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 Class 25 (stitching scratch), Class 26 (razor scratch), and Class 27 (skipping/repeating scratch)
AIT II Operation

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

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

- 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
- 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 \(\mu\)m line array).

• Increase Sensitivity \(\rightarrow\) Increase Defect Capture
• To Keep Total Count Reasonable \(\rightarrow\) 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 its 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

<table>
<thead>
<tr>
<th></th>
<th>1 Man</th>
<th>5 Man</th>
<th>12 Man</th>
<th>13 Man</th>
<th>21 Man</th>
<th>25 Man</th>
<th>Purity</th>
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<td>570</td>
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<td>Accuracy</td>
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<td>0.35</td>
<td>0.11</td>
<td>0.64</td>
<td>0.61</td>
<td></td>
</tr>
</tbody>
</table>

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

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

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

*Source: KLA-Tencor IMPACT ADC Best Practices Document
Experimental Cu Slurry Recipe Comparison Total Defects

Normalized Defect Totals For Current and New Recipe - Experimental Cu Slurry

- Current Recipe Normalized Defect Total
- New Recipe Normalized Defect Total

 normalized defect total vs wafer number graph
Experimental Cu Slurry Recipe
Comparison Defect Distribution

- ~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

Defect Capture Comparison For Fine Line Arrays

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

- 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

- 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 Å) remove by Barrier CMP
### Experimental Cu Slurry Target Defect Type

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Number</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Class 254&quot; Roughness</td>
<td>High</td>
<td>Low</td>
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<tr>
<td>Class 14 Die-to-Die Polish Variation</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Class 23 Multiple Residue</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Class 26 Razor Scratch</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Class 31 Multiple Spots</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Class 21 Dark / Hard Spot</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Class 22 Residue</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Class 28 Short Scratch</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Class 27 Skip/Repeat Scratch</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Class 17 Corrosion</td>
<td>Low</td>
<td>Low?</td>
</tr>
</tbody>
</table>

- 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

\[ R^2 = 0.7941 \]

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

\[ R^2 = 0.7786 \]


\[ R^2 = 0.9144 \]

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

\[ R^2 = 0.7691 \]
Experimental Barrier Slurry

Target Defect Type

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Number</th>
<th>Impact</th>
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<tbody>
<tr>
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<tr>
<td>Razor Scratch</td>
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<td>Class 28</td>
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<tr>
<td>Short Scratch</td>
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<tr>
<td>Class 21</td>
<td>Medium</td>
<td>Med?</td>
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<tr>
<td>Dark / Hard Spot</td>
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<tr>
<td>Class 31</td>
<td>Medium</td>
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<tr>
<td>Multiple Spots</td>
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<tr>
<td>Class 27</td>
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<td>High</td>
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<tr>
<td>Skip/Repeat Scratch</td>
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<td>Stitching Scratch</td>
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<td>Residue</td>
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<td>Class 14</td>
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<td>Die-to-Die Polish Variation</td>
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<tr>
<td>Corrosion</td>
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</table>

- 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 >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.
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