IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

Control of Pad Damage Using Prober Operational Parameters

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Overview

- Introduction / Background
- Objectives
- Materials and Methods
- Results
- Analysis / Discussion
- Conclusions

Introduction

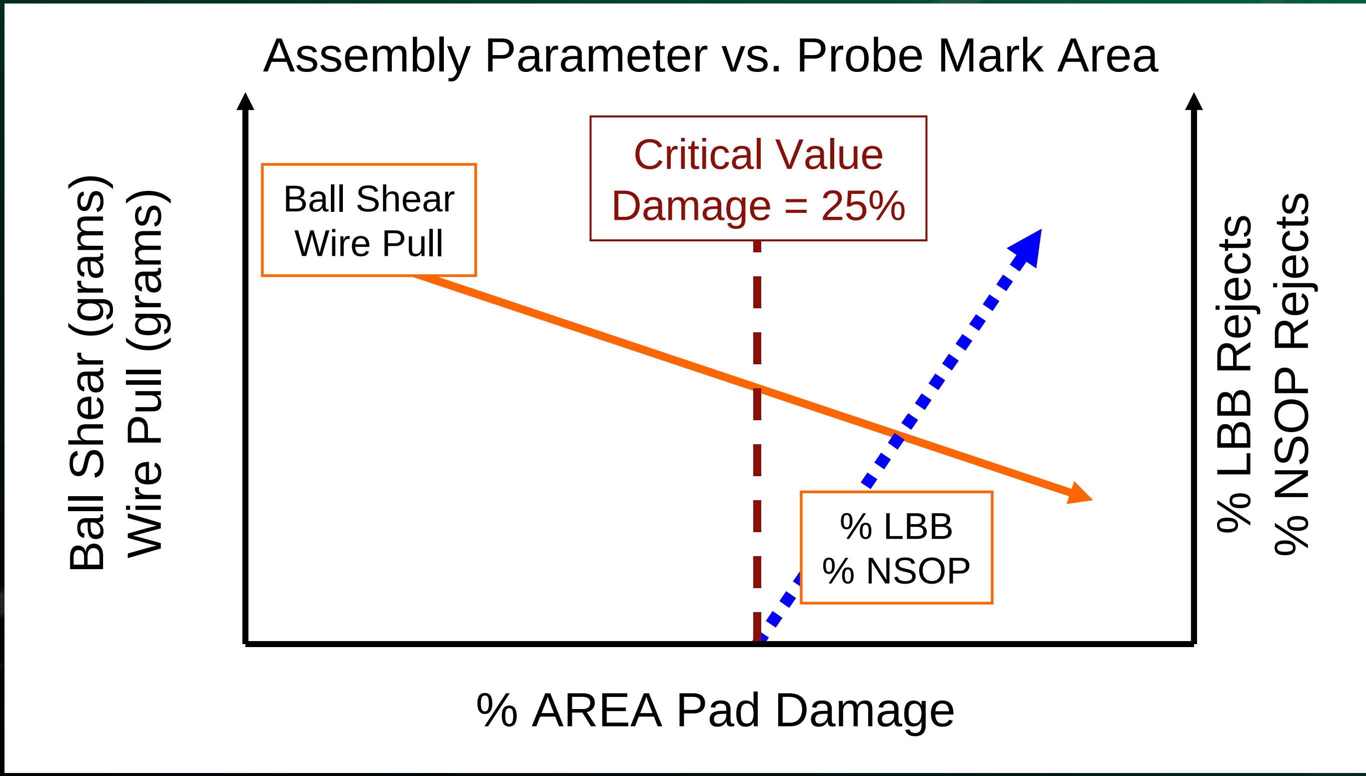
- Probe card technologies have become advanced; however, the basics of wafer sort really have not changed
- ALL probe technologies have a contact area substantially harder than the pads or solder balls of the device
- “Contact and slide” is CRITICAL to break surface oxide(s), but results in localized plastic deformation, i.e. a probe mark
- Volume of material displaced and/or transferred is a complex function of dynamic contact mechanics, metallic interactions, frictional effects, and other tribological properties

- *Disclaimer:* scrub mark photos, pad profiles, and pad structures shown in this presentation are not considered representative of or meant to infer anything about the process of record for Micron products.

Background – Area Effects

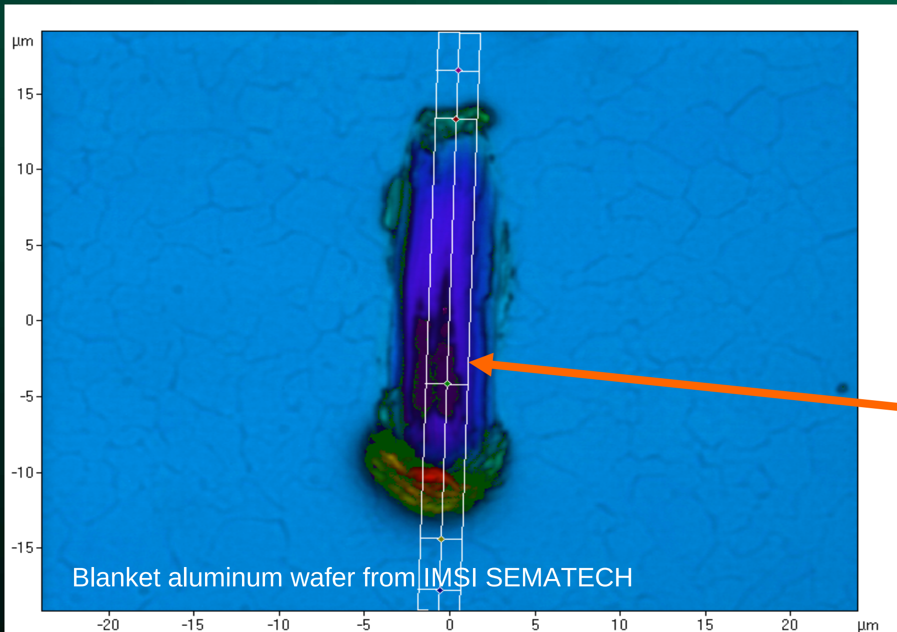
Pad damage due to probe has been positively correlated to bondability issues.

- Reduced ball shear strength and wire pull strength
- Increased NSOP (no stick on pad) and LBB (lifted ball bond)



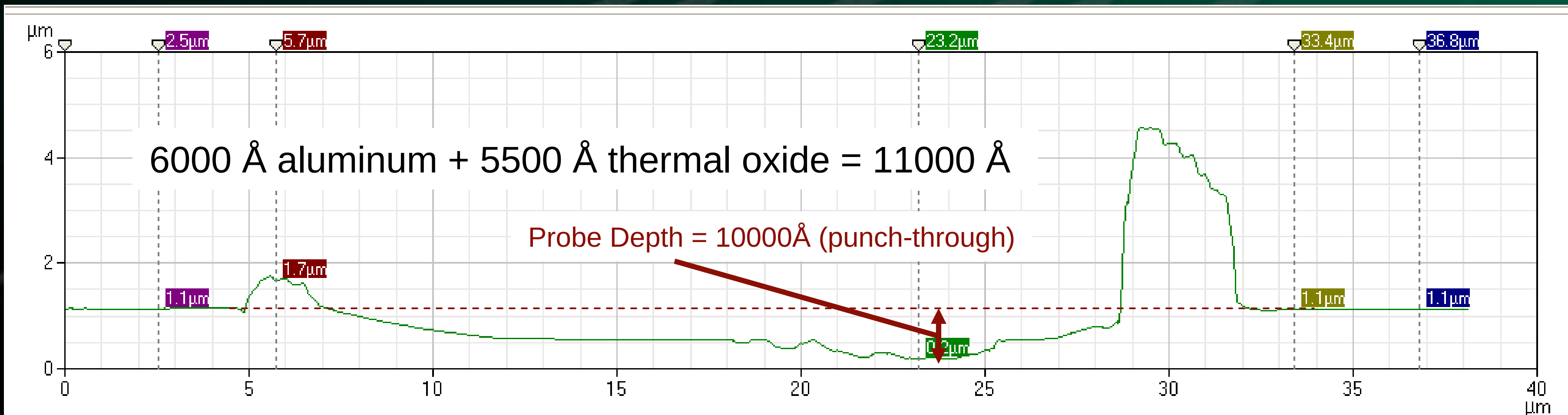
Sources …
Tran, et al., ECTC -2000
Tran, et al., SWTW-2000
Langlois, et al, SWTW-2001
Hotchkiss, et al., ECTC-2001
Hothckiss, et al., IRPS-2001
Among others …

Area Effects Are Not Enough !



A probe mark can have a relatively small area of damage, but exceed the critical allowable depth.

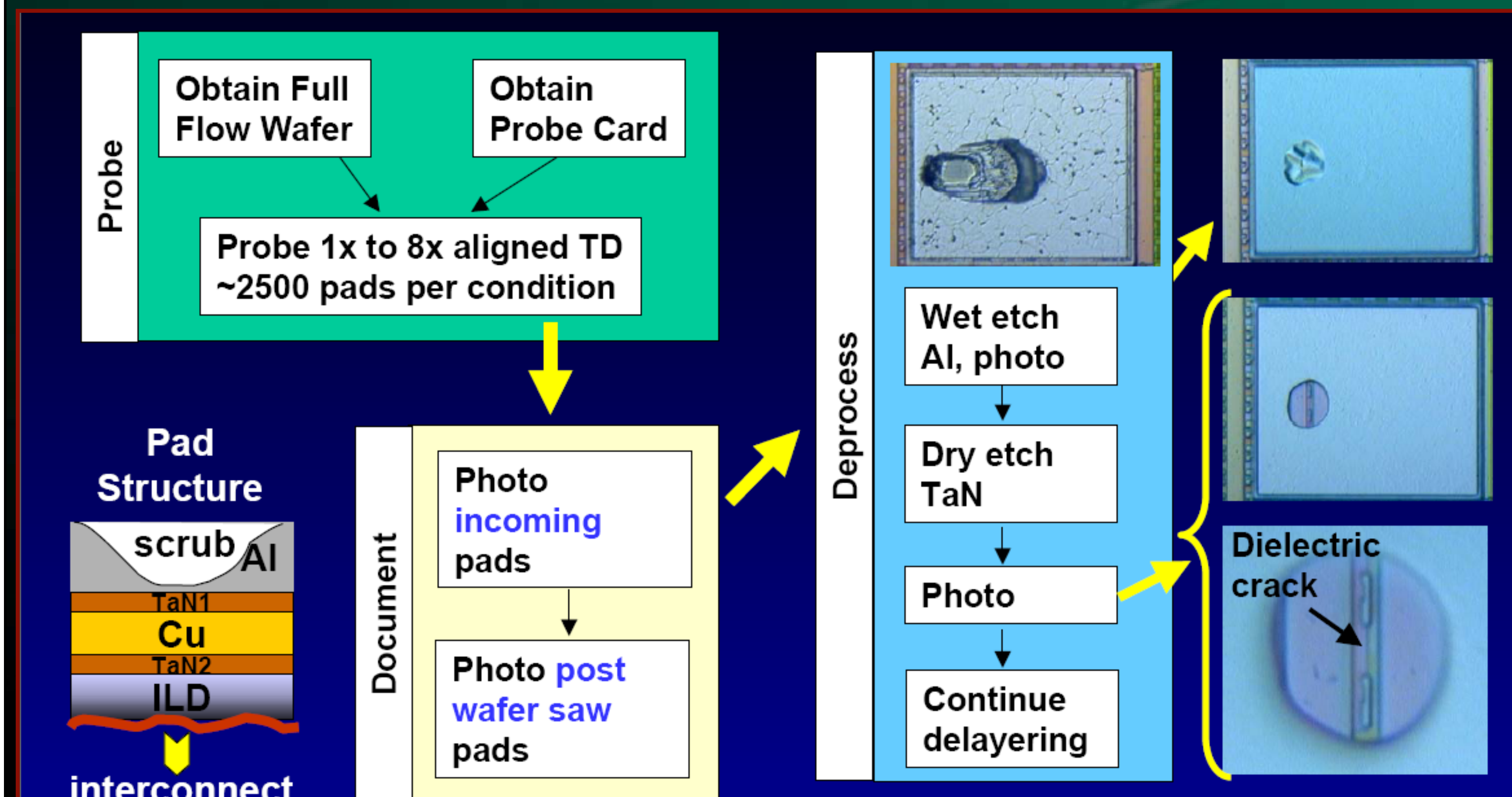
- % Area Damage = 8.8% which is within limits
- Depth = 10000Å which is excessively deep



Background – Depth Effects

Excessively deep probe marks can cause …

- Underlying layer damage (low-k dielectric, circuitry under bond pads, and aluminum capped copper pads)
- Bondability and long term reliability issues



Images from Hartfield, et al, SWTW-2003

Many steps are needed to assess cracks.

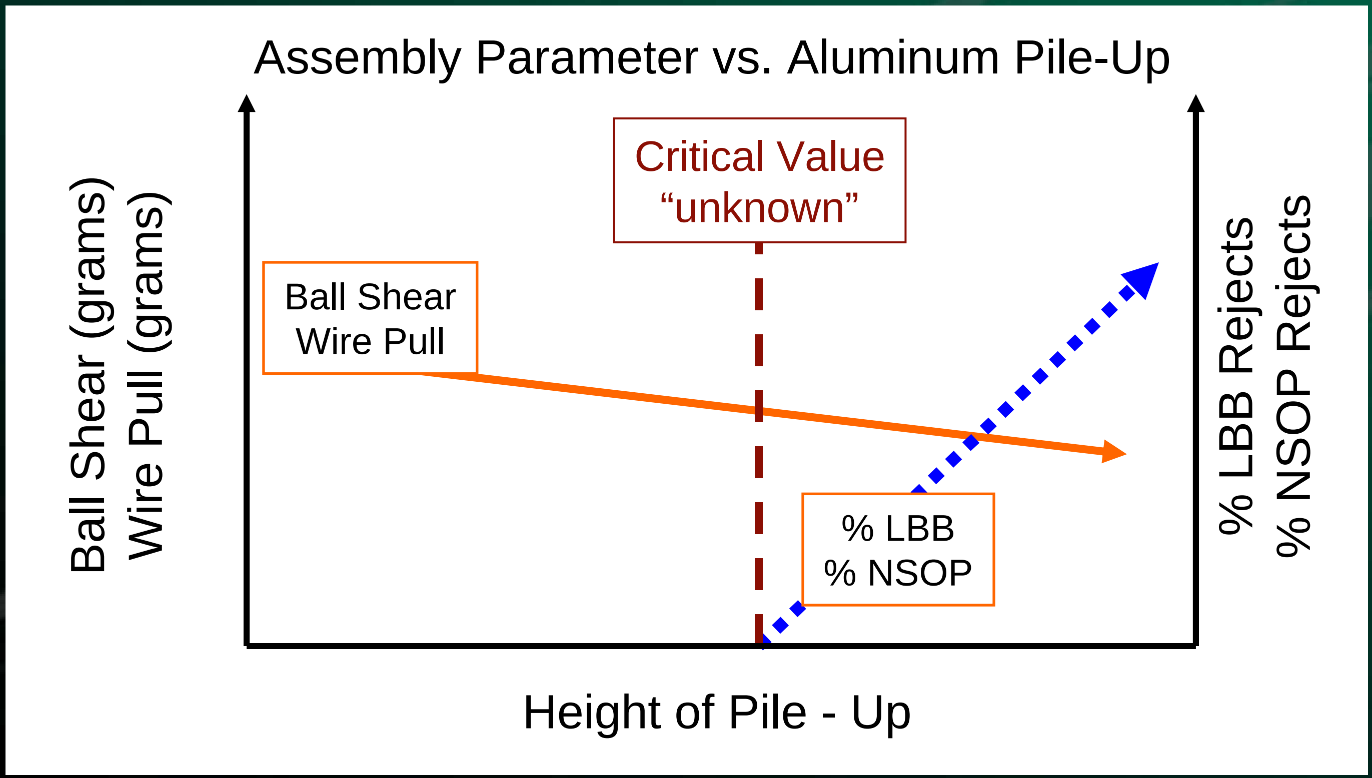
Sources …
Hartfield, et al, SWTW-2003
Martens, et. al., SWTW-2003
Hartfield, et al., SWTW-2004
Stillman, et al., SWTW-2005
Among others …

Background – Height Effects

Pad material pile-up has also been correlated to bondability issues.

– Reduced ball shear strength and wire pull strength

– Increased NSOP (no stick on pad) and LBB (lifted ball bond)



Sources …

Langlois, et al, SWTW-2001

Among others …

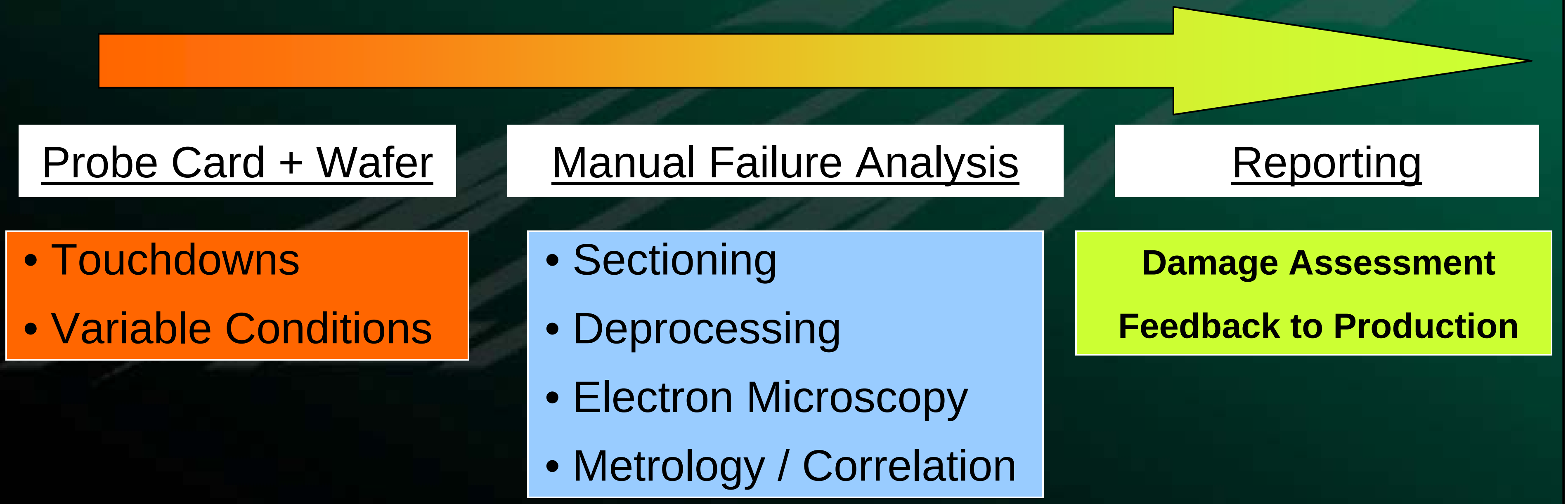
Controlling the Damage

- The depth of the probe mark can be controlled with modifications to the probe card technology
  - Low force probe cards (various manufacturers)
  - Optimized probe to pad interactions
- Probers can effectively change the z-stage motion just before contact and during overtravel to reduce damage
  - Variable Speed Probing by Accretech®
  - Micro-Touch™ by Electroglas®
  - Micro-Force™ Probing by Tokyo Electron Limited® (TEL)

Assessing the Damage

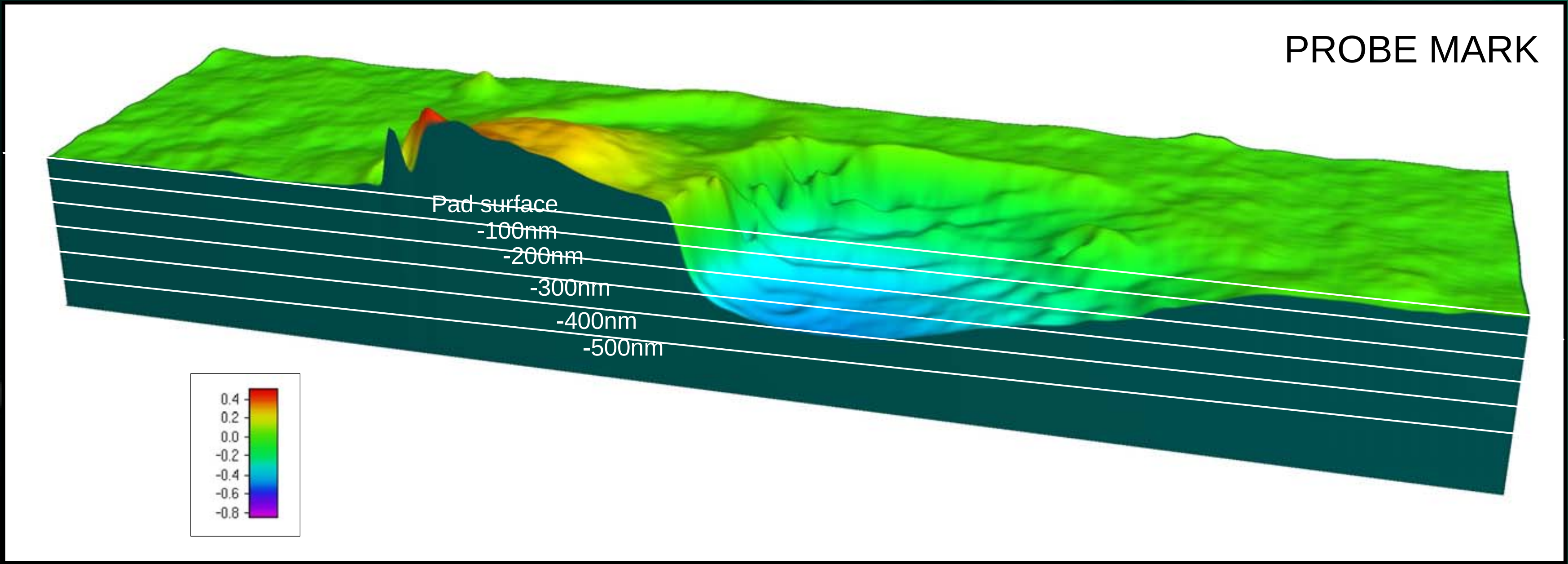
Traditional depth, volume, and height measurements are time consuming and can have long cycle times.

- Probing under different conditions
- Wafers must be scrapped
- Careful wafer sectioning
- Sample preparation and de-processing
- Electron-based microscopy



Probe Mark 3D Cross Section

- From the wafer sort standpoint …
  Displaced volume can be correlated to key sort parameters, e.g. z-stage speed, overtravel, probe force, cracking, punch-through, etc.
- From a cleaning standpoint …
  Displaced volume provides insight into accumulation rates and material adherence.



Objectives

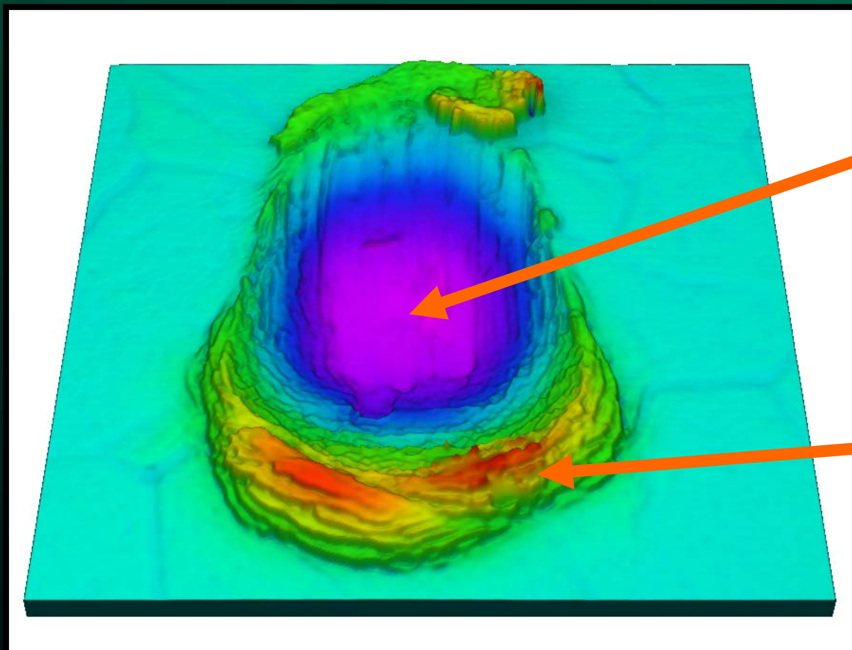
- Develop a multi-variable parametric DoE to identify primary prober operational contributors to probe damage
- Perform a statistically valid and practical failure analysis on damaged bond pads without cross-sectioning or de-processing the wafers
  - 3D confocal, non-contact microscopy with a better than 50nm resolution
  - Wafers must be available for follow-on metrology
- Identify an optimized combination of prober operational settings to reduce the overall area and volumetric probe damage, i.e. disturbed pad area

  Can reasonable steps be taken with existing technologies (e.g., an existing probe card and a prober) to reduce pad damage in a cost-effective manner ?

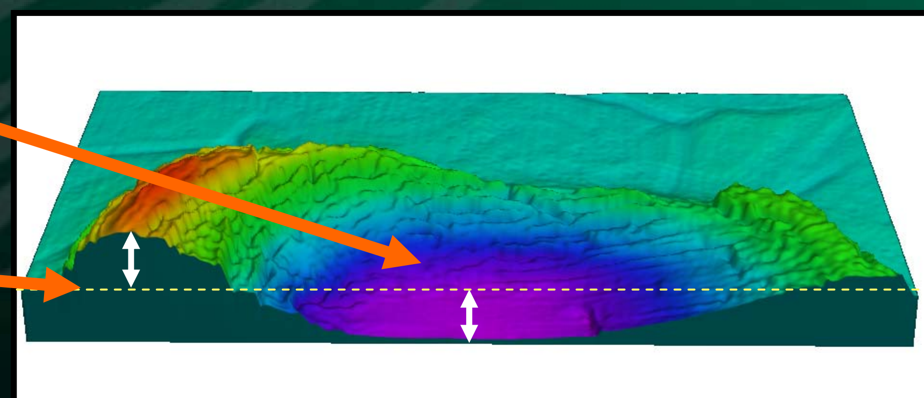
Factors (Prober Operational Settings)

- Number of Touchdowns
  Single vs. Double
- Overtravel Magnitude
  Low (50um) vs. Middle (63um) vs. High (75um)
- Undertravel Magnitude
  Low (0um) vs. Middle (10um) vs. High (20um)
- Pin-Update Execution
  - Abbreviated pin alignment to compensate for thermal movement
  - On vs. Off
- Wafer Chuck Speed
  Low (6000 um/sec) vs. High (18000 um/sec)
- Chuck Revise Execution
  - Re-zero of the wafer chuck to compensate for thermal movement
  - On vs. Off

Responses (Probe Mark Features)



- Probe Mark
  - Area
  - Volume
- Pile-up
  - Area
  - Volume
- Probe Mark Depth
- Pile-up Height



Design of Experiment (DoE)

	Touchdowns	Undertravel	Pin-Update	Wafer Chuck Speed	Chuck Revise	Overtravel
ID						
1	Single	Off	On	High	Off	63
20	Single	10	Off	High	On	50
17	Single	20	On	High	On	50
9	Single	Off	Off	Low	On	50
21	Single	10	Off	High	Off	63
13	Single	20	Off	Low	Off	63
7	Single	10	On	Low	On	75
12	Single	20	Off	Low	Off	75
11	Single	Off	On	Low	Off	75
15	Double	10	On	Low	Off	50
14	Double	20	Off	Low	Off	50
23	Double	Off	On	High	Off	50
8	Double	10	On	Low	On	63
19	Double	20	On	High	On	63
10	Double	Off	Off	Low	On	63
24	Double	10	Off	High	Off	75
18	Double	20	On	High	On	75
16	Double	Off	Off	High	On	75

Control

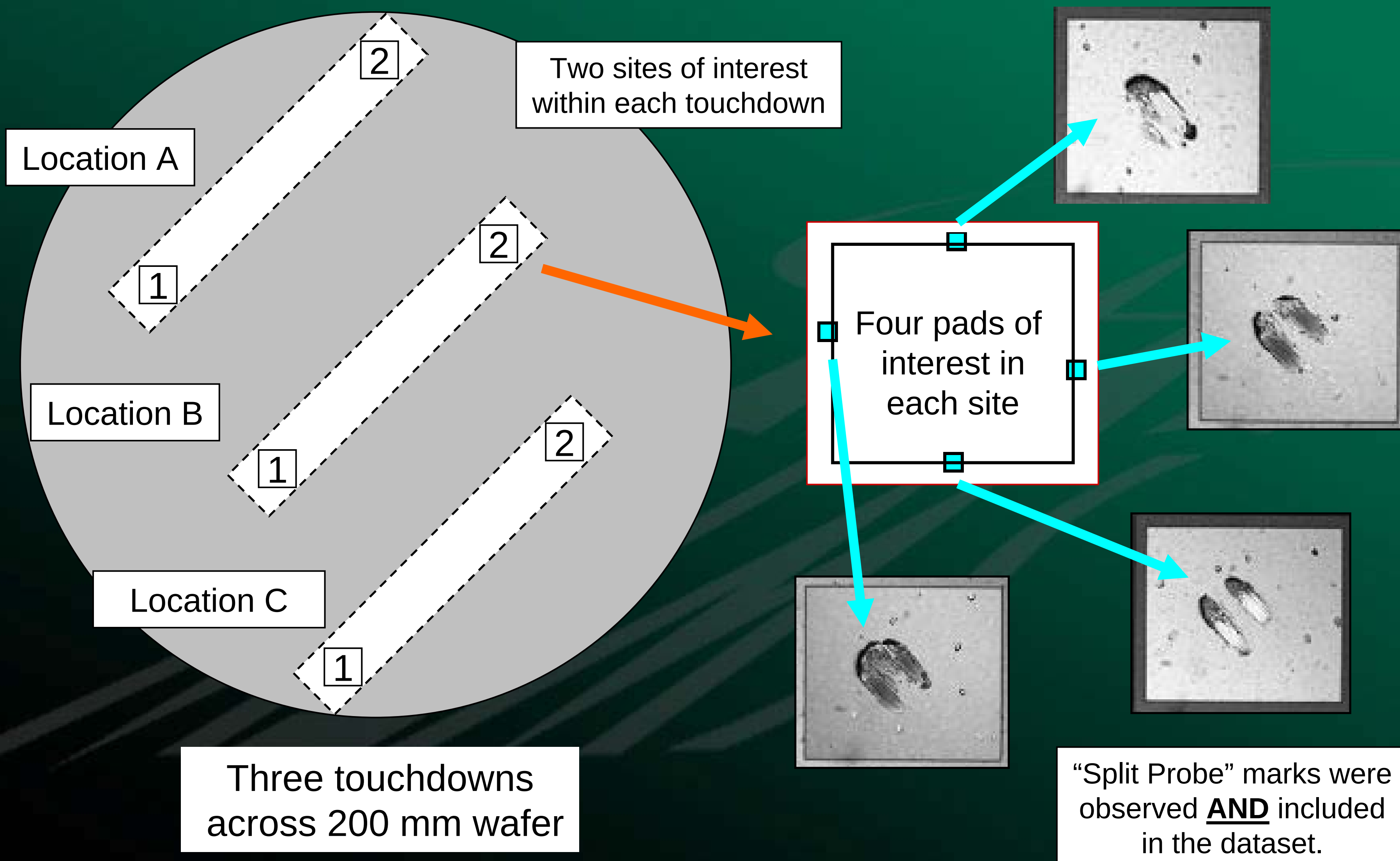
indicates a condition different than the CONTROL

Materials and Methods

Wafer Sort Tools

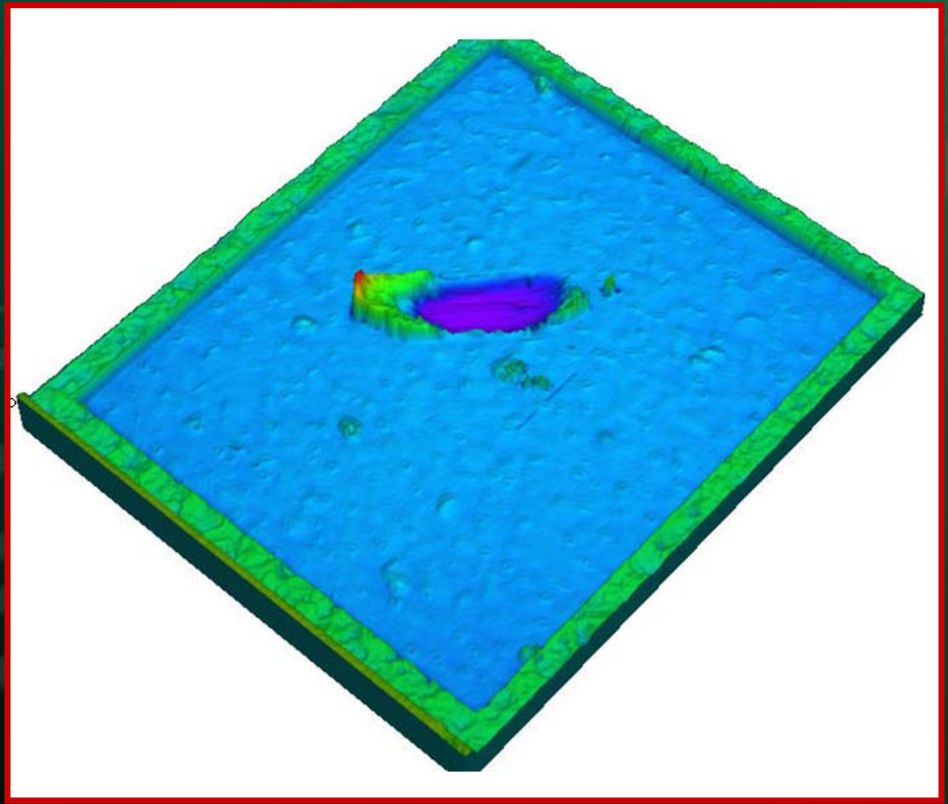
- Cantilevered probe card
  Diagonal multi-site (X8) probe card representative of production.
- 25-wafer LOT
  Pad Lot wafer representative of pad metal layer.
- Production Tester + Prober combination
  Test cell with a “known good” condition.
- One operator
  Operator variability kept to a minimum.

Probe Mark Inspection Layout



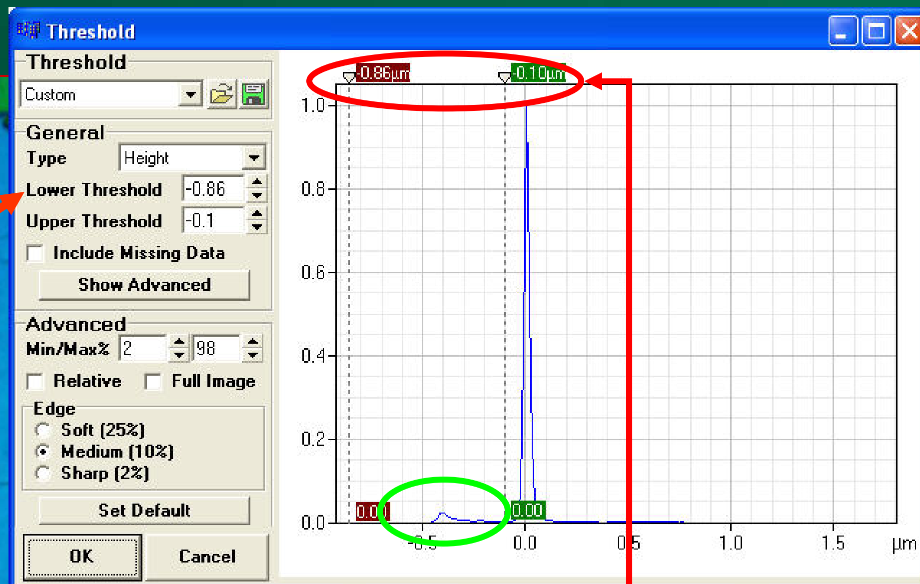
Probe Mark Metrology

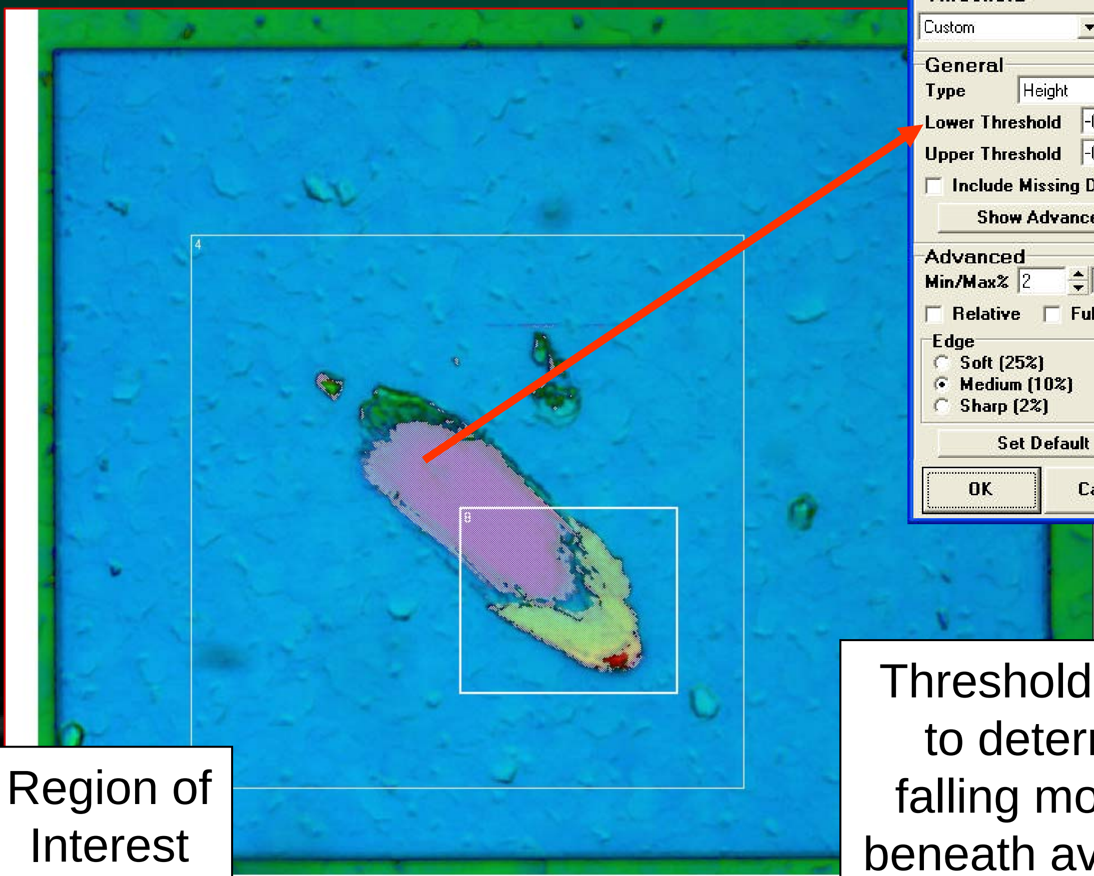
- Scrub mark volume and area
- Pile up volume and area
- Maximum depth



Scrub Mark Measurement

Signal threshold reference level at the pad surface.



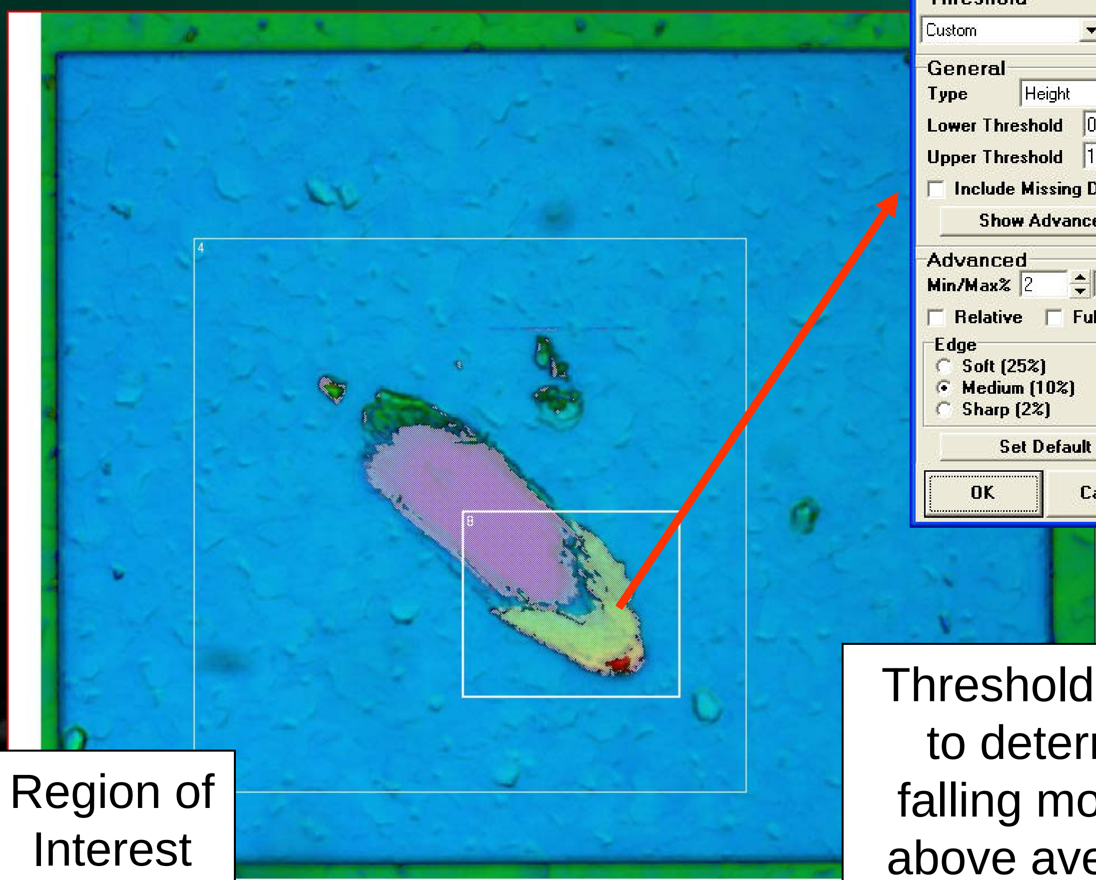


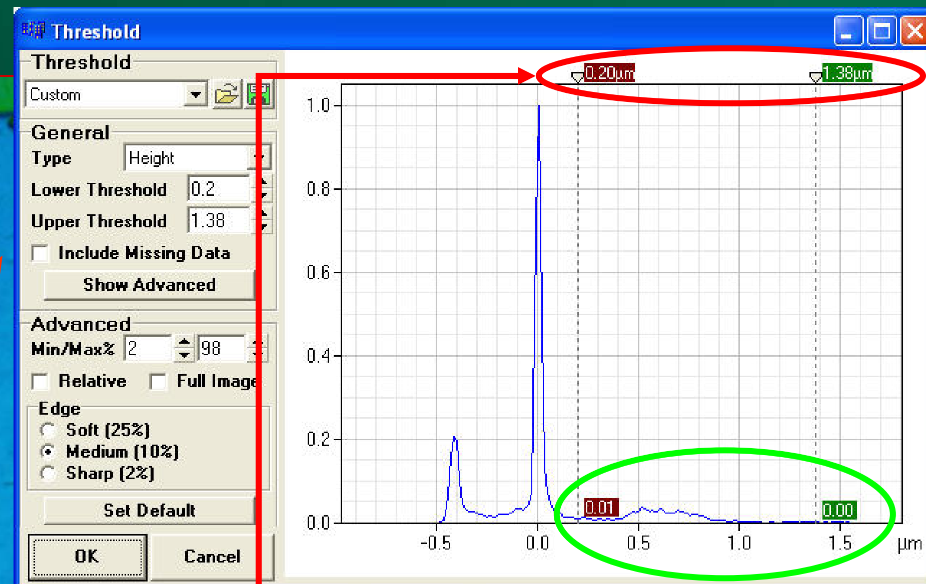
Region of Interest

Threshold parameters set to determine the area falling more than 100nm beneath average pad level.

Pile-up Measurement

Signal threshold reference level at the pad surface.



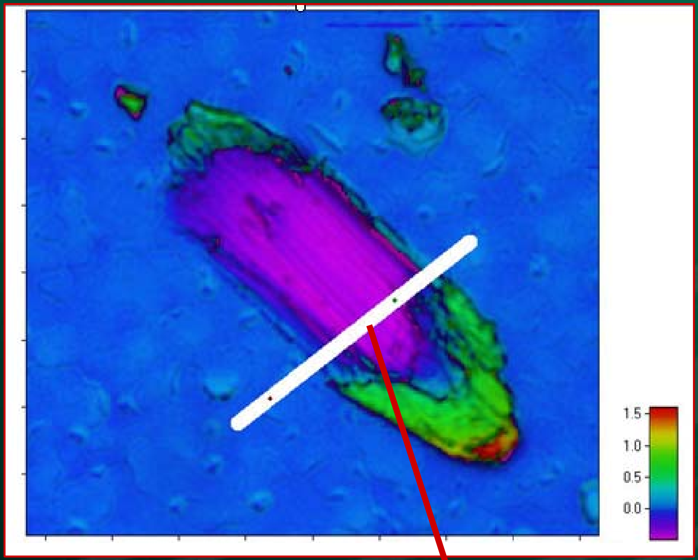


Region of Interest

Threshold parameters set to determine the area falling more than 200nm above average pad level.

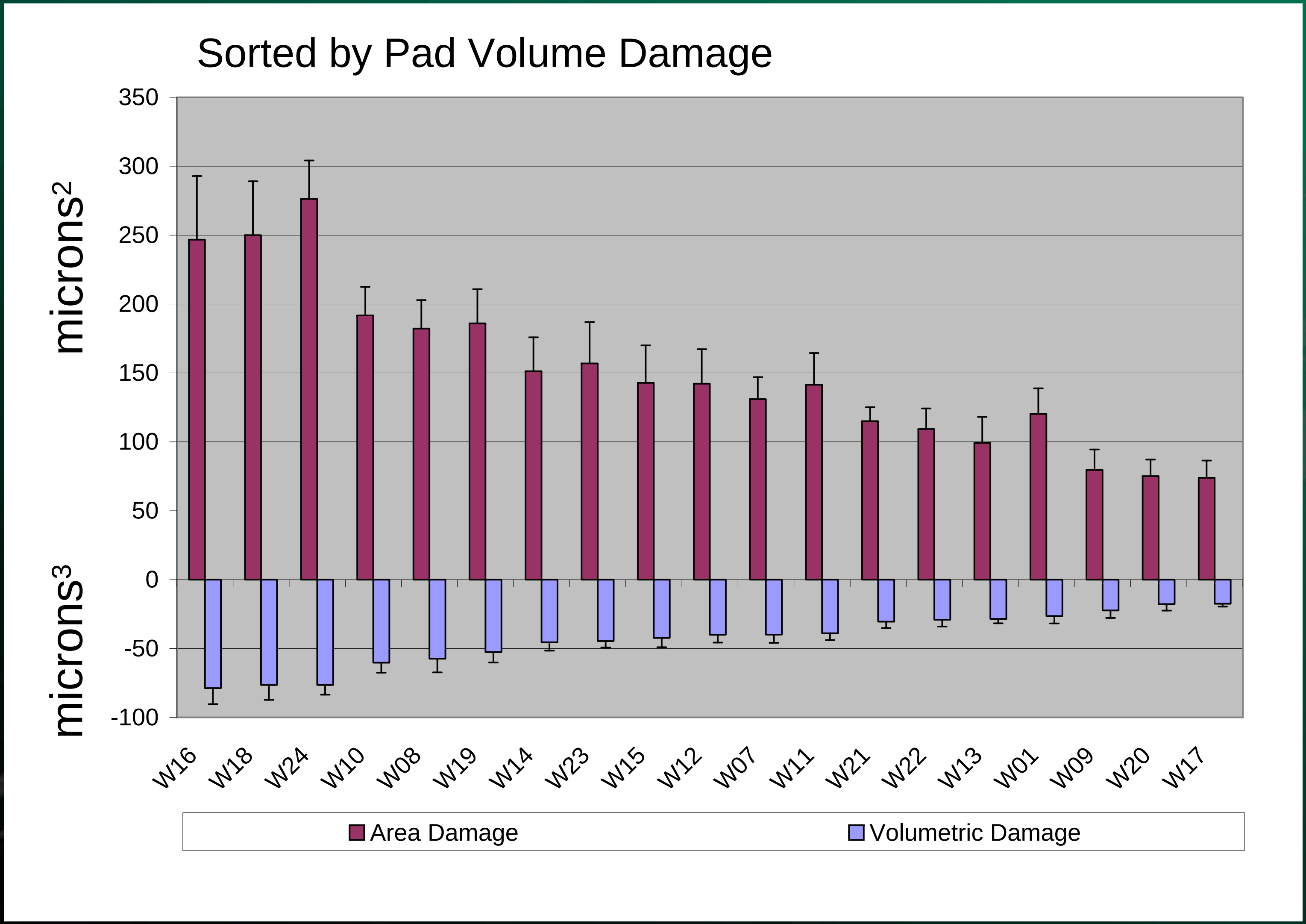
Depth Measurement

A cross-section tool is used to measure the probe depth.

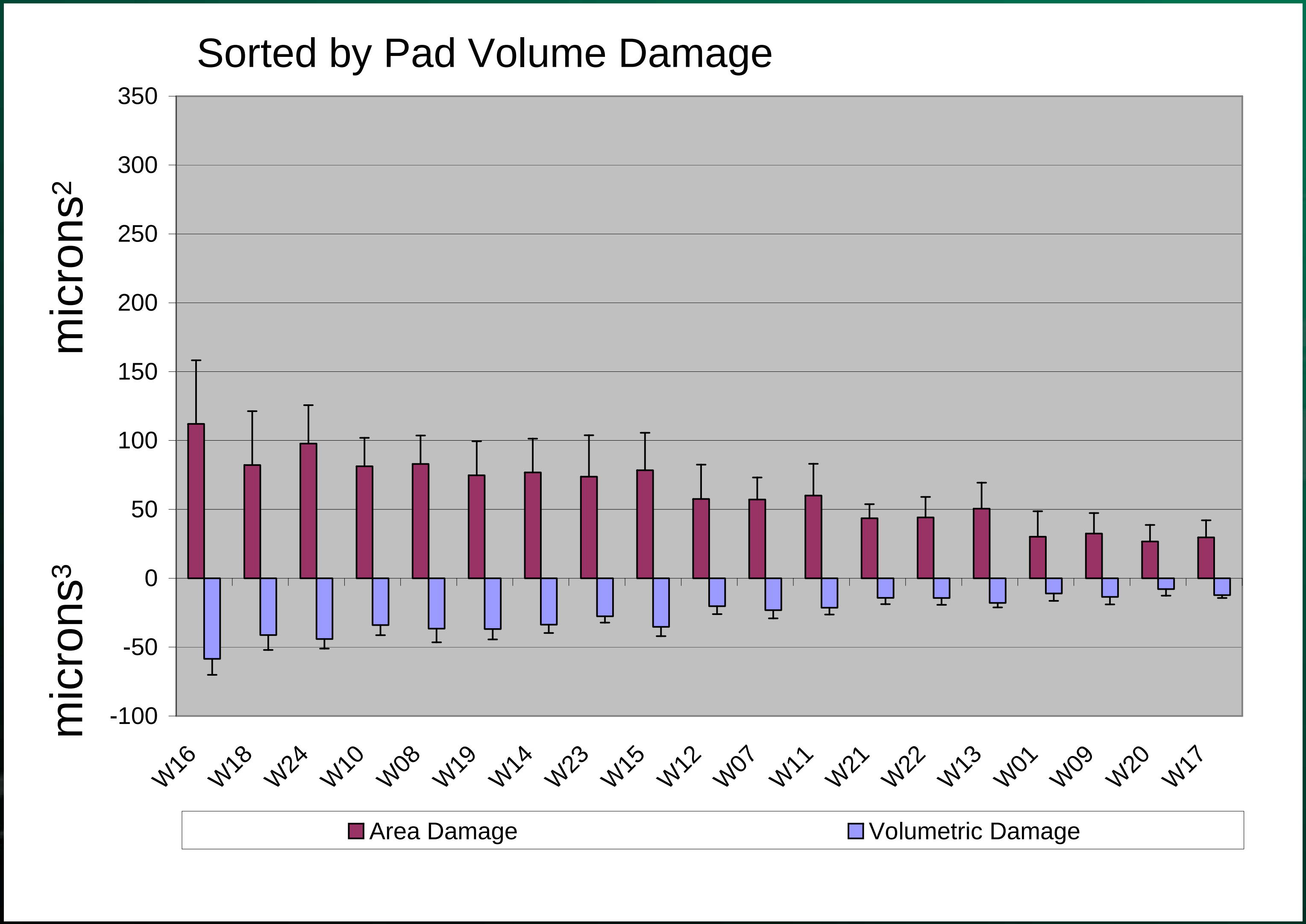


Test Results

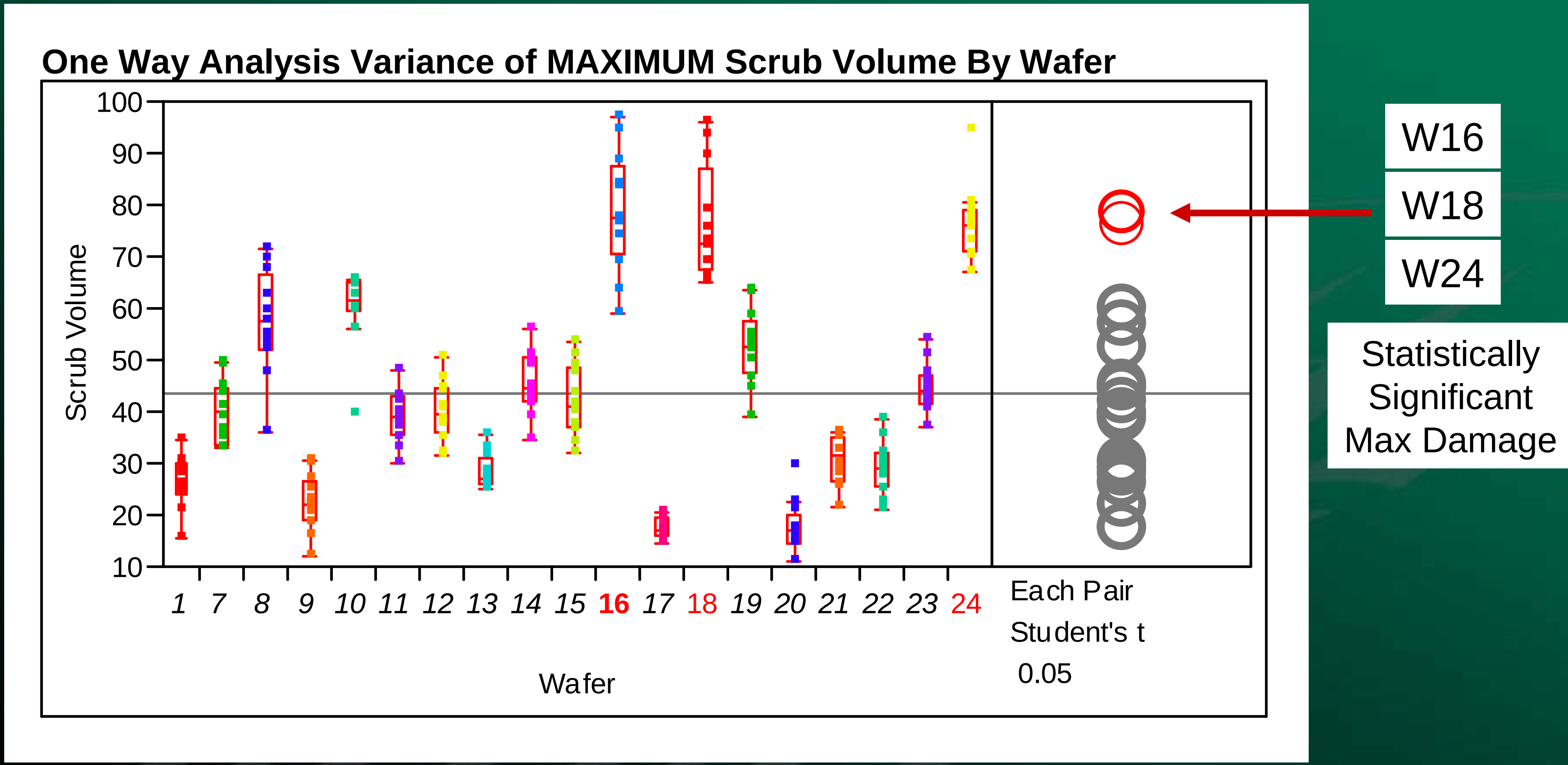
Pad Damage Pareto



Pile-up Pareto

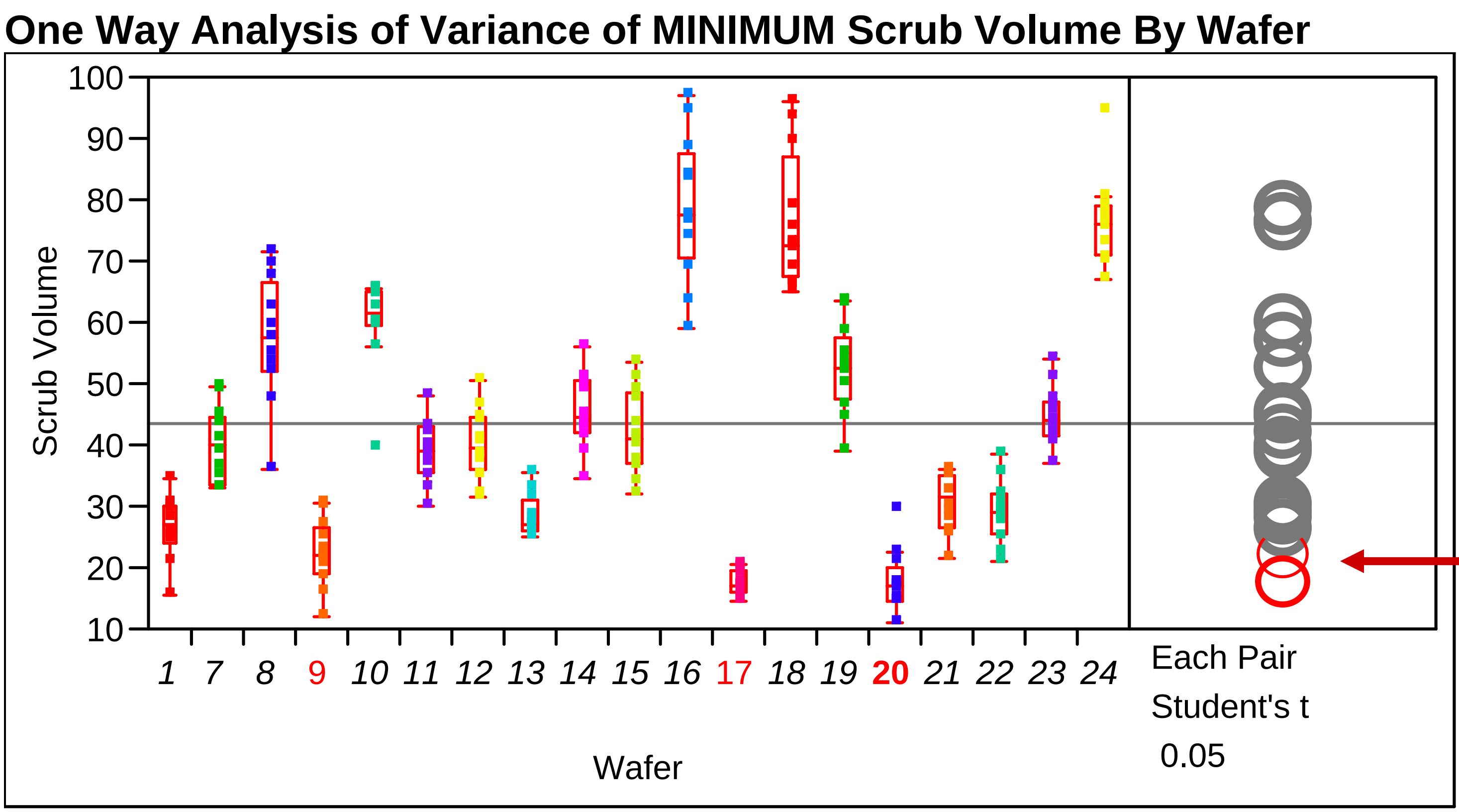


Maximum Scrub Volume



	Touchdowns	Undertravel	Pin-Update	Wafer Chuck Speed	Chuck Revise	Overtravel
24	Double	10	Off	High	Off	75
18	Double	20	On	High	On	75
16	Double	Off	Off	High	On	75

Minimum Scrub Volume



Borderline Statistically Significant Min Damage

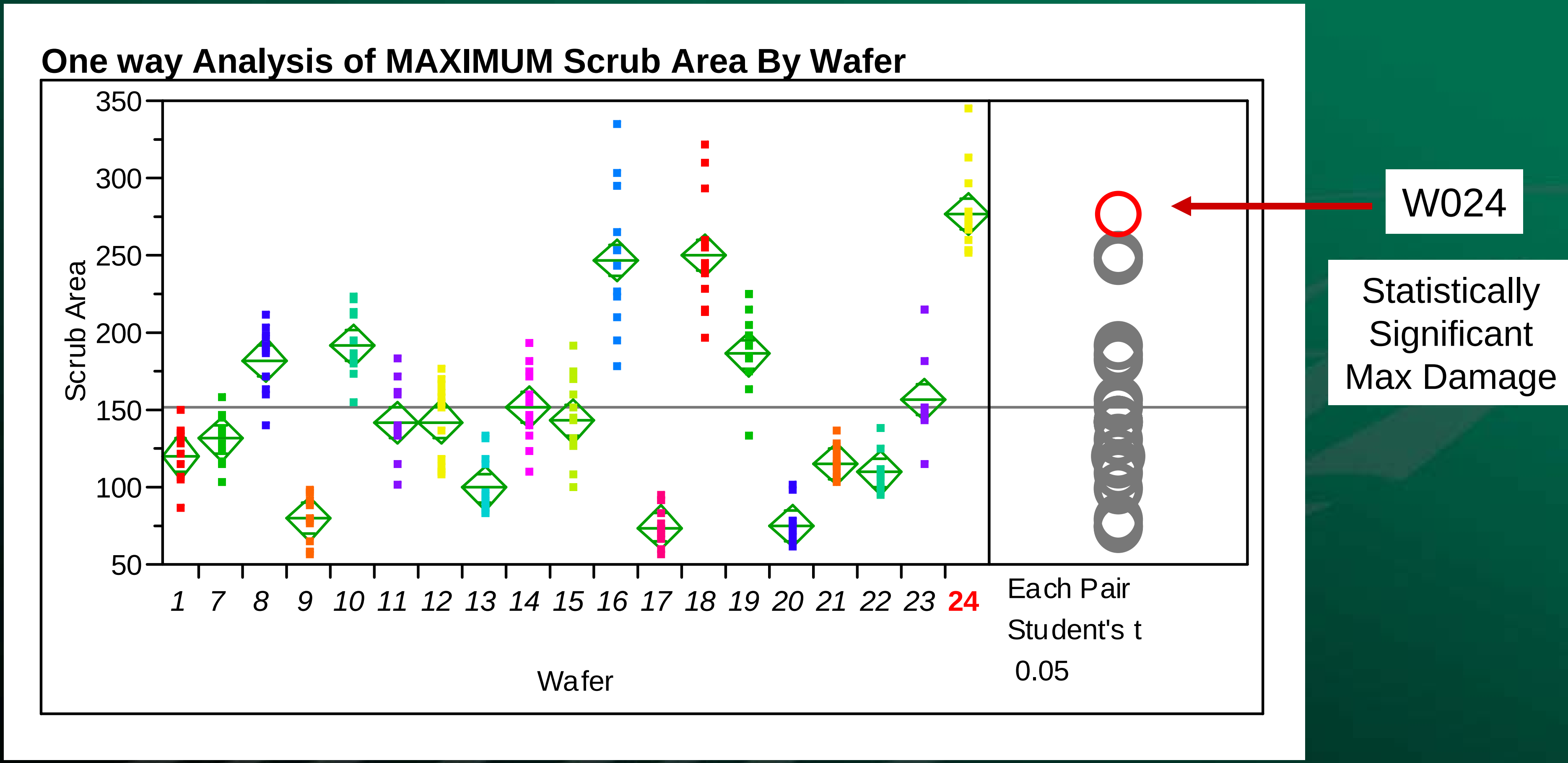
W09

W17

W20

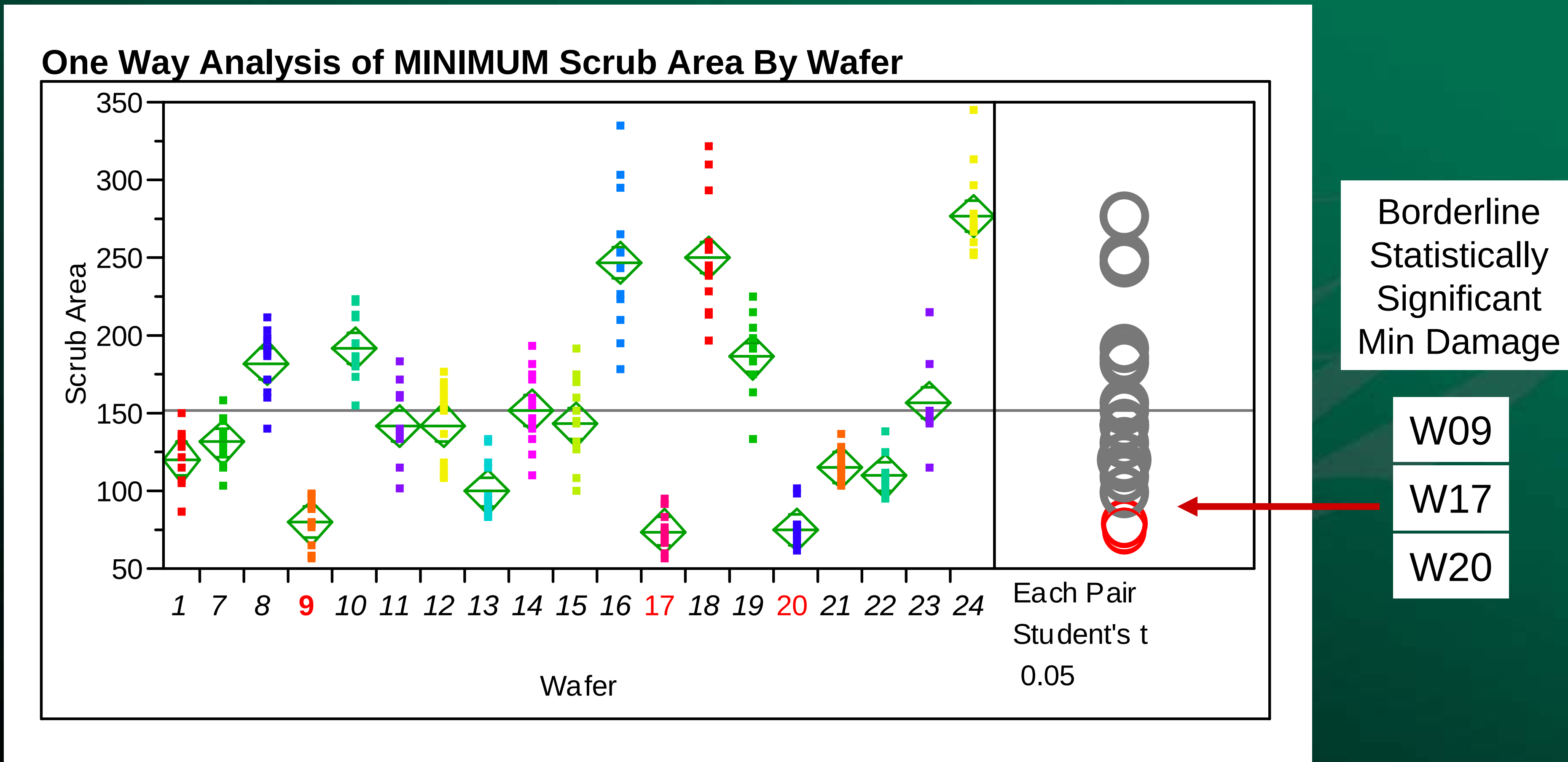
	Touchdowns	Undertravel	Pin-Update	Wafer Chuck Speed	Chuck Revise	Overtravel
20	Single	10	Off	High	On	50
17	Single	20	On	High	On	50
9	Single	Off	Off	Low	On	50

Maximum Scrub Area



	Touchdowns	Undertravel	Pin-Update	Wafer Chuck Speed	Chuck Revise	Overtravel
24	Double	10	Off	High	Off	75

Minimum Scrub Area



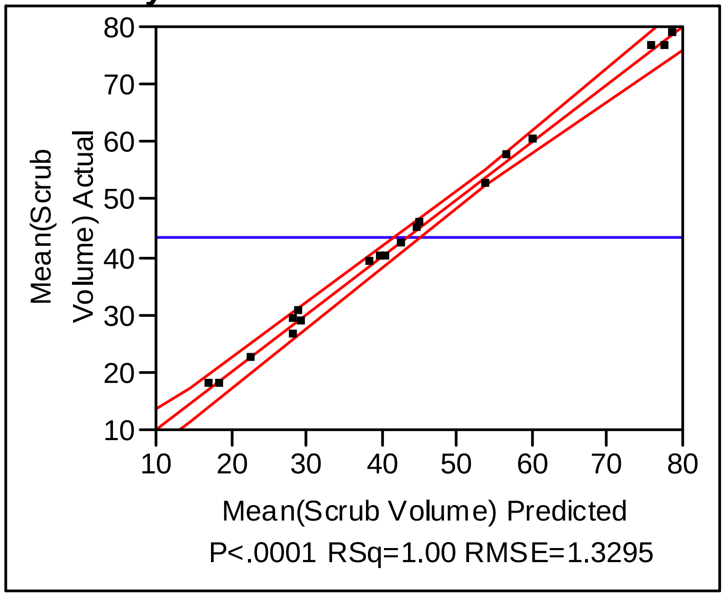
	Touchdowns	Undertravel	Pin-Update	Wafer Chuck Speed	Chuck Revise	Overtravel
20	Single	10	Off	High	On	50
17	Single	20	On	High	On	50
9	Single	Off	Off	Low	On	50

Analysis / Discussion

Scrub Mark Data Modeled in JMP

Actual vs. Predicted Results

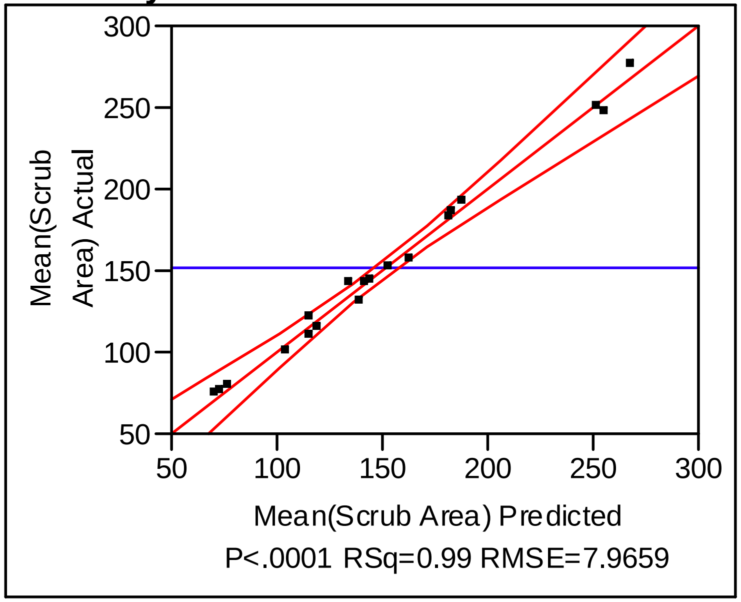
Response Mean (Scrub Volume)
Actual by Predicted Plot



Summary of Fit

RSquare	0.998152
RSquare Adj	0.995249
Root Mean Square Error	1.329477
Mean of Response	43.43426
Observations (or Sum Wgts)	19

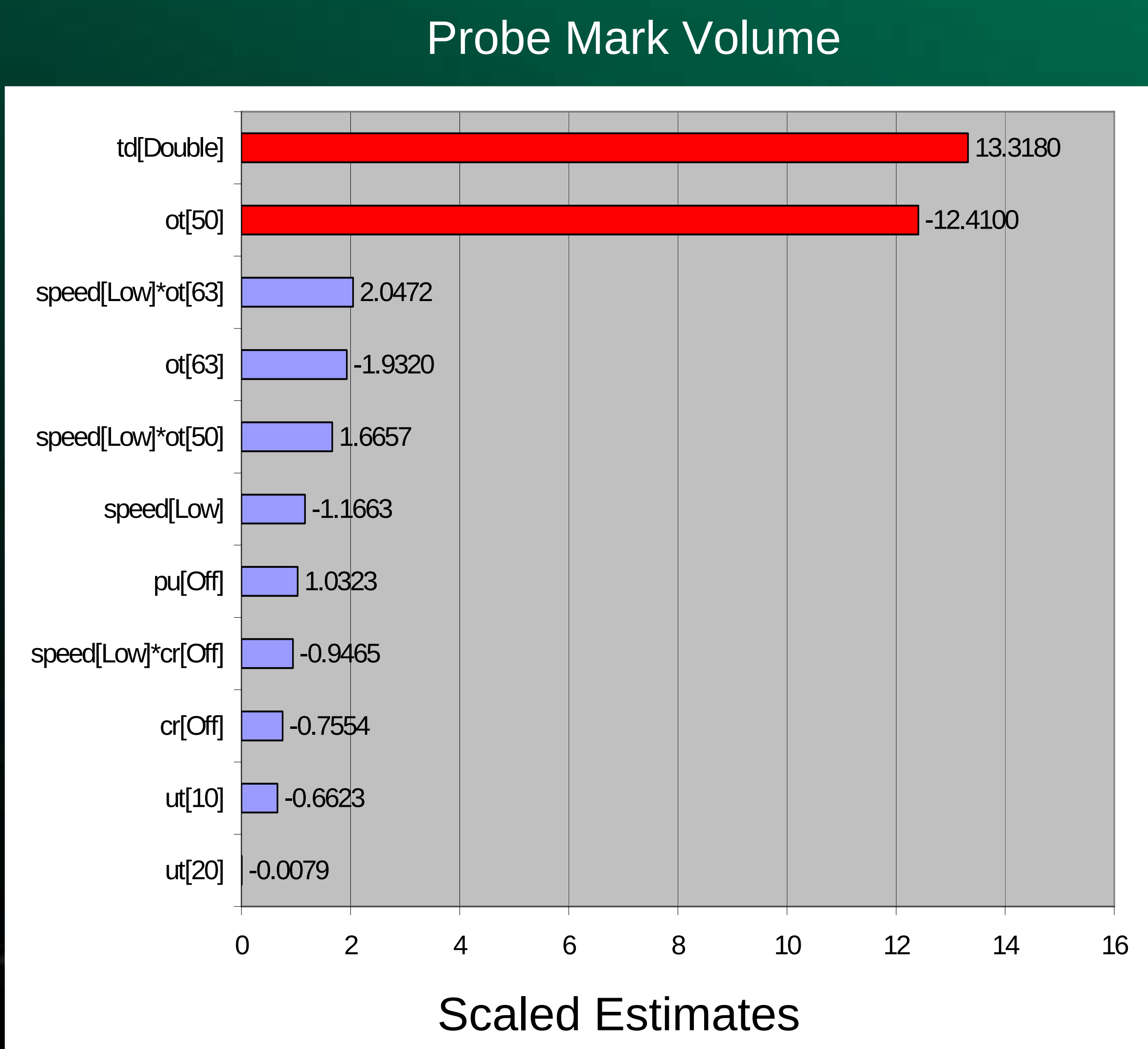
Response Mean (Scrub Area)
Actual by Predicted Plot



Summary of Fit

RSquare	0.992907
RSquare Adj	0.981761
Root Mean Square Error	7.965932
Mean of Response	151.0761
Observations (or Sum Wgts)	19

Significant Factor Estimates



Primary Responses

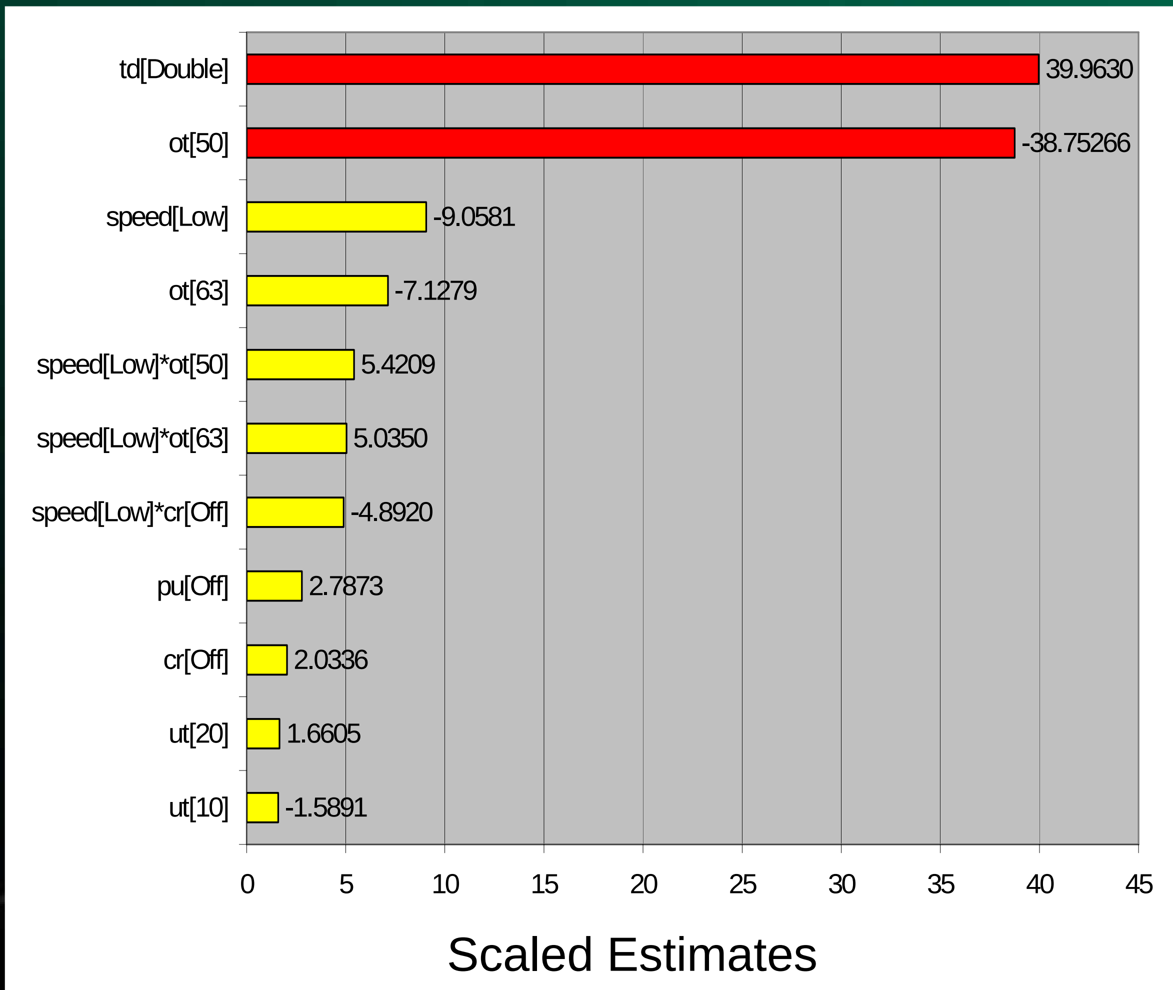
Single vs. Double Touchdown
Minimum vs. Maximum Overtravel

Secondary Responses

No clear wafer chuck speed dependency was surprising.

Significant Factor Estimates

Probe Mark Area



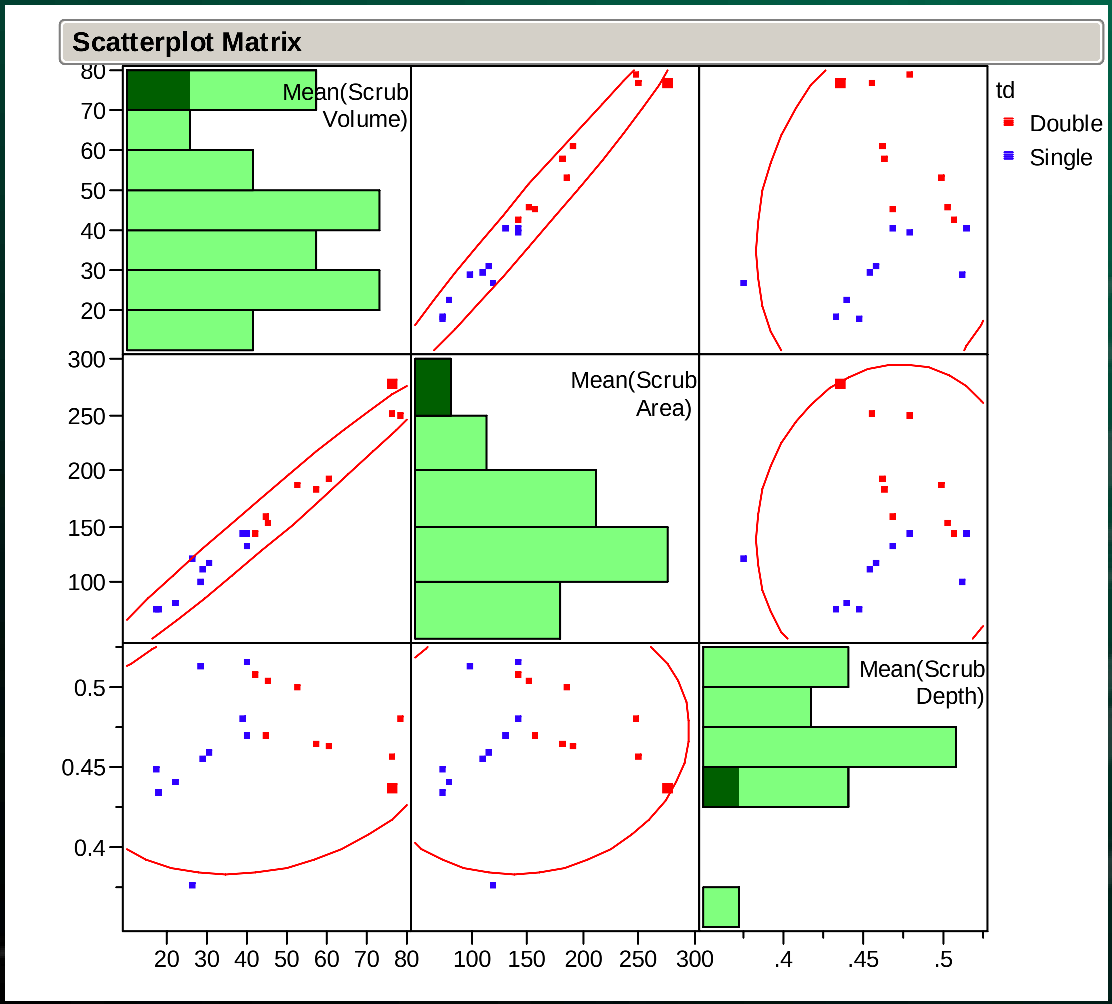
Primary Responses

Single vs. Double Touchdown
Minimum vs. Maximum Overtravel

Secondary Responses

A reduced dataset analysis showed that speed was the third largest factor contributing to the probe mark area response.

Correlation Between Responses

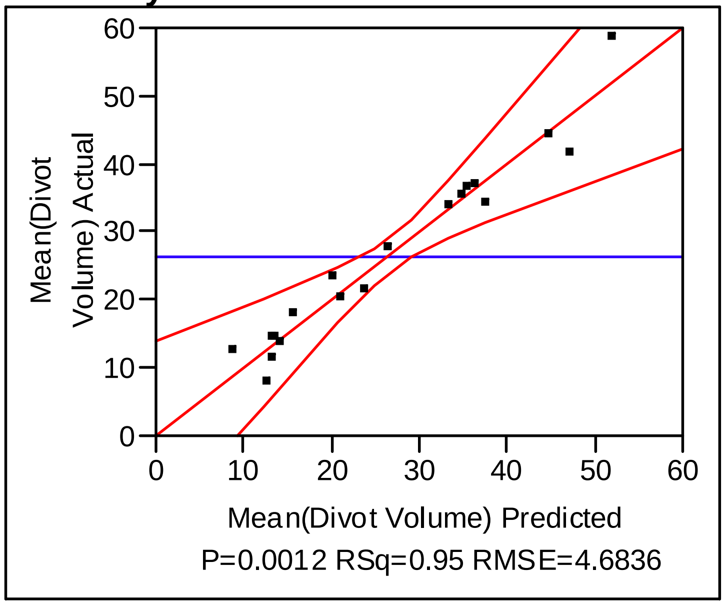


- As expected, the probe mark scrub area and scrub volume showed statistically high correlations to each other
- The correlation between probe mark depth and volume was not statistically significant
- Possible reasons for lack of correlation to probe depth
  - Small sample size effects
  - Operator-induced variability
  - Probe tip diameter
  - Probe gram force

Pile-up Data Modeled in JMP

Actual vs. Predicted Results

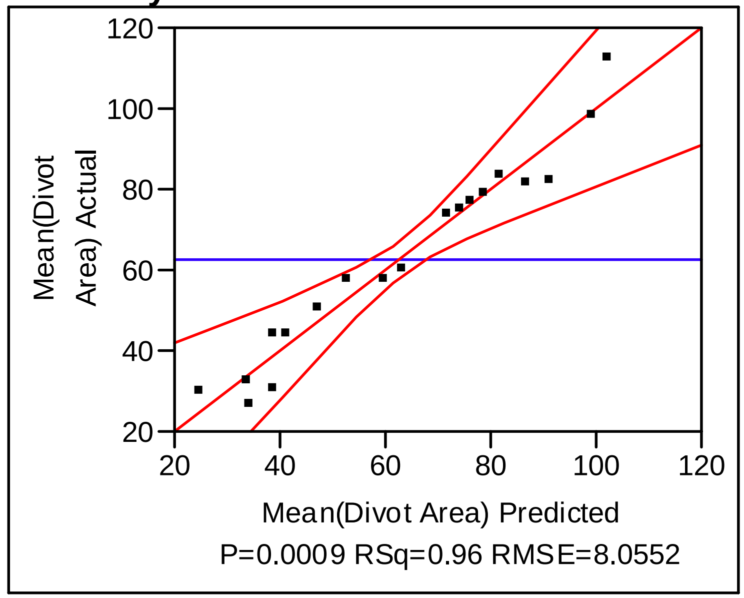
Response Mean (Pile Up Volume)
Actual by Predicted Plot



Summary of Fit

RSquare	0.954192
RSquare Adj	0.882209
Root Mean Square Error	4.683565
Mean of Response	26.51567
Observations (or Sum Wgts)	19

Response Mean (Pile Up Area)
Actual by Predicted Plot

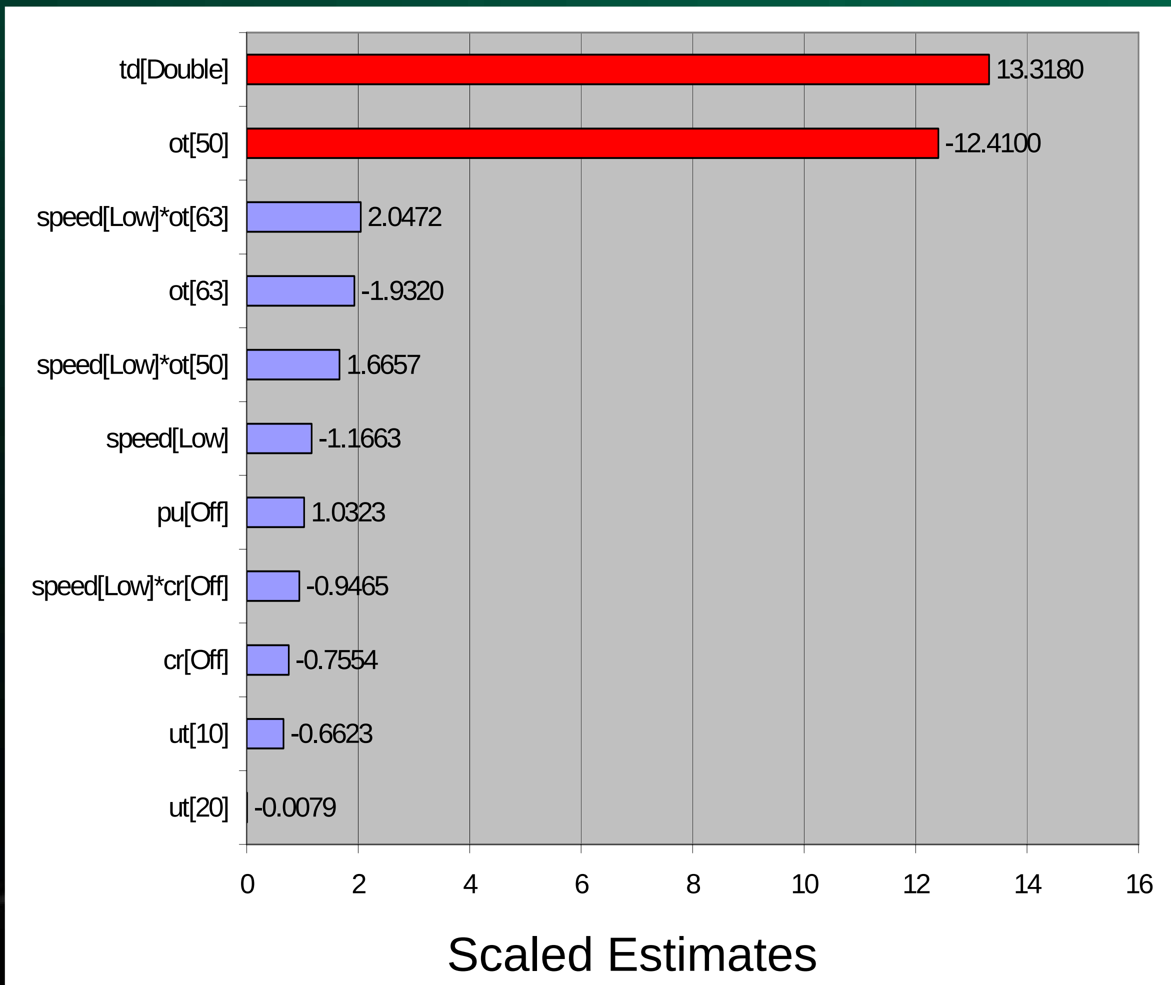


Summary of Fit

RSquare	0.957954
RSquare Adj	0.891882
Root Mean Square Error	8.055216
Mean of Response	62.74199
Observations (or Sum Wgts)	19

Significant Factor Estimates

Pile-up Volume



Primary Responses

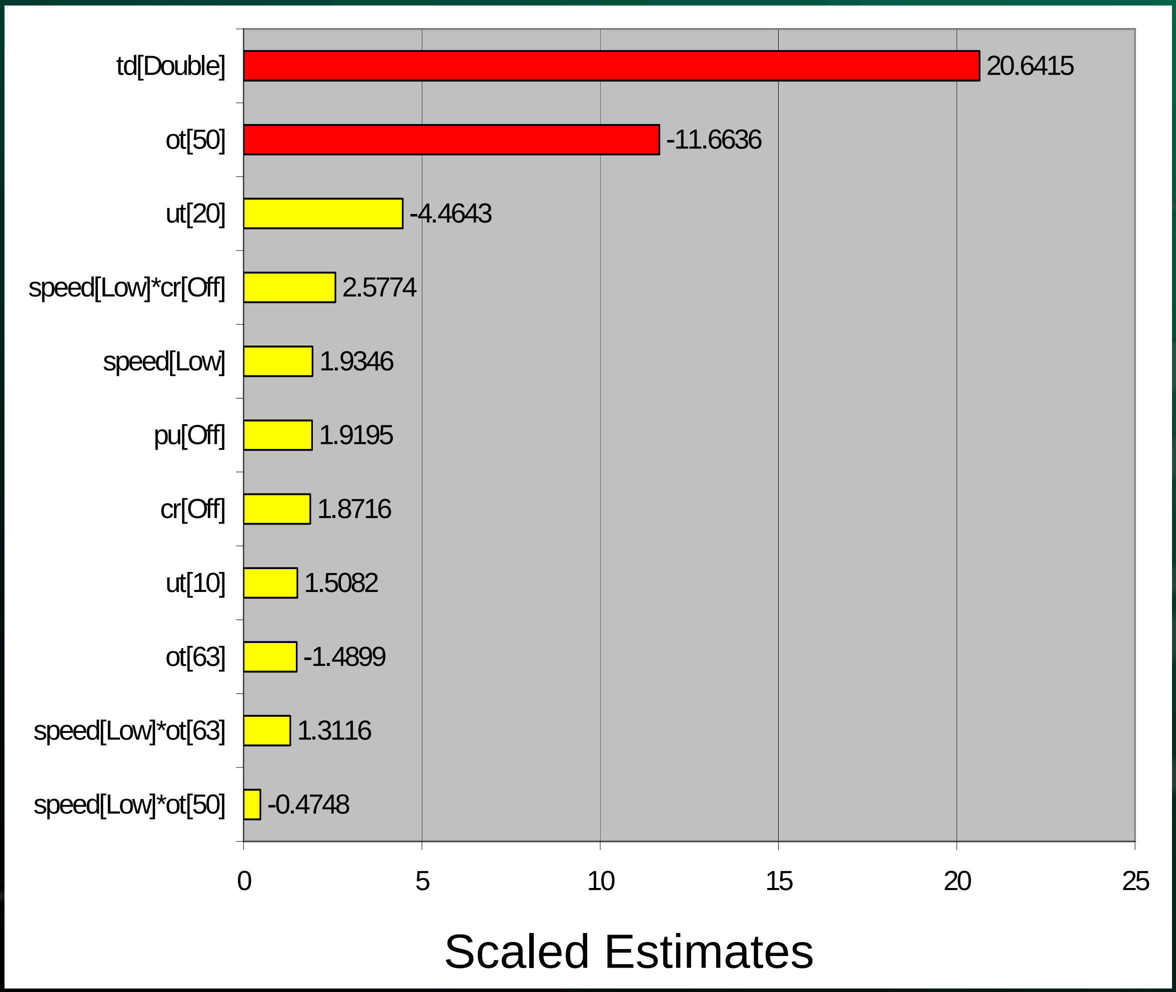
Single vs. Double Touchdown
Minimum vs. Maximum Overtravel

Secondary Responses

Additional dataset analysis showed that speed was a contributing factor for pile-up volume

Significant Factor Estimates

Pile Up Area



Primary Responses

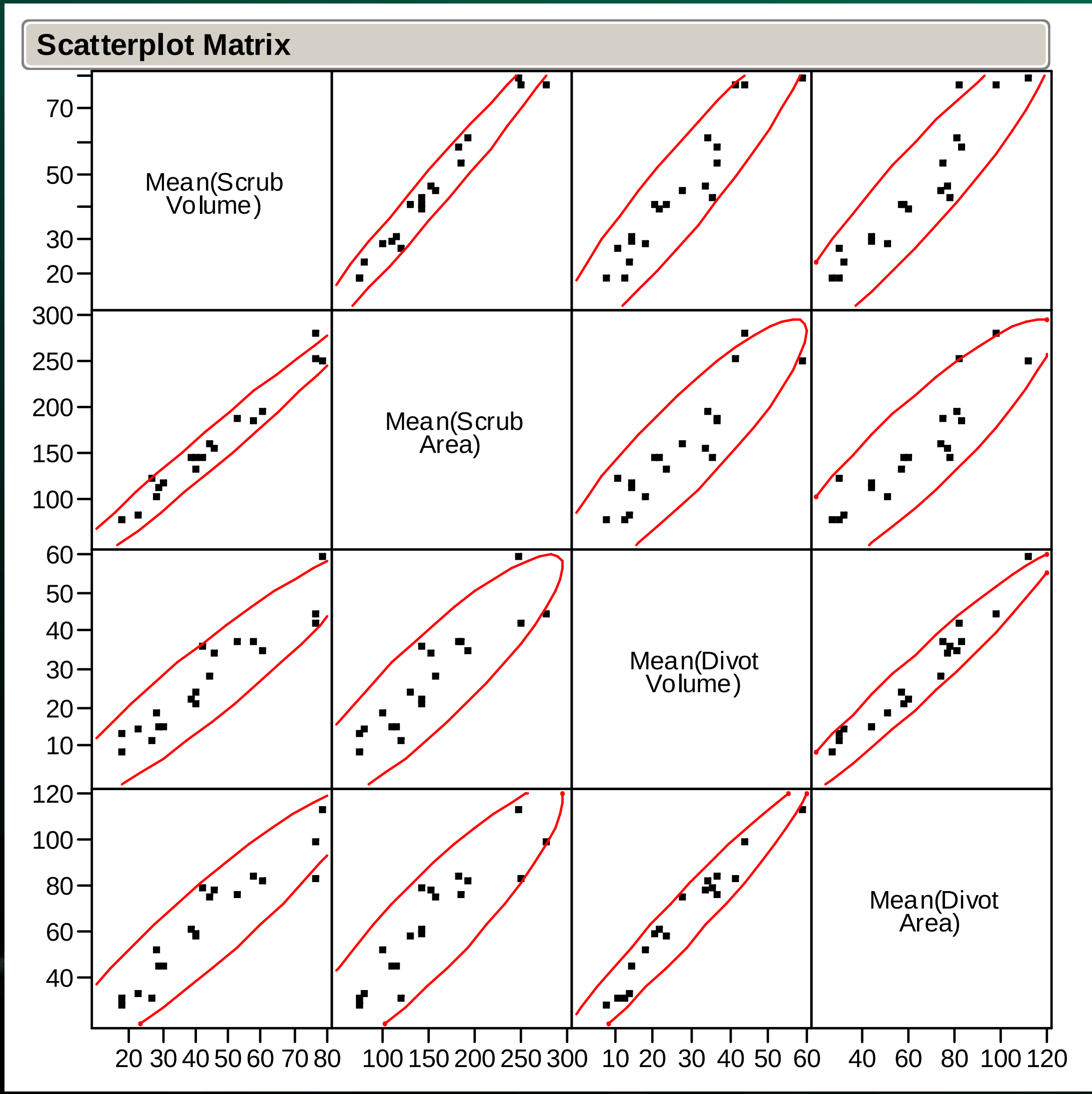
Single vs. Double Touchdown
Minimum vs. Maximum Overtravel

Secondary Responses

No clear wafer chuck speed dependency was surprising.

Undertravel was a more significant contributing factor than chuck speed.

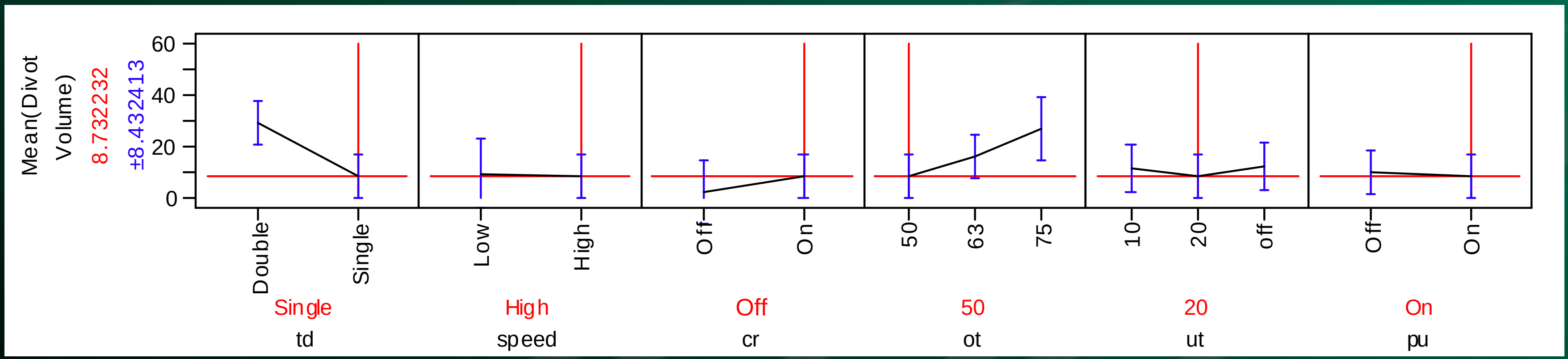
Correlation Between Responses

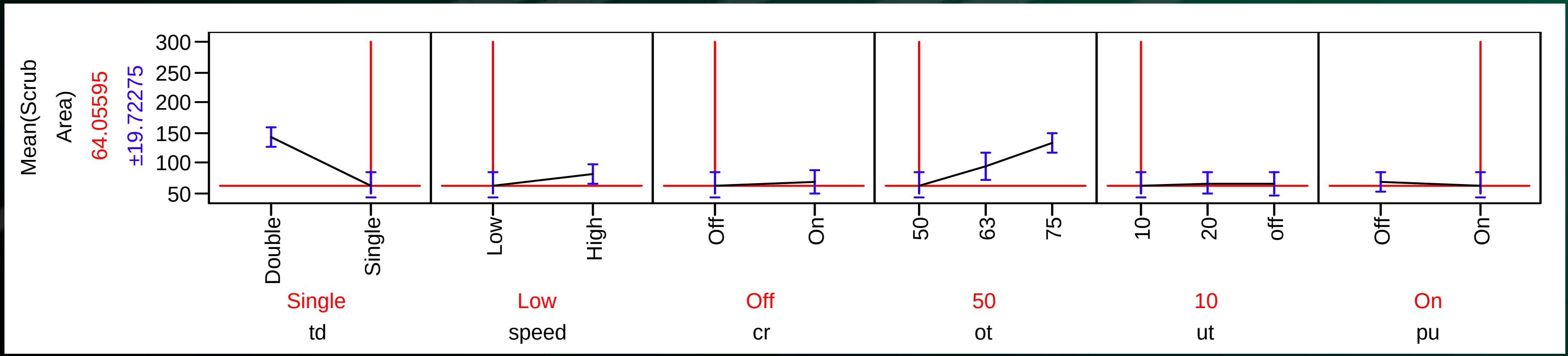


- Statistically significant correlation between the primary responses (area and volume) was observed.
- Modeled data can be used to investigate optimal conditions.

Best Case Combinations

- Modeled response data can be used to investigate the effects of changing one parameter and keeping the other constant.
  - Slopes of the lines can give some indication of sensitivity to the change.





Summary / Conclusions

- Reasonable steps can be taken with “existing” hardware to reduce pad damage in a cost-effective manner.
- Volumetric probe damage assessment can be used to optimize probe/pad interaction and reduce yield fallout.
  - Non-contact methods are critical for statistically valid and practical failure analysis without de-processing and/or cross-sectioning.
- Even with the small sample size, the statistical power was adequate to give an indication for response sensitivity to primary process factors.
- The influence of second order factors for fine-tuning the operational parameters can be performed using modeled response data.

Follow-On Work

- Investigate improved height and depth measurements
  - Larger sample size
  - Improved automated methods to reduce operator induced variability
- Consider probe card parameters
  - Probe tip diameter
  - Probe gram force
- Validate test results using a secondary metrology evaluation
- Further assessment of the “optimized” operational parameter combination
  - CRES performance evaluation
  - Bondability testing

Acknowledgements

- Chuck Jensen, Micron Technology, Inc.
- Brett Crump, Micron Technology, Inc.
- John Little, Hyphenated Systems, LLC