Controlling Contact Resistance with Probe Tip Shape and Cleaning Recipe Optimization

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Outline

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● Materials and Methods
● Contact Resistance Characterization
  ➢ Contact Mechanisms
  ➢ Non-Destructive Cleaning
● Methodology Development
  ➢ Assessing Incremental CRES Improvement
● Application of Methodology to Test Die
  ➢ Cleaning Recipe Optimization
● Summary
Objectives / Approach

- Develop a systematic methodology to attain stable wafer level test of a 60-um pitch device
  - Initial characterization using blanket aluminum wafer to assess the probe card behavior
  - Compare flat tip probe CRES behavior with radius tip behavior using processed wafers with electrically shorted Test Die

- Quantify and address device specific contact resistance stability issues
  - Iterative experiments using FAB processed wafers with two different electrically shorted Test Die

- Optimize cleaning recipes to maintain low and stable contact resistance for fine pitch devices
  - Assess “non-destructive” alternatives to abrasive cleaning that are able to remove adherent pad material
Materials and Methods

● Probe Cards
  - Cantilevered probe cards built for testing 60-um pitch devices
    - Tungsten-Rhenium (WRe) Flat Tipped Probes
    - Tungsten-Rhenium (WRe) electrochemically polished (ECP) radius tip probes

● Test Wafers
  - “Reference” wafers – blanket aluminum with 8000Å metal thickness
  - Processed wafers – several different Test Die with electrically shorted bond pads

● “Non-destructive” Probe Tip Cleaning Materials
  - Probe Polish 201 (PP201)
  - Probe Polish 210 (PP210)
CASE 1:
CRES Characterization Using a Blanket Aluminum “Reference” Wafer
Focus of CASE 1

- Develop a test methodology to characterize the CRES behavior using a blanket aluminum wafer
  - Use “best practices” to evaluate CRES vs. Touchdown (TD) behavior
  - Characterize CRES stability of a cantilevered, 60-um pitch probe card design
  - Contrast tip shape effects – flat tip vs. radius tip

- Apply fundamental electrical contact theory to understand the CRES behavior
CRES Characterization on Aluminum Wafer

- Wafers were tested using a standard prober and testhead configuration
  - Images of the probe tips were collected at 50, 100, 500, and 1000 TD intervals
  - Aluminum “tails” were present on the probe tips and along the tip length at each interval
- Stable CRES was observed when probing across the blanket Al-wafer
  - Adherent materials did not affect the CRES stability of either probe tip shape
  - Multiple wafers were probed and all yielded similar CRES behavior
Application of Electrical Contact Theory

- First Order Approximation Model for Contact Resistance (R. Holm, 1967)

\[ C_{RES} = \frac{\rho_{probe} + \rho_{wafer}}{4} \sqrt{\frac{\pi H}{F}} + \frac{\sigma_{film} H}{F} + R_{trace} \]

- \( C_{RES} \) = contact resistance
- \( \rho_{probe} \) = bulk resistivity of tungsten-rhenium probe \( \approx 10E-8 \ \Omega m \)
- \( \rho_{wafer} \) = bulk resistivity of aluminum \( \approx 4E-8 \ \Omega m \)
- \( H \) = hardness of the softer material \( \approx 1.3E10 \ \text{g/m}^2 \)
- \( \sigma_{film} \) = film resistivity \( \approx 10E-12 \ \Omega m \)
- \( F \) = probe force at overtravel \( \approx 2.25 \text{ to } 3.25 \ \text{grams} \)
- \( R_{trace} \) = trace resistance contribution
The film resistance contribution of the blanket aluminum wafer was negligible for both the flat and ECP radius tipped probes.

- Lower curve was determined from Holm equation without the trace contribution.
- Upper curve included an approximate trace contribution, e.g. PCB, test cables, etc…
Summary of CASE 1

- The blanket aluminum wafers were useful for evaluating the CRES characteristics and performance of a new probe card design.

- Stable CRES, regardless of tip shape, was obtained during this Case Study; however, differences are expected when probing Test Die.

- The oxide layer contribution was negligible and CRES behavior could be described by the Holm Model for Contact Resistance.
CASE 2:  
CRES Characterization using 
Test Die with Electrically Shorted Pads
Focus of CASE 2

- Characterize the effects of probe tip shape on the CRES behavior of Test Die A
  - Flat Tip probe CRES vs. Touchdowns
  - Radius Tip probes CRES vs. Touchdowns

- Develop a basic approach to identify incremental improvements in CRES stability
  - Dramatic changes in CRES behavior are relatively “easy” to identify
  - Incremental improvement or degradation in overall CRES behavior can be difficult to objectively quantify
Stable CRES on the Test Die wafer was not observed
- 535 Test Die were probed on each wafer with no cleaning performed
- Images were collected at 50, 100, 500, and 1000 (after two wafers) TD intervals
- Adherent material was observed on the contact region of the flat tip probes

The ECP radius probes demonstrated “better” CRES behavior than flat tipped
- ~12.7-um radiused tip shape was obtained using electrochemical polishing methods.
Tip Shape Effects – Flat Tips

- Region of adherent material increases in size with repeated touchdowns
- Adherent material region and electrical contact region will eventually overlap
- For a blanket aluminum, the CRES was not significantly affected by the overlap of the contact regions.

Adapted from Maekawa, et al., 2000
Tip Shape Effects – Radius Tips

- Aluminum adheres to the rear of the probe
- Aluminum adhesion was observed on the “lagging” edge of the probes.
- Adherent material and electrical contact regions are separated.
- Stable CRES is expected for a tip radius in the range of $7 \text{-um} < R < 22\text{-um}$ (Maekawa, et al., 2000)

Adapted from Maekawa, et al., 2000
Quantifying Incremental CRES Improvement

- **CRES vs. Touchdown Charts** – the scatter plots demonstrate unstable CRES after multiple touchdowns
  - **Advantages** –
    - Demonstrate CRES stability during wafer test
    - Indicative of when cleaning is required to reduce CRES
  - **Disadvantages** –
    - Difficult to assess *incremental changes* in CRES behavior

- **Cumulative Percentage Charts** – the ogive shape reflects the overall “level” of instability during probe
  - The cumulative frequency distribution (or percentage) plots the number of observations falling in (or below) a specified limit, e.g. maximum CRES.
  - **Advantages** –
    - Provides an easy way to compare different large data sets
    - Incremental changes in CRES behavior can be identified
  - **Disadvantages** –
    - Do not include a time component
The extended ogive is indicative of unstable CRES during the testing.

- Aluminum wafer with no cleaning ⇒ 100% of the probes had CRES < 5-Ω
- Test Die A - probed with flat tips and no cleaning ⇒ 70% of probes had CRES < 5-Ω
- Test Die A – probed with ECP radius tips and no cleaning ⇒ 90% of probes had CRES < 5-Ω
Summary of CASE 2

- Unlike the blanket Al-wafer, stable CRES was not obtained when probing the Test Die

- A substantial amount of bond pad material adhered to both flat and radius tipped probes
  - Similar to Maekawa, et al. (2000), the adherent material and electrical contact regions seemed to overlap on flat tip probes while remaining separated on the radius tipped probes
  - Due to the composition of adherent material from the bond pads, the CRES behavior was dominated by the film contribution.

- The cumulative percentage Charts (in conjunction with CRES vs. TDs) provided a useful means of assessing incremental changes in CRES behavior.
CASE 3:
CRES Characterization of a
Representative 60-um Pitch Test Die
Focus of CASE 3

- Quantify the effects of device specific contact resistance stability issues
  - Two different electrically shorted Test Die
    - Test Die A – representative of a development process flow
    - Test Die B – representative of a process flow for 60-um pitch devices
  - AMIS currently uses flat tips for wafer sort
    - Both Test Die were probed with flat tip probe cards

- Assess “non-destructive” alternatives to abrasive cleaning that are able to remove adherent pad material

- Optimize cleaning recipes to maintain low and stable contact resistance for fine pitch devices
  - Extend probe card life and reduce the need for maintenance
CRES Behavior – Test Die A vs. Test Die B

- Test Die B was processed with an emphasis on bond pads for 60-um pitch device test and assembly.
- Bond pad material adhered to the probe tip contact area; however, this material did not affect the CRES stability like Test Die A.
- Test Die B CRES stability was significantly better than Test Die A.
Probe Tip Cleaning is Needed

- Destructive cleaning (3-um grit) was necessary to reduce the CRES instability of Test Die A
  - Probe cards required frequent planarity and alignment adjustment
  - Debris from the abrasive cleaning was observed across the wafer

- For fine pitch probe cards, excessive abrasive cleaning can be quite costly and time consuming

- To address the requirements for fine pitch wafer sort, non-destructive cleaning media were evaluated
  - Probe Polish 201 (PP201)
  - Probe Polish 210 (PP210)
    - A cleaning frequency of 100-die interval was utilized
    - 150-mil of overtravel into the material
“Non-Destructive” Cleaning for Fine Pitch

100K TDs on 3-um grit Lapping Film

1M TDs on Probe Polish Material
Test Die A Cleaning Optimization

Flat Tip Probes
(no cleaning)

Cleaning PP201
(100 die interval cleaning)

Cleaning PP210
(100 die interval cleaning)
The cleaning media removed adherent material from the probe tip outer edges.

Although some CRES improvements were observed, neither cleaning media was able to properly scrub the entire probe contact surface.

Cleaning with lapping film was necessary to reduce the CRES instability.
Cleaning Effects – Test Die B

- **Flat Tip Probes** (no cleaning)
- **Cleaning PP201** (100 die interval cleaning)
- **Cleaning PP210** (100 die interval cleaning)
The cleaning media removed the contaminants from the probe tip outer edges as well as the entire probe contact surface.

Materials that collected on the probe surface from Test Die B seemed less adherent to the probe tip surface and along the tip length.
Summary for CASE 3

- Device specific bond pad material properties were observed
  - CRES stability differed significantly between the two test die
  - Tenacity of the adherent bond pad material to the flat probe tip reduced cleaning material efficiency

- For the fine pitch Test Die B, non-destructive cleaning recipes were used to achieve low and stable contact resistance
  - Extend probe card life
  - Reduce frequent off-line maintenance
  - Improved on-line utilization of the probe card
Summary of CRES Characterization
CASE Studies
Summary of CASES 1, 2, and 3

- A systematic test methodology was designed using best practices and applied to understand the CRES characteristics of a developing 60-um pitch device.

- Incremental improvements in the CRES behavior resulting from probe tip shape and cleaning recipe were quantified using time based and normalized methodologies.

- Optimized non-destructive cleaning recipes were identified and applied to extend probe card life to maintain stable contact resistance.

- Additional work is in progress to better quantify the effects of tip shaping and further optimize the cleaning recipes for fine pitch devices.
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