Controlling Contact Resistance with Probe Tip Shape and Cleaning Recipe Optimization

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Outline

- **Objectives / Approach**
- **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)

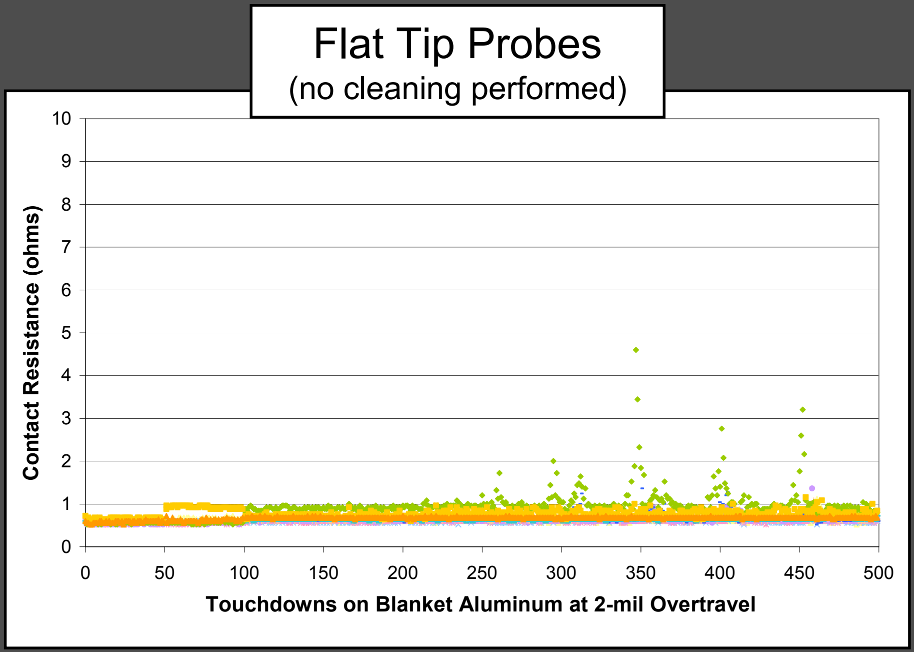
CASE 1 :
CRES Characterization Using a Blanket Aluminum "Reference" Wafer

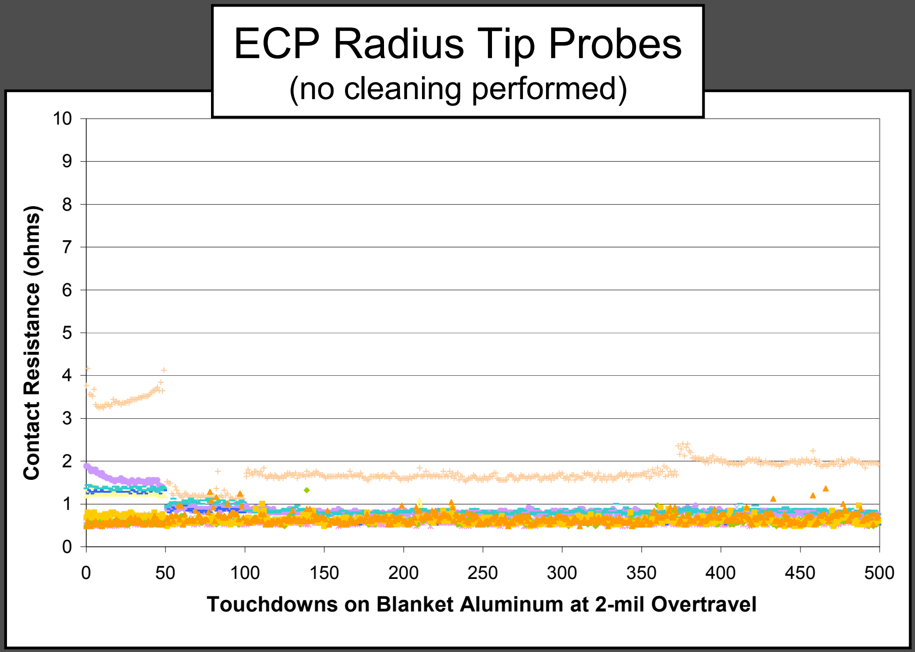
Focus of CASE 1

- **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

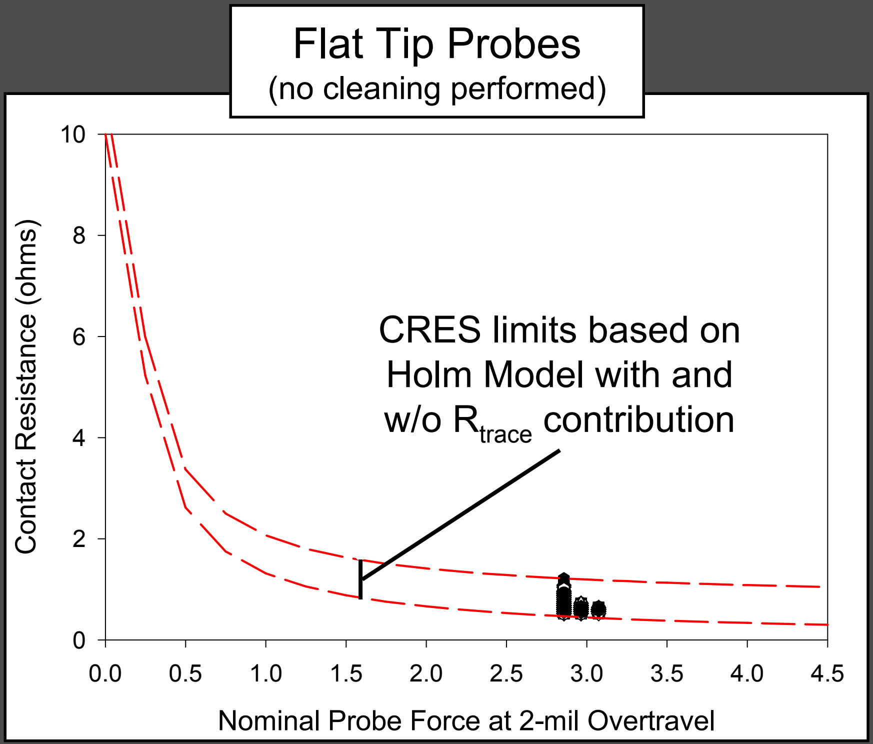
Application of Electrical Contact Theory

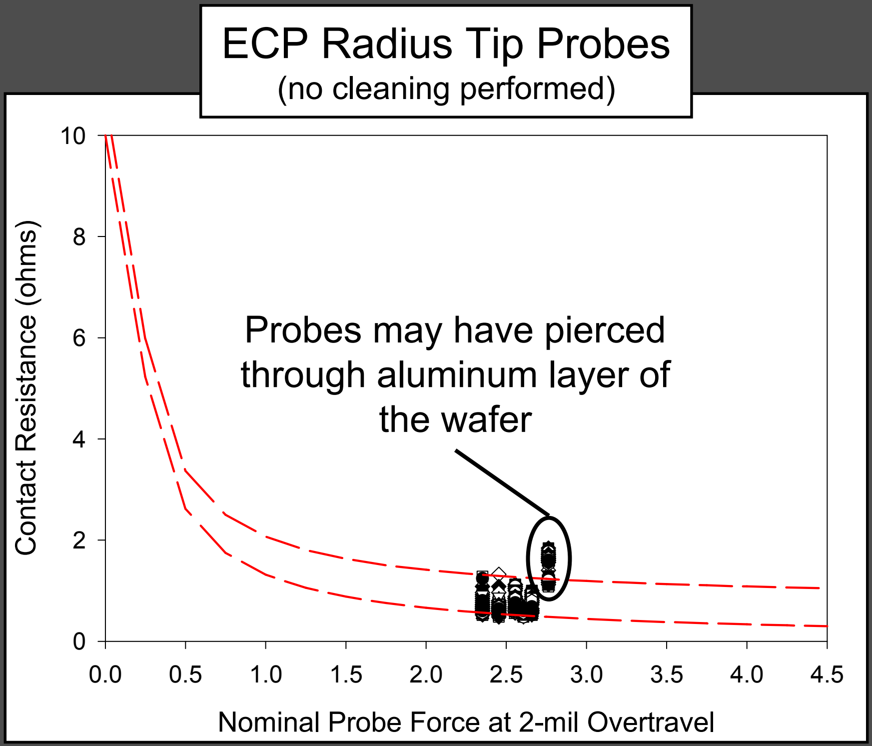
- First Order Approximation Model for Contact Resistance (R. Holm, 1967)

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

- C_{RES} = contact resistance
- ρ_{probe} = bulk resistivity of tungsten-rhenium probe ≈ 10E-8 Ωm
- ρ_{wafer} = bulk resistivity of aluminum ≈ 4E-8 Ωm
- H = hardness of the softer material ≈ 1.3E10 g/m^2
- σ_{film} = film resistivity ≈ 10E-12 Ωm
- F = probe force at overtravel ≈ 2.25 to 3.25 grams
- R_{trace} = trace resistance contribution

Contact Resistance on Blanket Al-Wafer





- 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.

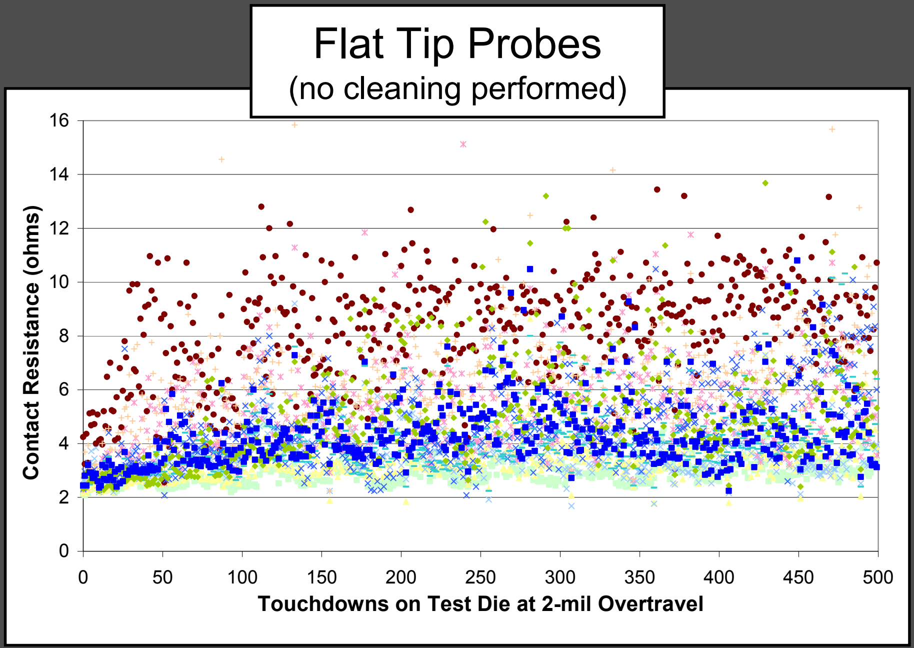
- The oxide layer contribution was negligible and CRES behavior could be described by the Holm Model for Contact Resistance

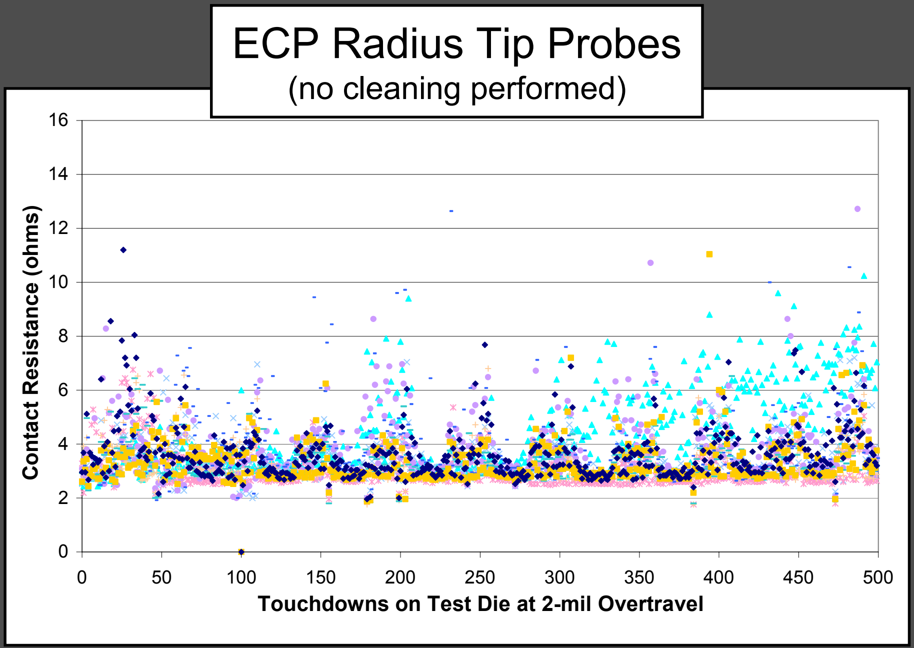
CASE 2 :
CRES Characterization using
Test Die with Electrically Shorted Pads

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

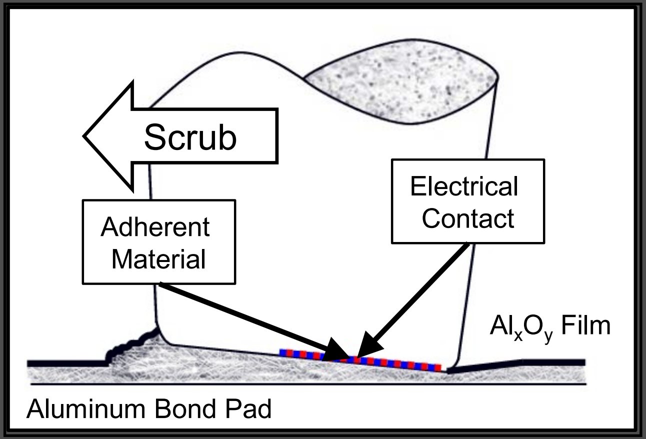
CRES vs. TDs – Test Die A





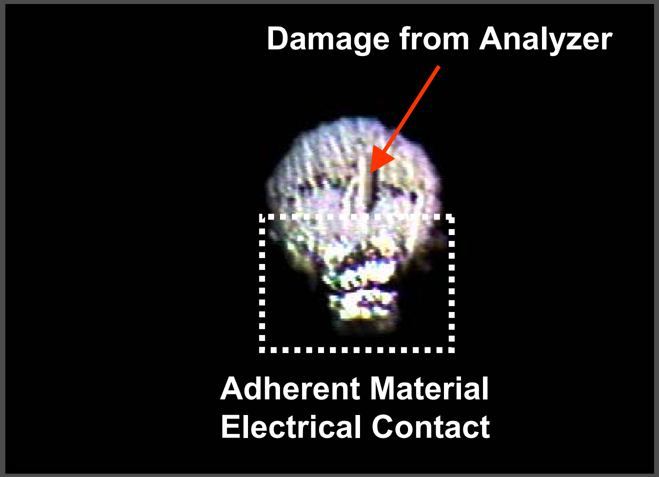
- Stable CRES on the Test Die wafer was not observed
  - 535 Test Die were probed on each wafer with no cleaning performed
  - Images were collected at 50, 100, 500, and 1000 (after two wafers) TD intervals
  - Adherent material was observed on the contact region of the flat tip probes
- The ECP radius probes demonstrated "better" CRES behavior than flat tipped
  - ~12.7-um radiused tip shape was obtained using electrochemical polishing methods.

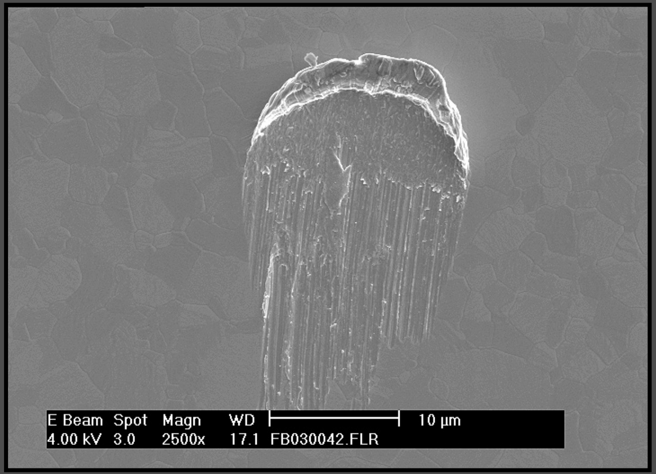
Tip Shape Effects – Flat Tips



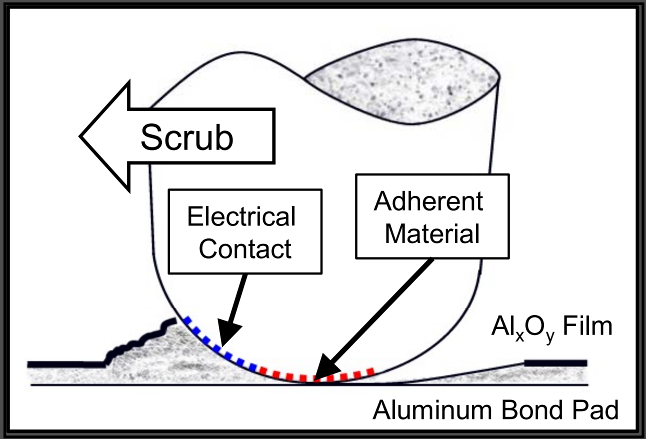
Adapted from Maekawa, et al., 2000

- 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.



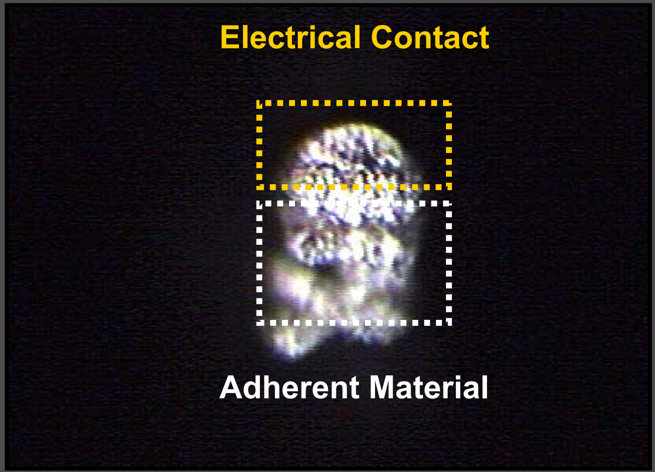


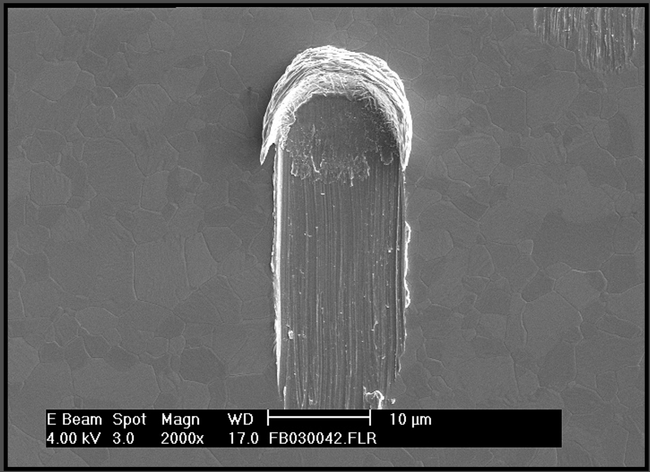
Tip Shape Effects – Radius Tips



Adapted from Maekawa, et al., 2000

- 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-um < R < 22-um (Maekawa, et al., 2000)



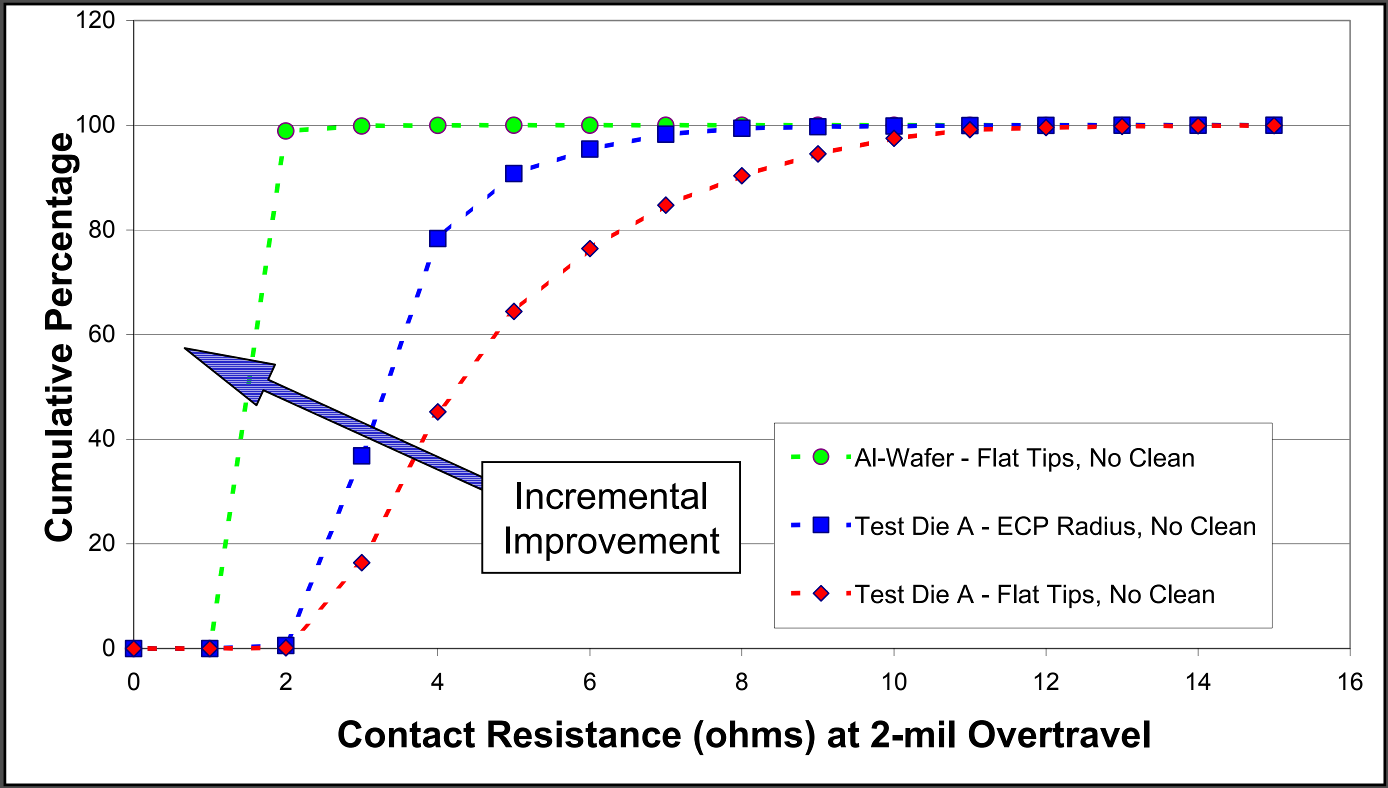


Quantifying Incremental CRES Improvement

- **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

Tip Shape Effects – CRES Assessment



- 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

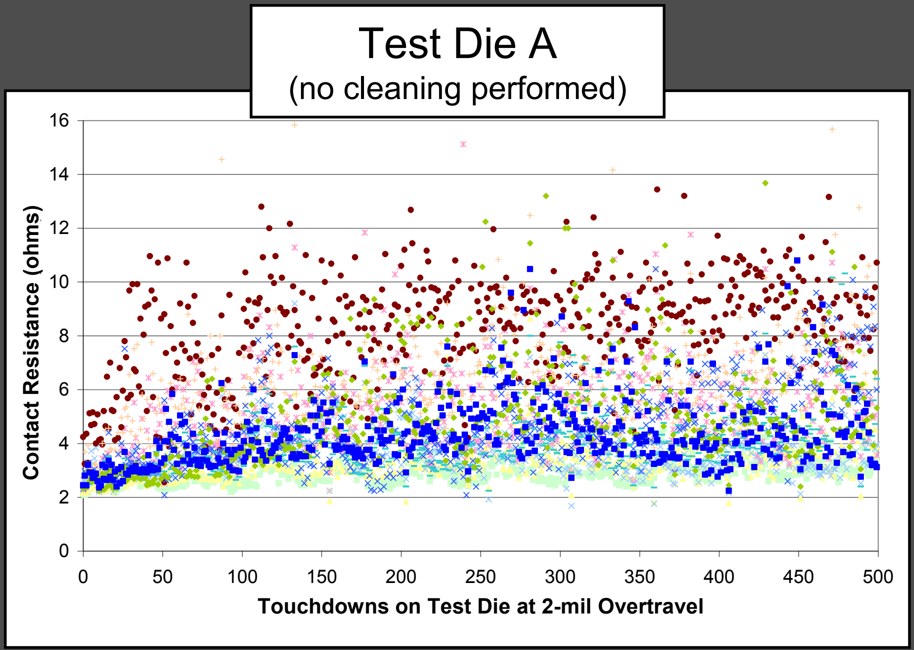
Focus of CASE 3

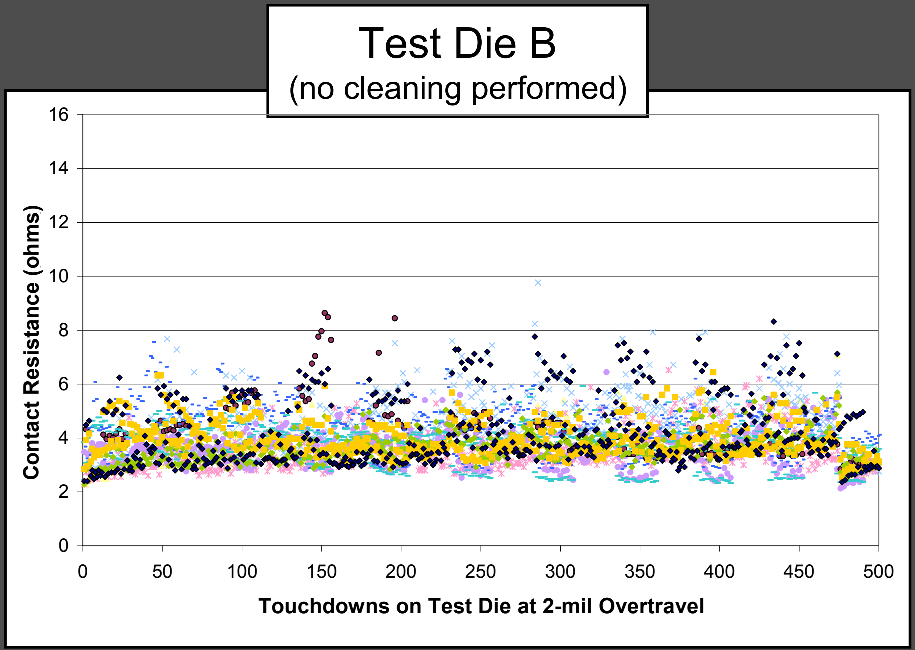
- **Quantify the effects of device specific contact resistance stability issues**
  - Two different electrically shorted Test Die
    - Test Die A – representative of a development process flow
    - Test Die B – representative of a process flow for 60-um pitch devices
  - AMIS currently uses flat tips 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





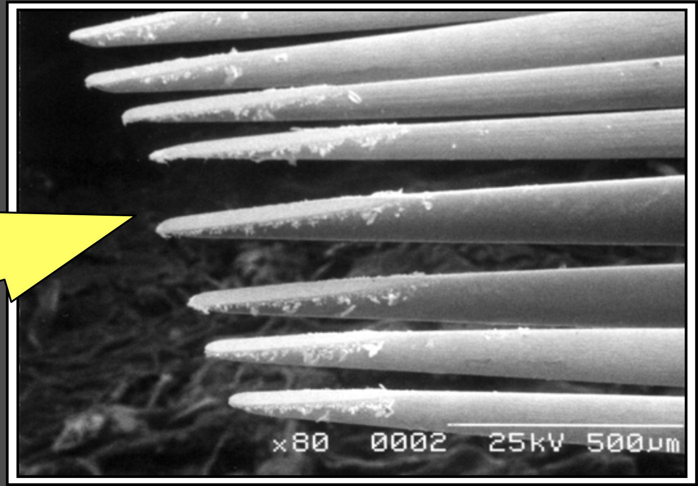
- Test Die B was processed with an emphasis on bond pads for 60-um pitch device test and assembly.
- Bond pad material adhered to the probe tip contact area; however, this material did not affect the CRES stability like Test Die A
- Test Die B CRES stability was significantly better than Test Die A

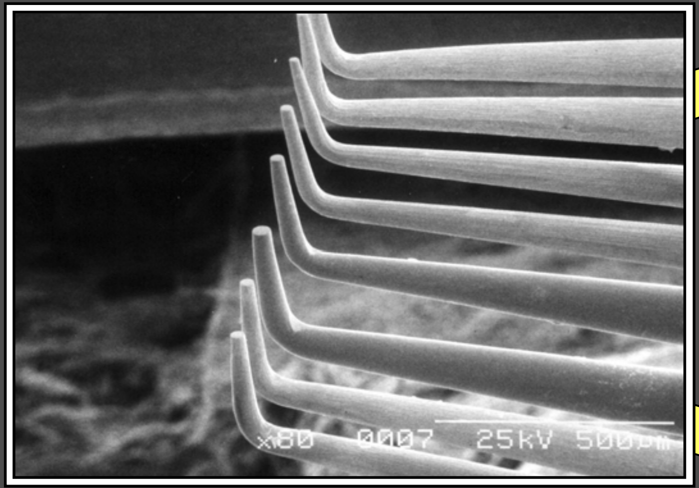
Probe Tip Cleaning is Needed

- **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

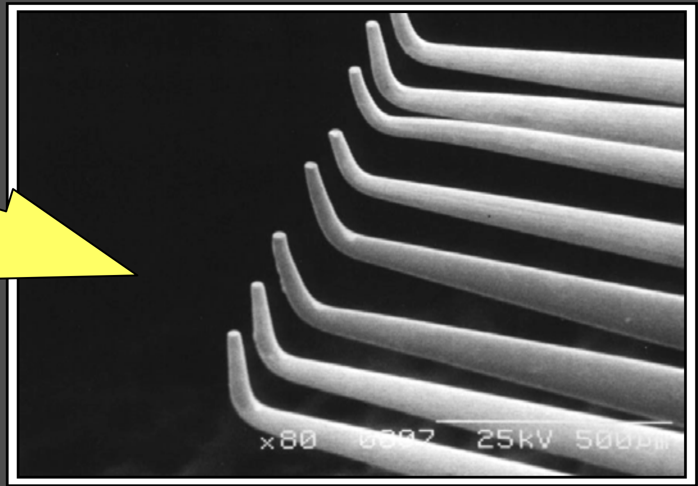
“Non-Destructive” Cleaning for Fine Pitch

100K TDs on
3-um grit Lapping Film



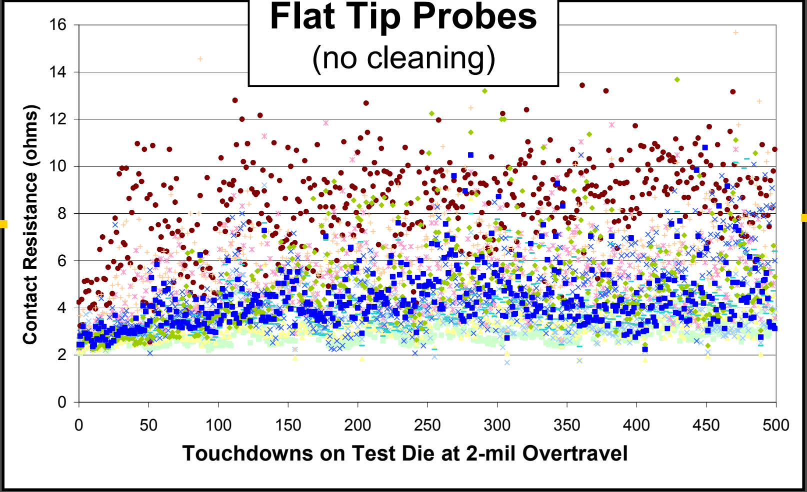


1M TDs on
Probe Polish Material



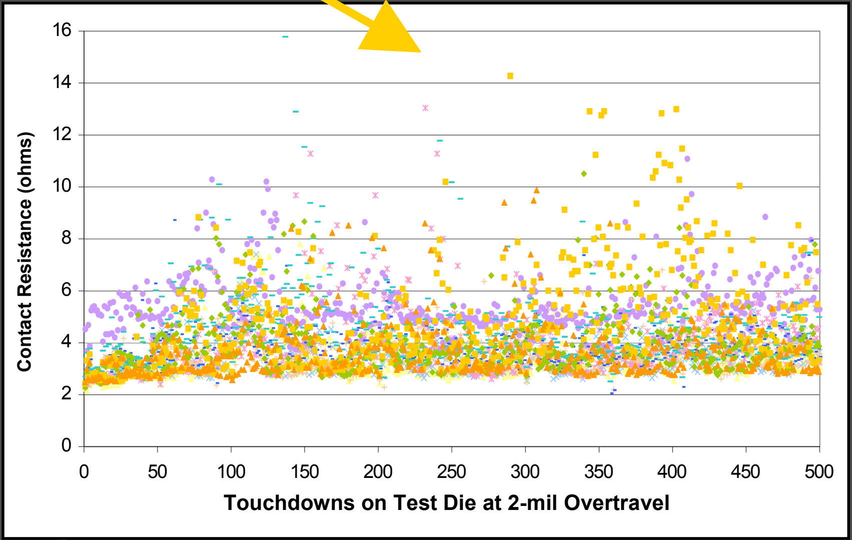
Test Die A Cleaning Optimization

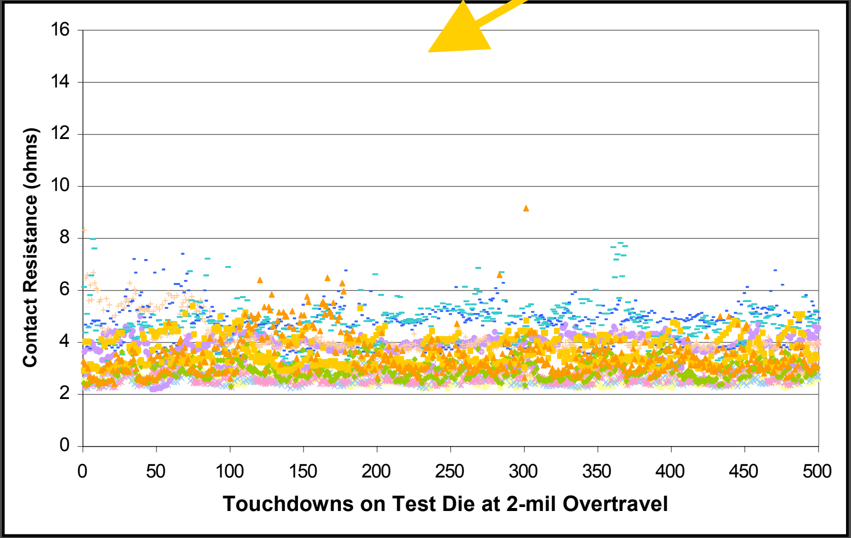
Flat Tip Probes
(no cleaning)



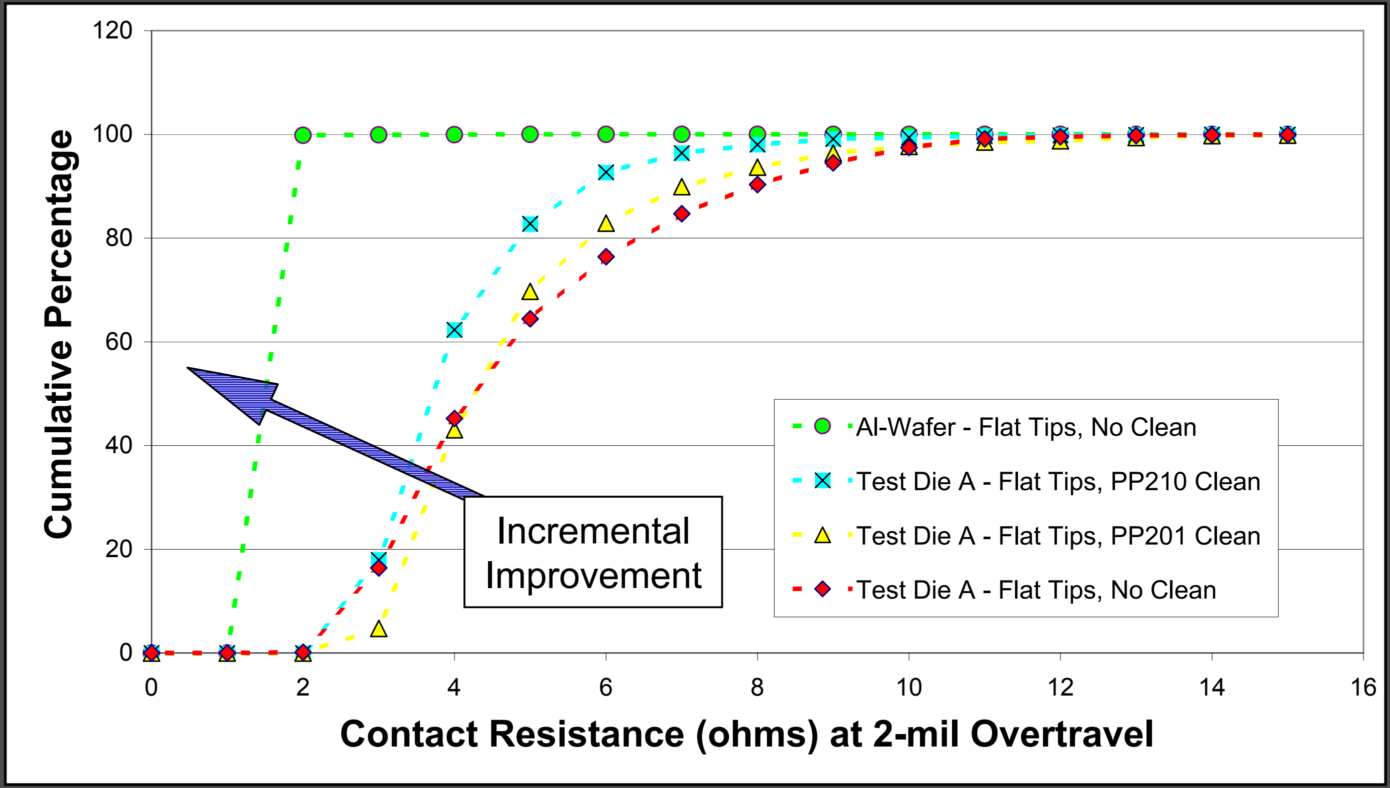
Cleaning PP201
(100 die interval cleaning)

Cleaning PP210
(100 die interval cleaning)





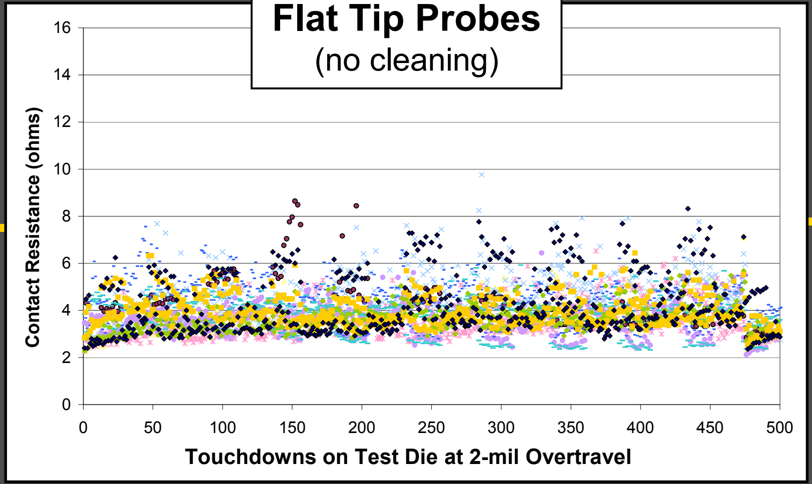
Test Die A – Cleaning Assessment



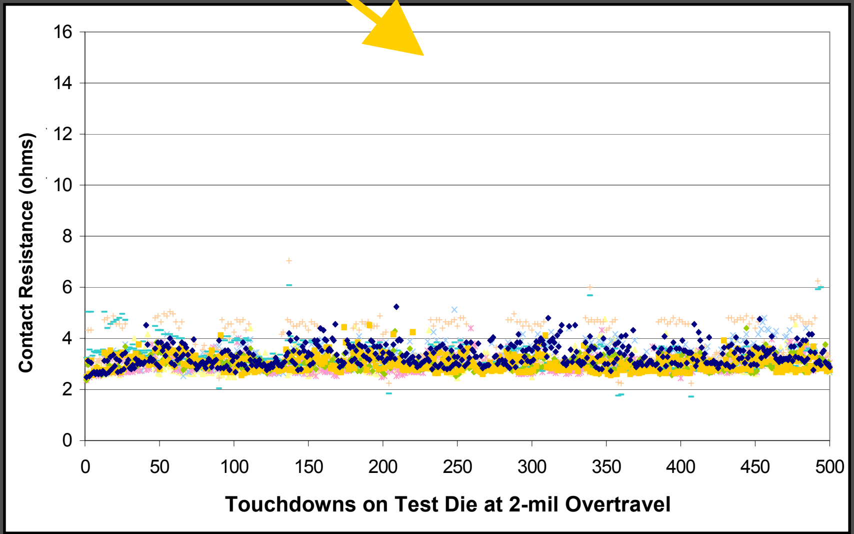
- The cleaning media removed adherent material from the probe tip outer edges.
- Although some CRES improvements were observed, neither cleaning media was able to properly scrub the entire probe contact surface
- Cleaning with lapping film was necessary to reduce the CRES instability

Cleaning Effects – Test Die B

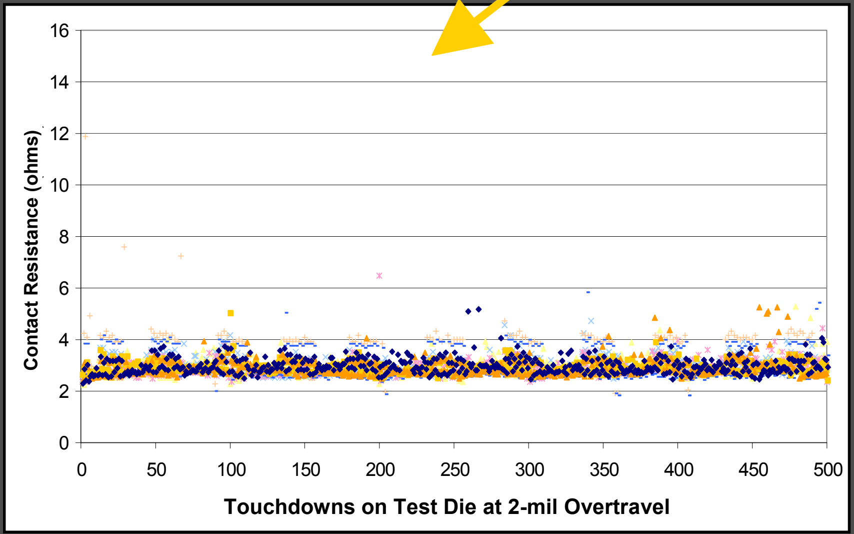
Flat Tip Probes
(no cleaning)



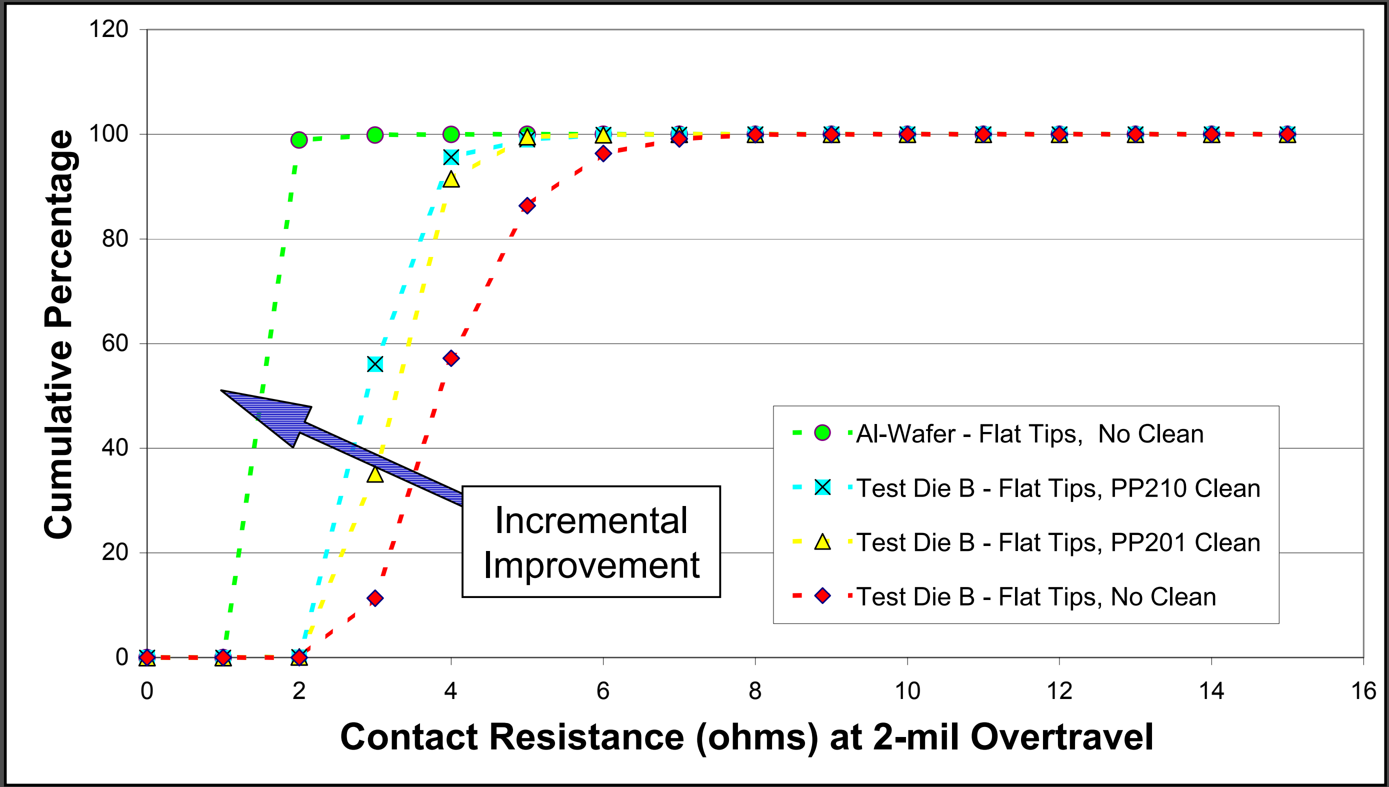
Cleaning PP201
(100 die interval cleaning)



Cleaning PP210
(100 die interval cleaning)



Test Die B – Cleaning Assessment



- 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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