IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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Achieving Tool-Tool Correlation and Tool Stability for Probe Mark Inspection (PMI) in Automotive Applications

RUDOLPH TECHNOLOGIES

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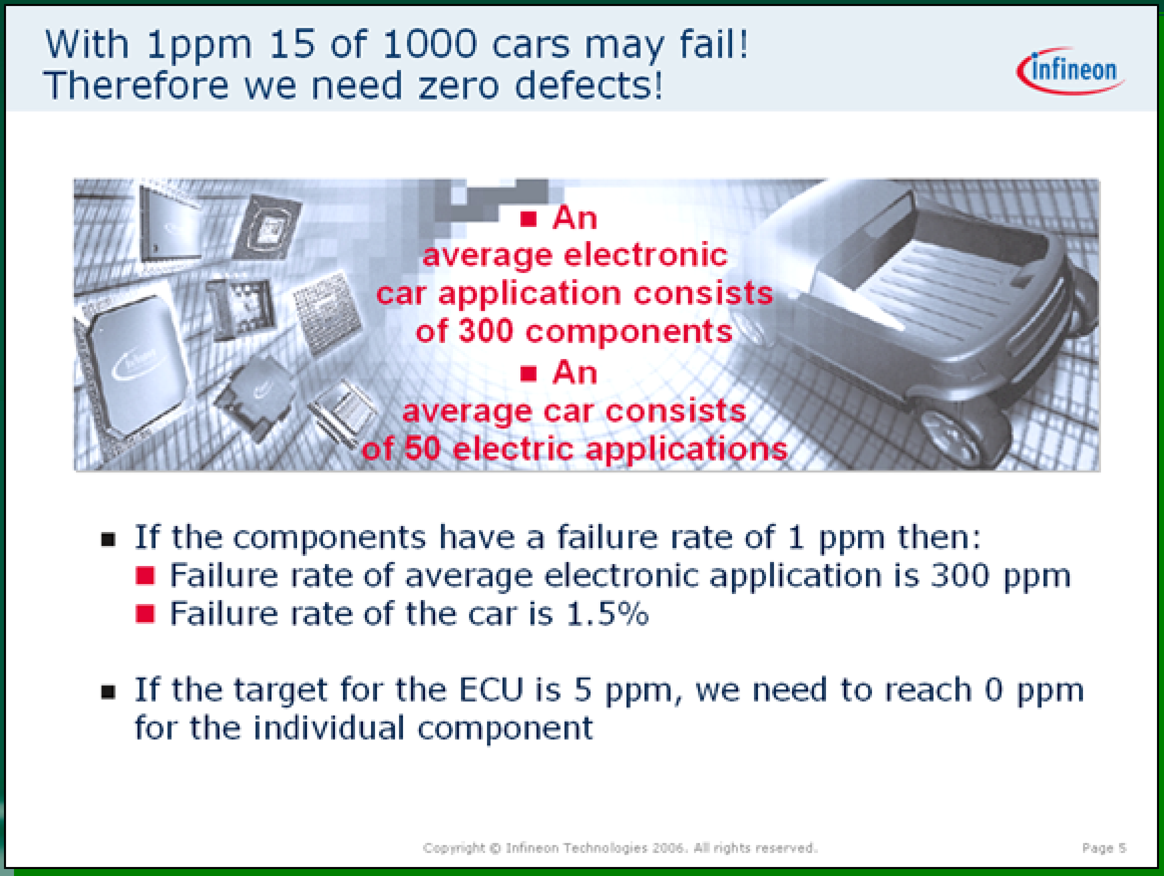
Overview

- Zero Defects and Automotive Semiconductor Industry
- Key Enablers of Zero Defects Program
- Reliability and Probe Mark Inspection
- Tool Matching
- Tool Stability
- Tool design for Tool Matching
  - Illumination matching
  - Flat-fielding
  - Distortion correction (warpage and scale)
- Manufacturing flow change
- Data on Tool Matching
- Summary

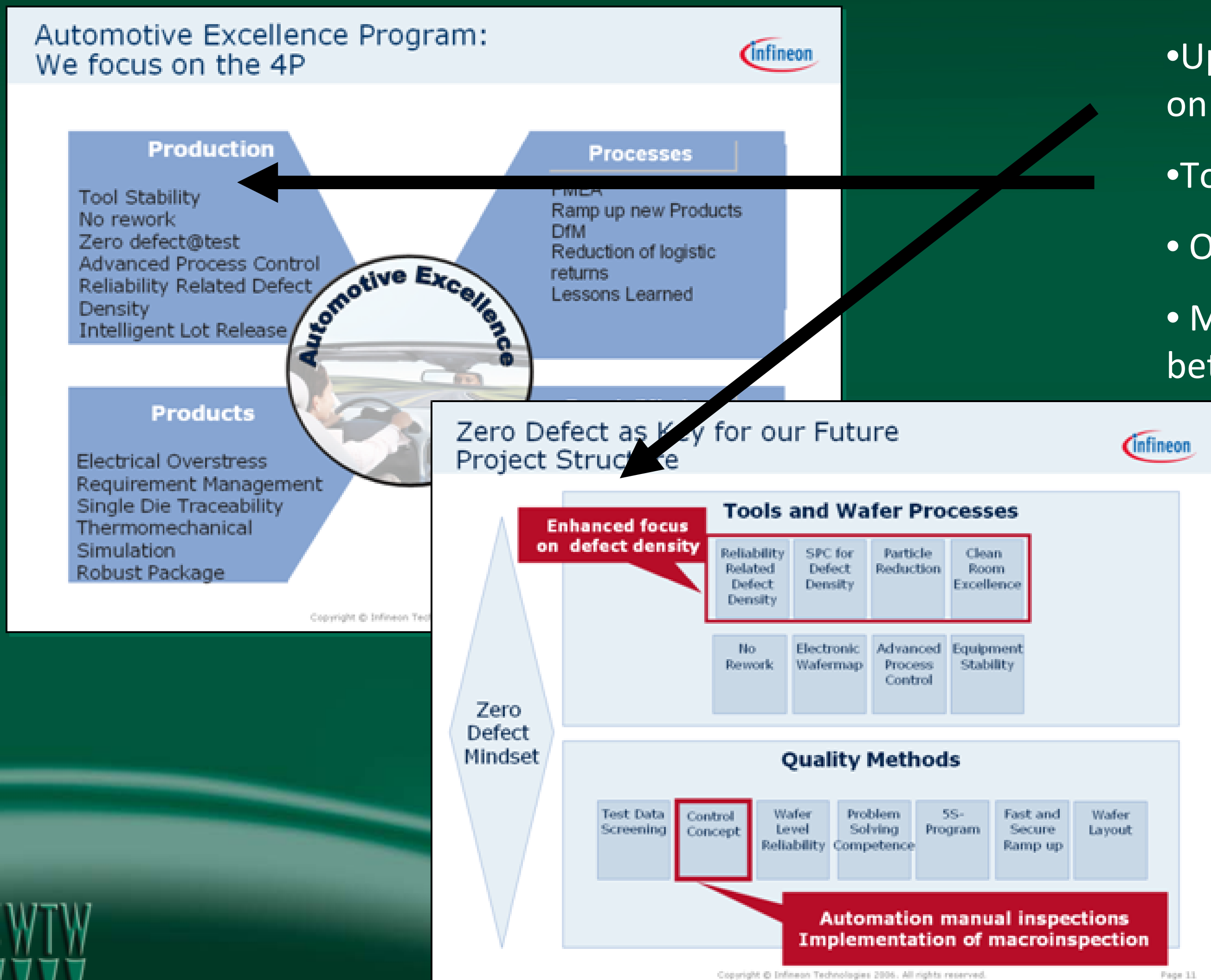
Zero Defects and Automotive Semiconductor Industry



Şafak Keçeci
IFAG AIM OPP FE T TR

June 12, 2007
Regensburg - Rudolph‘s European Yield Forum

Key Enablers of Zero Defects Program



<u>Inspection</u>

- Automated over manual
- Upstream, inline and focus on ***reliability***-related defects
- Tool Stability
- Operation over time
- Matching performance between tools

Reliability and Probe Mark Inspection

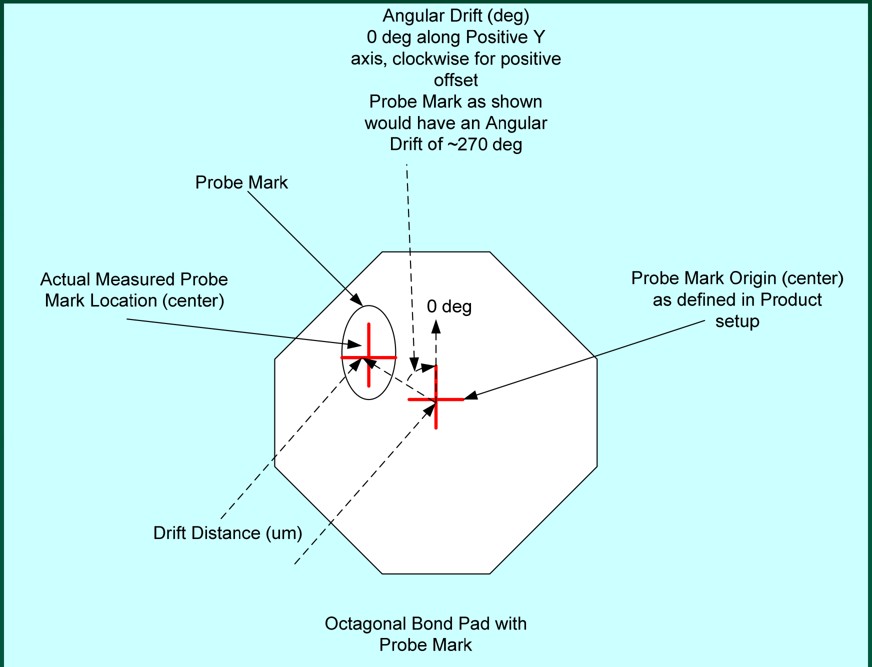
Relation between device reliability and probe mark inspection (metrology) is well known…..

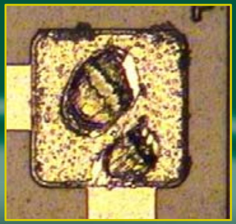
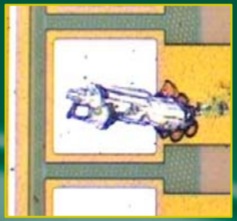
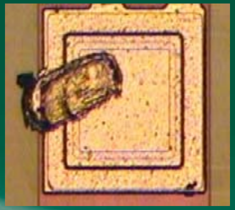
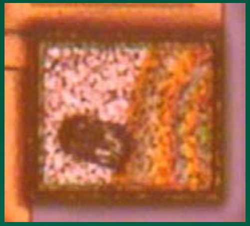
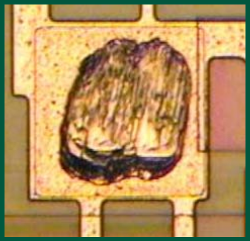
- Hotchkiss, G. et al "Probing and Wire Bonding of Al capped Cu Pads", Proceedings IEEE 40th Int'l Reliability Symposium, Dallas TX, 2002, pp140
- Hotchkiss, G. et al "Effects of Probe Damage on Wire Bond Integrity" Proceedings ECTC, Orlando, FL, 2001, pp1175
- Gahagan, D "Assessing Pad Damage and Bond Integrity for Fine Pitch Probing", SWTW 2001
- Thompson, K. et al "Building the Framework of an Integral Process to Ensure Fine Pitch Probe with Fine Pitch Wirebond". SWTW 2002
- Goulding, J. et al "Improving Yield for High Pin Count Wafer Probing Applications", SWTW 2000
- Brown, M "Controlling Pad Damage", SWTW 2000
- Huebner, H et al "Pad Damage due to Probing: Solutions for the Future", SWTW 2000
- Tran, T. et al "Fine Pitch Probing, Wire bonding, and Reliability of Aluminum Capped Copper Bond Pads", SWTW 2000

» And others….

Typical Probe Mark Parameters Measured

- Probe mark too big (> x%)
- Probe mark too small (<y%)
- Missing probe mark
- Pad discoloration
- Probe mark location (microns from bond pad center)
- Probe mark too close to edge (microns from bond pad center)



Tool Matching

How are the tools used in automotive applications?

Need #1 - Tool Matching

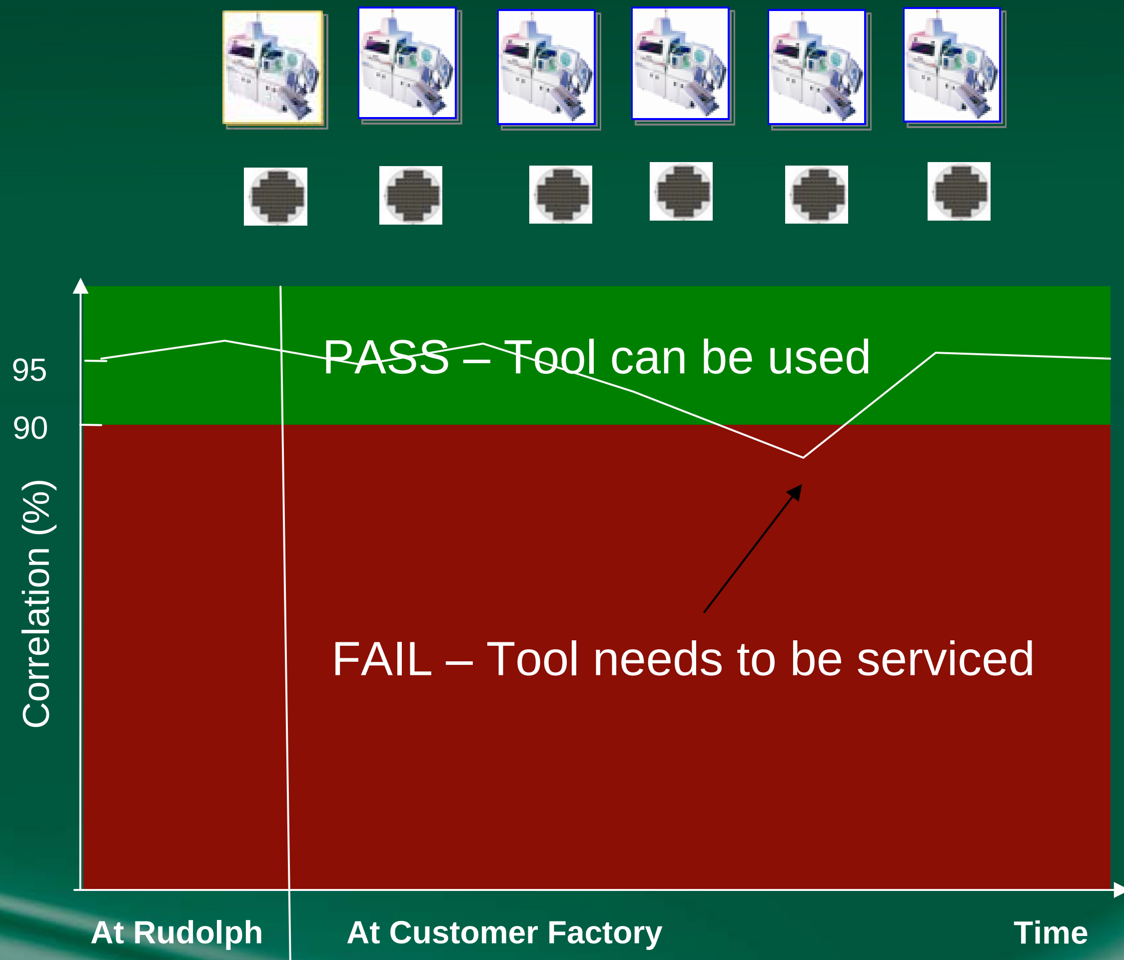
- Share recipe
- Process Lots through any tool based on availability
- Results should not be tool specific
- Results between need to correlate

Tool Stability

Monitoring Tool Health

Need #2 - <u>Tool Health</u>

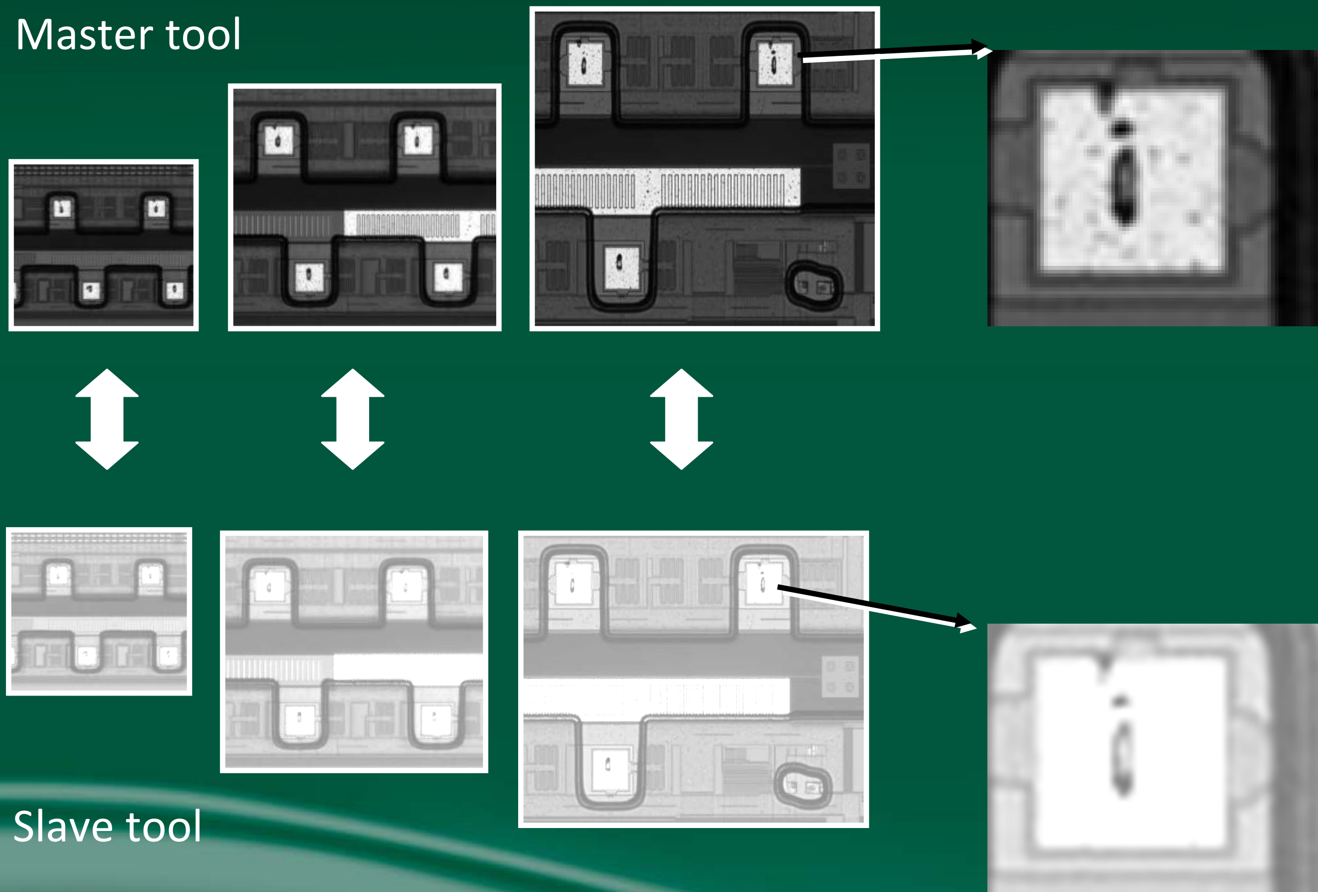
- How do you know if it is inspecting correctly?
- If tool has been moved or is down for PM, how do you know if you need to re-teach recipes?



What is needed to ensure the ability to match tools and monitor tool health?

- What we did to get there:
  - Spec components tighter–camera, lenses, illumination
  - Illumination matching
  - Flat-fielding
  - Image distortion correction
  - Re-do our system manufacturing build procedure
    - Put a “golden tool” in class 10 clean-room.
    - Implement a “golden wafer” or a standard wafer design.
    - Certify new standard wafers.
    - Certify all tools relative to “golden tool”.

Need for Illumination Matching



- Due to differences between light sources, aging of light source, light intensities with same illumination setting on different tools can be different
- Different calibration for each mag.
- Probe mark area calculation could vary

Need for Flat Fielding

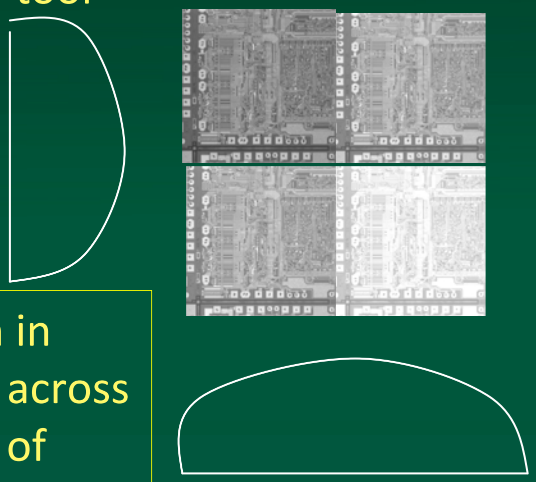
- Due to the inherent non-uniform light response of light source, optics, and camera across Field of View, gray values of pixels will vary across the field of view.

- If multiple dies fit in the Field of view, each die may result in different probe mark results even if probed "identically"

- Different flat-fielding for each mag.

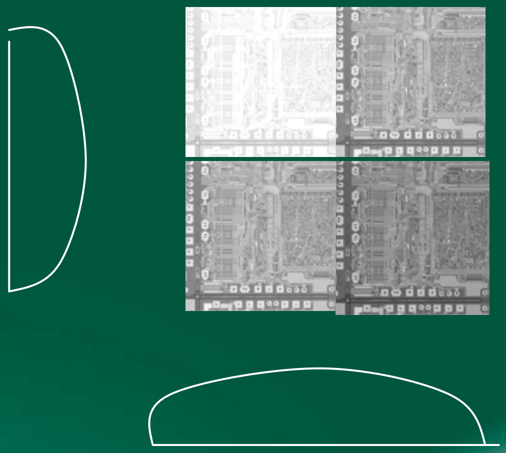
- Probe Mark Area calculation could vary from top left corner of Field of View to Bottom right corner of Field of View

Master tool



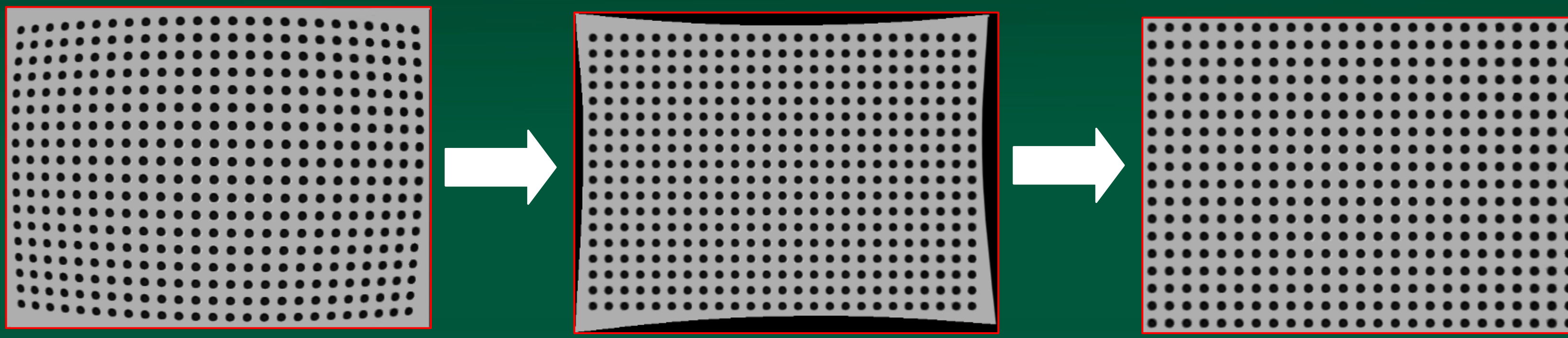
Variation in Intensity across the Field of View

Slave tool



Need for Image Distortion Correction

Original Image | Warpage Correction | Scale and Crop Correction



- Inherent imperfections in any optical system can cause non-linear image distortions on one system and scale (pixel size) variations between different systems
- Image distortion can cause inspection errors when the size of an object varies as its location in image changes
- Image Distortion correction are needed to correlate between tools for Probe Mark Location AND area

Manufacturing Strategy

- KGT – “Known Good Tool”
- Key components MUST meet Rudolph specification
  - Optics, camera, illumination

Pass

- Tool MUST meet correlate to Golden Tool
  - 95% Repeatability on Cert Wafer within tool
  - 90% Correlation on Cert Wafer to master tool defect list

Master Tool

Ship

Tool to be shipped

Definitions

- Repeatability of defects from run to run

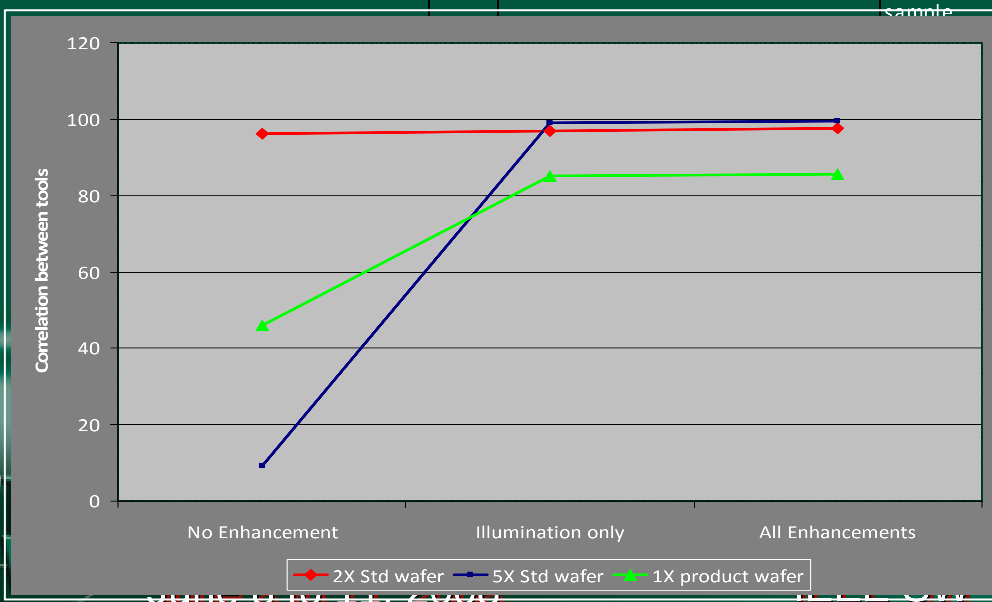
- Total Count Repeatability = **100 x (1 – σ / *mean*),** where **σ** is the standard deviation of the defect counts and ***mean*** is the average defect count for the inspection runs

- **Calculation Method:**
  - 10 runs of the same wafer are made. Wafer is removed between runs
  - Defect locations are used to determine a run-to-run defect match
  - A 5 pixel defect radius is used to decide if it is the same defect across runs

- **Specification Target**
  - 95% Repeatability for the same tool
  - 90% Correlation between two different tools

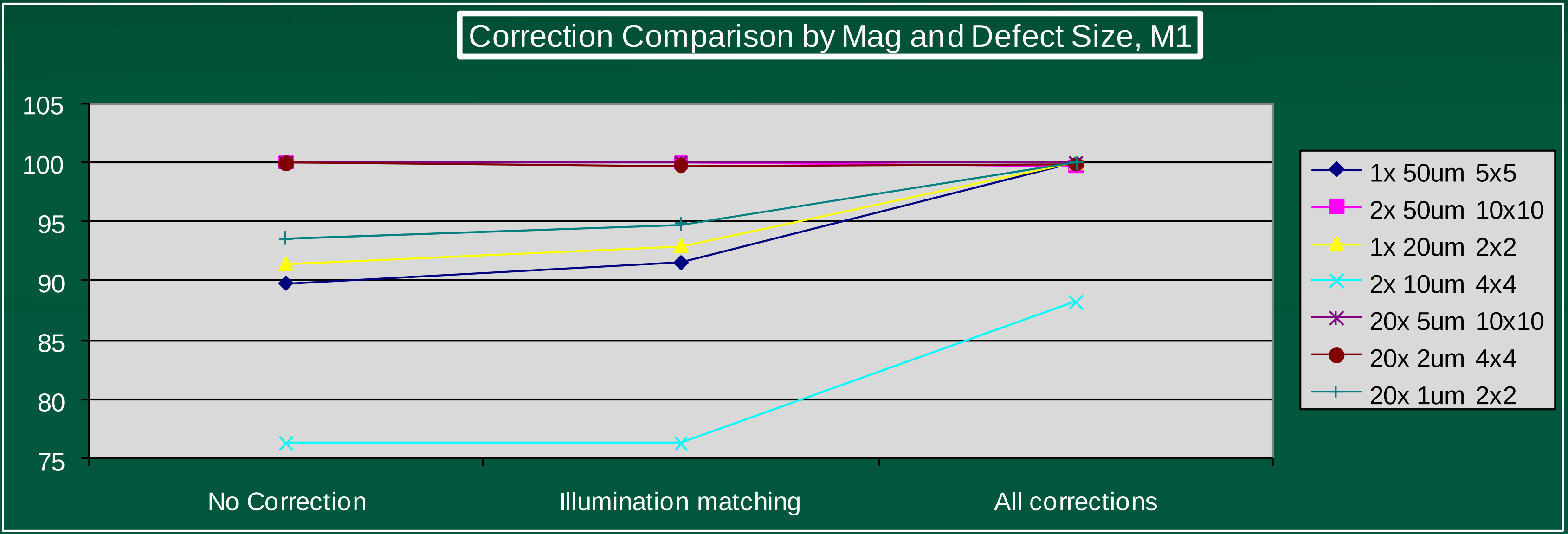
Show me…

Test Num	Test Type	Wafer	Tool 1 Yield	Tool 2 Yield	Tool 1 Repeatability	Tool 2 Repeatability	Correlation
1	2X insp without Image Enhancements	12" standard	74.23%	73.80%	99.96%	99.94%	99.40%
	Defect-level correlation				99.68%	99.58%	96.25%
2	2X insp with illum matching only	12" standard	74.27%	73.85%	99.98%	99.86%	99.54%
	Defect-level correlation				99.81%	98.76%	96.90%
3	2X insp with all enhancements	12" standard	74.11%	73.47%	99.96%	99.82%	99.66%
	Defect-level correlation				99.68%	98.75%	97.66%
7	5X insp without Image Enhancements	12" standard	49.50%	46.52%	100.00%	97.40%	96.88%
	Defect-level correlation				99.99%	92.78%	91.70%
8	5X insp with illum matching only	12" standard	49.53%	49.40%	99.97%	99.88%	99.73%
	Defect-level correlation				99.91%	99.60%	99.03%
9	5X insp with all enhancements	12" standard	49.52%	49.51%	99.99%	99.97%	99.89%
	Defect-level correlation				99.96%	99.93%	99.55%
19	1X insp without image enhancements	8" Customer sample	98.47%	0.00%	99.98%	100.00%	1.53%
	Defect-level correlation				99.96%	82.67%	45.92%
20	1X insp with illum matching only	8" Customer sample	98.51%	97.32%	99.94%	99.77%	98.54%
	Defect-level correlation				98.14%	96.33%	85.20%
21	1X insp with all enhancements	8" Customer sample	98.13%	97.36%	99.85%	99.98%	98.68%
					96.10%	95.24%	85.51%



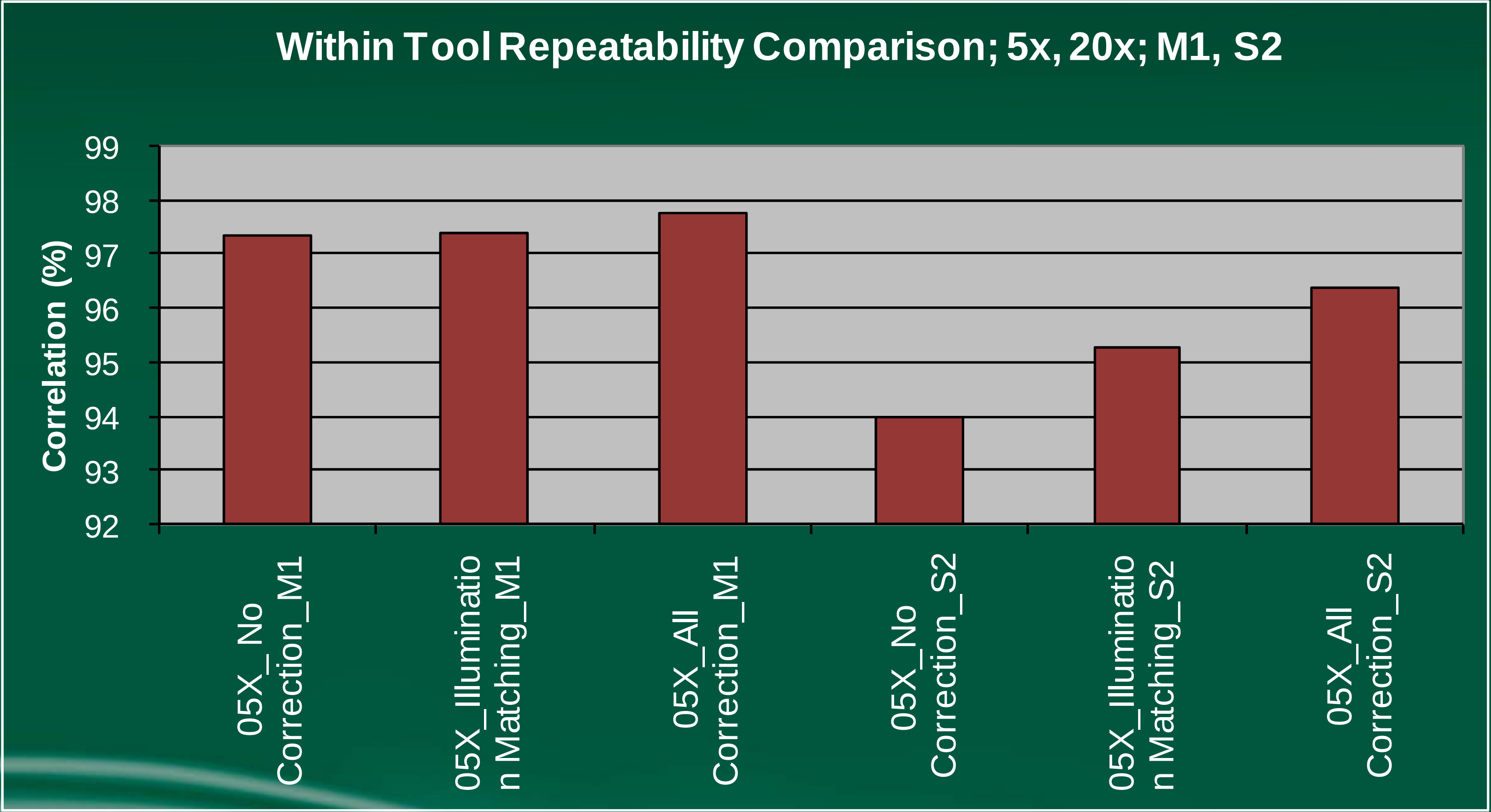
Impact of turning on corrections

Impact on Correlation by Mag and Defect Size for Product Wafer



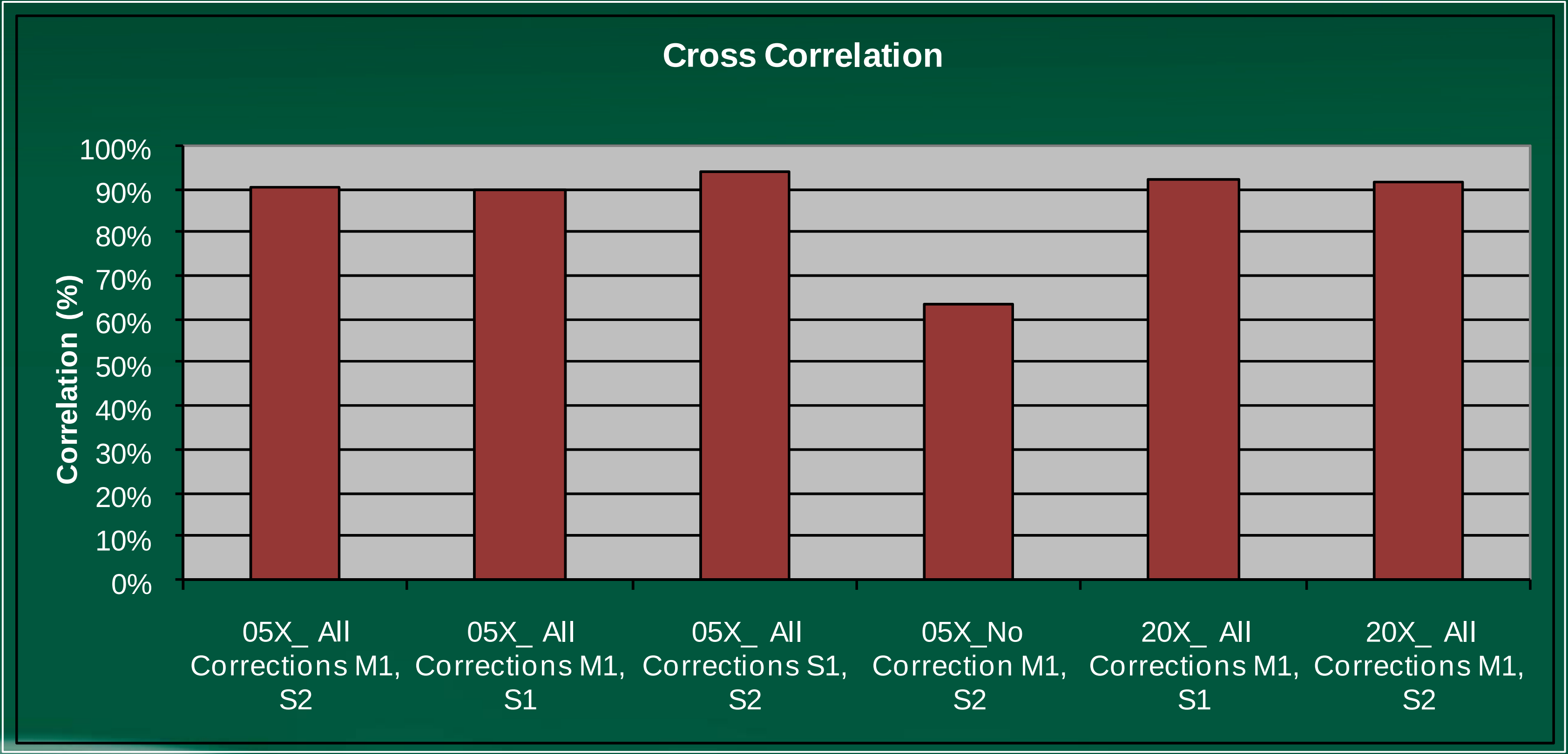
Test for Correlation

Between 3 tools M1, S1 and S2



Test for Correlation

Between 3 tools M1, S1 and S2

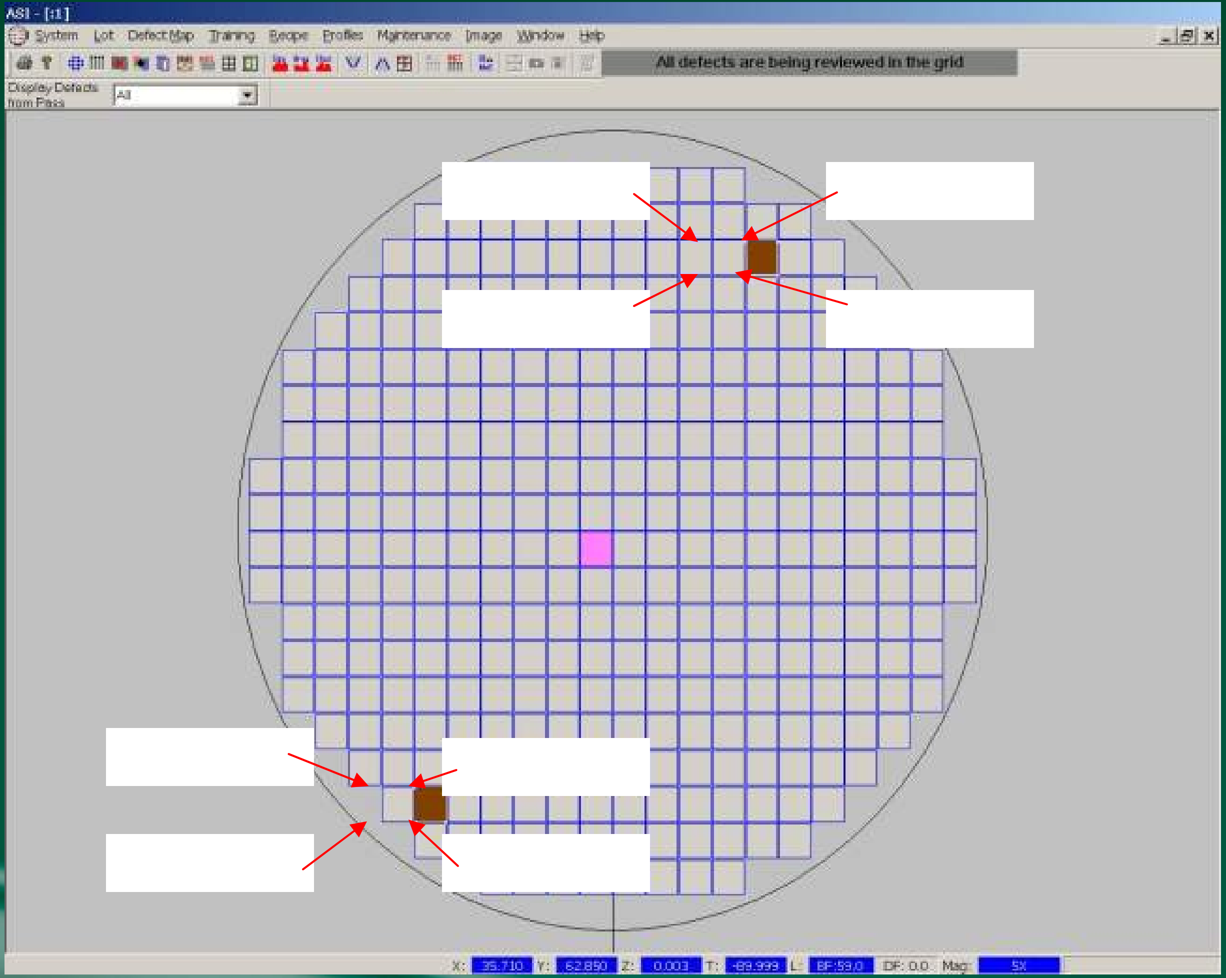


Now for the Real Test: PMI

Correlation at Customer Site DOE Overview

- T2T correlation and repeatability study was performed using PMI metrology data at customer site
  - Tool Type: NSX115 with Basler Camera
  - Wafer was chosen and eight bond pads were sampled for probe mark inspection.
  - The product setup was created on RU02 and copied over to RU01 without detector training.
  - The wafer was inspected 15 times on each tool. Each time, PMI raw data report was generated and saved.
  - The inspection was performed using 5X objective.

Sample Plan



ASI - [:1]
System
Lot
Defect Map
Training
Recipe
Profiles
Maintenance
Image
Window
Help
All defects are being reviewed in the grid
Display Defects from Pass
All
X: 35.710
Y: 62.850
Z: 0.003
T: -89.999
L: BF:59.0
DF: 0.0
Mag: 5X

Left Edge Proximity (μm)

Results

RU02 Left Edge Proximity (um)								
	Bondpad 1	Bondpad 2	Bondpad 3	Bondpad 4	Bondpad 5	Bondpad 6	Bondpad 7	Bondpad 8
RUN1	13.465	28.612	11.221	20.603	15.274	26.717	11.536	20.674
RUN2	13.432	25.895	10.96	21.114	15.669	26.329	11.441	20.624
RUN3	13.517	26.469	11.284	20.564	15.275	26.73	11.264	20.625
RUN4	13.331	26.457	11.62	20.648	15.425	28.909	11.285	20.635
RUN5	12.994	26.353	11.569	20.875	15.633	28.826	11.273	22.937
RUN6	13.181	26.413	11.371	19.743	15.519	26.71	11.275	20.645
RUN7	13.437	26.505	10.986	20.4	15.598	28.735	11.281	20.595
RUN8	13.252	25.949	11.54	20.706	15.545	28.76	11.28	20.493
RUN9	13.116	26.86	11.466	20.484	15.635	28.804	11.381	23.049
RUN10	13.212	26.456	11.505	20.798	15.501	28.645	11.273	20.679
RUN11	13.038	26.598	11.003	20.379	15.573	26.631	11.37	20.644
RUN12	13.356	26.786	11.534	19.774	15.553	28.721	11.273	19.912
RUN13	13.493	26.439	11.518	19.931	15.622	26.332	11.207	20.611
RUN14	13.146	26.414	11.489	21.012	15.498	26.532	11.259	19.961
RUN15	13.457	26.796	11.261	20.156	15.741	28.637	11.44	23.03
AVG	13.2951333	26.6001333	11.3551333	20.4791333	15.5374	27.7345333	11.3225333	21.0076
3 Sigma	0.51974373	1.85166075	0.6755054	1.2698092	0.39598506	3.40961617	0.27124206	3.18534937

RU01 Left Edge Proximity (um)								
	Bondpad 1	Bondpad 2	Bondpad 3	Bondpad 4	Bondpad 5	Bondpad 6	Bondpad 7	Bondpad 8
RUN1	13.294	25.815	12.292	20.916	15.78	29.949	12.254	21.616
RUN2	13.245	29.206	12.437	20.127	15.61	29.912	12.012	21.329
RUN3	13.331	27.862	12.511	21.38	15.494	29.34	12.164	20.99
RUN4	13.303	28.16	12.571	20.946	15.696	27.984	12.664	21.354
RUN5	13.155	29.004	12.588	19.787	15.3	29.499	12.948	21.329
RUN6	13.393	27.662	12.023	19.833	15.537	28.049	12.274	21.423
RUN7	13.194	29.082	12.024	19.793	15.502	27.853	12.969	21.527
RUN8	13.673	25.734	12.54	19.787	15.707	27.817	13.068	20.986
RUN9	13.572	29.024	12.511	20.002	15.558	28.1	12.149	21.408
RUN10	13.078	29.355	12.127	19.673	15.691	29.561	12.589	20.948
RUN11	13.317	29.098	12.326	19.891	15.545	27.979	12.196	21.388
RUN12	13.353	27.532	12.314	20.033	15.698	29.481	12.137	20.99
RUN13	13.333	27.636	11.977	20.045	15.438	28.123	12.5	21.372
RUN14	13.262	27.679	12.233	19.68	15.594	29.686	12.914	20.962
RUN15	13.756	25.701	12.316	21.141	15.662	29.371	12.478	21.354
AVG	13.3506	27.9033333	12.3193333	20.2022667	15.5874667	28.8469333	12.4877333	21.2650667
3 Sigma	0.55693654	3.87777005	0.62571673	1.74348953	0.37471338	2.55731919	1.06300525	0.67524231

Average Left Edge Proximity (µm)

Results

Average Left Edge Proximity (um)								
	Bondpad 1	Bondpad 2	Bondpad 3	Bondpad 4	Bondpad 5	Bondpad 6	Bondpad 7	Bondpad 8
RU02	13.29513333	26.60013333	11.35513333	20.47913333	15.5374	27.73453333	11.32253333	21.0076
RU01	13.3506	27.90333333	12.31933333	20.20226667	15.58746667	28.84693333	12.48773333	21.26506667
Difference (um)	0.05546667	1.3032	0.9642	0.27686667	0.05006667	1.1124	1.1652	0.25746667
Difference (%)	0.41632682	4.78208114	8.14548445	1.36114621	0.3217149	3.93202957	9.78737463	1.21812361
Average Difference (um)		0.64810833						
Average Difference (%)		3.74553517						

Average correlation between two tools running the same wafer >96% for bond pad edge proximity

Probe Mark Area (μm^2)

Results

RU02 Probe Mark Area (um^2)								
	Bondpad 1	Bondpad 2	Bondpad 3	Bondpad 4	Bondpad 5	Bondpad 6	Bondpad 7	Bondpad 8
RUN1	624.334	549.827	761.266	593.009	593.853	419.268	540.659	612.253
RUN2	619.683	563.481	770.345	592.071	586.232	432.269	542.969	614.776
RUN3	633.228	556.225	771.315	595.558	587.184	419.585	543.3	613.378
RUN4	619.688	554.09	764.587	574.003	587.521	432.199	540.916	615.94
RUN5	624.886	559.253	771.617	577.259	589.976	440.383	532.597	600.129
RUN6	624.275	554	777.249	604.39	596.444	431.602	546.331	613.67
RUN7	616.548	556.642	771.242	574.823	587.13	435.571	546.116	613.52
RUN8	620.236	562.685	775.533	574.931	582.266	443.387	565.788	620.846
RUN9	623.815	549.105	764.176	574.337	577.414	431.491	570.929	598.453
RUN10	624.598	559.93	765.979	590.943	588.238	434.742	535.8	615.203
RUN11	631.273	556.61	751.443	573.167	577.393	428.345	538.673	615.472
RUN12	635.468	551.847	763.603	603.67	589.306	435.34	539.754	619.648
RUN13	624.128	551.717	760.786	594.818	585.267	435.767	578.913	613.15
RUN14	628.177	558.035	764.454	578.136	577.267	427.936	541.776	617.366
RUN15	629.524	552.68	751.833	596.494	579.48	436.344	571.925	603.26
AVG	625.324067	555.7418	765.6952	586.507267	585.664733	432.281933	549.0964	612.470933
3 Sigma	16.026499	13.1884662	22.6473525	34.6399265	17.692174	19.8005456	44.567703	19.9153913

RU01 Probe Mark Area (um^2)								
	Bondpad1	Bondpad2	Bondpad3	Bondpad4	Bondpad5	Bondpad6	Bondpad7	Bondpad8
RUN1	629.524	552.68	751.833	596.494	579.48	436.344	571.925	603.26
RUN2	569.278	523.341	679.321	545.005	566.909	427.286	468.557	567.541
RUN3	571.834	541.016	680.811	535.44	567.791	421.87	471.357	573.426
RUN4	566.192	539.966	681.761	543.223	567.676	418.919	469.595	569.808
RUN5	567.547	523.968	683.46	546.568	567.798	426.119	493.918	570.705
RUN6	567.18	545.422	681.578	552.204	568.684	422.867	471.912	570.585
RUN7	567.111	525.034	690.971	545.39	569.415	420.042	495.38	569.397
RUN8	570.215	537.141	676.591	544.413	562.692	415.516	501.253	572.965
RUN9	570.827	527.469	679.49	547.939	569.58	421.94	475.803	568.984
RUN10	567.041	525.227	681.715	542.374	565.909	420.942	496.551	572.837
RUN11	566.517	527.302	692.886	547.161	569.619	417.627	477.221	567.84
RUN12	569.092	541.501	694.976	544.651	570.804	426.442	497.324	574.086
RUN13	570.979	543.313	678.817	544.716	568.01	420.707	474.977	568.959
RUN14	564.756	541.954	692.753	543.928	570.727	421.999	481.008	572.356
RUN15	568.793	532.354	682.697	535.611	568.722	422.018	477.221	574.99
AVG	572.459067	535.1792	688.644	547.674467	568.921067	422.7092	488.2668	573.1826
3 Sigma	47.7412187	28.0203584	55.2865068	42.4525607	10.6489376	14.8037293	77.4032315	25.9074784

Average Probe Mark Area (µm²)

Results

Average Probe Mark Area (um^2)								
	Bondpad 1	Bondpad 2	Bondpad 3	Bondpad 4	Bondpad 5	Bondpad 6	Bondpad 7	Bondpad 8
RU02	625.3240667	555.7418	765.6952	586.5072667	585.6647333	432.2819333	549.0964	612.4709333
RU01	572.4590667	535.1792	688.644	547.6744667	568.9210667	422.7092	488.2668	573.1826
Difference (um^2)	52.865	20.5626	77.0512	38.8328	16.7436667	9.57273333	60.8296	39.2883333
Difference (%)	8.82714049	3.76976885	10.5960425	6.84772094	2.90037634	2.23925909	11.7277343	6.62728735
Average Difference (um^2)		39.4682417						
Average Difference (%)		6.69191624						

Average correlation between two tools running the same wafer >93% for probe mark area

Summary

- Automotive industry requires a metrology approach to inspection
- Tools have to be designed ground up for tool matching
- Must implement *Standard Wafer* and the concept of *Golden Tool* in manufacturing
- Implement manufacturing methodologies – stringent key component quality along with tool certification procedures
- Using a single recipe, defects with >90% correlation between tools is achievable
- When correlation between two tools is proven, correlation of data over time (tool health monitoring) is a matter of trend analysis

Acknowledgements

- Chris Meier
  - Rudolph Tool Correlation Guru
- Woo Young Han
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THANK YOU

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