Non-contact Sheet Resistance for Determining Polish Rates

KLA-Tencor
Walter Johnson, HaiJing Peng
Outline

• Abstract
• Technology
• Typical Performance
  • Repeatability
  • Effects of frequency change
• Use Case
  • ECP Copper monitors
  • Polish Rate on monitors
  • ECP Copper on pattern wafers
With the move to larger wafers, monitor wafers are getting more expensive. The introduction of non-contact Rs measurements to replace traditional contact Four-point Probe measurements saves money through measuring directly on pattern wafers. There are also advantages when determining, polishing rates with a non-contact method, in that 4PP generated particles or pits are avoided allowing the same wafer to be used for both particle inspection and thickness. Eliminating these particles or pits can also prevent their affect on subsequent polishing steps.
Non-contact Sheet Resistance (NCRs) capability for thick metal films

- Technology:
  - Conductive layer close to the coil modifies the coil impedance

- Benefits:
  - Better repeatability performance on thick-metal layers with low resistivity (Cu)
    - Unaffected by surface oxidation
    - Superior Repeatability: 0.3% NCRs vs. 4PP at 0.5%
  - Product wafer capability – Rs measurement on complete Copper process (Barrier/seed, pre/post Cu CMP)
    - No mechanical damage to the film or underlying structures
    - ‘Real’ Rs for process monitoring of thick-metal layers
    - Reduces monitor wafer usage, low COO
Correlation between 4PP and NCRs

**Map comparison: 4PP and NC**
- 8" wafer, 625 site, 4mm edge exclusion

- Slight difference in average value due to spot size difference
  - 4PP spot size ~ 4mm
  - NC probe spot size ~ 2mm

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**4PP & NC correlation**

- y = 0.9954x
- $R^2 = 1$

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**4PP & NC correlation**

- y = 0.9986x
- $R^2 = 0.9999$

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**Result Spec.**

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Result</th>
<th>Spec.</th>
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</thead>
<tbody>
<tr>
<td>R = 0.9999</td>
<td>R &gt; 0.99</td>
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</tbody>
</table>

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**4PP Rs (Ohm/sq)**

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**NC Rs (Ohm/sq)**

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**4PP Rs (Ohm/sq)**
Long Term NCRs Repeatability

10 Day Repeatability
KT spec = 5 day < 0.5%, Beta agreement 10 day < 0.5%

<table>
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<tr>
<th>Repeat</th>
<th>12.7 K Cu</th>
<th>12K Cu</th>
<th>11.5K Cu</th>
<th>9K Cu</th>
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<tbody>
<tr>
<td>AM 9/2</td>
<td>0.23%</td>
<td>0.19%</td>
<td>0.18%</td>
<td>0.15%</td>
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<td>PM 9/3</td>
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<td>AM 9/12</td>
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</table>
10MHz Long Term Repeatability (2)

- Total 11 wafers (200mm), Rs: 0.003~6Ω/□, different film thickness/material
- Test conditions: 49 sites/test, 5 tests/day, 6 days
- $1\sigma$ is calculated based on Rs of each individual site

### Long term repeatability

**1$\sigma$ of individual site**

![Graph showing long term repeatability](image)

- Thickness
- Material
- Rs (Ω/□)

**Spec.**

- Specified value for long term repeatability.
2MHz Dynamic Repeatability
Reduced $1\sigma$ at extremely low Rs

- Total 4 wafers (200mm), Rs: $0.003\sim0.02\Omega/□$, different film thickness/ material
- Test conditions: 49 sites/test, 18 repeats, with load/unload
- $1\sigma$ is calculated based on average Rs of each test
Measurement Range

- NCRs is complementary to 4PP measurement, towards extremely low sheet resistance

### Material | ρ Ratio
--- | ---
Cu | 1.00
Al | 1.64
Mo | 3.02
W | 3.22
Pt | 6.09
Ta | 7.60
Ti | 24.8
TiSi₂ | 9.30
TiN | 12.8
TaN | 130
Ag | 0.94
Ni | 4.20
Co | 3.85

$\rho_{Cu} = 1.7\mu\Omega\cdot cm$

Under development

Rs (Ohms/sq)
NCRs Edge Exclusion

Edge Exclusion (EE) Calculation:

$$EE = \frac{\text{Measured Gap} - \text{Physical Gap}}{2}$$

NC probe line scan with 0.2mm step

NC Probe used in EE test: SN37817, w/ shield
Cross Wafer Uniformity Pre & Post Polish

Pre and Post Polish Diameter Scans With RS300 4PP and RS300 NCRs

Good correlation between 4PP and NCRs from the same tool
Copper Removal on 10 Wafers (EC vs 4PP)

Sequential Diameter Scans Across 10 Wafers (plotted on one chart)

Tool Comparison of Pre-Post Polish Measurement

- Rs200 4PP
- Rs200 E.C.

Position across slots 1-12
Removal Rate Correlation

Removal is in total thickness With units in Angstroms (Å)

Perfect Cu removal rate correlation between 4PP and NCRs
18 Month Operation (without re-cal)
NCRs Throughput

Throughput Tests

<table>
<thead>
<tr>
<th>Sites</th>
<th>Spec</th>
<th>Measured</th>
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<td>5</td>
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<td>59</td>
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<tr>
<td>49</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>81</td>
<td>6</td>
<td>7</td>
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</table>
# Particle Tests

## Baseline

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<tr>
<th>Slot #</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>Original Defects</td>
<td>373</td>
<td>251</td>
<td>232</td>
<td>329</td>
<td>204</td>
<td>284</td>
<td>234</td>
<td>283</td>
<td>286</td>
<td>289</td>
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<tr>
<td>Defects Added</td>
<td>54</td>
<td>42</td>
<td>53</td>
<td>70</td>
<td>66</td>
<td>70</td>
<td>89</td>
<td>57</td>
<td>24</td>
<td>149</td>
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<tr>
<td>Tested Wafers</td>
<td>54</td>
<td>53</td>
<td>66</td>
<td>89</td>
<td>24</td>
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<tr>
<td>Control Wafers</td>
<td>42</td>
<td>70</td>
<td>70</td>
<td>57</td>
<td>449</td>
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</tbody>
</table>

Slot 10 (a control) was the top wafer and was removed from the calculations.

Average of -2 PWP indicate there is no particles added.
Pattern ECP Cu Demo Information

- Demo purpose:
  - Demonstrate the ability to measure sheet resistance of ECP pattern wafer with non-contact Eddy Current method on RS 300 platform, including:
    - EC Rs correlation with Cu thickness
    - Dynamic repeatability without pattern recognition to show positioning accuracy and impact to measurement result

- Wafers:
  - ECP pattern wafer with ~ 1 µm electroplated Cu
  - Diameter: 300 mm
  - Edge: ~2 mm edge clearance
Pattern Structure

- Step x: 18.36 mm
- Step y: 14.17 mm
- Upper Left Corner: (-6 mm, 0 mm)
Small-Area Map

- Map scan (2mm square) in a circular area of 80 mm diameter near the center
  - Periodical RS pattern aligned with dies and scribe line features
    - Step X: 18.36 mm
    - Step Y: 14.16 mm
Diameter Scan Across Whole Wafer

- 3 Line scans with step size 400 µm, 1 for x direction and 2 for y direction
  - X scan at Y = 0 (diameter scan across COW)
  - Y scan at X = 0 (diameter scan across COW)
  - Y scan at X = -6 mm (scribe line)

![Graph showing Rs (Ohm/sq) vs X or Y (mm)]
A typical copper resistivity of 1.85 $\mu$Ω-cm was used for this conversion. Lines scans at two X values are used for comparison.
Overall Map

- Dense map with 1209 sites (square array, up to $R = 145.5$ mm)
  - Some internal feature of the dies visible
  - Overall non-uniformity of $Rs$
Map at Scribe Line Crossing

- Rs mapped at 262 scribe line crossing sites up to \( R = 145.9 \) mm
  - No feature of die visible
  - Overall non-uniformity of Rs

\[
X(\text{mm}) = -6.0 + \text{column} \times 18.36 \\
Y(\text{mm}) = +0.0 + \text{row} \times 14.16
\]
Short Term Repeatability Map on Die Center

- Dynamic repeatability shows current system is well below the standard Rs system spec of 0.5%
  - 254 dies, 20 load/unload repeats
  - Average Rs and 1 sigma based on each die

Each point represents the mean of 20 repeats

Each line represents a row of dies

Each point represents 1σ of 20 repeats
<table>
<thead>
<tr>
<th>BENEFIT</th>
<th>NCRs</th>
<th>4PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved thick metal Rs measurement</td>
<td>No probing damage to films; inert to surface oxidation; better repeatability</td>
<td>Performance subject to native surface oxide and probe metal contamination</td>
</tr>
<tr>
<td>Blanket film on-product-wafer Rs measurement capability</td>
<td>Metal Rs capability on Cu ECP process. Measurement of barrier/seed/Cu films on product wafer</td>
<td>Probing damage to patterned structures underneath metal films</td>
</tr>
<tr>
<td>No metal cross contamination</td>
<td>Non-contact</td>
<td>Residue metal on probe causes cross contamination</td>
</tr>
<tr>
<td>Lower CoO</td>
<td>No consumables</td>
<td>Probes are a consumable item</td>
</tr>
<tr>
<td>Single platform advantage</td>
<td>Cover entire sheet resistivity application space; on-tool calibration for Eddy current; customers do not need to justify a stand-alone tool</td>
<td></td>
</tr>
</tbody>
</table>
Summary

- Non-contact Rs (NCRs) or thickness shown for thick metal films
- NCRs can eliminate issues resulting from 4PP marks on monitors which could effect polishing, particle tests or reclaim
- Huge cost savings
- Product or pattern wafers can be used instead of monitor wafers in many cases (using die intersection values)
- Potential valuable on-product information relating to over die or pattern values