Methods Of Defect Inspection and Detection For Copper CMP

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Outline

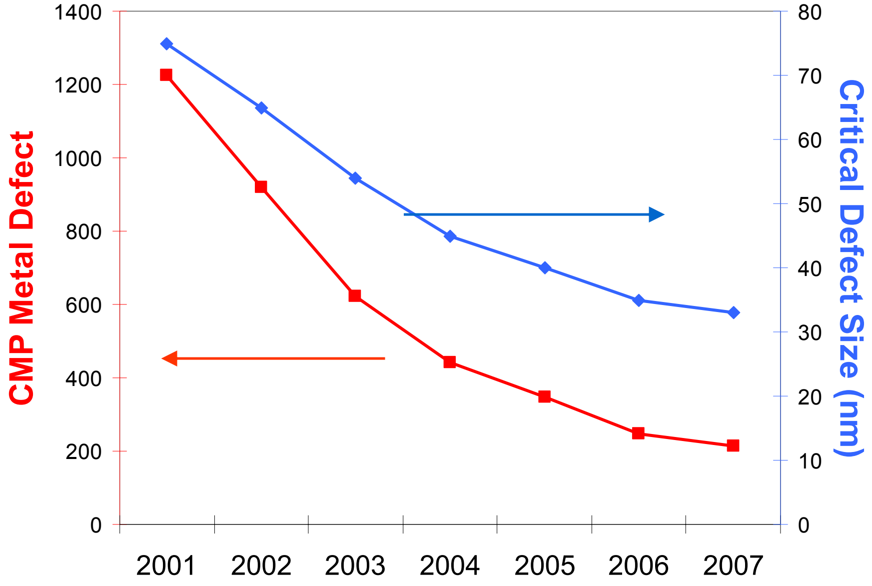
- **Project goal**
  - Defect reduction, a collaborative effort by consumables and equipment companies
- **Motivation**
  - Industry trend for reduced defects as technology nodes shrink
- **Application of defect inspection**
  - Copper slurry
  - Barrier slurry
- **Summary**

Project Goal

Equipment and Consumables companies will jointly develop methodology for reducing CMP induced defectivity.

Why is (defect) methodology development important?

- As feature size is reduced, what is considered a tolerable defect becomes intolerable.
- Generally speaking, intolerable defects are greater than half the feature size. For a 0.13 µm line that would be any defect greater than .065 µm (160 nm) in size.



Source: ITRS Roadmap

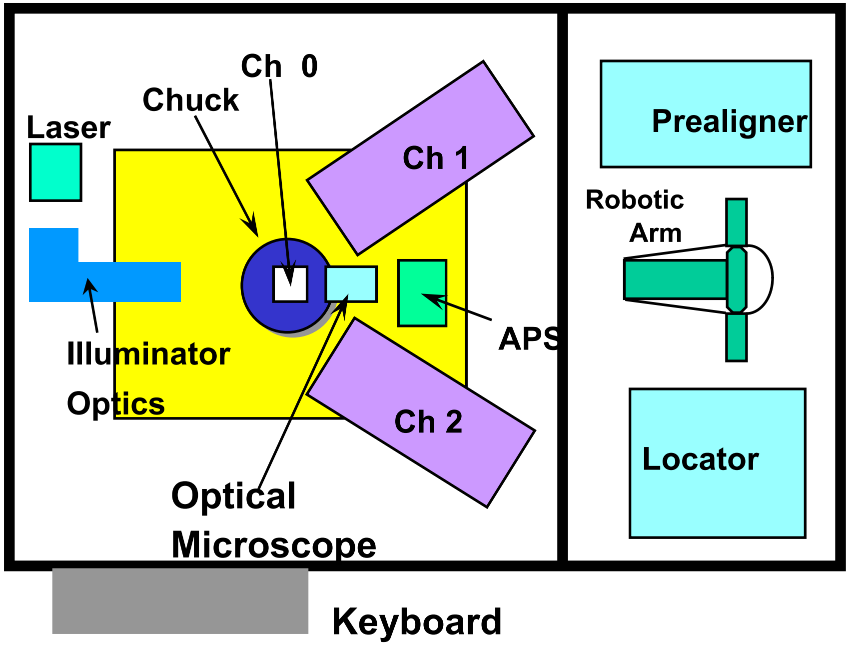
- We understand that detection tools have to constantly improve to keep up with industry demands, but if there is not an understanding of how to properly utilize the tool, the data collected is misleading or incorrect.

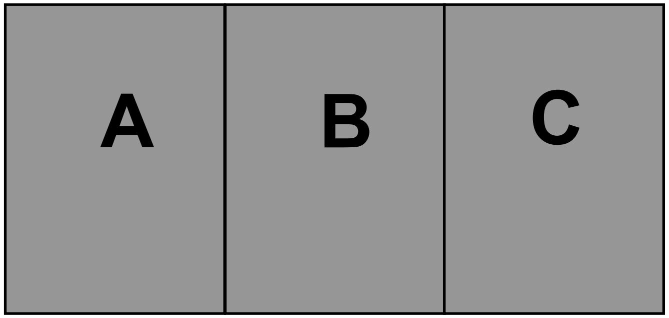
Understanding how to detect, classify, and eliminate defects is extremely important to CMC and KLA-Tencor.

Terms Defined

- **AIT** (Advanced Inspection Tool) - Darkfield (laser based) pattern wafer inspection tool. Detects the light a defect scatters when illuminated with a laser.
- **ADC** (Automatic Defect Classification) - A software / hardware system that uses a set of user defined images to automatically classify defects.
- **RTC** (Real Time Classification) - A rough classification of defects that occurs during the AIT inspection scan, real time.
- **Defect Class** (Manual Class) - A name and number assigned to a type of defect (Example: Skipping/Repeating scratch is a Class 27 defect)
- **Defect Bin** (ADC Bin or Fine Bin, RTC Bin or Rough Bin) - A group of defect classes used by the classifier (Example: Bin 25 consists of Class25 (stitching scratch), Class 26 (razor scratch), and Class 27 (skipping/repeating scratch)

AIT II Operation





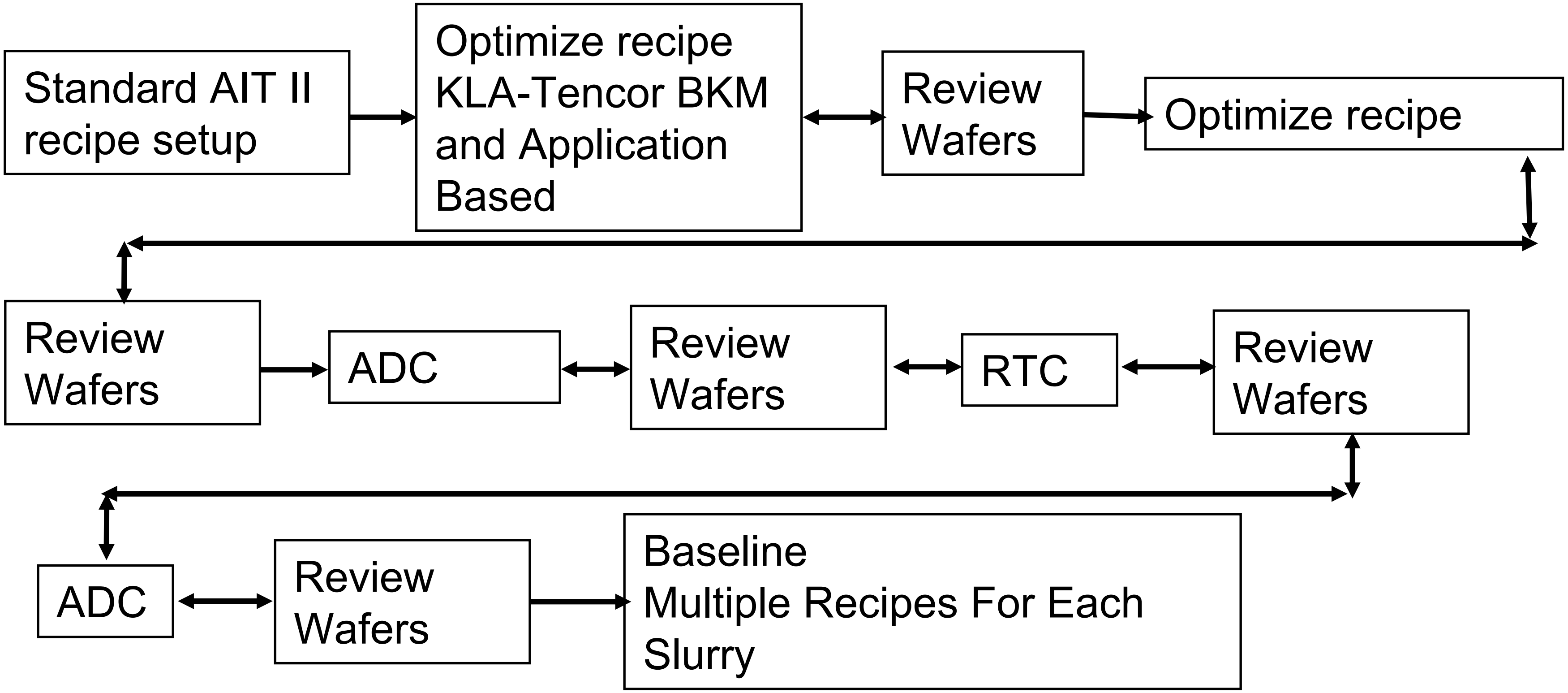
A is compared to **B**
(**B** compared to **A** in parallel)
C is compared to **B**
(**B** is compared to **C** in parallel)

- Double Darkfield Inspection maximizes signal-to-noise ratio
- Defects detected in Ch.1 and Ch.2 are combined for total defects.

- Die-to-Die comparison done to determine if die contains defects
- Defect must be doubly detected to be considered real, singly on edge

Recipe Generation

The recipe generation step is a series of sub-steps (AIT/ADC/RTC):



Standard AIT II recipe setup

Optimize recipe KLA-Tencor BKM and Application Based

Review Wafers

Optimize recipe

Review Wafers

ADC

Review Wafers

RTC

Review Wafers

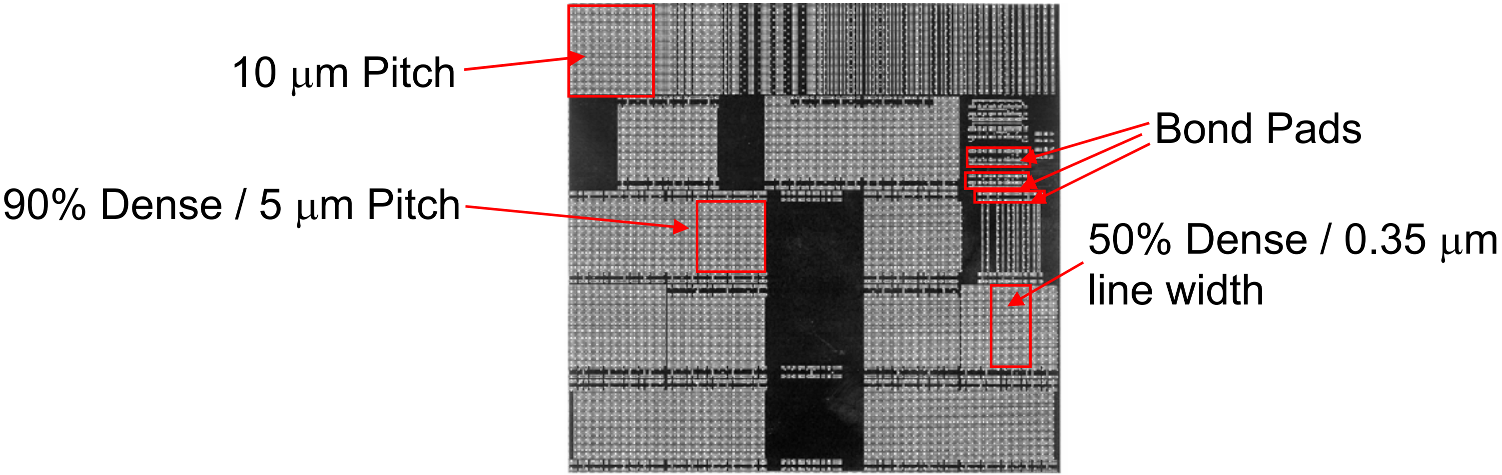
ADC

Review Wafers

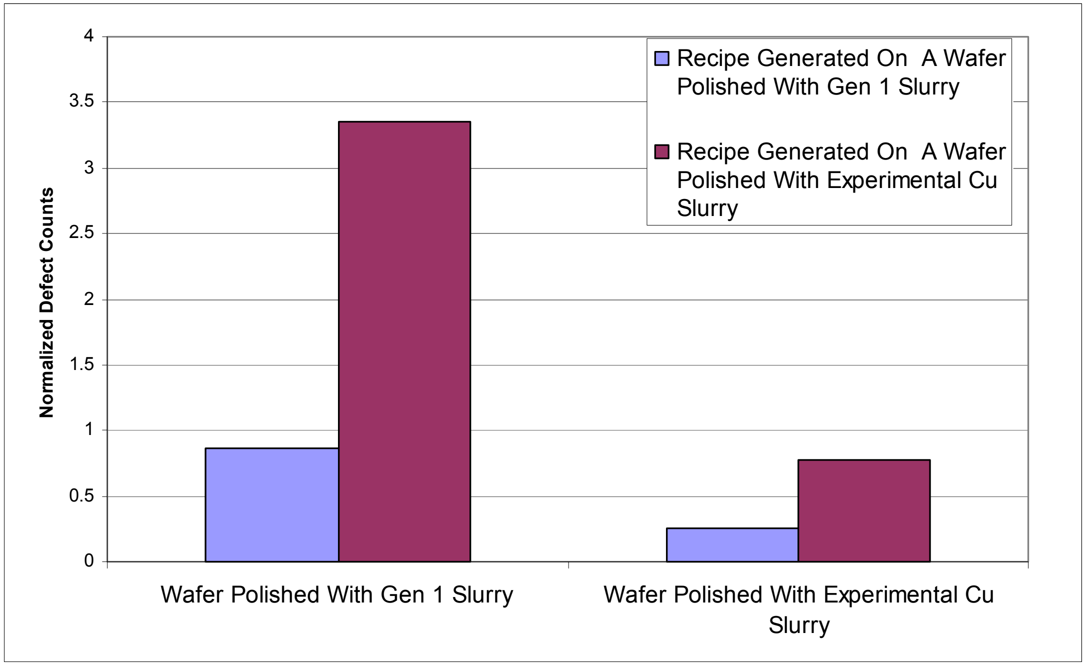
Baseline
Multiple Recipes For Each Slurry

- Optimization (Multiple recipes and ADC) + Baseline (Multiple recipes and ADC for each slurry) = ~400 reviews (250 defects per review) = 100,000 reviewed defects

- Criteria For New Recipes:
  - Defect total on control wafers should be reasonable and contain defects of interest. The defect type pareto should be comparable for both recipes. Increased defect detection in fine line arrays, still detecting in large features. Detect new defect types / smaller defects (Recipe optimized on a defect in 0.35 μm line array).
- Increase Sensitivity ⟶ Increase Defect Capture
- To Keep Total Count Reasonable ⟶ Decrease Inspection Area
- Decide to keep same number of die and reduce the number of sub-die regions



Each Slurry Type Has Its Own Recipe - Until recipe was setup on a wafer polished in current generation slurry and then used on a wafer polished in an experimental slurry, not obvious that each slurry needs it's own recipe to truly improve that slurry from the previous generation.



General recipe can be used to screen slurry
If true reduction needed, then specific recipe needed for that slurry type

ADC Overview

- AIT detects defects, then ADC classifies defects
- ADC classifies defects based on a set of user defined images
- ADC “sees” defects by doing a die-to-die comparison, AIT can detect defects much smaller than ADC can “see” (Redetection Error)
- The “goodness” of the ADC will depend on the defect types, number of bins, and the types of examples chosen

Accuracy and Purity

	1 Man	5 Man	12 Man	13 Man	21 Man	25 Man	Purity
1 ADC	244	0	84	124	69	12	0.46
5 ADC	9	0	8	21	2	2	0
12 ADC	7	0	104	155	29	40	0.46
13 ADC	12	0	10	60	34	75	0.31
21 ADC	60	0	84	25	570	360	0.52
25 ADC	30	1	5	139	172	768	0.69
252 ADC	12	0	3	26	16	5	
254 ADC	0	0	0	4	2	0	
255 ADC	0	0	2	0	0	0	
Accuracy	0.65	0	0.35	0.11	0.64	0.61	

*

Overall Accuracy: 0.521

Overall Purity: 0.538

Confusion

Bin1: Type14 (Overpolish Barrier / Cu underpolish)

Bin5: Type14 (Overpolish Barrier / Cu underpolish)

Bin12: Type14 (Overpolish Barrier / Cu underpolish)

Bin13: Type27 (Skipping/Repeating Scratch)

Bin21: Type27 (Skipping/Repeating Scratch)

Bin25: Type17, Type28, and Type31 (General Corrosion, Short Scratch, and Multiple Spots)

Bin252: Type14 (Overpolish Barrier / Cu underpolish)

- Accuracy is a measure of the ADC "capture rate" of a certain defect type

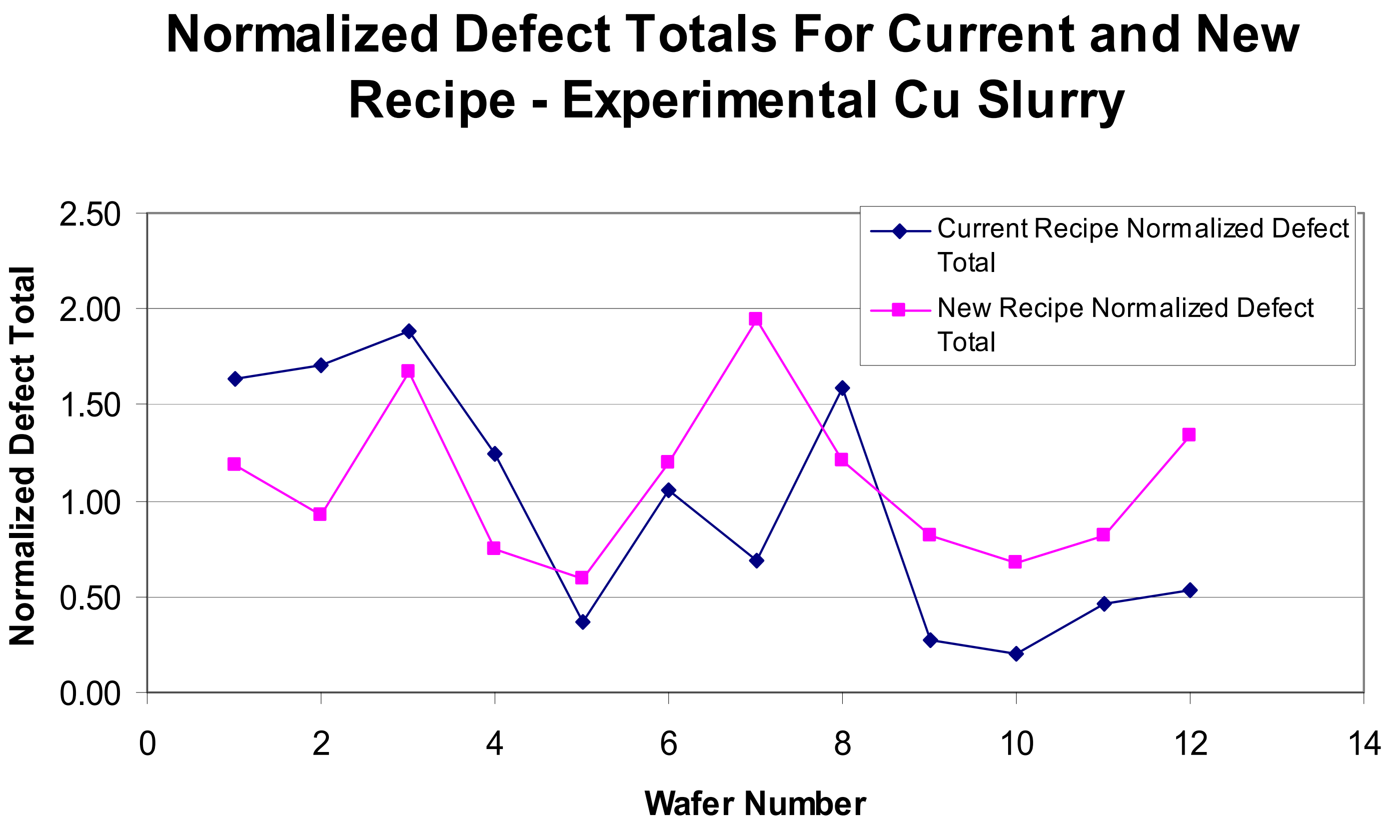
- Purity is a measure of the ADC "reliability" of certain defect type

$$\text{Accuracy} = \frac{\text{Number of Correctly Classified Defects}}{\text{Number of Manually Classified Defects}}$$

**Source: KLA-Tencor IMPACT ADC Best Practices Document*

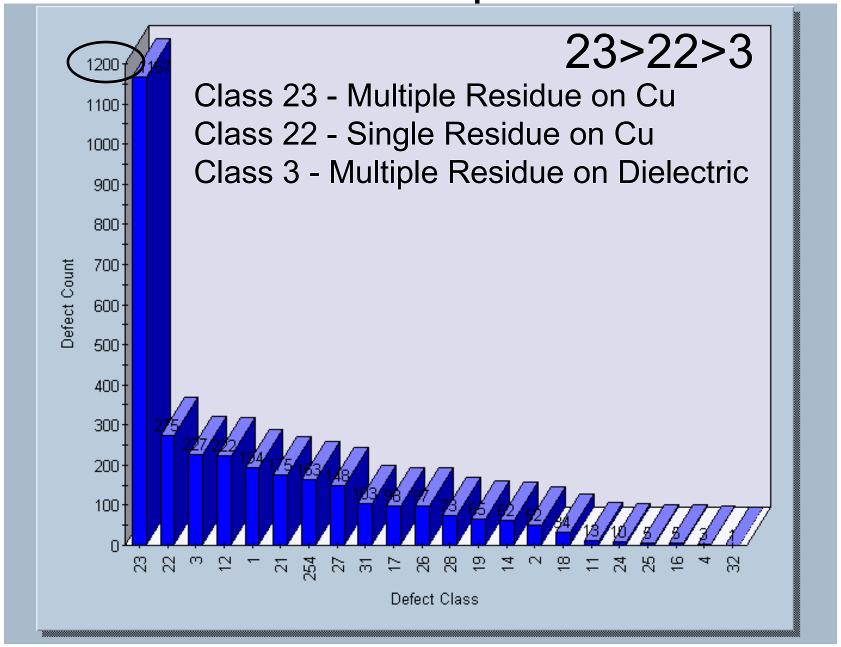
$$\text{Purity} = \frac{\text{Number of Correctly Classified Defects}}{\text{Number of ADC Classified Defects}}$$

Experimental Cu Slurry Recipe Comparison Total Defects

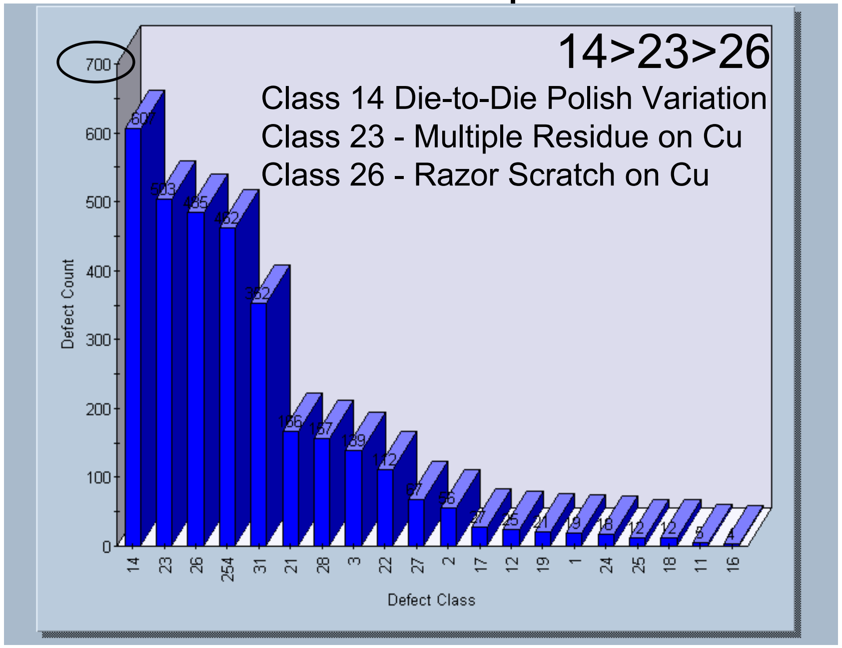


Experimental Cu Slurry Recipe Comparison Defect Distribution

Manual Review Distribution For Experimental Cu Slurry Current Recipe

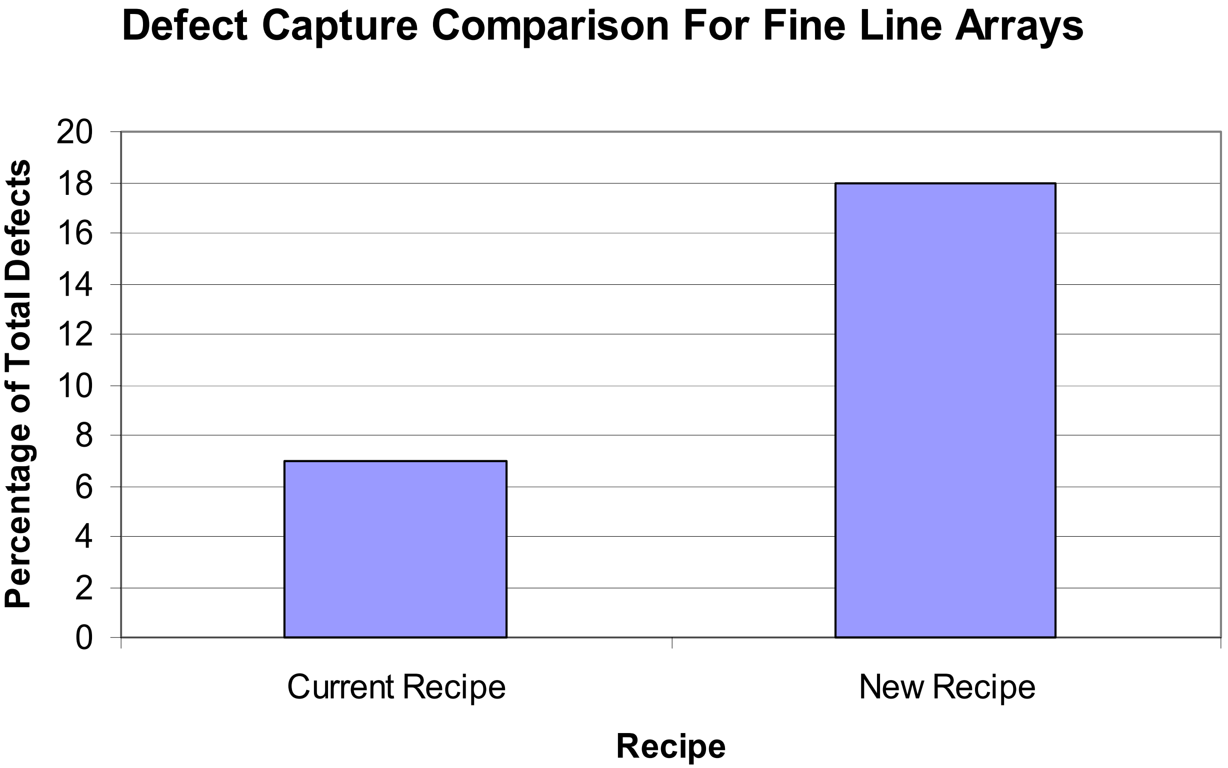


Manual Review Distribution For Experimental Cu Slurry New Recipe



- **~ 3250 defects manually reviewed for each recipe (recipe set for very high sensitivity)**
- **Increased sensitivity and increased number of defects in 0.35 μm array can account for changes in distribution - increase in Class 14 (die-to-die polish variation).**
- **"Class 254" defects are bond pad roughness.**
- **Major defect type not scratching, much improved over Gen 1 copper slurries.**

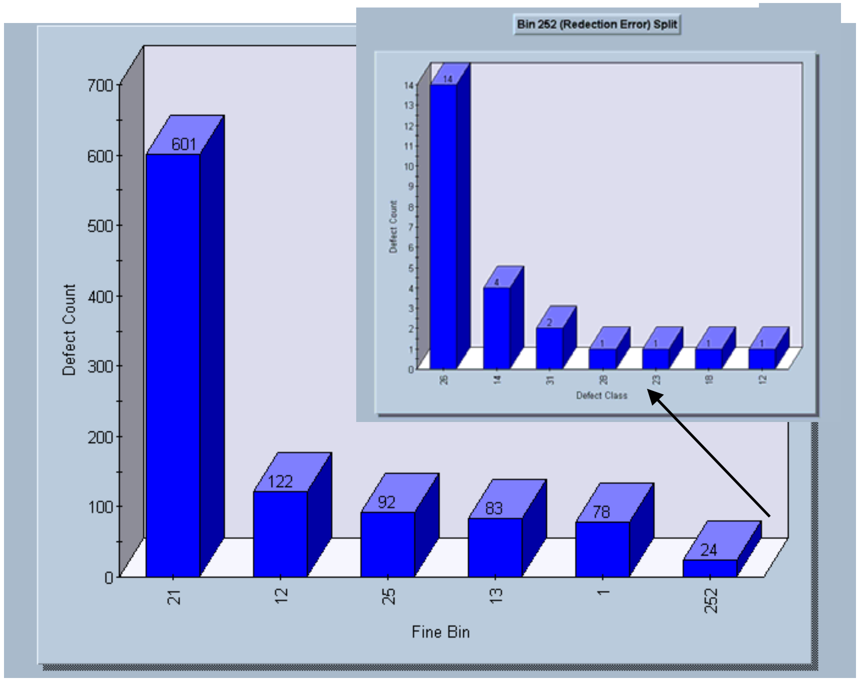
Experimental Cu Slurry Recipe Comparison Defect Distribution



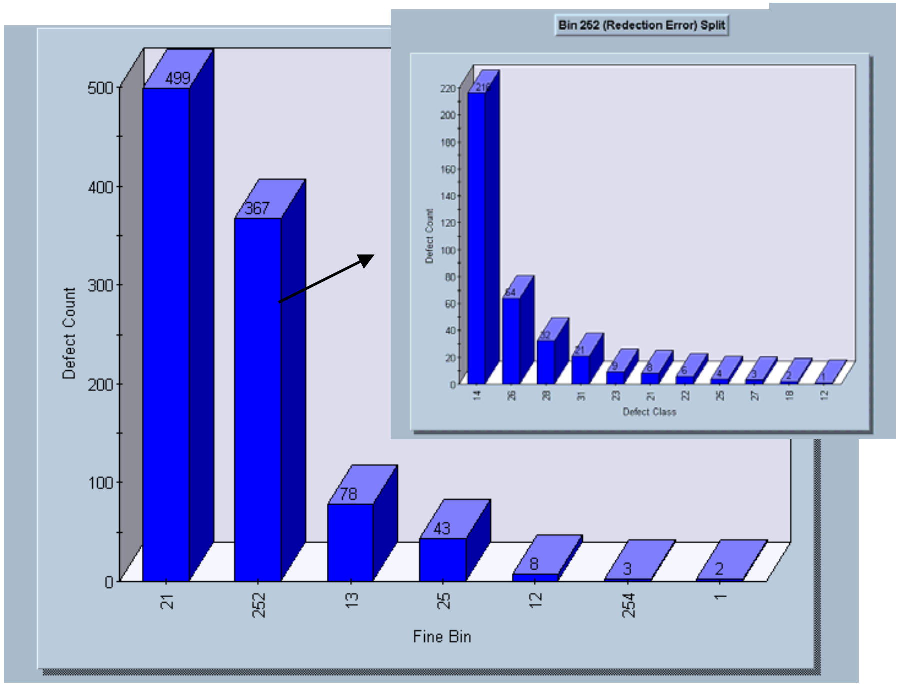
New recipe captures more defects in 0.35 μm array.
Less inspected area in new recipe, but fine line array makes up a larger fraction of the total area.

Experimental Cu Slurry Recipe Comparison ADC Comparison

ADC Distribution For Experimental Cu Slurry Current Recipe and Classifier

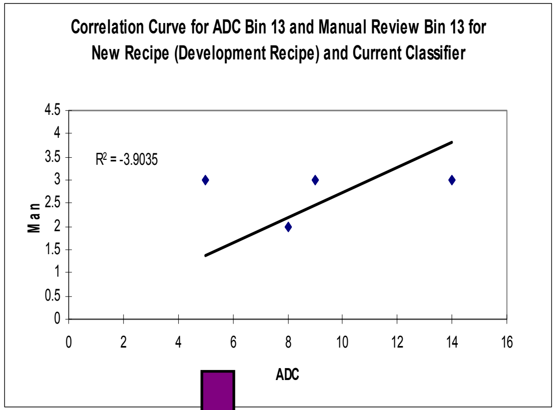


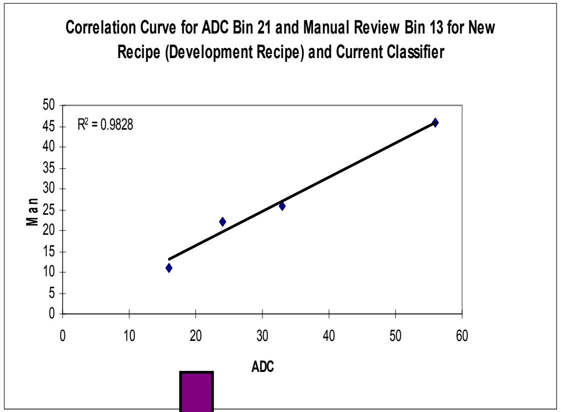
ADC Distribution For Experimental Cu Slurry New Recipe and Classifier

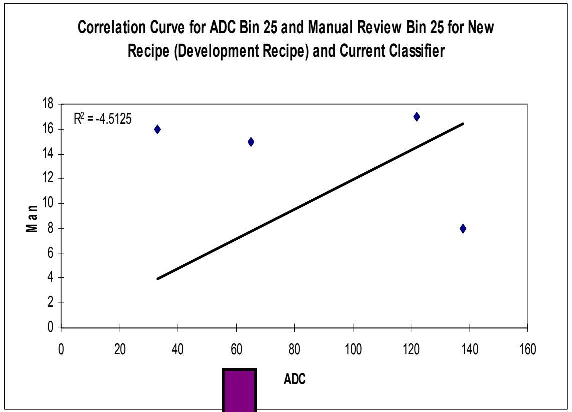


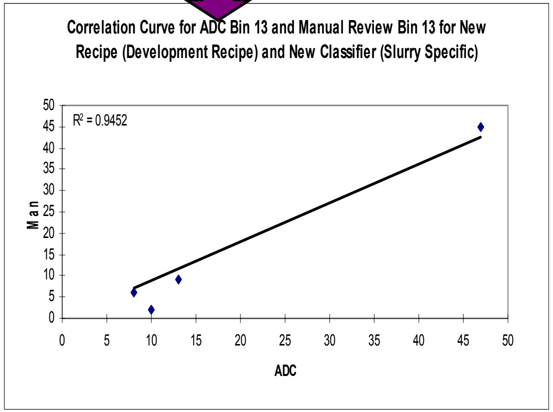
- Within Bin 252 the class shifts from 26 (razor) to 14 (die-to-die polish variation)
- Bin 252 is a standard ADC Bin (Redetection Error).

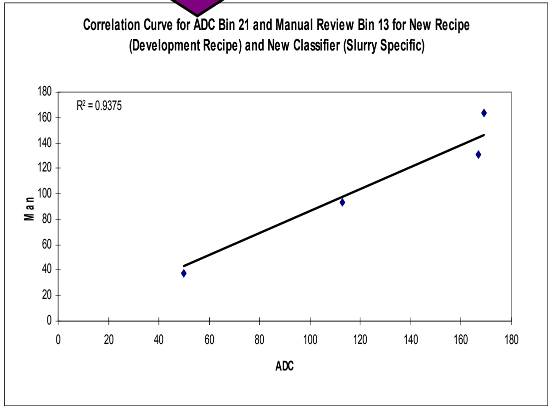
Experimental Cu Slurry Recipe Comparison ADC Comparison

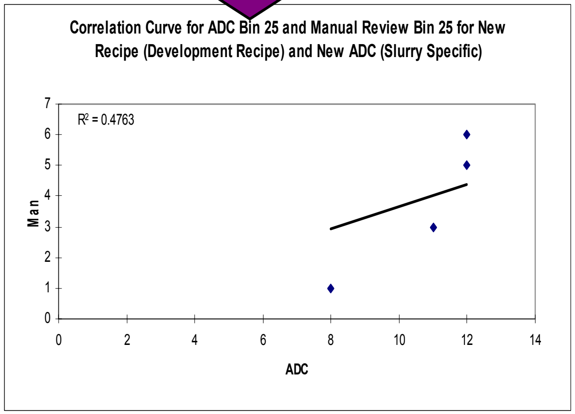

Correlation Curve for ADC Bin 13 and Manual Review Bin 13 for New Recipe (Development Recipe) and Current Classifier


Correlation Curve for ADC Bin 21 and Manual Review Bin 13 for New Recipe (Development Recipe) and Current Classifier


Correlation Curve for ADC Bin 25 and Manual Review Bin 25 for New Recipe (Development Recipe) and Current Classifier


Correlation Curve for ADC Bin 13 and Manual Review Bin 13 for New Recipe (Development Recipe) and New Classifier (Slurry Specific)

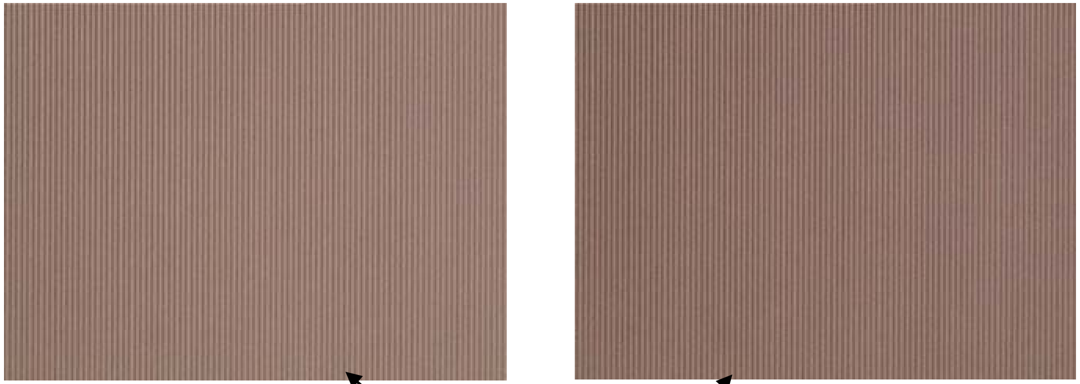

Correlation Curve for ADC Bin 21 and Manual Review Bin 13 for New Recipe (Development Recipe) and New Classifier (Slurry Specific)


Correlation Curve for ADC Bin 25 and Manual Review Bin 25 for New Recipe (Development Recipe) and New ADC (Slurry Specific)

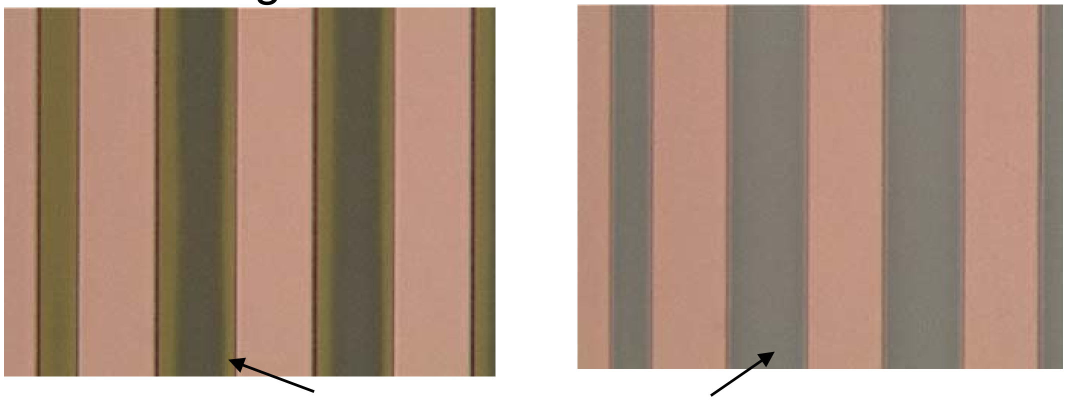
- Improvement in bins that contain corrosion, some improvement in scratch.
- Currently working to further improve scratch bin, not the predominant defect type

Experimental Cu Slurry Defect Type Examples

Defect Class 14 (Die-To-Die Polish Variation)



Note slight variation in color from die-to-die

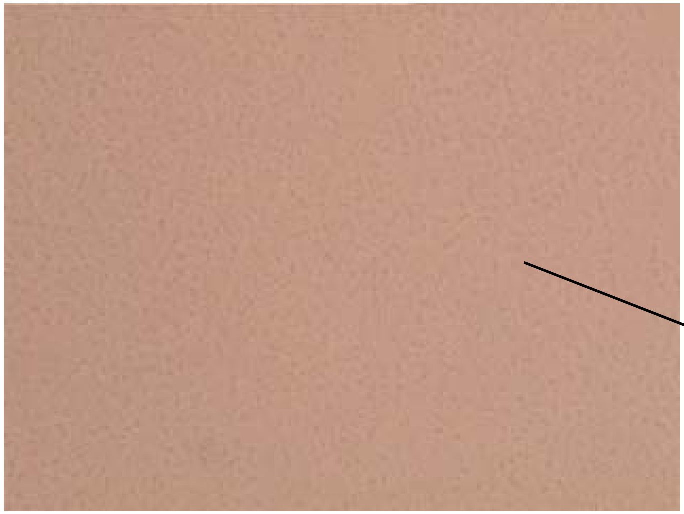


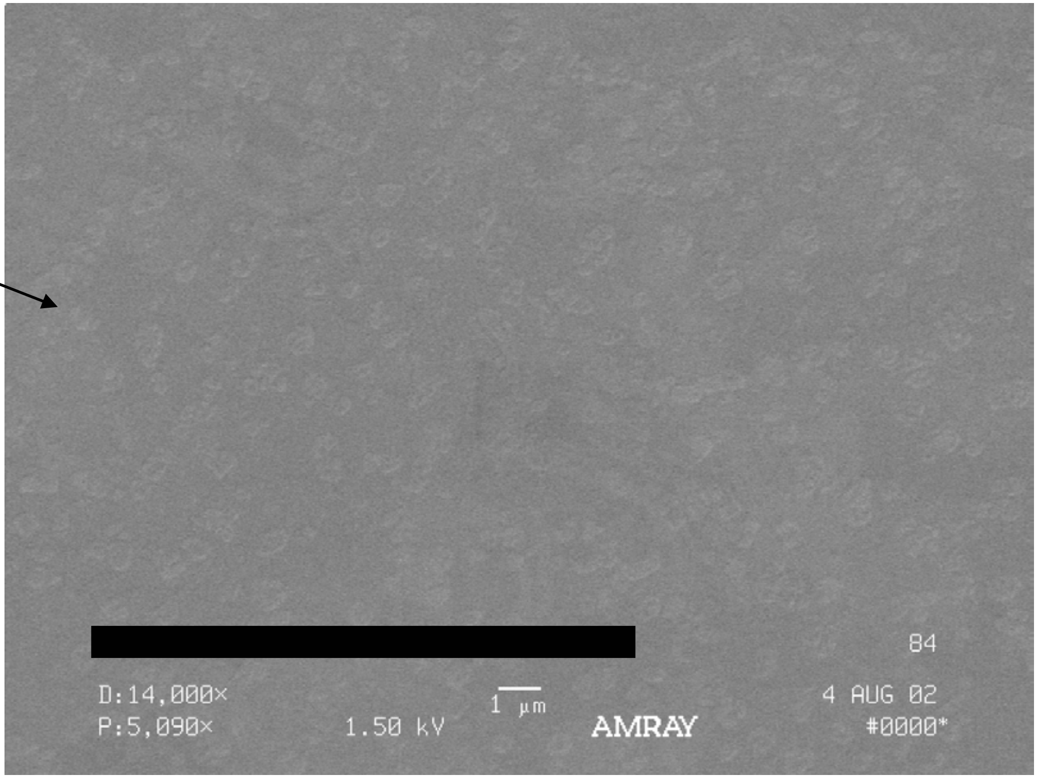
Note over-polish variation from die-to-die

Experimental Cu Slurry Defect Type Examples

Defect “Class 254” (Roughness)

Now referred to as Class 31 (Multiple Spots on Cu)





Roughness (3-11 A)
remove by Barrier CMP

Experimental Cu Slurry Target Defect Type

Defect Type	Number	Impact
"Class 254" Roughness	High	Low
Class 14 Die-to-Die Polish Variation	High	Low
Class 23 Multiple Residue	High	Low
Class 26 Razor Scratch	High	Low
Class 31 Multiple Spots	Med to High	Low
Class 21 Dark / Hard Spot	Med	Low
Class 22 Residue	Med	Low
Class 28 Short Scratch	Med	Low
Class 27 Skip/Repeat Scratch	Low	High
Class 17 Corrosion	Low	Low?

- Defect map overlay work has revealed that most defects rated as low impact because Barrier polish will remove them.

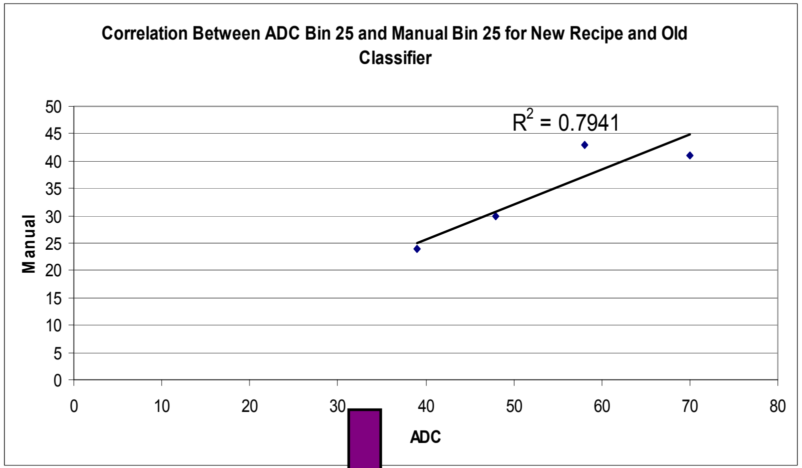
- Class 27 low number, but high impact.

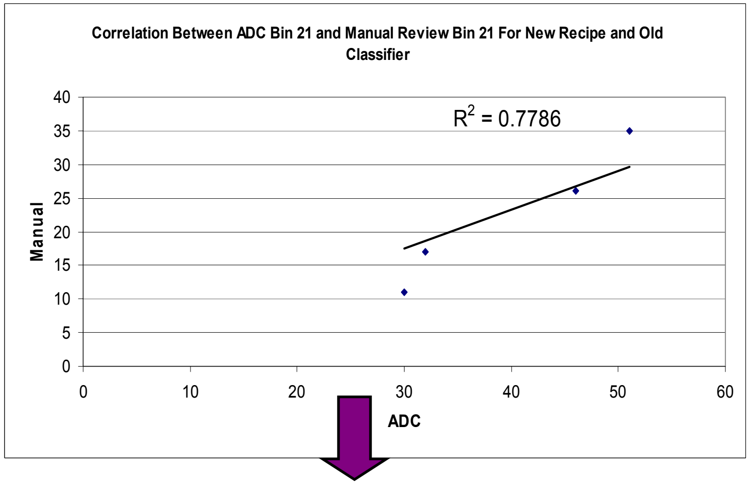
- Class 27 (Skipping/Repeating Scratch on Cu) is the target defect type.

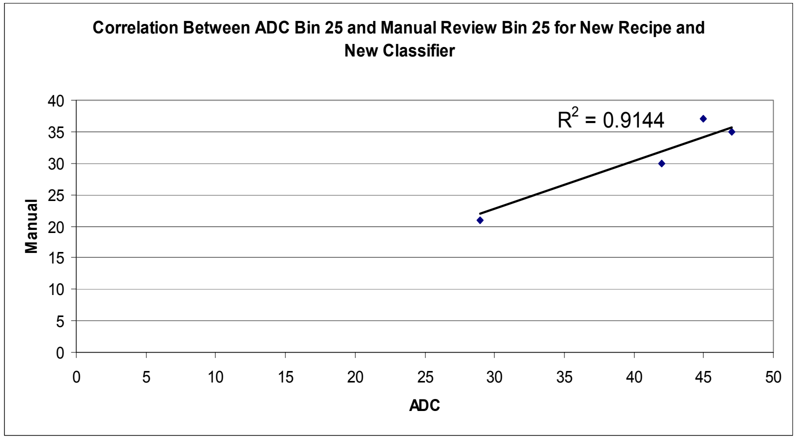
- Feature size where defects occur needs to be taken into account.

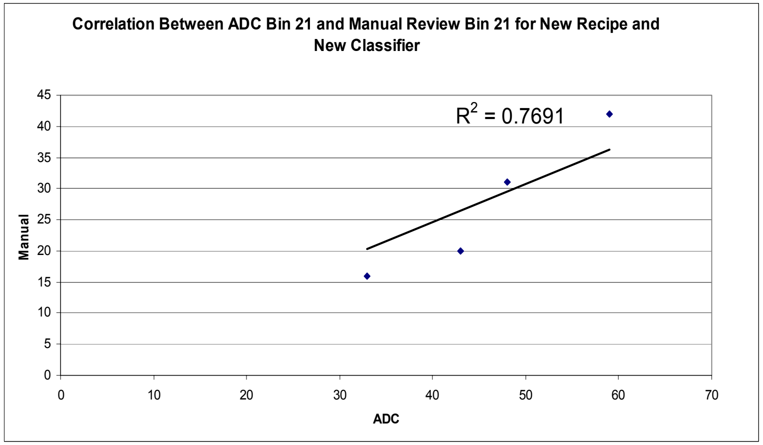
- Experimental Cu slurry has **~8x less skip/repeat scratch defects and ~2.5x less total scratches than Gen 1 slurry.**

Experimental Barrier Slurry ADC Comparison New Recipe


Correlation Between ADC Bin 25 and Manual Bin 25 for New Recipe and Old Classifier


Correlation Between ADC Bin 21 and Manual Review Bin 21 For New Recipe and Old Classifier


Correlation Between ADC Bin 25 and Manual Review Bin 25 for New Recipe and New Classifier


Correlation Between ADC Bin 21 and Manual Review Bin 21 for New Recipe and New Classifier

Experimental Barrier Slurry Target Defect Type

Defect Type	Number	Impact
Class 26 Razor Scratch	High	High/Med?
Class 28 Short Scratch	Medium	Med?
Class 21 Dark / Hard Spot	Medium	Med?
Class 31 Multiple Spots	Medium	Med?
Class 27 Skip/Repeat Scratch	Medium	High
Class 25 Stitching Scratch	Medium	Med?
Class 22 Residue	Low	Med?
Class 14 Die-to-Die Polish Variation	Low	Low/Med ?
Class 12 Fall-on	Low	High
Class 17 Corrosion	Low	High

- Many defects are classified as high impact after Barrier polish, because this is what the customer sees.

- Overlay of Cu and Barrier polish needs to be done to identify which defects occur at which step, and to identify which defects Barrier polish removes.

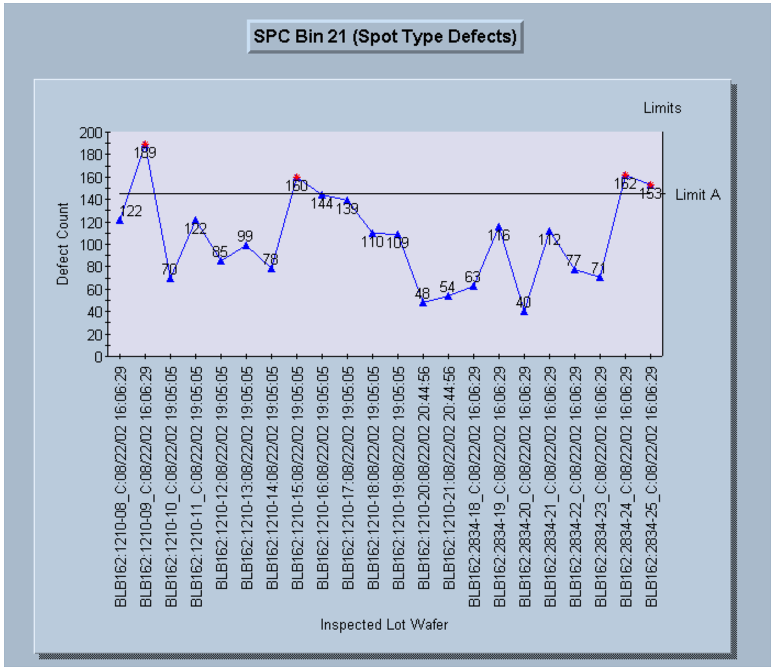
- Barrier polishing erases Razor and Stitching scratches, and sometimes leaves remains of Skipping/Repeating behind from Cu polish as Multiple Spots.

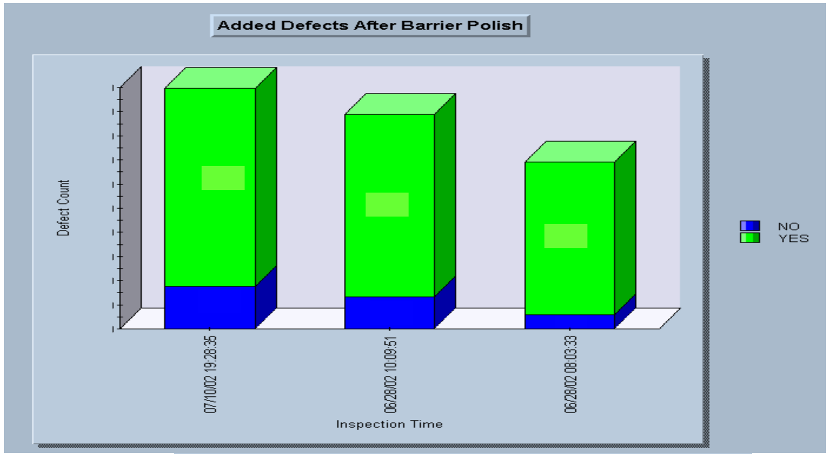
- Target defects should be Class 26 (Razor Scratch on Cu) and Class 27 (Skipping/Repeating Scratch on Cu).

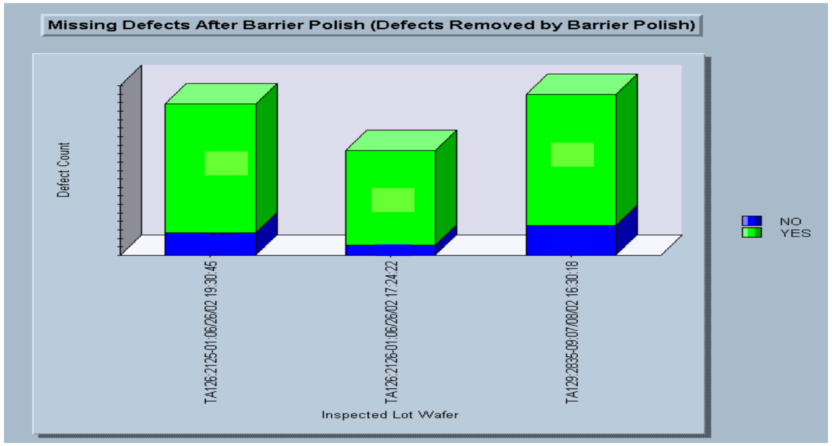
- Development work in the last 12 months has shown a a **>50% reduction** in razor scratch defects.

Performance Monitoring

- After baseline is complete, Klarity Defect will be used to monitor experiment results.
- Klarity Defect also used to differentiate between defects generated after Cu polish and after Barrier polish.







Summary

- Consumable suppliers and metrology equipment suppliers are jointly developing a CMP defect reduction methodology by joining skills of slurry optimization and inspection method optimization.
- To truly optimize a slurry, a unique inspection recipe is required. Recipes (classifiers) have to be modified as slurry improves. SEM inspection essential to keep accuracy high.
- Total number of defects important, knowing the distribution of the defect types even more important.
- Many experimental Cu slurry defect types removed by barrier slurry polish and the major defect type is not scratching, a large improvement over first generation slurries.

Acknowledgements

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