Probe Needle Wear and Contact Resistance

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Participants

- **SEMATECH**
  - Probes PTAB
- **Probe Needles**
  - Advanced Probing Systems, Inc.
- **Probe Cards**
  - CerProbe Corporation
  - JEM America
  - Micro-Probe, Inc.
  - Probe Technology Corporation
  - Wentworth Laboratories
- **Testing Facilities**
  - Applied Precision, Inc. (John Strom, Kenneth Sokol, Bryce Ekstrom)
  - Sandia National Laboratories (David Monroe, Scot Swanson)

Research Objectives

- No Benchmarking
  - Probe card construction was specified for this study
  - Overall performance between cards WAS NOT compared
- **Quantify abrasive cleaning effects**
  - Probe tip wear due to burnishing
  - Appropriate cleaning procedures
- **Evaluate probe needle wear behavior**
  - Room and elevated temperature touchdown testing
  - Appropriate probe needle metal system

Research Focus

- **SEMATECH 1997 Development Roadmap**
  - Room temperature *(hot chuck at 30°C)*
  - Elevated temperature *(hot chuck at 85°C)*
- **“Practice” for probe card cleaning**
  - 3-µm grit burnishing pad *(hot chuck at 30°C)*
- **“Practices” used for 70 µm pitch probe cards**
  - Tungsten and tungsten-rhenium probe materials
  - 0.005” and 0.007” diameter probe needles
  - Three-tiered epoxy ring probe cards
  - **For this presentation only Tier 1 behavior will be discussed**

Probe Needles

- **Testing Environments**
  - Abrasive cleaning
  - Room temperature(30°C)
  - High temperature (85°C)
  - “Low” forcing current (50 mA)
- **Focus on “Primary” Probe Needle Properties**
  - Material
  - Probe and probe tip diameter
  - Etch length

Probe Card

- **Consistent “Secondary” Probe Needle Variables**
  - Balanced contact force
  - Overtravel
  - Beam angle
  - Tip angle
  - Etc….

Probe Needle Specifications

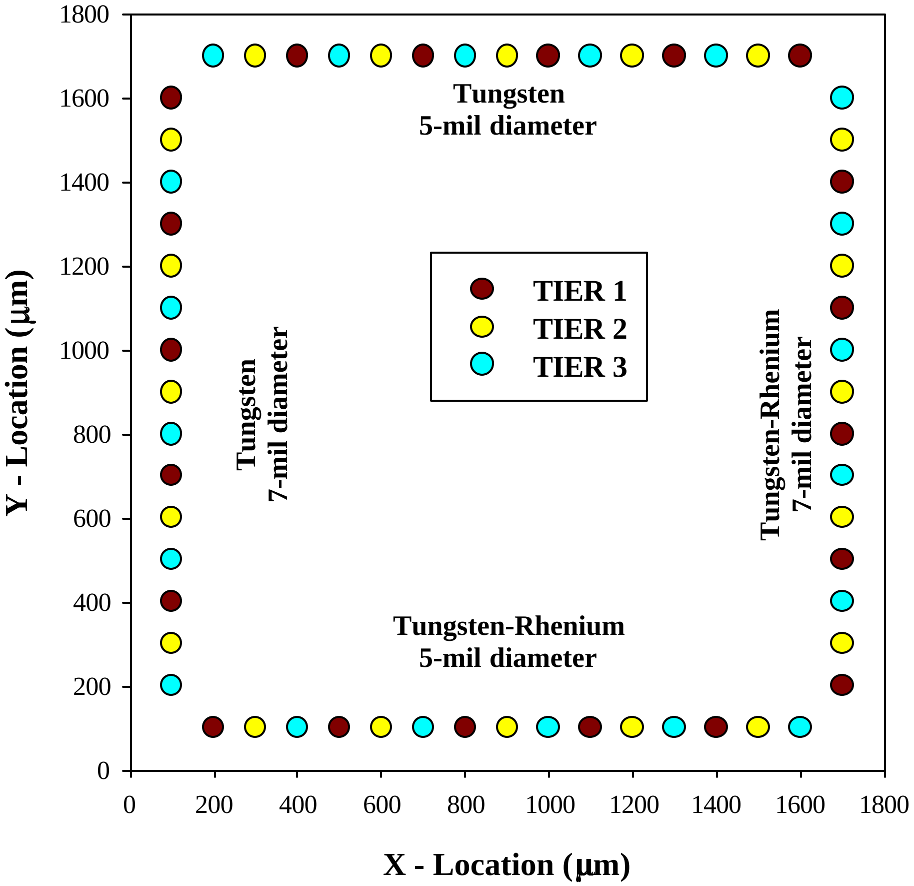
- **Isolinear™ Probe Needles**
  - Known probe tip geometry
  - Tip diameter and length mathematically related

Probe Needle	**Etch Length** (inch)	**Etch "Rate"** (deg)	**Finish**
5-mil Diameter	0.070 0.080 0.090	4.1 3.6 3.2	Tungsten (W): Matte Tungsten-Rhenium (WRe): Polish
7-mil Diameter	0.090 0.100 0.110	4.5 4.0 3.6	Tungsten (W): Matte Tungsten-Rhenium (WRe): Polish

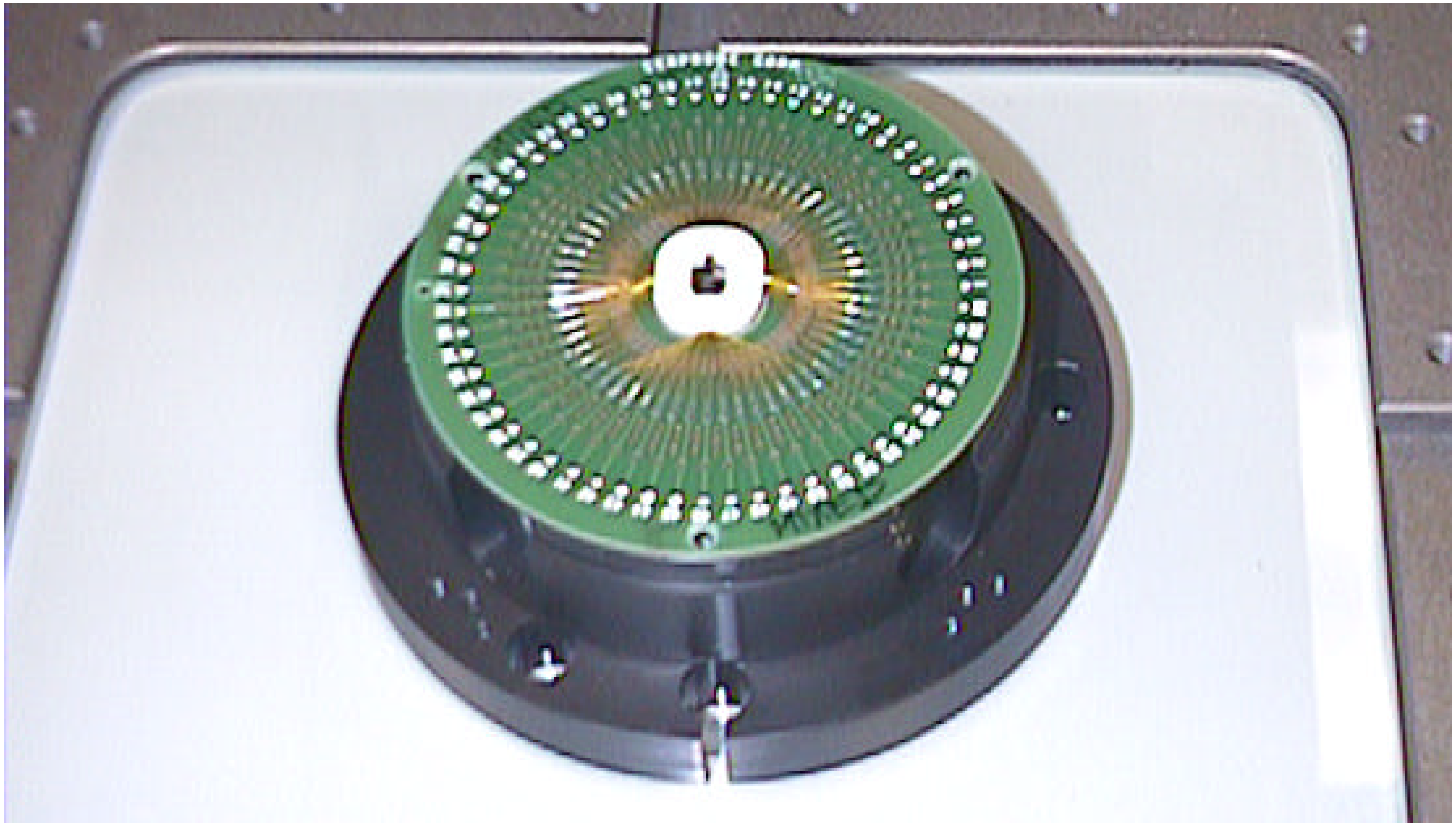
Probe Card Specifications

Board Style:	HP 4062, 4" PCB
Test Temperature:	25^{o} to 85^{o}C
Tip Diameter:	1.2 ± 0.1 mils
Tip Shape:	Flat
Tip Angle:	103 ± 3 deg.
Beam Angle:	10 deg.
Pad Material:	Aluminum
Fanout:	0 ± 3 deg.
Probe Depth:	150 mils
Ring Material:	*Ceramic*
Overdrive:	3 mils
Planarity:	± 0.5 mils
Alignment:	± 0.5 mils
Leakage:	100 nA
Contact Resistance	1.5 to 2.0 Ω
Gram Force:	2 grams/mil
BCF:	± 20%

60-Pin Configuration



Probe Card

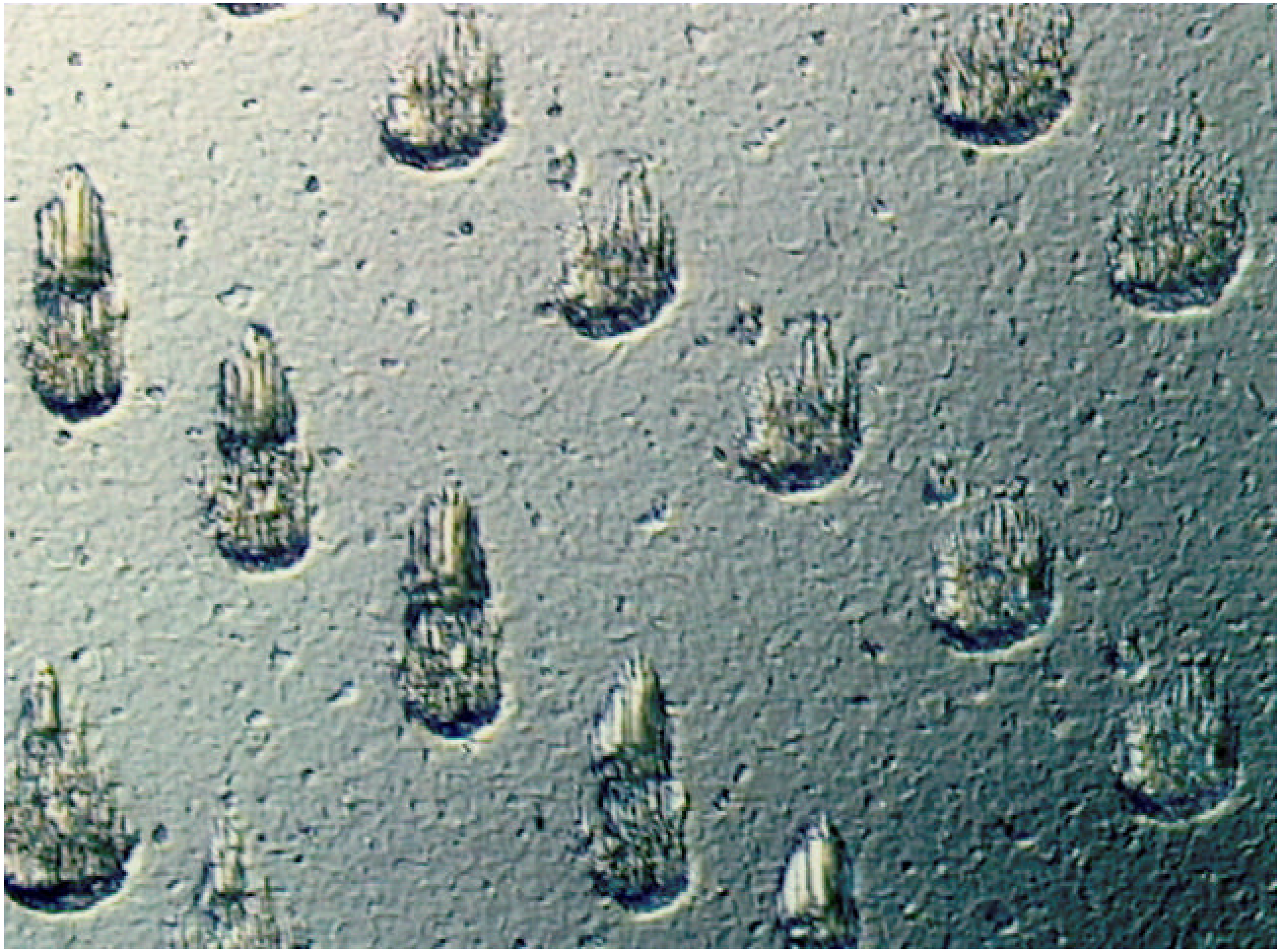


Test Wafers

- **Abrasive Testing**
  - 6-inch “scrap” metallized wafer
  - 3-μm abrasive pad , i.e. “the pink stuff”

- **Touchdown Testing**
  - 8-inch metallized wafer manufactured by SEMATECH
  - Titanium-nitride substrate
  - 1-μm thick Aluminum layer

Stepping Pattern



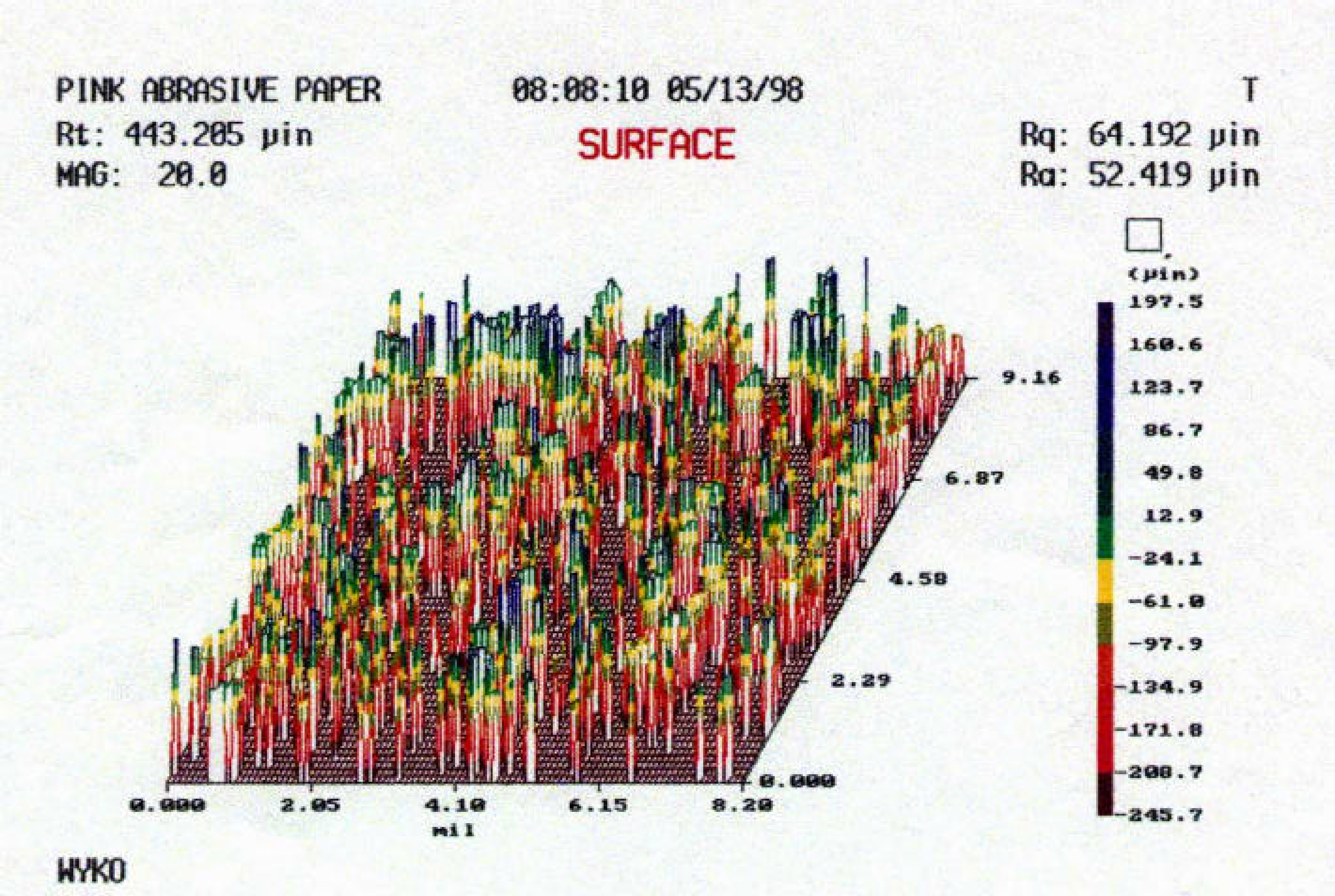
Test Equipment

- **ElectroGlas-4080 Tester with “Hot Chuck”**
  - Burnishing pad touchdown testing
  - Metallized wafer touchdown testing at 30^{o}C and 85^{o}C
- **HP4062 Parametric 48-Channel Analyzer**
  - On-line contact resistance measurements
- **Applied Precision PRVX$_2$ -Probe Card Analyzer**
  - Probe tip diameter
  - Contact resistance
  - Balanced contact force

Touchdown “Test Flow”

- **3-μm Abrasive Pad**
  - 3.0-mil overtravel, linear mode, double-touchdown mode
  - $PRVX_2$ metrology performed after 0, 7.5K, and 15K touchdowns
    - ○ Contact resistance
    - ○ Tip diameter
- **Metallized Wafer at 30^o and 85^{o}C**
  - 3.0 mil overdrive, double-touchdown mode (8 touchdowns/second)
  - Contact resistance measurements every 5K touchdowns
  - $PRVX_2$ metrology performed after 0, 250K, and 500K touchdowns
    - ○ Contact resistance
    - ○ Tip diameter

3-µm Abrasive Pad



PINK ABRASIVE PAPER 08:08:10 05/13/98 T

Rt: 443.285 µin

MAG: 20.0

Rq: 64.192 µin

Ra: 52.419 µin

3-µm Abrasive Pad

- **Tungsten vs. Tungsten-Rhenium**
  - Abrasive particles are considerably harder than both probe materials
  - No “significant” differences between materials in amount of tip length removed
- **5-mil vs. 7-mil Diameter Probe Needles**
  - Amount of tip length removed from the 5-mil probes was greater than that of the 7-mil probes
- **Contact Resistance Measurements**
  - Baseline (“as delivered”) and post-touchdown C_{RES} values were higher than expected
  - Cleaning was performed and C_{RES} values were considerably reduced
  - Contamination on probe tip surface - tungsten-oxide? other residue?

3-µm Abrasive Pad

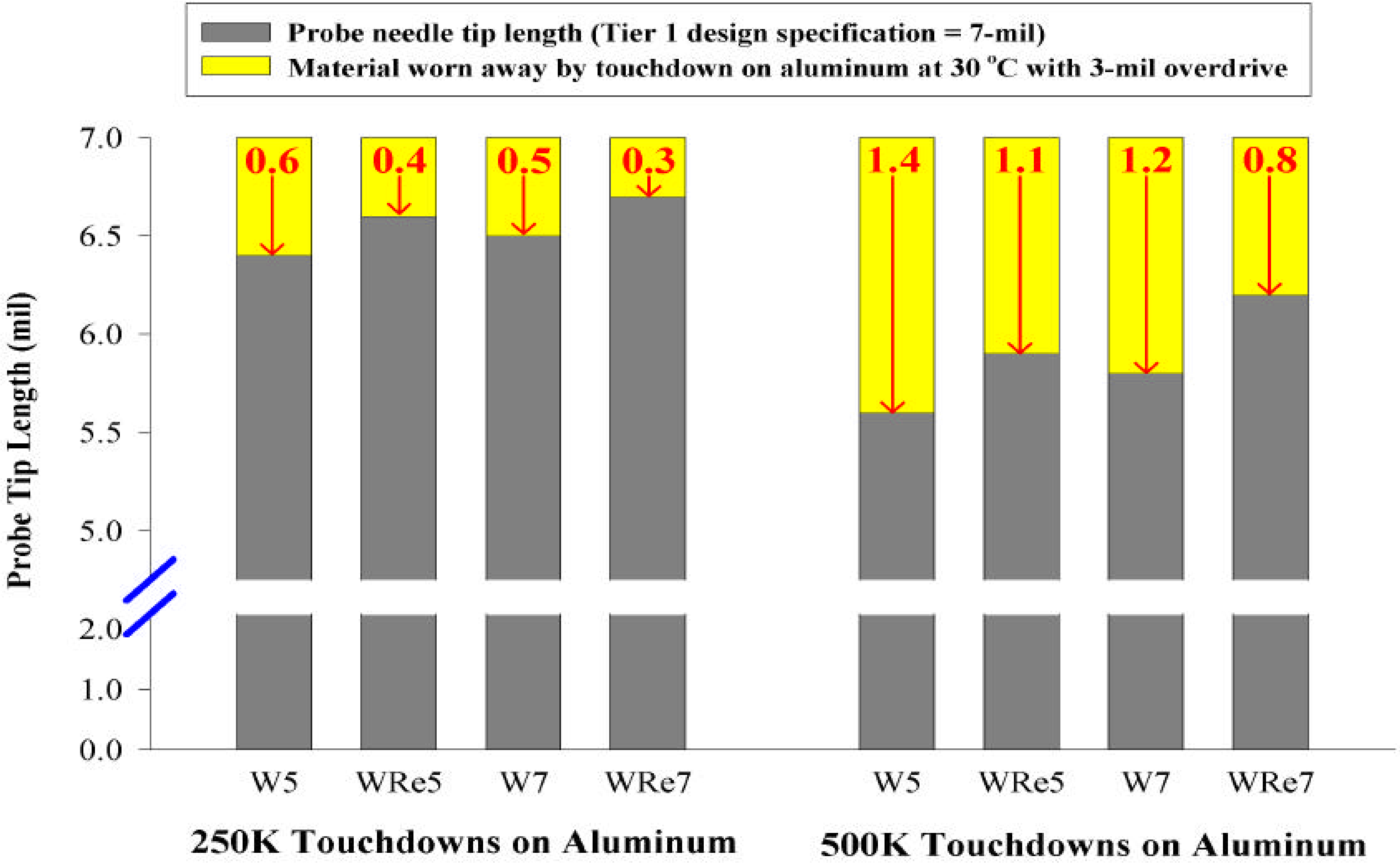
- **“Approximate” Wear Rates**
  - Changes in tip geometry occur with each touchdown
  - **Wear rate = *f*(overtravel, scrub length, BCF, etch length, contact materials)**
  - Conservative “first approximation” of abrasive wear rates

	“Estimated” amount of material removed **0 to 7.5K**	**“Estimated” amount of material removed** **0 to 15K**
5-mil diameter	**38 Å per touchdown**	**52 Å per touchdown**
7-mil diameter	**35 Å per touchdown**	**48 Å per touchdown**

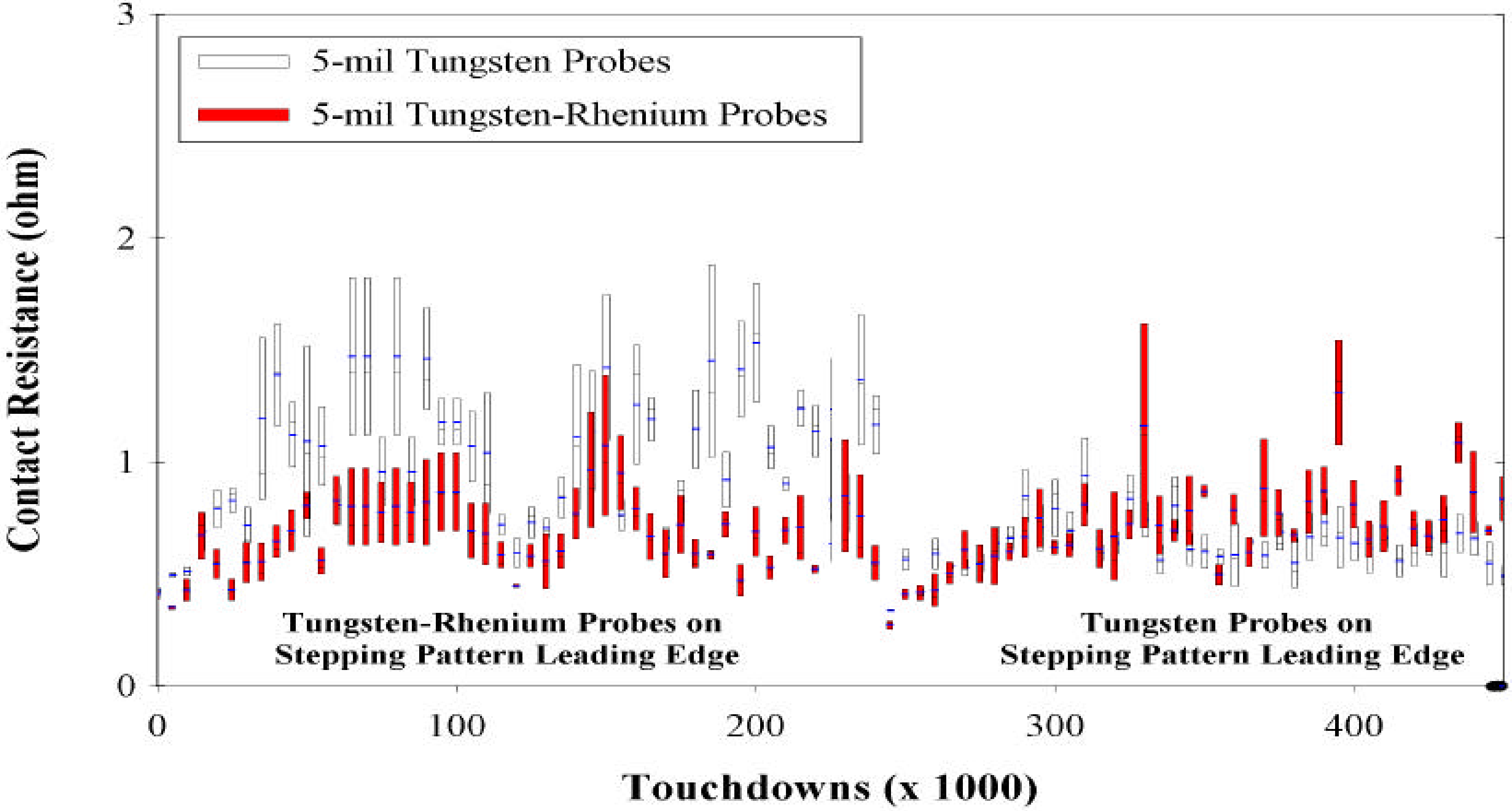
Al-Wafer at 30º and 85ºC

- **Probe Tip Wear Characteristics**
  - Isolinear™ taper shape was used to calculate average tip length changes

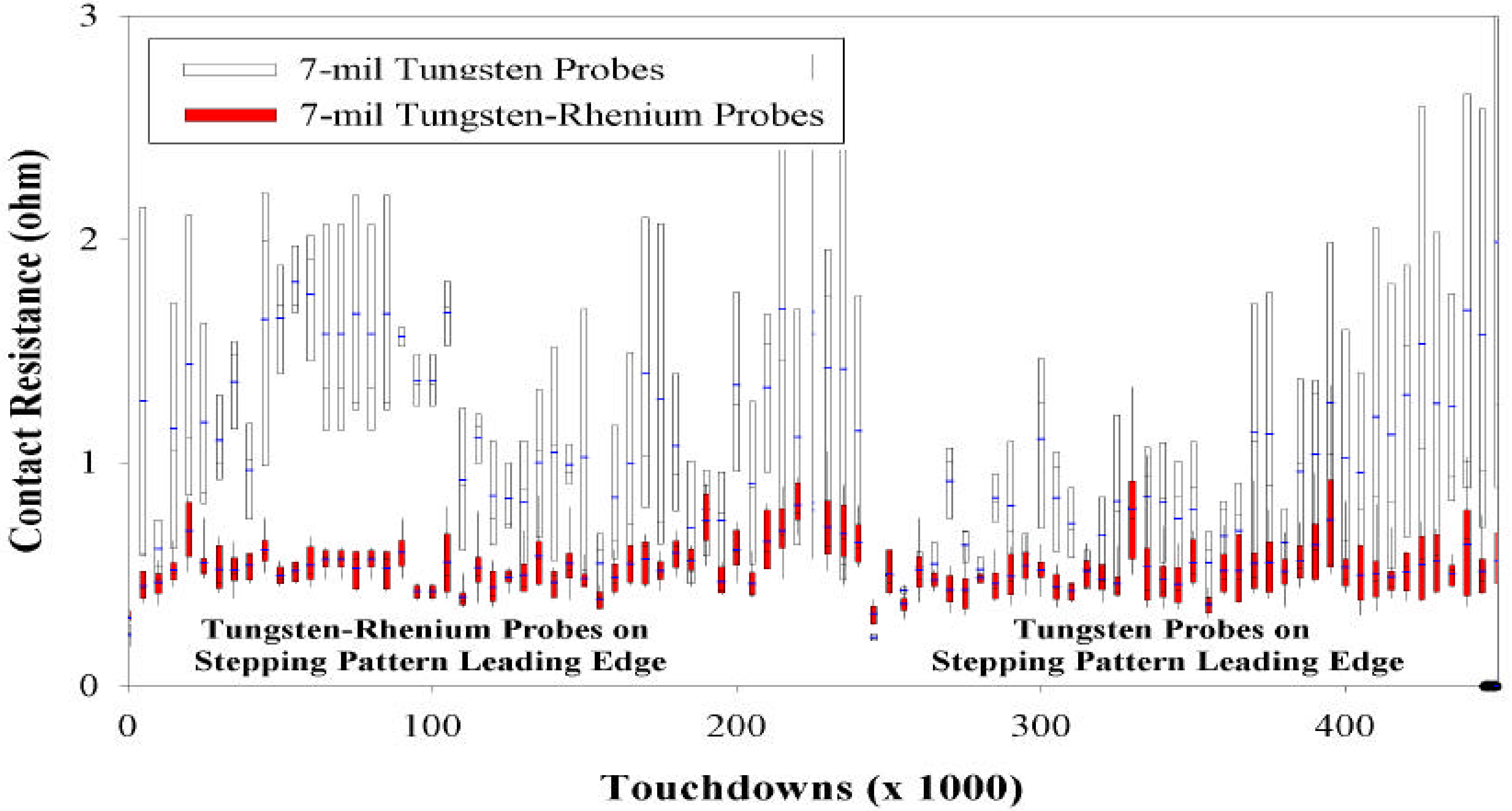
- **Contact Resistance**
  - Box plots were used to show the range and mean of C_{RES} values for material


Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 30 °C with 3-mil overdrive
Probe Tip Length (mil)
7.0
6.5
6.0
5.5
5.0
2.0
1.0
0.0
0.6
0.4
0.5
0.3
1.4
1.1
1.2
0.8
W5
WRe5
W7
WRe7
W5
WRe5
W7
WRe7
250K Touchdowns on Aluminum
500K Touchdowns on Aluminum

Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 30°C)



Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 30°C)

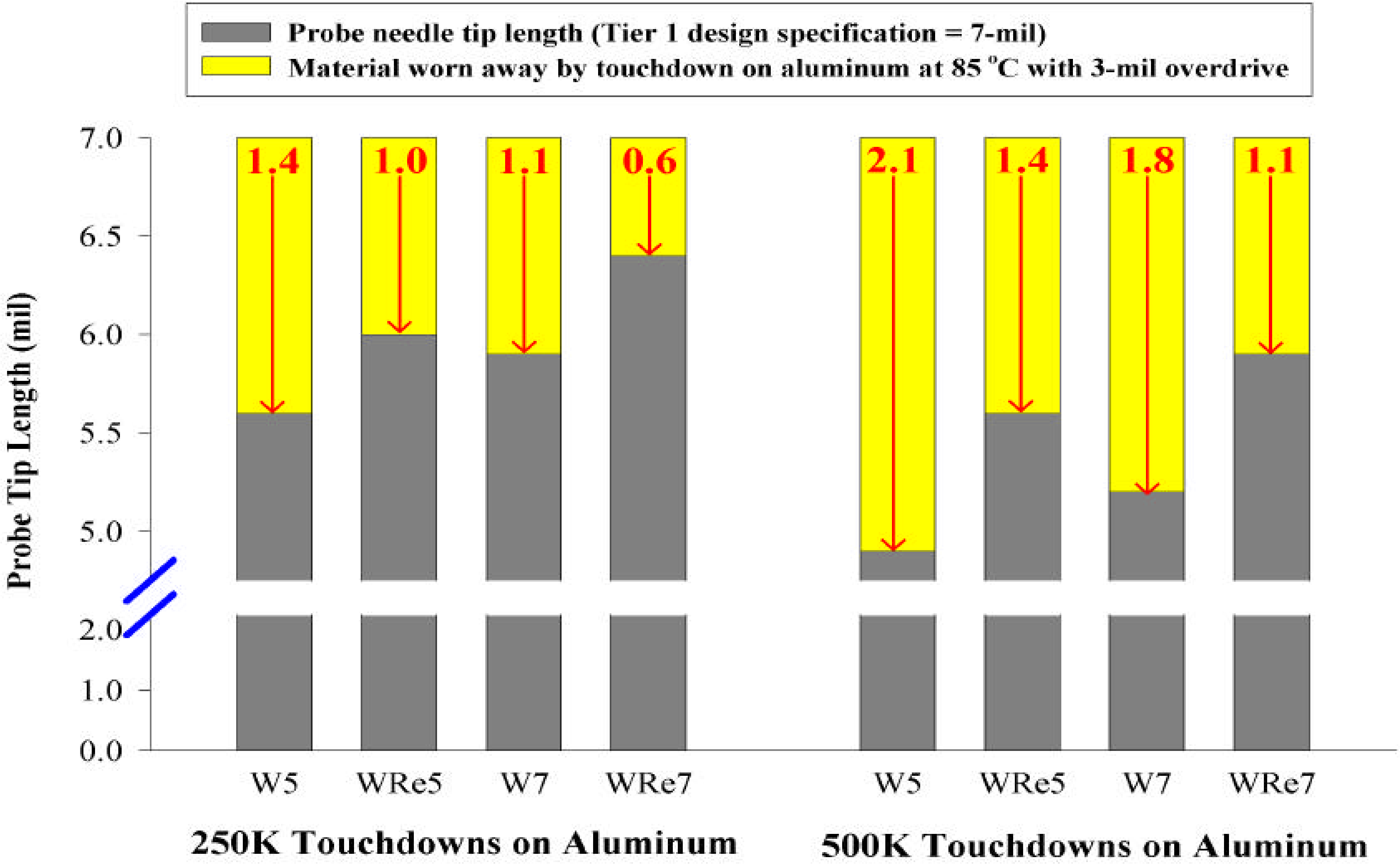


Al-Wafer at 30ºC

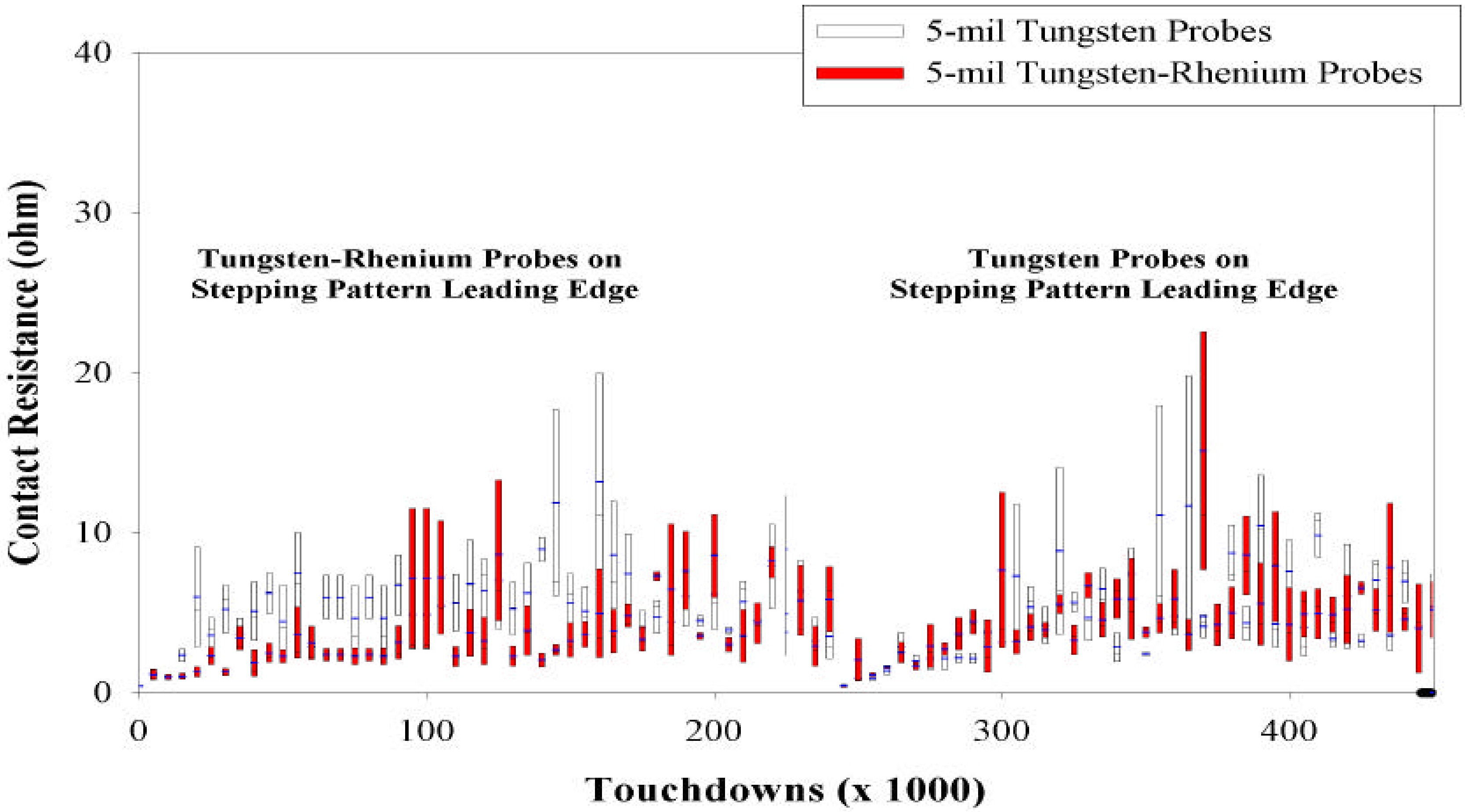
- **Wear and C_{RES}**
  - 7-mil WRe-probes demonstrated significantly lower C_{RES} values than 7-mil W-probes
  - Differences between the 5-mil probes were not as significant
  - Microhardness values of the probes

	W005	WRe005	W007	WRe007
VHN (kg/mm^2)	738 ± 47	736 ± 33	718 ± 45	804 ± 23

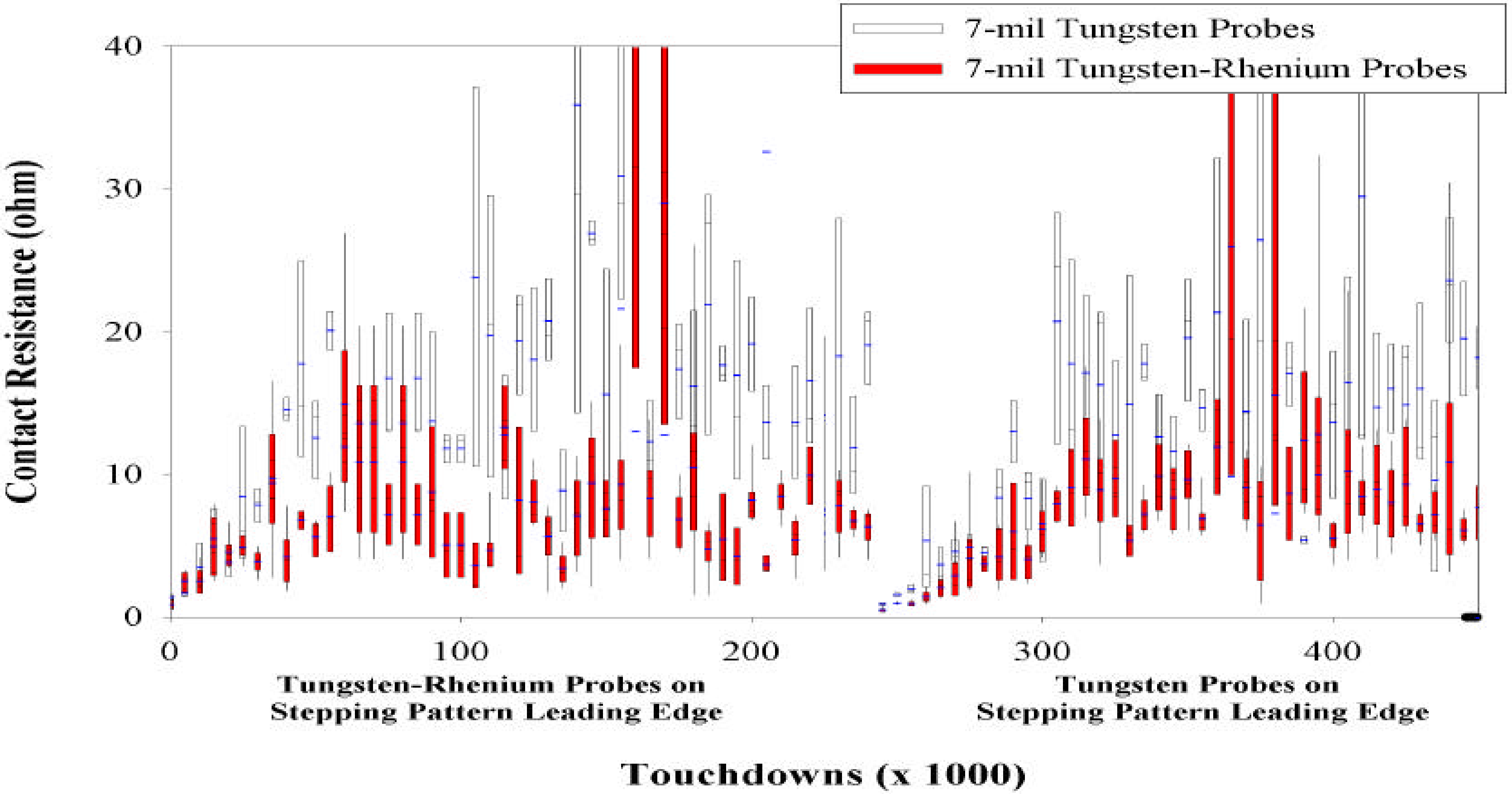
- **C_{RES} on “Virgin” vs. “Scrubbed” Aluminum**
  - C_{RES} response of the WRe-probes unaffected by wafer surface condition
  - On the other hand, the W-probes demonstrated marked differences


Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 85 °C with 3-mil overdrive
Probe Tip Length (mil)
7.0
6.5
6.0
5.5
5.0
2.0
1.0
0.0
1.4
1.0
1.1
0.6
2.1
1.4
1.8
1.1
W5
WRe5
W7
WRe7
W5
WRe5
W7
WRe7
250K Touchdowns on Aluminum
500K Touchdowns on Aluminum

Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 85°C)



Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 85°C)



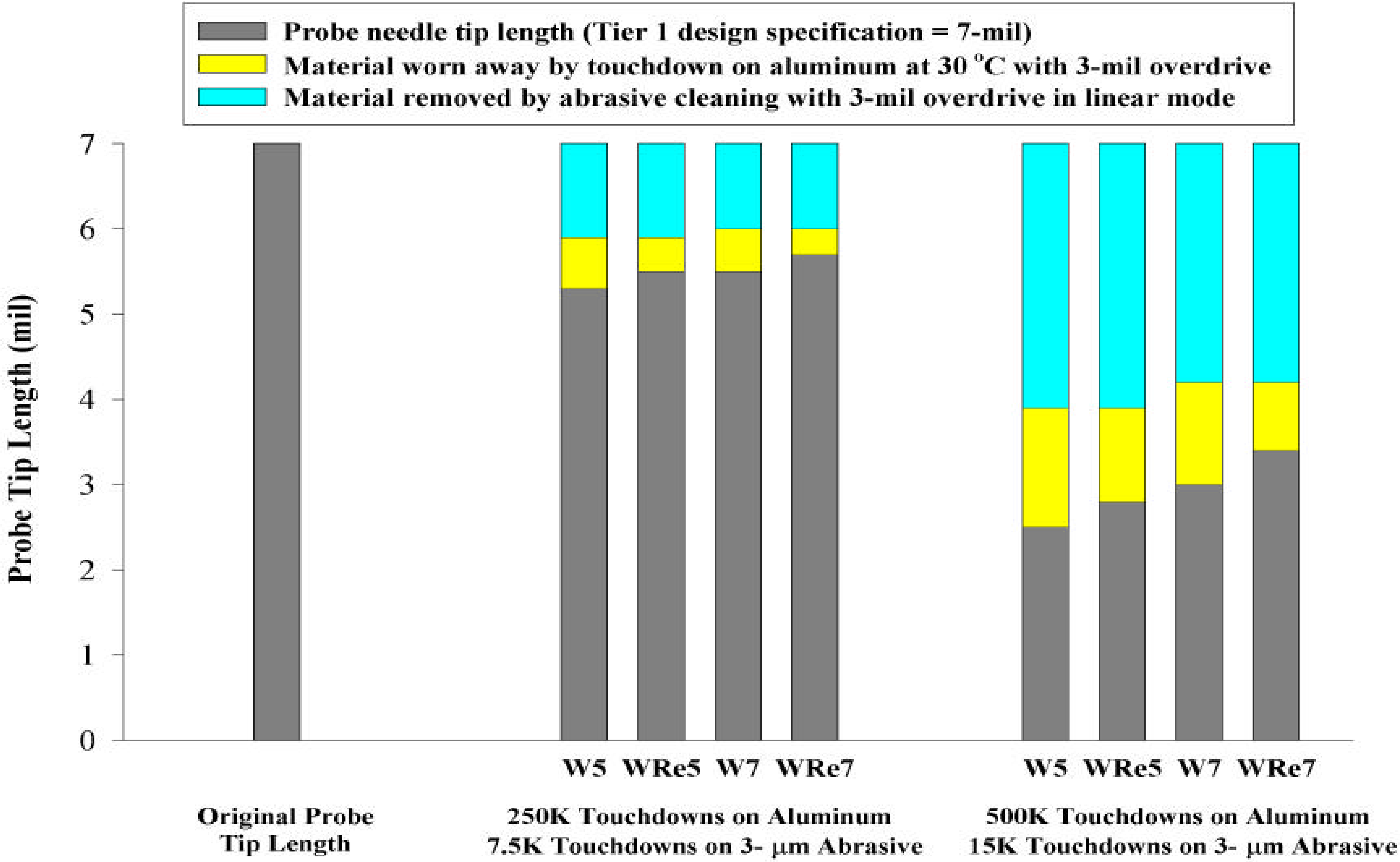
Al-Wafer at 85ºC

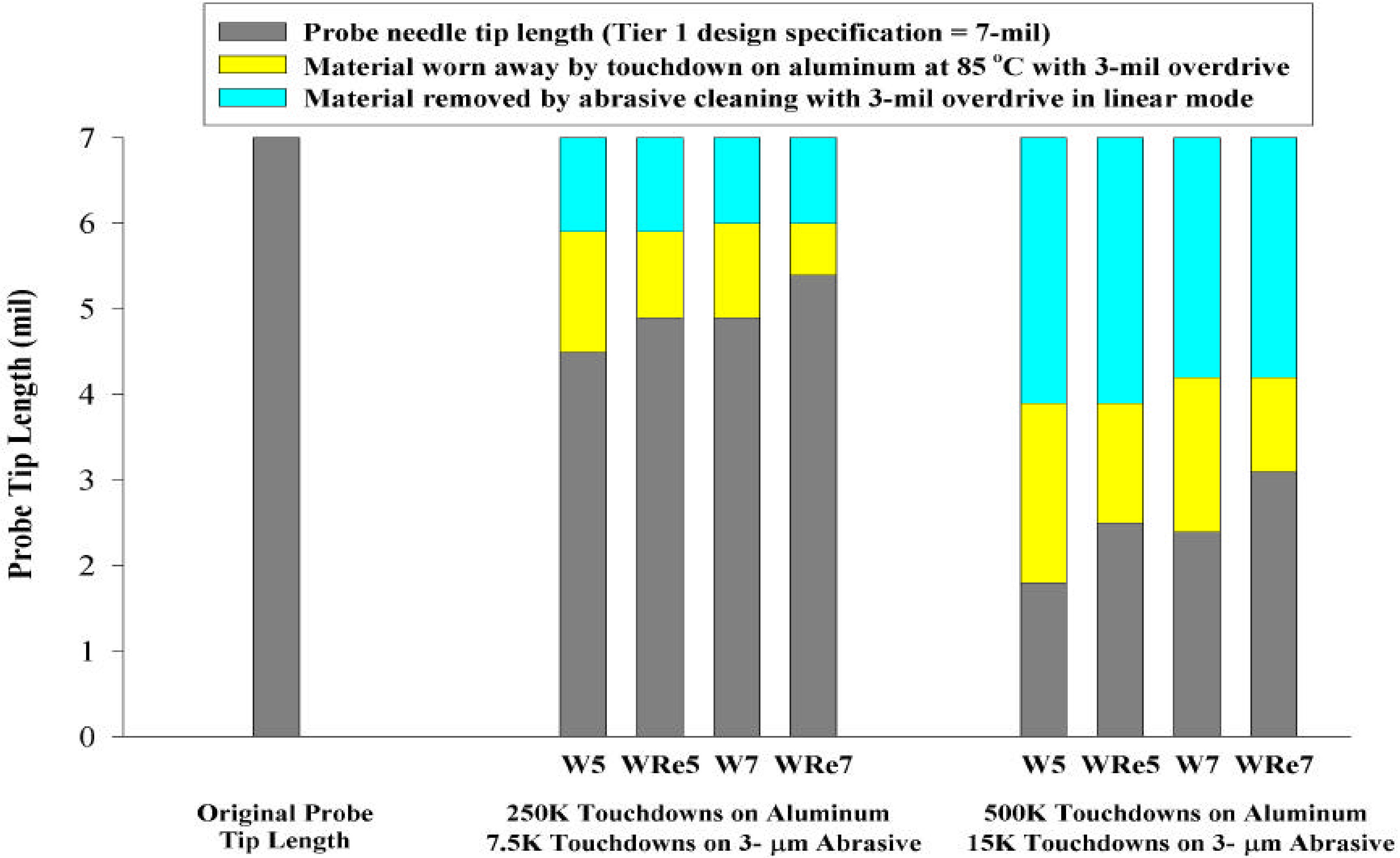
- **Wear and C_{RES}**
  - Reductions in WRe-probe tip lengths were significantly less than those of the W-probes
  - Overall, the WRe-probes demonstrated lower and “more stable” C_{RES} behavior
- **Temperature Effects**
  - Metallurgical fact - materials soften with increased temperature
  - Rhenium stabilizes small diameter wire grain structure at high temperatures
  - Grain structure affects hardness and wear characteristics of probe needles
  - The “softening rate” of WRe-probes differs from than that of W-probes

Application of Results

"A Thought Experiment"

- **Probe card required to test 500K die**
- **Testing performed at room and high temperature**
- **"Triple Hit" cleaning every 100 die**
  - 7.5K cleaning touchdowns after 250K die
  - 15K cleaning touchdowns after 500K die
- **Can an estimate be made of the probe service life?**
  - Reduction in tip length
  - Increase in tip diameter


Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 30 °C with 3-mil overdrive
Material removed by abrasive cleaning with 3-mil overdrive in linear mode
Probe Tip Length (mil)
7
6
5
4
3
2
1
0
W5
WRe5
W7
WRe7
W5
WRe5
W7
WRe7
Original Probe Tip Length
250K Touchdowns on Aluminum
7.5K Touchdowns on 3- µm Abrasive
500K Touchdowns on Aluminum
15K Touchdowns on 3- µm Abrasive


Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 85 °C with 3-mil overdrive
Material removed by abrasive cleaning with 3-mil overdrive in linear mode
Probe Tip Length (mil)
0
1
2
3
4
5
6
7
W5
WRe5
W7
WRe7
W5
WRe5
W7
WRe7
Original Probe Tip Length
250K Touchdowns on Aluminum
7.5K Touchdowns on 3- µm Abrasive
500K Touchdowns on Aluminum
15K Touchdowns on 3- µm Abrasive

Summary

TIER 1 ONLY

- **No Benchmarking**

- **Probe Needle Wear**
  - Abrasive Cleaning
    - Cleaning pad material is dramatically harder than both probe materials
    - No significant differences in the amount of tip length removed
    - Wear rate "first approximations" based on 15K cleanings: 52 and 48 Å per touchdown for 5-mil and 7-mil probes, respectively
    - Wear rate = *f*(overtravel, scrub length, BCF, etch length, contact materials)

Summary

- **Probe Needle Wear**
  - Aluminum-wafer at 30^{o}C
    - Difference in wear behavior were observed for the 7-mil probes and not as severe for the 5-mil probes
    - Wear rate “first approximations” based on 500K touchdowns: 700, 560, 600, and 380 Å per 1K-touchdowns for W005, WRe005, W007, and WRe007, respectively
    - Hardness values of the 7-mil WRe-probes were significantly higher than those of the W-probes
    - The 5-mil probes had comparable hardness values and hence demonstrated similar wear characteristics
    - As the diameter of the probe needles decreases, the hardness of tungsten and tungsten-rhenium become similar

Summary

- **Probe Needle Wear**
  - Al-Wafer at 85^{o}C
    - Wear differences were exacerbated by the higher temperature
    - Wear rate “first approximations” based on 500K touchdowns: 1100, 700, 900, and 560 Å per 1K-touchdowns for W005, WRe005, W007, and WRe007, respectively
    - Increased temperature results in a thicker Al-oxide layer and a reduction in the probe needle hardness
    - Changes of the WRe-probe tip lengths were significantly less than those of the W-probes
    - Alloying with rhenium stabilizes the grain structure and hardness at high temperatures
    - The temperature dependent “softening” of WRe-probes is different than that of W-probes

Summary

- **Contact Resistance**
  - Al-Wafer at 30°C
    - C_{RES} consistency of the W-probes was affected by the wafer surface condition
    - W-probes demonstrated higher C_{RES} values on the “scrubbed” portion
    - WRe-probes demonstrated consistent C_{RES} values regardless of the wafer surface, i.e.“virgin” vs. “scrubbed”
  - Al-Wafer at 85°C
    - C_{RES} variance of all probe needles was greater at higher temperature
    - C_{RES} consistency of the W-probes was affected by the wafer surface condition; but not as dramatically as at room temperature
    - C_{RES} behavior of the WRe-probes was unaffected by the wafer surface condition
    - Overall, the WRe-probes demonstrated lower and consistent C_{RES} values

Summary

- **Probe Service Life Estimates**
  - “First approximations of the service life” for Tier 1 were made
  - Differences in probe tip wear are over-shadowed by abrasive cleaning
  - Service Life = f(temperature, current, overtravel, scrub length, BCF, cleaning frequency, and contact material)
  - The results indicate that WRe-probes would provide a longer service life than W-probes at high temperatures

- **Benefits of Tungsten-Rhenium**
  - At room temperature, WRe-probes provide C_{RES} consistency with slight improvements in wear that over-shadowed by abrasive cleaning
  - At high temperature, WRe-probes provide C_{RES} consistency and significant improvements in wear

Side Bar

- **Additional Observations**
  - C_{RES} values of probes that never touched a wafer were higher than expected
  - Cleaning was performed and C_{RES} values were considerably reduced
  - Contamination on probe tip surface - tungsten-oxide? other residue? who really knows?
- **Future Work**
  - Analysis of Tier 2 and Tier 3 behavior