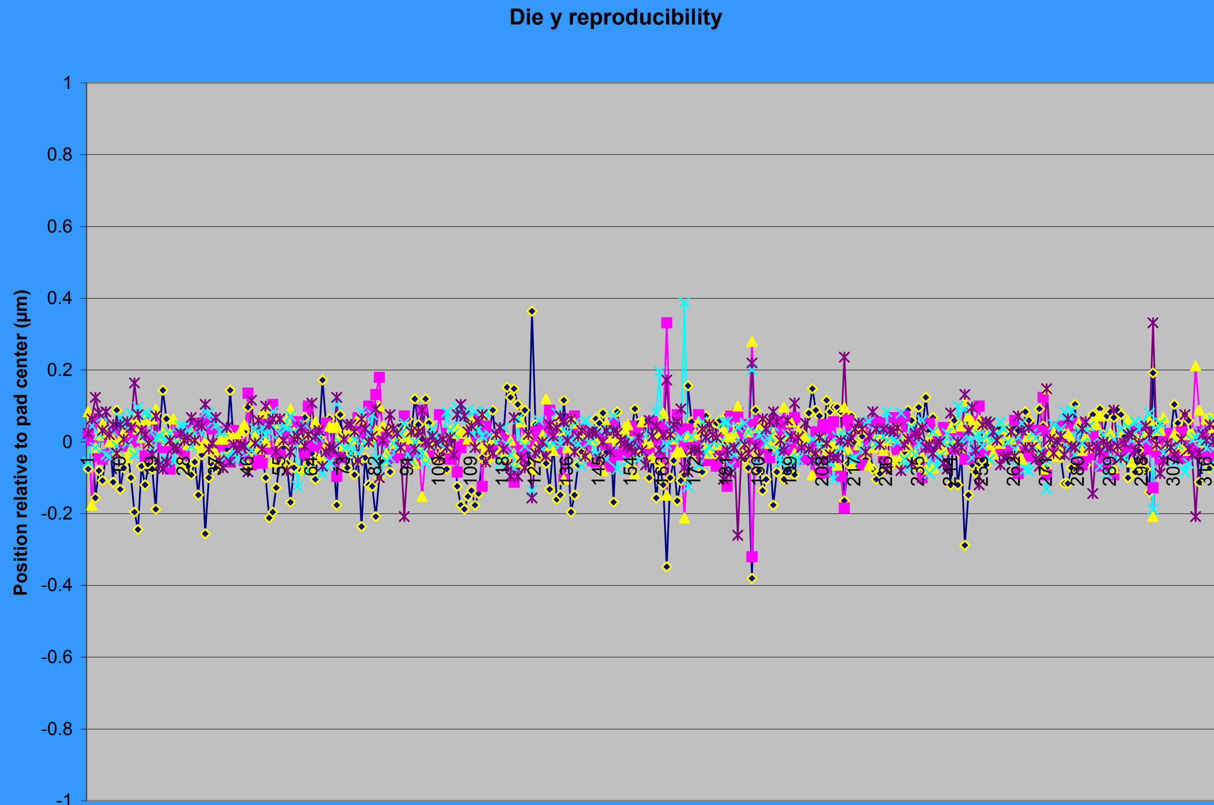
Reproducibility of Pad Measurements - y axis



Reproducibility of Die Measurements - x axis



Reproducibility of Die Measurements - y axis



Quantitative Evaluation of Repeatability and Reproducibility

		pad	die
Repeatability (3σ)	x	2.02 μm	0.36 μm
	y	2.06 μm	0.33 μm
Reproducibility (3σ)	x	1.3 μm	0.25 μm
	y	1.1 μm	0.19 μm
σ_{gage}	x		0.15 μm
	y		0.13 μm

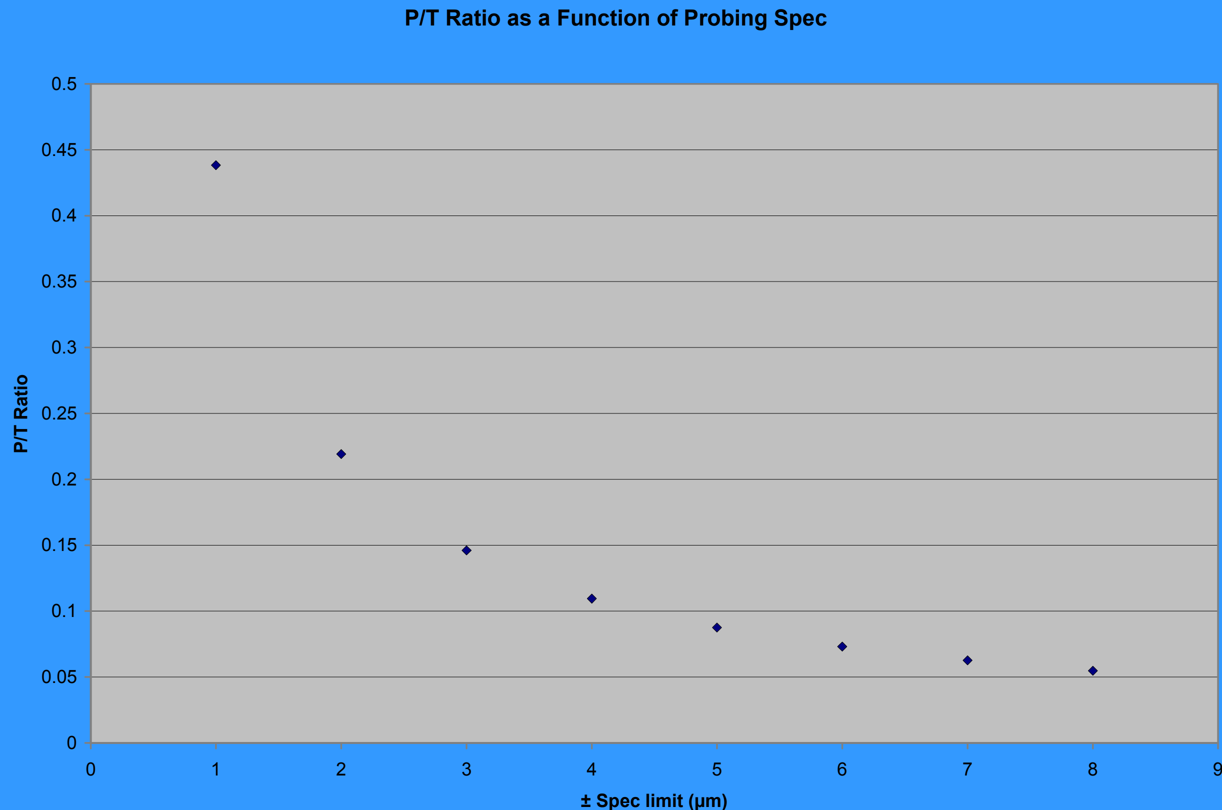
Evaluation of Precision to Tolerance Ratio

- Similar in concept to process capability (Cp)

$$\sigma^2_{gage} = \sigma^2_{repeatability} + \sigma^2_{reproducibility}$$

- For a ±4 µm probing accuracy, the P/T ratio is approximately 0.1

WaferWoRx P/T Ratio as a function of Probing Specifications



Prober Accuracy

- Accuracy is evaluated by comparing waferWoRx output for wafers with known stepping errors
- 5 wafers were probed with known scaling errors, created by using wrong die size

Controlled Probing error

- Nominal die size 6.5 x 6.5 mm

Scaling (ppm)	Die size (mm)
-100	6.49935
-50	6.499675
0	6.5
50	6.500325
100	6.50065

Comparing waferWoRx Output

- waferWoRx outputs probing error in µm
- For a 200 mm wafer scaling can be calculated as

$$error(ppm) = \frac{error(\mu m)}{wafer\ diameter(\mu m)} * 10^6$$

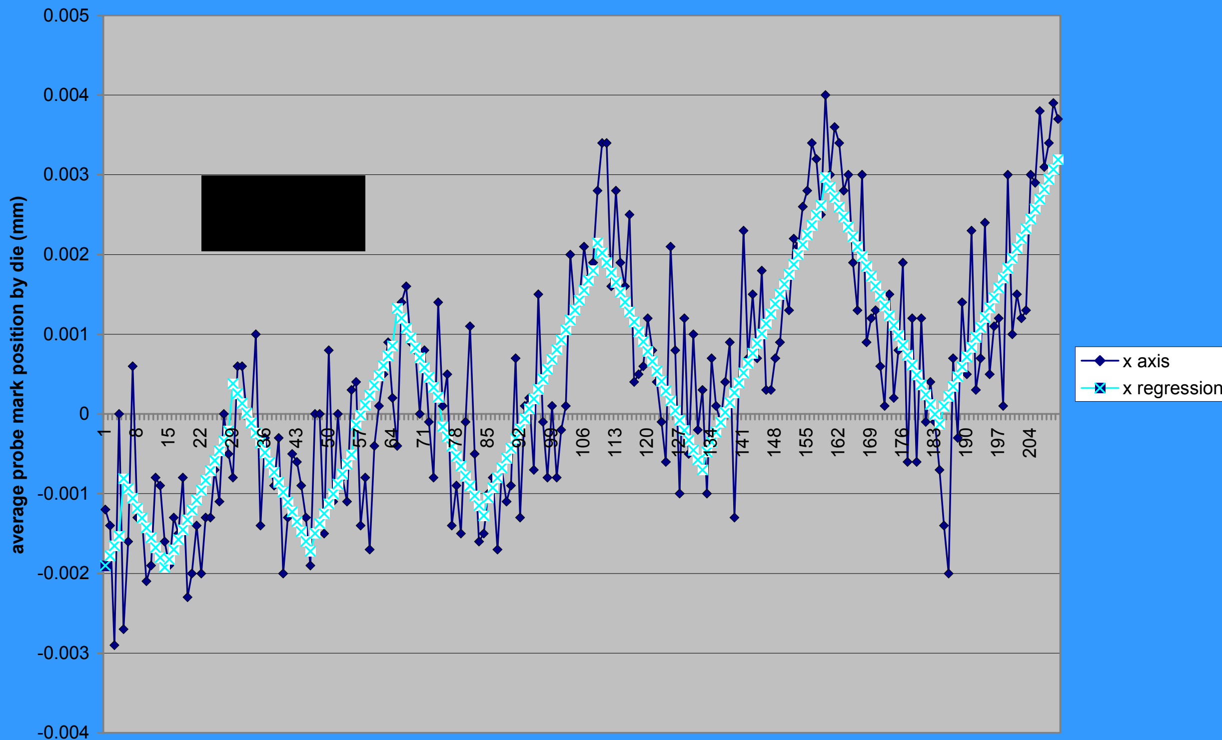
- 4 µm scaling error on a 200 mm wafer =

$$\frac{4}{200{,}000} \cdot 10^6 = 20\ ppm$$

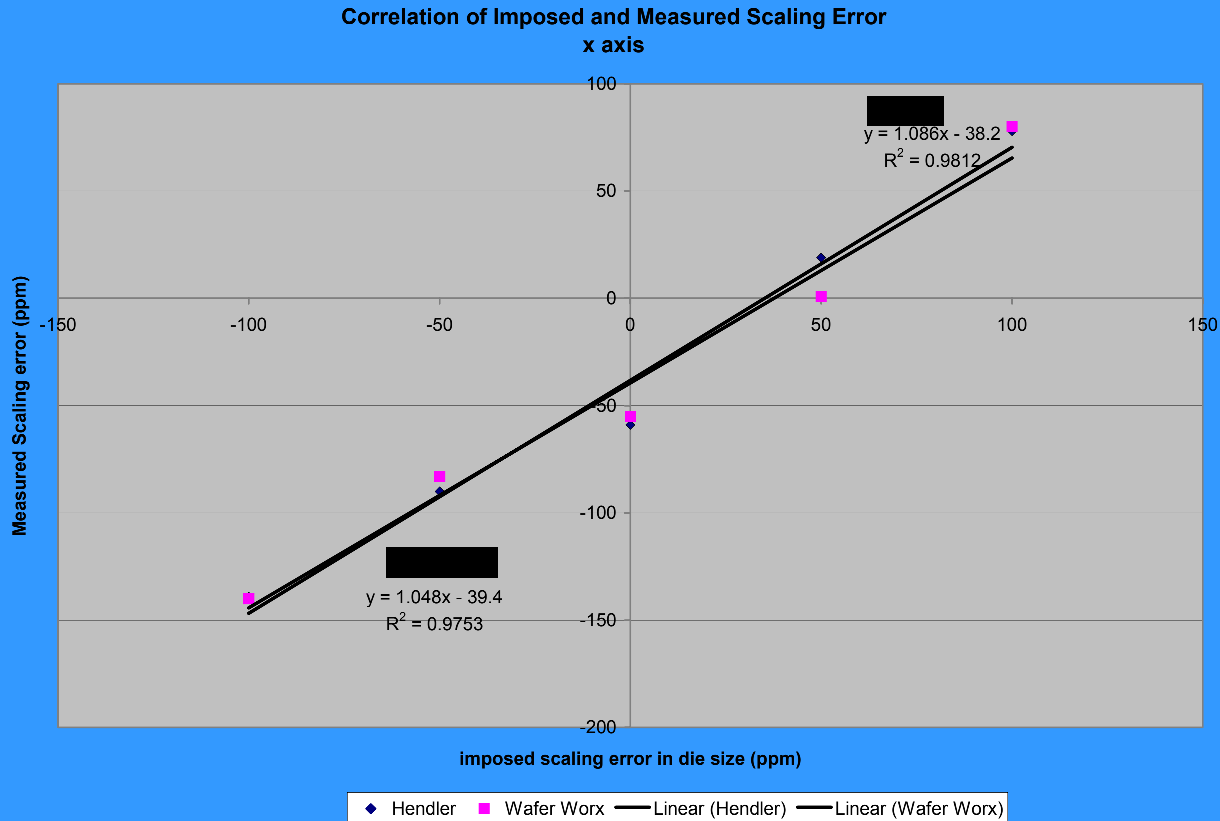
Regression Analysis

- We can fit the die data to linear transformations for scaling, rotation, and offset.
- We can then compare waferWoRx accuracy to EG Scaling calculations
- The result is a comparison of known scaling error to measured scaling error, providing an estimate of measurement accuracy

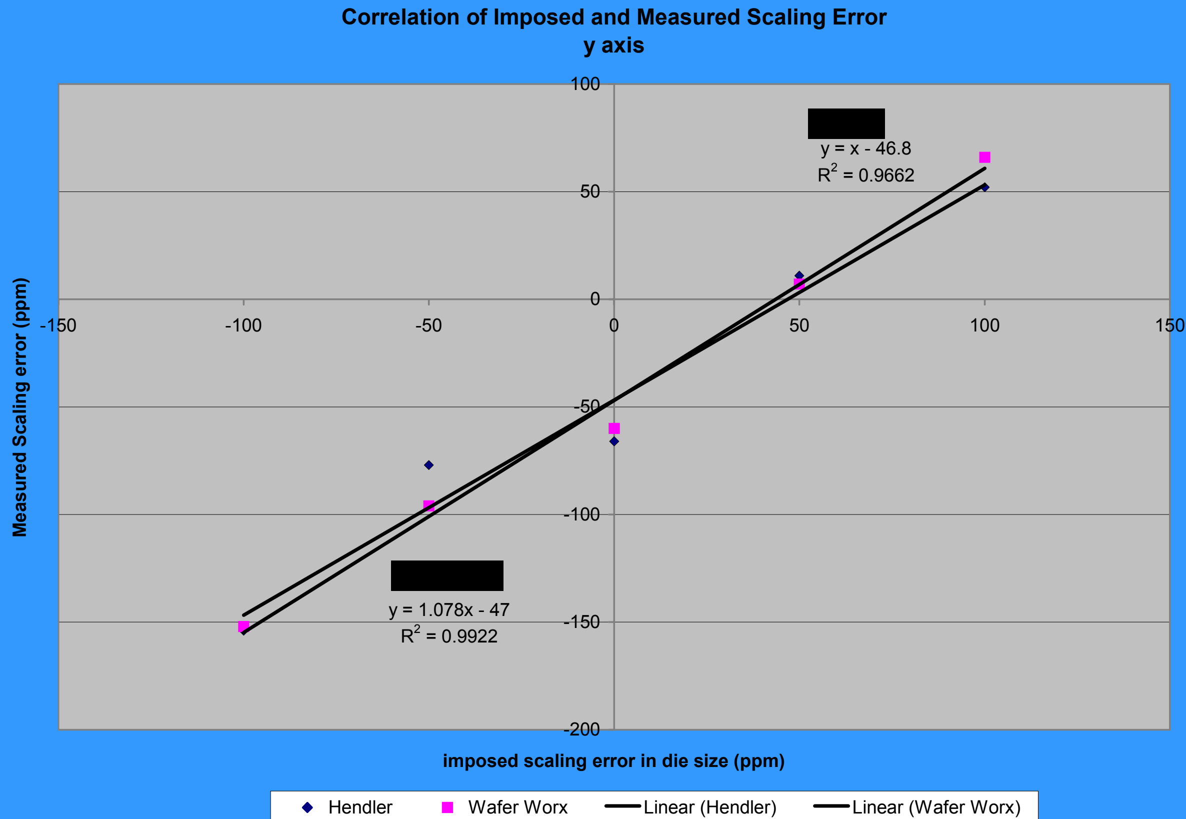
Regression Analysis



Accuracy of the waferWoRx



Accuracy of the waferWoRx



Accuracy Summary

- There is no accuracy standard
- 5% accuracy is reasonable

	Regression	waferWoRx
x axis	1.086	1.048
y axis	1	1.078
mean	1.043	1.063

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Summary and Future Evaluations

Summary
Repeatability and Reproducibility

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Summary

Accuracy

Induced scaling:		+100 ppm	+50 ppm	0 ppm	-50 ppm	-100 ppm
waferWoRx (μm)	x	16	0.25	11	16.75	28
	y	13.25	1.5	12	19.25	30.5
waferWoRx (equivalent ppm)	x	80	1	-55	-83	-140
	y	66	7	-60	-96	-152
Hendler Transformation	x	78	19	-59	-90	-139
	y	52	11	-66	-77	-154

- Regression algorithm concurs with waferWoRx
- both are within 5% of imposed scaling error

Summary
P/T ratio

- waferWoRx is a viable tool for verifying probing accuracy specified at ±4 µm
- P/T ratio for ±4 µm probing is 0.1

Future Evaluations

- Future probers will be specified at ±2 µm accuracy.
- To evaluate and verify probing accuracy an inspection tool will need to achieve

$$\hat{\sigma}_{gage} = 0.07$$

- API has recently provided a software upgrade that is being evaluated for its improvement in gage capability