BiTS™

Burn-in & Test Socket Workshop

March 6-9, 2005
Hilton Phoenix East / Mesa Hotel
Mesa, Arizona

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Burn-in & Test
Socket Workshop

Technical Program

Session 1

Monday 3/07/05 8:30AM

MAKING BETTER CONTACT

"Enhanced High Strength/High Conductivity Copper-Beryllium Strip For Demanding BiTS Applications"

John C. Harkness - Brush Wellman Inc.

"Challenges Of Contacting Lead-Free Devices"

Brian William Sheposh – Johnstech International

"Application Of Socket Cleaning And Contact Restoration To Reduce Burn-In, Test & Device Programming Cost"

Erik Orwoll – Nu Signal LLC **Jason Hughes** – IBM Microelectronics

Enhanced High Strength/ High Conductivity Copper-Beryllium Strip for Demanding BiTS Applications

John C. Harkness FASM
Brush Wellman Inc.

Burn-in & Test
Socket Workshop

2005 Burn-in and Test
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Outline

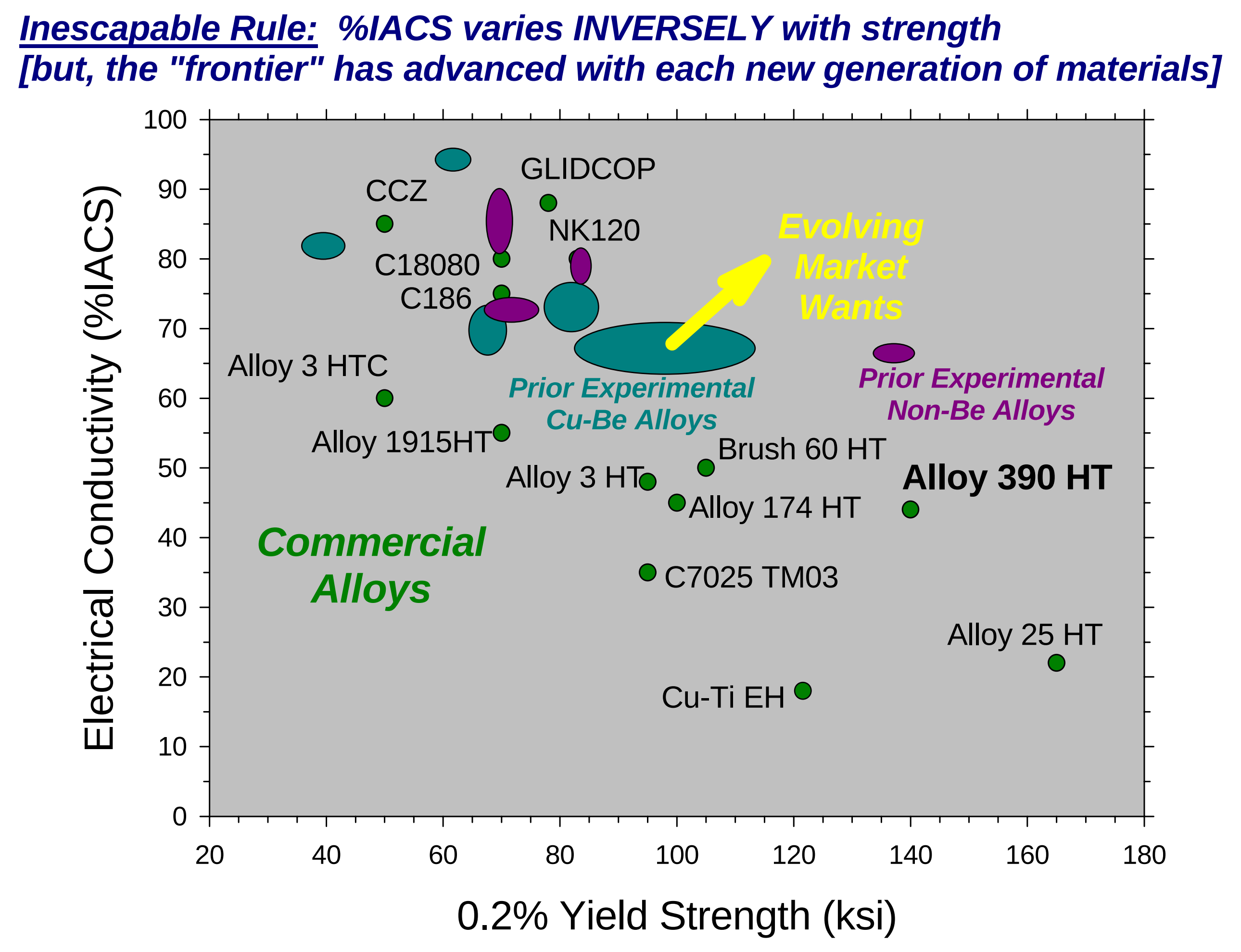
- BiTS -- materials challenges
- %IACS vs. YS in Cu alloys … then & now
- Brushform 65™ & Alloy 390™
  - Product development methodology
  - Chemistry, mechanical/physical props
  - Conductivity vs. T
  - Stress relaxation
- Alloy comparisons
- BiTS applications feedback
- Summary

BiTS Materials Challenges

- Driving Forces
  - Larger wafers, smaller pitch, higher pin count, shorter contacts create new problems in ...
    - Fabrication
    - Co-planarity
    - Compliance
  - Thermal management
  - Higher power/lower voltage
  - Long socket life (cycles)
    - Performance stability

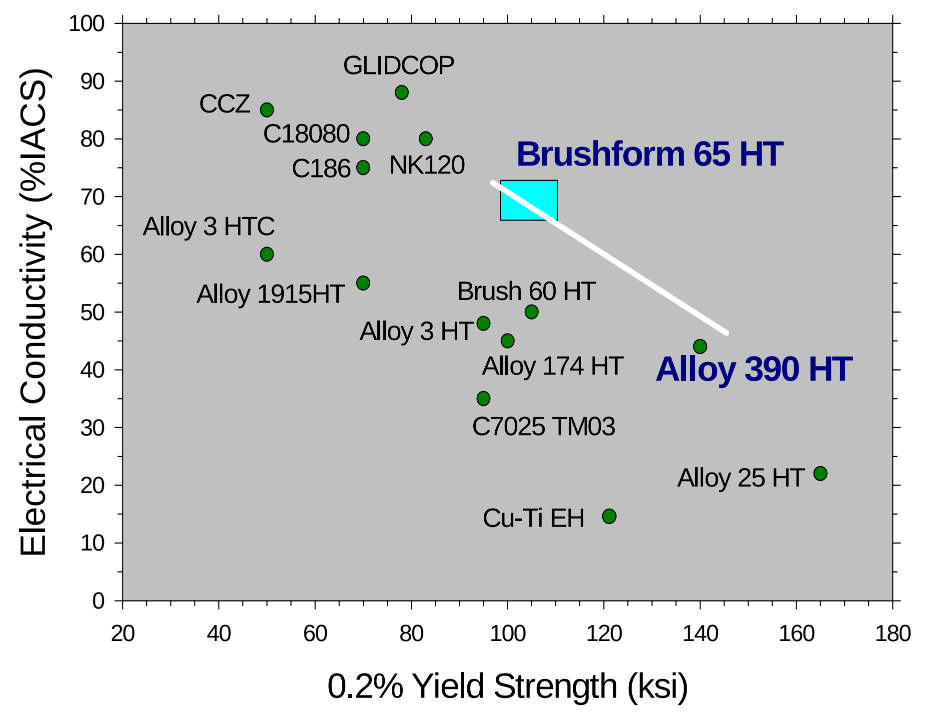
- Base Metal Requirements
  - High yield strength
  - Moderate elastic modulus
  - Good formability
  - High electrical & thermal conductivity
  - Good stress relaxation resistance
  - Good fatigue strength
  - Low/uniform residual stress

Historical Conductivity vs. Strength Relationships in Cu Alloys



A New Shift in the %IACS vs. YS Frontier

- ***Brushform 65™ HT Strip***
  - **Strength & formability of prior high performance Cu-Be alloys (Alloy 3, Brush 60™, Alloy 174™)**
  - **Net 15-20 %IACS *greater* electrical conductivity**
- ***Alloy 390 HT™ Strip***
  - **Conductivity of prior high performance Cu-Be alloys**
  - **Nominal 40 ksi *higher* YS**
- **Existing UNS Cu-Be chemistry & proprietary mill hardening processes**
  - ***Consistent* properties & residual stress**



Outputs of Brush Wellman's "Stage Gate" New Product Development Process

“Stage Gate” New Product Development Process (I)

- Identify a new competitive product with a good value proposition for the customer
- Market/customer focus
- Benchmark vs. competing & historical products
- Front-end planning
- Early & clearly defined product attributes
- Cross-functional team & champion

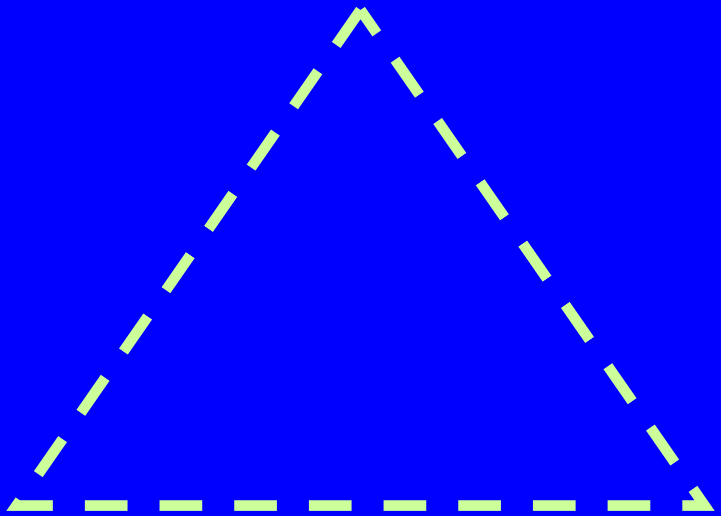
“Stage Gate” New Product Development Process (II)

- Work to company strengths
- Tough new product launch criteria
- Rigorous/disciplined process -- tough “go/no go” criteria
- Speed -- but not at expense of execution quality
- Detailed/high quality execution of each project phase

Partnering for Success in Next Generation BiTS (Harsh Environments)

Design requirements

OEM



Material Supplier (Brush Wellman)

Alloy development, sample material,
production inventory, technical support

Socket Maker

Trial stamping, testing,
performance feedback

Alloy 390^{TM} HT
Data Sheet (I)

C17460 = (0.15-0.5)Be-(1.00-1.40)Ni-0.5maxZr-Cu

Physical Property	English Units	Metric Units
Density	0.318 lb/in^3	8.81 g/cm^3
Melting Range	1975F–1880F	1080C-1030C
Electrical Cond. (Room T)	***44 %IACS min.***	0.38 Megmho-cm
Thermal Cond.	***135 BTU/hr ft F (@ 200 F)***	235 W/mK (@ 100 C)

Alloy 390^{TM} HT
Data Sheet (II)

Mech. Property	English Units	Metric Units
0.2% YS	***135-153 ksi***	***930-1055 MPa***
UTS	138-158 ksi	950-1090 MPa
Elongation	1% min	1% min
Elastic Modulus	20 msi	138 GPa
Hardness (DPH)	275-340	275-340
90 deg Bend*	2 R/t GW & BW	2 R/t GW & BW

*** Up to 0.004 in. (0.10 mm) thick**

Brushform 65™
PRELIMINARY Data Sheet (I)
C17460 = (0.15-0.5)Be-(1.00-1.40)Ni-0.5maxZr-Cu

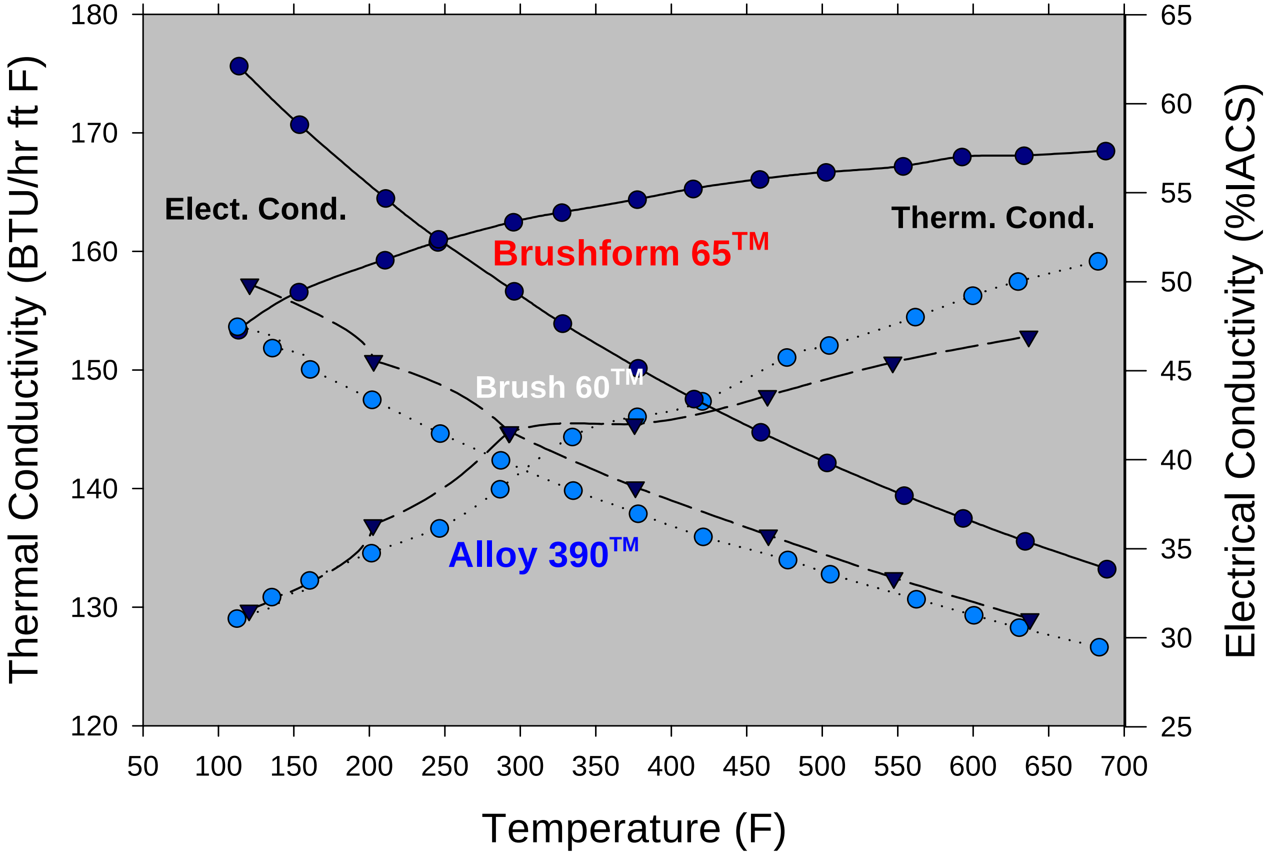
Physical Property	English Units	Metric Units
Density	0.318 lb/in^3	8.81 g/cm^3
Melting Range	1975F–1880F	1080C-1030C
Electrical Cond. (Room T)	***65 %IACS min.***	0.56 Megmho-cm
Thermal Cond.	***160 BTU/hr ft F (@ 200 F)***	275 W/mK (@ 100 C)

Brushform 65™
PRELIMINARY Data Sheet (II)

Mech. Property	English Units	Metric Units
0.2% YS	***100 ksi min.***	***689 Mpa min.***
UTS	110 ksi min.	758 MPa min.
Elongation	5% min.	5% min.
Elastic Modulus	20 msi	138 GPa
Hardness	225 DPH min.	225 DPH min.
90 deg Bend (Nom. 0.006 in.)	1.3 R/t GW & BW	1.3 R/t GW & BW

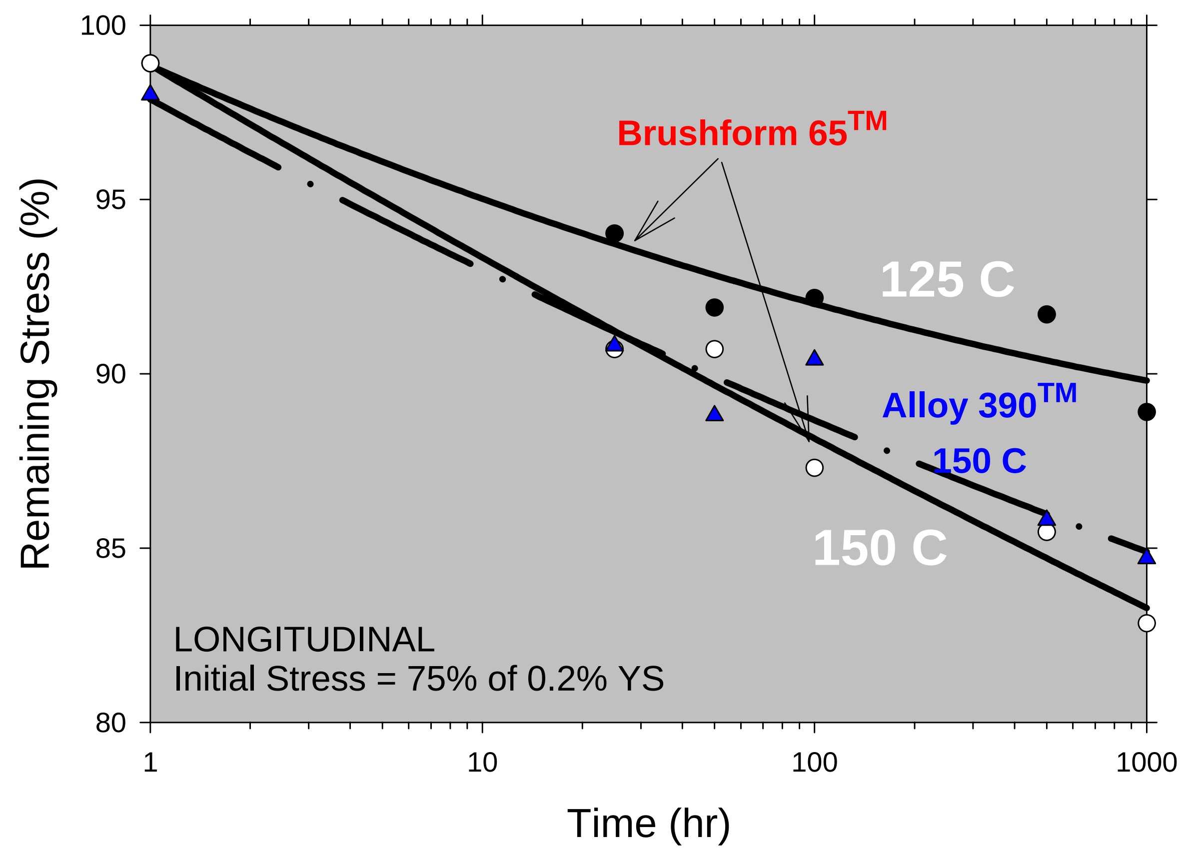
Enhanced Electrical & Thermal Conductivity

Brushform 65^{TM} HT Strip



Good Stress Relaxation Resistance

Alloy 390^{TM} & Brushform 65^{TM}



Alloys for Comparison

Alloy	0.2%YS (ksi)	El. Cond. (%IACS)	T Cond. W/mK	90 deg R/t (GW/BW)	150 C/1k hr (%RS)
190 HM	110	17	105	2/2	74
3 HT	95	48	238	2/2	85
Brush 60™ HT	105	50	220	1.5/1.5	89
Alloy 390™ HT	140	45	220	2/2	85
Brushform™ 65 HT	100	65	275	1.3/1.3	83
C7025 TM02	85	35	170	2.5/2.5	88
C199 EH	114	12	55	2/6	98
C18080	72	82	320	2/1	>88

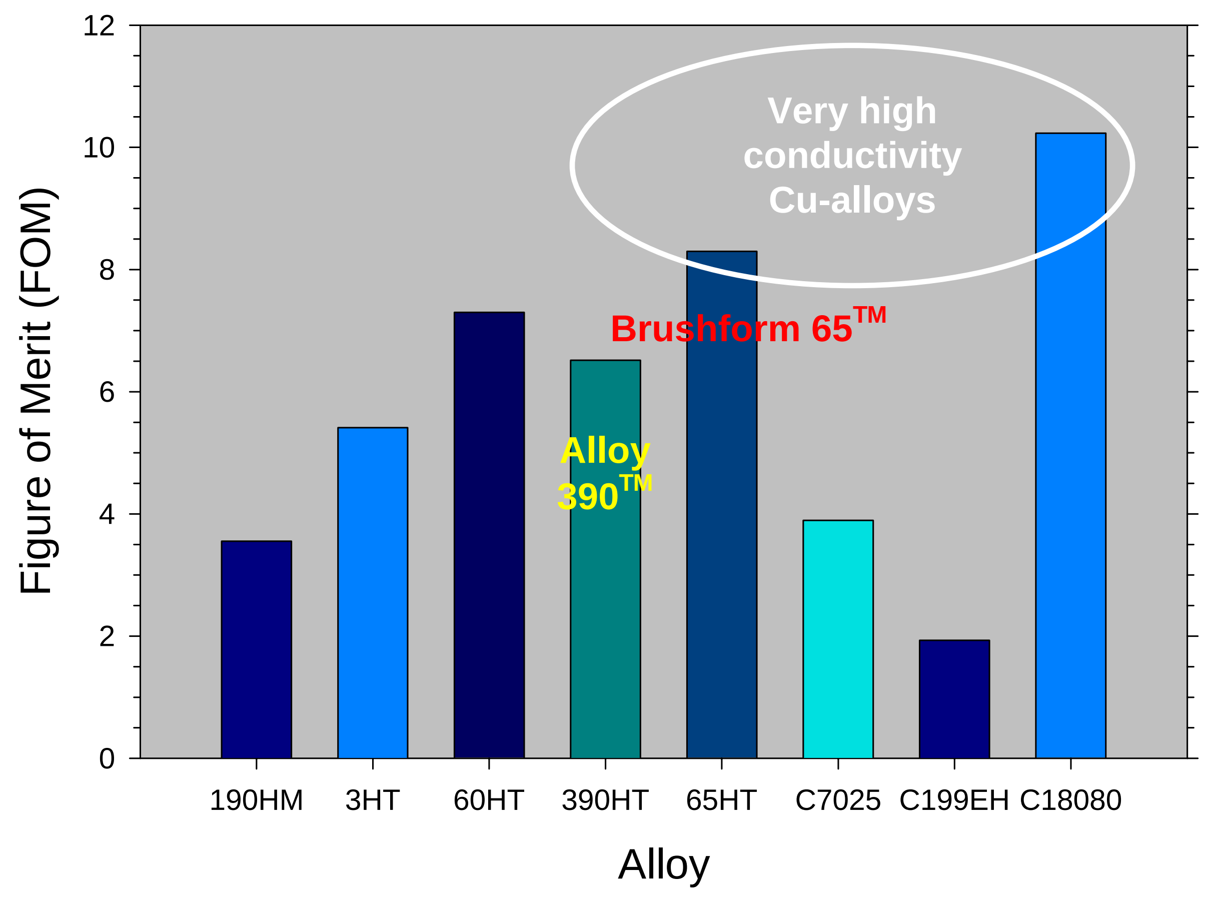
Non-Be alloy data from manufacturer’s data sheet and/or sample exam

Connector Alloy Performance “Figure of Merit”

$$\mathrm{FOM} = \frac{(\mathrm{YS} + 2 \times \%\mathrm{IACS}) \times \%\mathrm{RS}}{(1 + \mathrm{BWR/t}) \times 1000}$$

- **Numerator: Increasing property value -- improves performance**
- **Denominator: Decreasing property value -- improves performance**
  - **“(1 + BWR/t)” enables 0 R/t value entry**
  - **“1000” = normalizing factor to keep FOM << 100**

Alloy Comparison: "Figure of Merit"



Temperature Rise

- Function of the bulk resistivity of the material
- More important as contacts become smaller, with increased current carrying requirements

current

beam length

change in
temperature

$$\Delta T = \frac{J^2 l^2}{2\gamma k A^2}$$

area

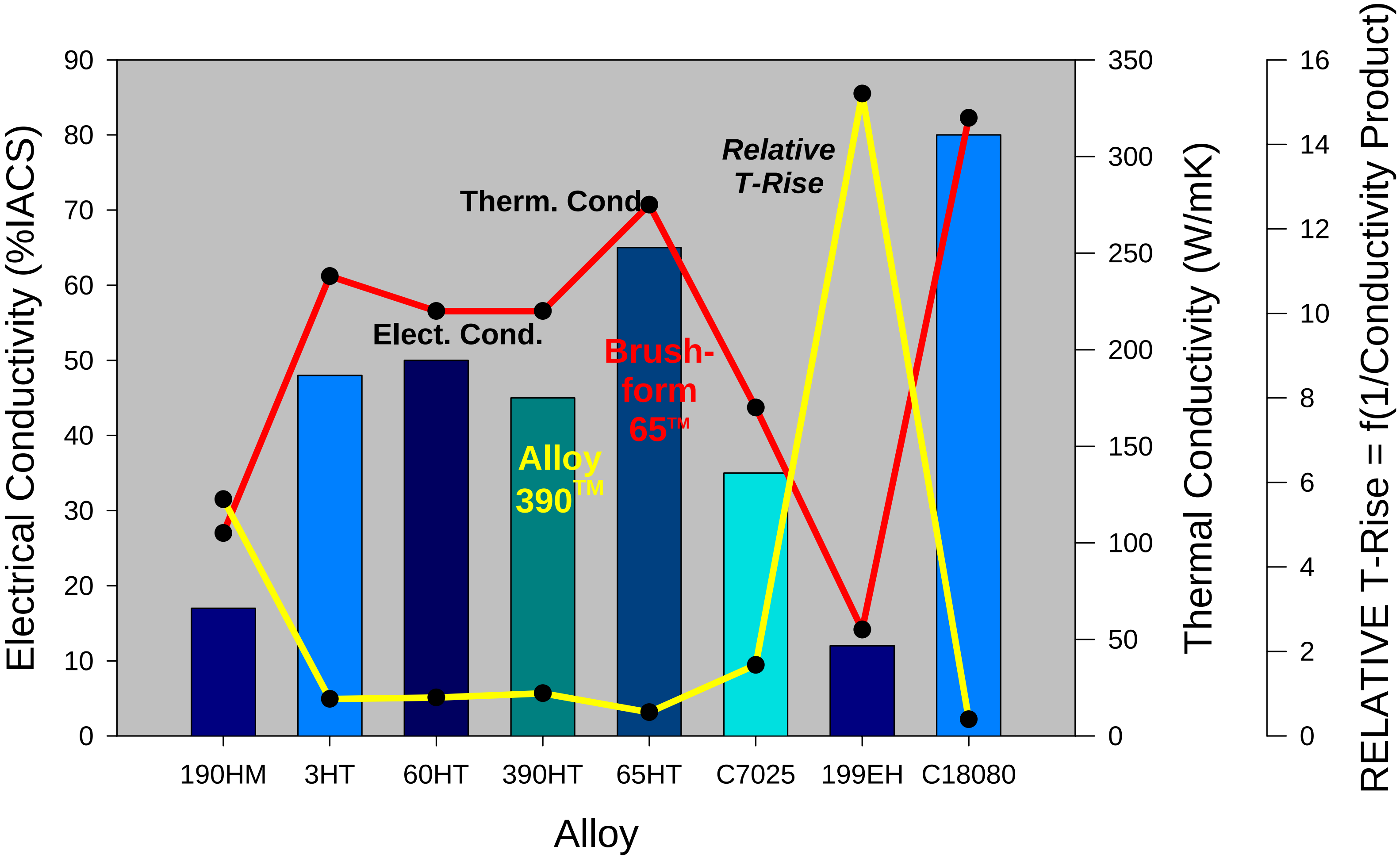
electrical
conductivity

thermal conductivity

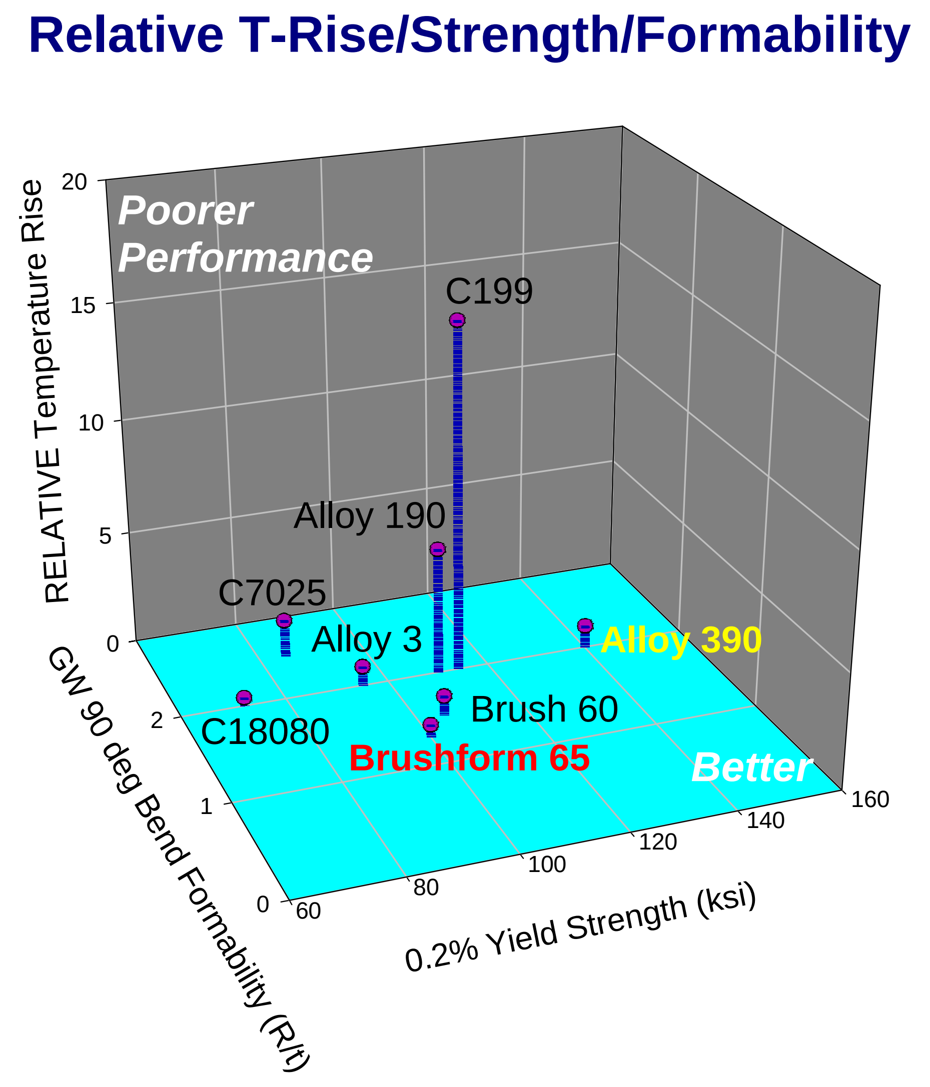
[Conductivity Product]

Does not take heat transfer via CONVECTION or RADIATION into account

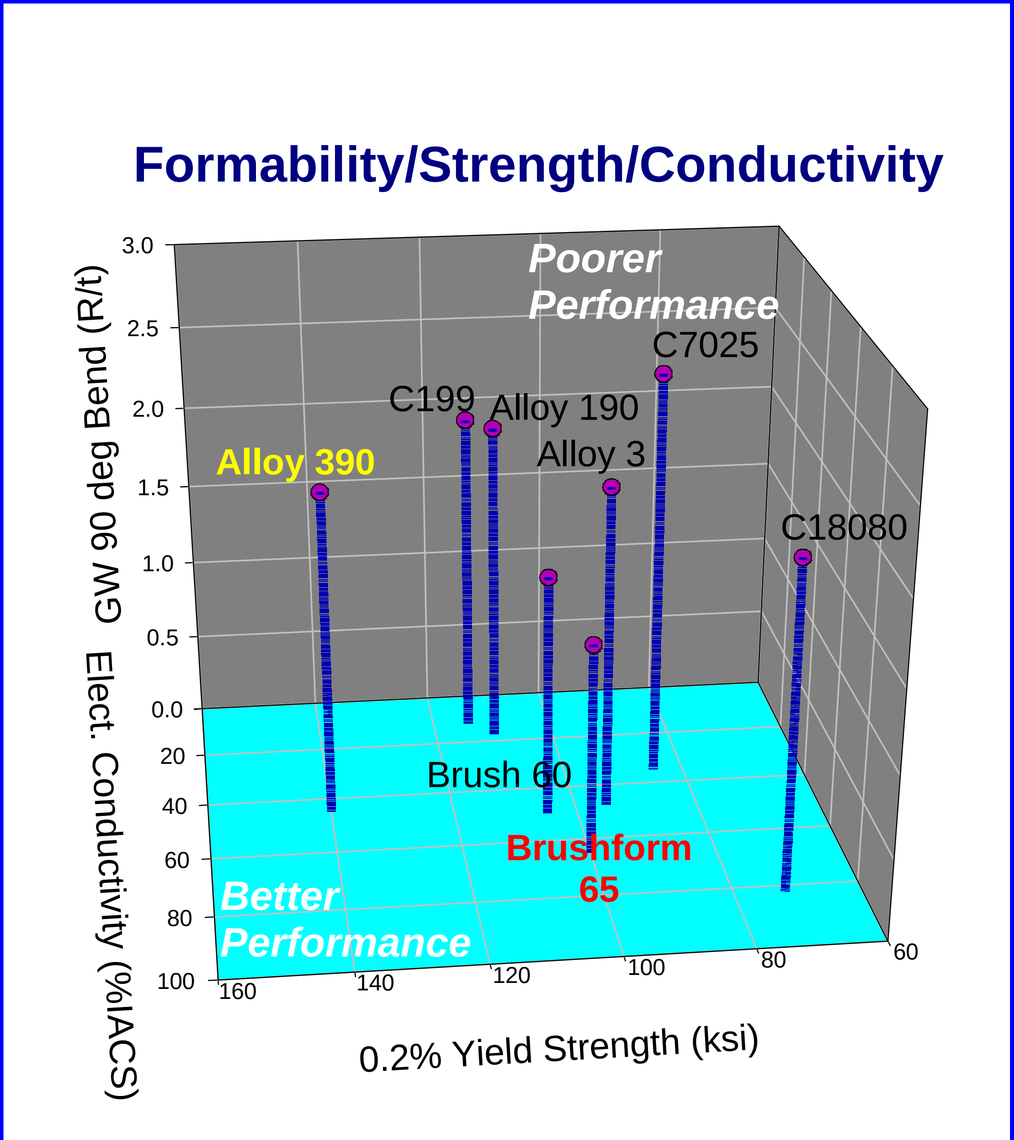
Alloy Comparison: Relative T-Rise



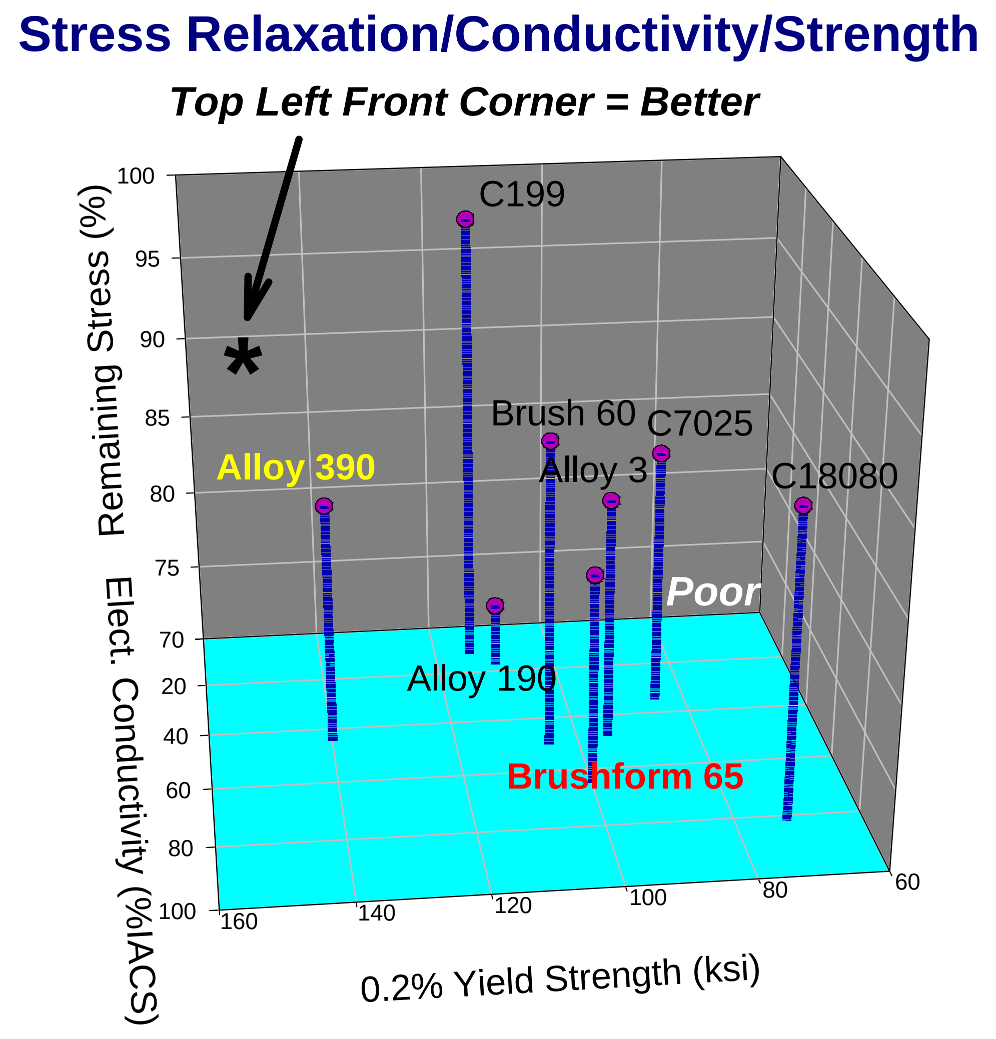
3-Attribute Comparison (I)



3-Attribute Alloy Comparisons (II)



3-Attribute Alloy Comparisons (III)



Alloy 390^{TM} HT in BiTS

- "Proven technology" in on-going BiTS applications
  - LGA (strength)
  - **Low power** (44 %IACS)
    - But less T-rise than lower %IACS Cu-alloys
  - Meets demanding performance requirements
    - Mill hardened
      - No heat treat distortion issues
      - Uniform residual stress -- high stamping yield
      - Consistent strength/hardness
    - Meets higher spring force requirements
    - Passes increased cycle life test standards

Brushform 65^{TM} in BiTS

- “Alpha customer” trials feedback (**POWER** apps.)
  - Stampability similar to other 100 ksi Cu-alloys
  - > 25% improvement in specific resistance vs. Alloy 390 (65 %IACS vs. 44 %IACS)
  - 14% increase in Amperage carried vs. Alloy 390
    - Improved **current carrying capacity**
  - Trial stamping in tooling for higher YS alloy unintentionally compromised mechanical performance
    - Different elastic springback (dimensional control)
    - Higher initial permanent set (minor design change could overcome -- offset by benefits of greater electrical performance)

Summary (I)

- **Brushform 65^{TM} HT** & **Alloy 390^{TM} HT** meet BiTS material challenges for demanding applications
  - Results of a rigorous “stage gate” New Product Development Process
  - Examples of OEM/Stamper/Supplier partnership for success in next generation BiTS for harsh applications
- Both alloys exhibit good stress relaxation resistance and provide desirable 3-attribute combinations
  - Relative T-rise/strength/formability
  - Formability/strength/conductivity
  - Stress relaxation/strength/conductivity

Summary (II)

- **Alloy 390^{TM} HT** is a lean Cu-Be strip product with **enhanced strength** relative to traditional “high conductivity” Cu-Be alloys
  - Performance Figure of Merit > competitive non-Be Cu-alloys of similar or lower %IACS
  - Strength within the mill hardened “high strength” Cu-Be alloy range, with 44 %IACS minimum
  - Established in on-going LOW POWER BiTS applications
    - Consistent residual stress & strength, high cycle life

Summary (III)

- **Brushform 65^{TM}** is a new lean Cu-Ni-Be strip product with **enhanced conductivity/strength combination** relative to all other Cu-base connector alloys
  - Performance Figure of Merit in the same league as competitive very high conductivity Cu alloys
  - High "conductivity product" = low temperature rise
  - BiTS application trials (HIGH CURRENT/POWER)
    - Good stampability
    - Improved specific resistance & current carrying capacity vs. Alloy 390^{TM}
    - NO insurmountable mechanical performance issues

Challenges of Contacting Lead-Free Devices

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BiTS Burn-in & Test Socket Workshop ™

Brian William Sheposh

Johnstech International

Discussion Topics

- Defining Interconnect Success
- Lead-free Material Trends and Applications
- Specifics of Lead-Free Alloys
- The Impact on Interconnect Success
- Conclusion: Achieving Interconnect Success

Interconnect Success

- **Goal: Minimize and sustain the junction resistance between the device lead and contact.**

$$R_{total} = R_c + R_{film}$$

<u>Constriction</u>

$R_c \propto F^{-1/2}$ **(force) ;** $R_c \propto \rho_{tip}$ **(plating)**

<u>Film</u>

$R_{film} >> R_C$ **(oxide, debris)**

Challenges to Interconnect Success

- **Maintaining bias throughout product life.** $\boxed{R_c \propto F^{-1/2}}$
- **R_{film} develops on the surface of the contact over insertion (debris and oxide).** $\boxed{R_{film} >> R_C}$
- **Wear of the contact tip can compromise the interconnect integrity:** $\boxed{R_c \propto \rho_{tip}}$ $\boxed{R_c \propto F^{-1/2}}$
  - Plating (contact under-plate metallic oxidizes)
  - Function (wipe, piercing, etc.)

Industry Lead-Free Trends

- **Leaded and Pad Packages**
  - Matte Sn
  - NiPd ; NiPdAu
  - SnBi
  - Au
- **Ball Grid Array Packages (BGA)**
  - $SnAg_{3.0\text{-}4.0}Cu_{0.5}$

Challenges in the Field

- **Matte Sn**
  - Customers see faster rise in resistance which leads to more frequent cleaning when compared to SnPb.
  - Reduced contact life has been observed vs. SnPb, but not as great as with NiPdAu.
- **NiPdAu**
  - Customers observe good contact resistance until the contact plating wears, which promotes a drastic drop in 1st pass yields.
  - Contact life is much less when testing NiPdAu vs. Sn Pb.

Qualification of Interconnect Success

- **Contactor Designs**
- **BGA Contactor**
  - $Sn_{63}Pb_{37}$ eutectic
  - $Sn_{95.5}Ag_{4.0}Cu_{0.5}$
- **Pad Contactor : ROL200 Design**
  - $Sn_{90}Pb_{10}$
  - Matte Sn_{100}
  - NiPdAu

Qualification of Interconnect Success

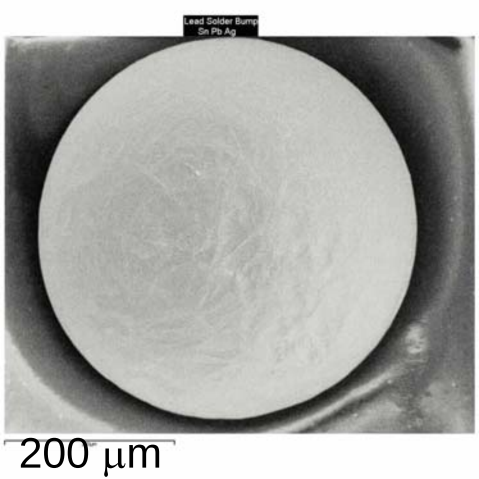
- **Contacts were populated into a contactor and mounted to a test board.**
- **Force Testing: Contact force was measured in real-time as devices were inserted into the contactor.**
- **Resistance Testing: The test board and devices were designed so that four-point Kelvin resistance measurements were made across pairs of contacts throughout the contactor.**

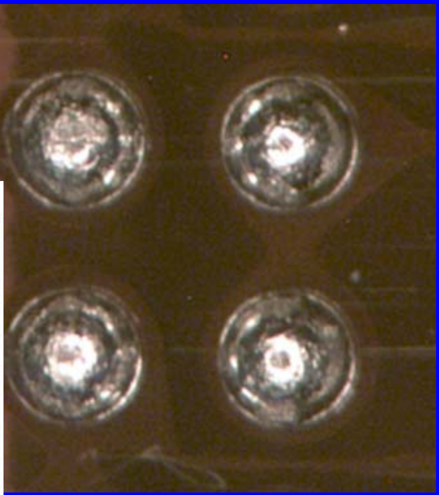
Qualification of Interconnect Success

- **Resistance Testing cont.: Packaged devices were cycled through the contactor and Kelvin resistance measurements were recorded:**
  - BGA Devices: Each device was cycled ten times with resistance readings at the first and sixth insertion (reduce cost)
  - Pad Devices: Each device was cycled only once, insuring virgin plating material on each insertion.

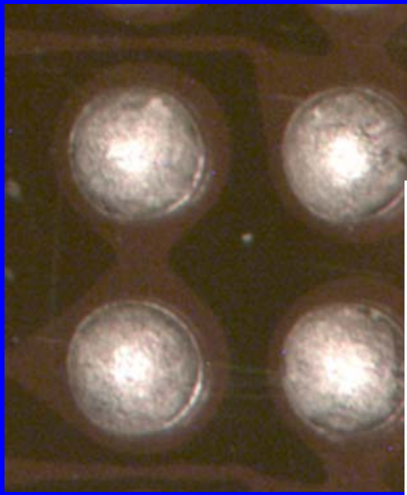
SnAgCu Balls
Physical Appearance

- **A dull, grainy, matte finish on the SnAgCu balls due to the formation of pure Sn dendrites on the surface of the ball.**

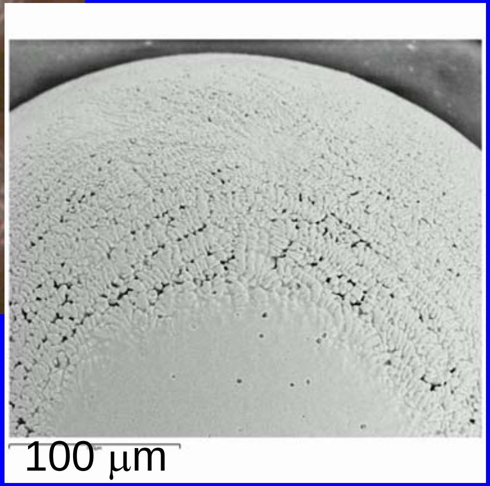




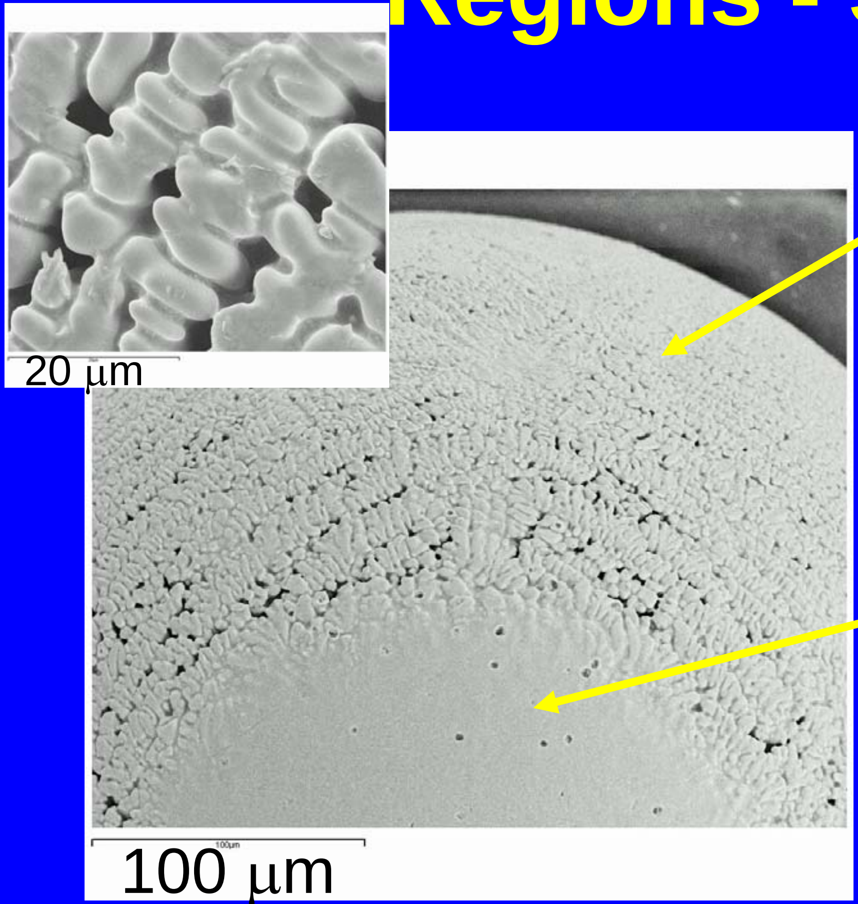
SnPb



SnAgCu



EDS Spectrum of Dendrite Rich Regions - SnAgCu Balls



Average composition in dendritic rich region

Sn	99.8%
Cu	0.2%
Ag	<0.1%

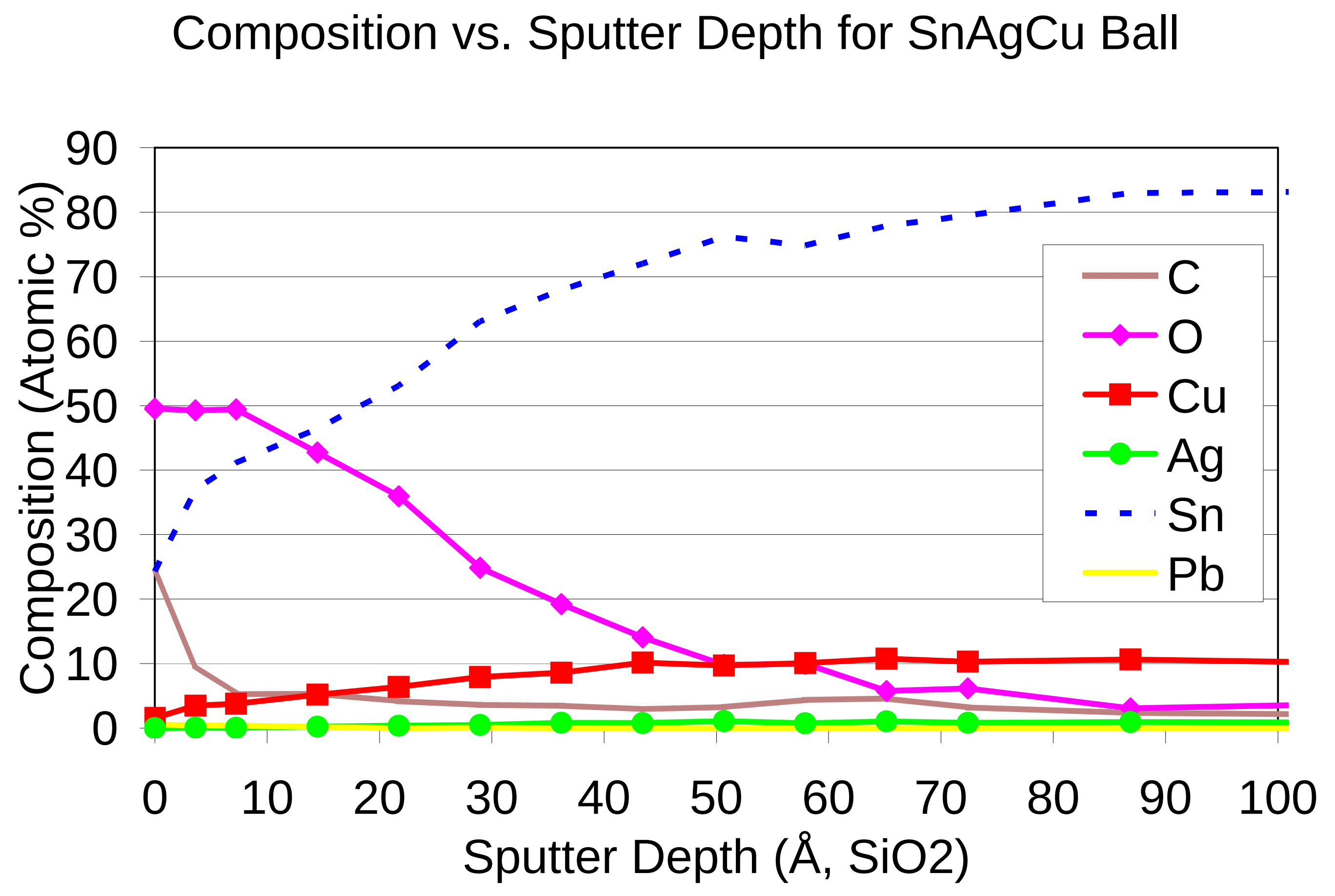
Average composition in non-dendritic region

Sn	96.1%
Cu	2.3%
Ag	1.6%

XPS Analysis of SnPb and SnAgCu Balls

- <u>XPS: X-Ray Photoelectron Spectroscopy</u>
- A beam of x-rays was focused on the sample surface, which generates photoelectrons that are energy analyzed and counted.
- The atomic composition and chemistry of the sample surface can be determined from the emitted photoelectrons.
- Oxide thickness was defined as the depth at which the oxygen concentration fell to 50% of its peak value.

XPS Analysis of SnAgCu Balls



Oxide Depth ≈ 29Å

Å = 10^{-10}

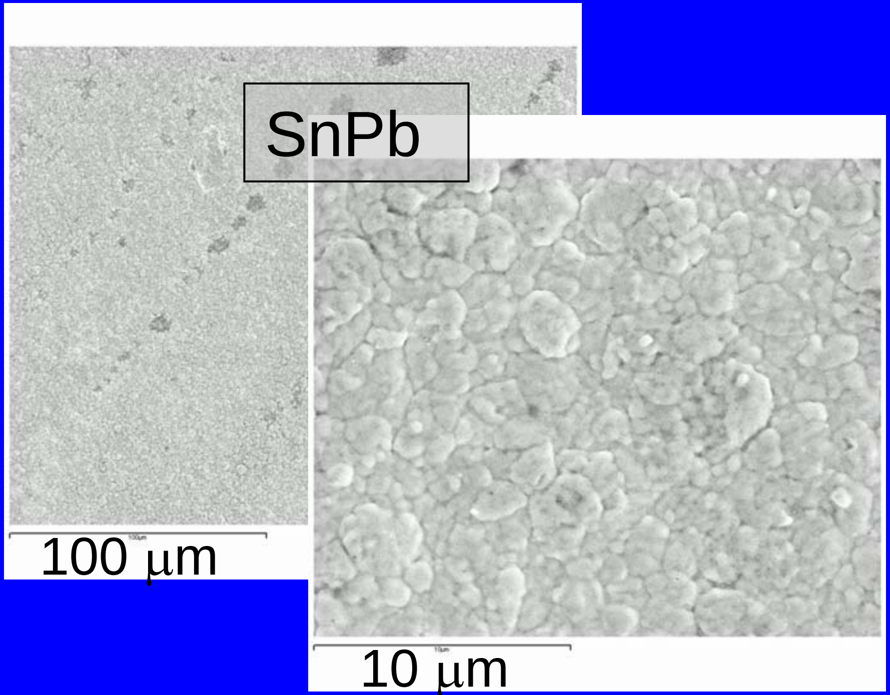
angstrom

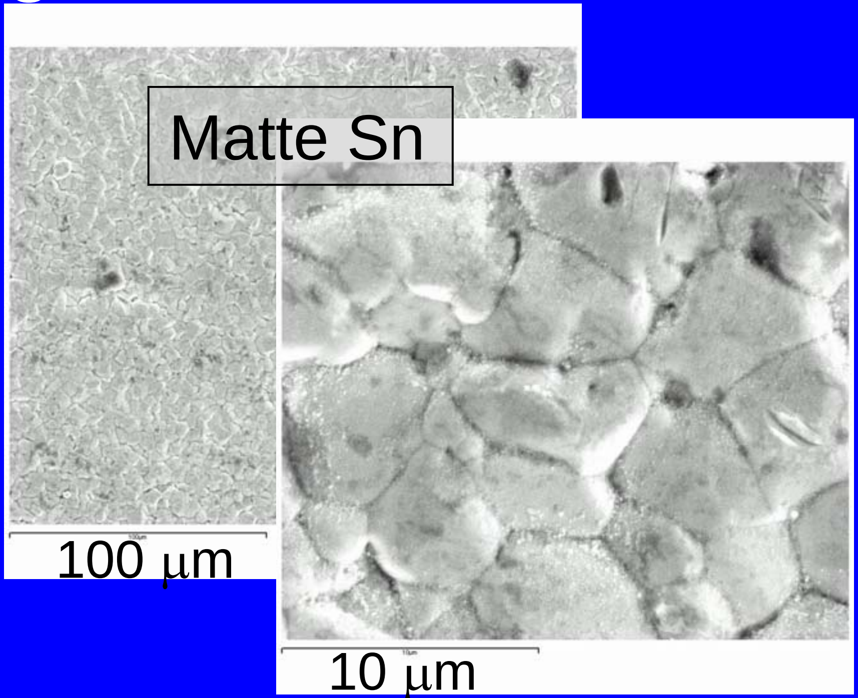
XPS/SEM Analysis of SnPb and SnAgCu Balls

- **Conclusions From XPS and SEM:**
  - Both SnPb and SnAgCu had Sn oxide dominated layers of approx. 29Å.
  - Surface roughness of the SnAgCu was much greater than that of SnPb and caused by pure Sn dendrites.
  - No Sn dendritic growth was observed with SnPb balls.

Matte Sn Pad
Physical Appearance

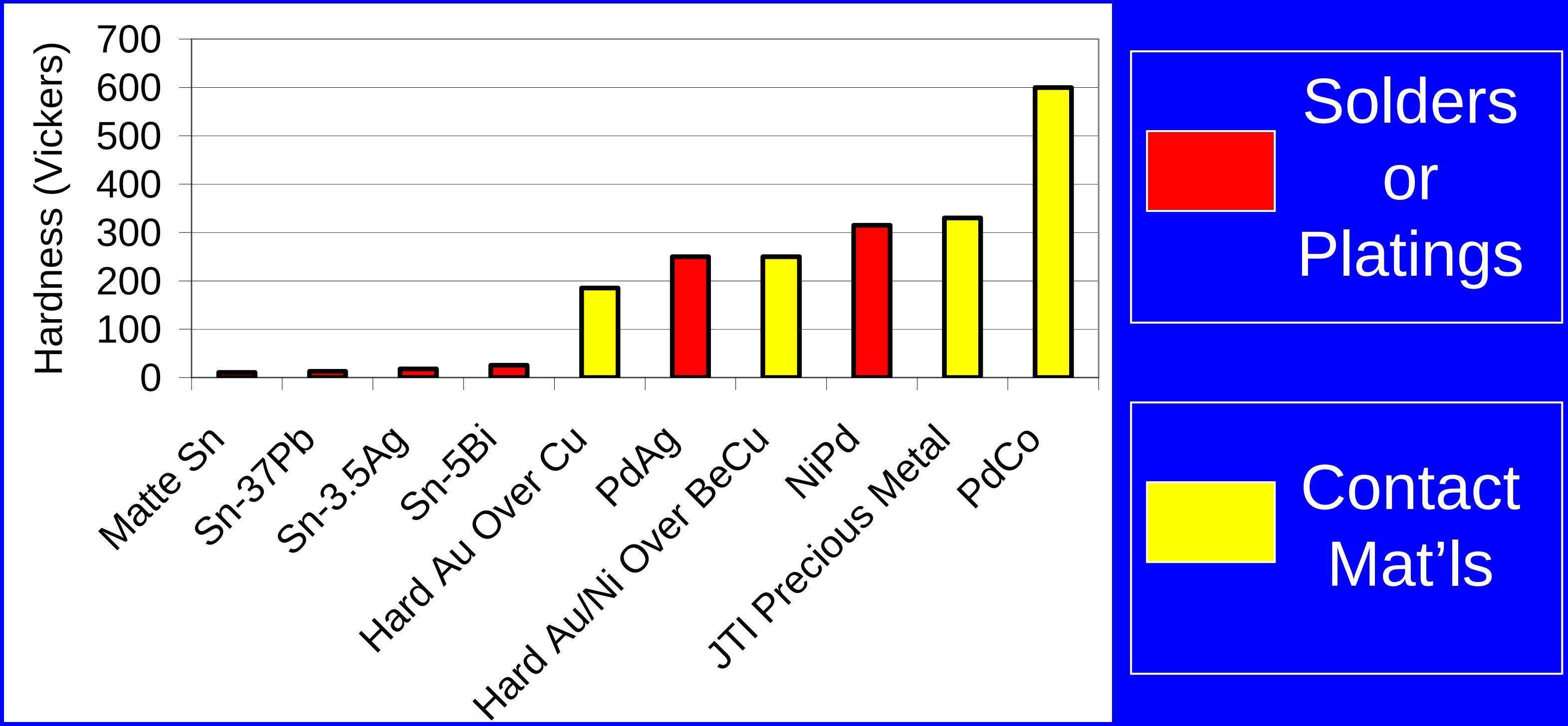
- **Matte Sn pad surfaces were observed having large, Sn-rich grains.**



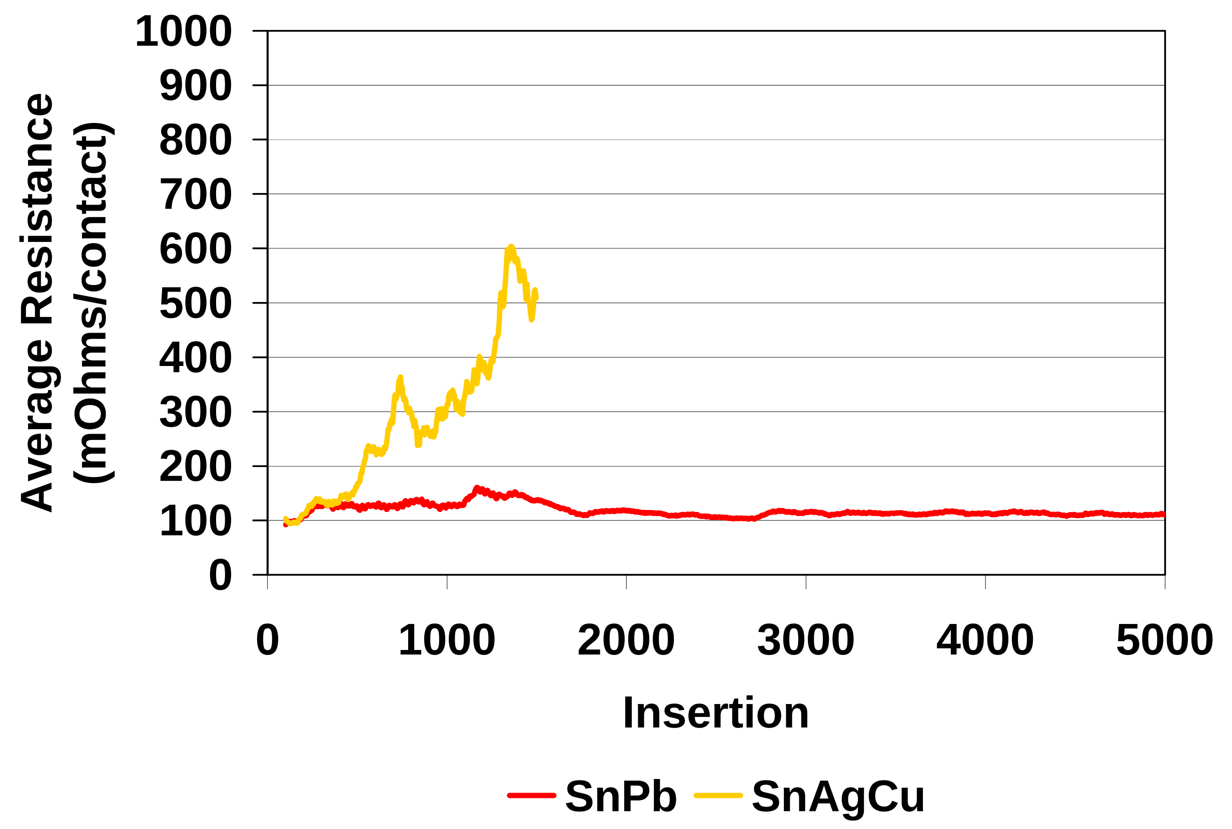


NiPdAu Pad Properties

- **NiPdAu plating is approximately 20x harder than standard solder alloys.**



SnPb vs. SnAgCu BGA Resistance Performance



Approximate

Force = 17gm

SnPb

Avg = 118mΩ

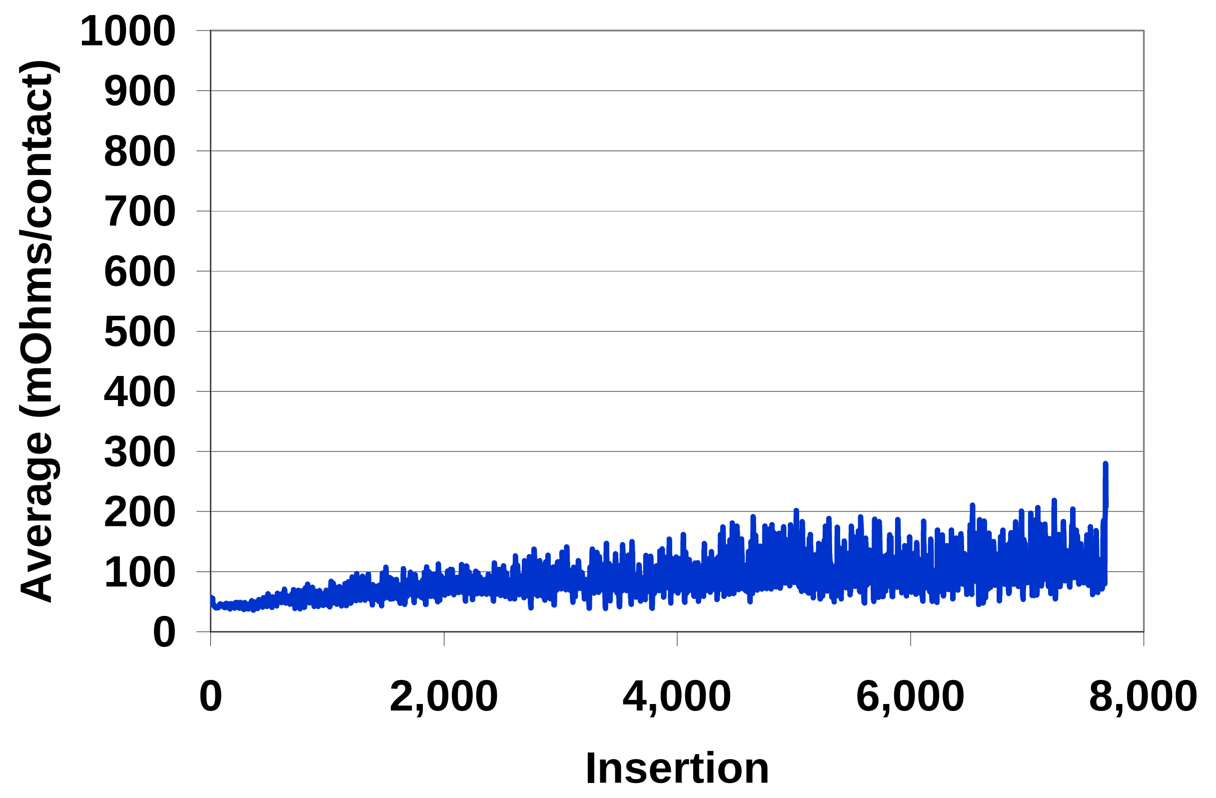
Stdev = 43mΩ

SnAgCu

Avg = 389mΩ

Stdev = 490mΩ

Increased Force BGA
SnAgCu Resistance Performance



Approximate

Force = 50gm

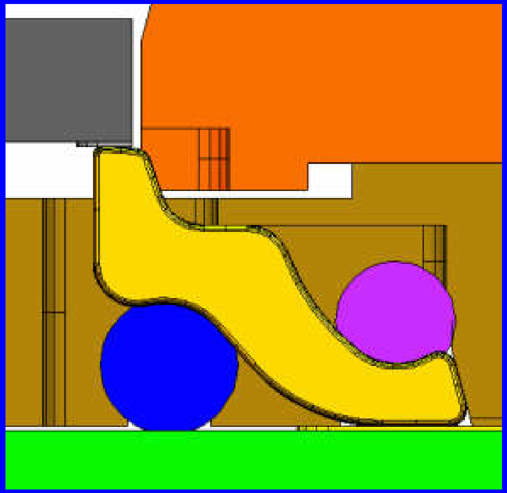
SnAgCu

Avg = 91mΩ

Stdev = 47mΩ

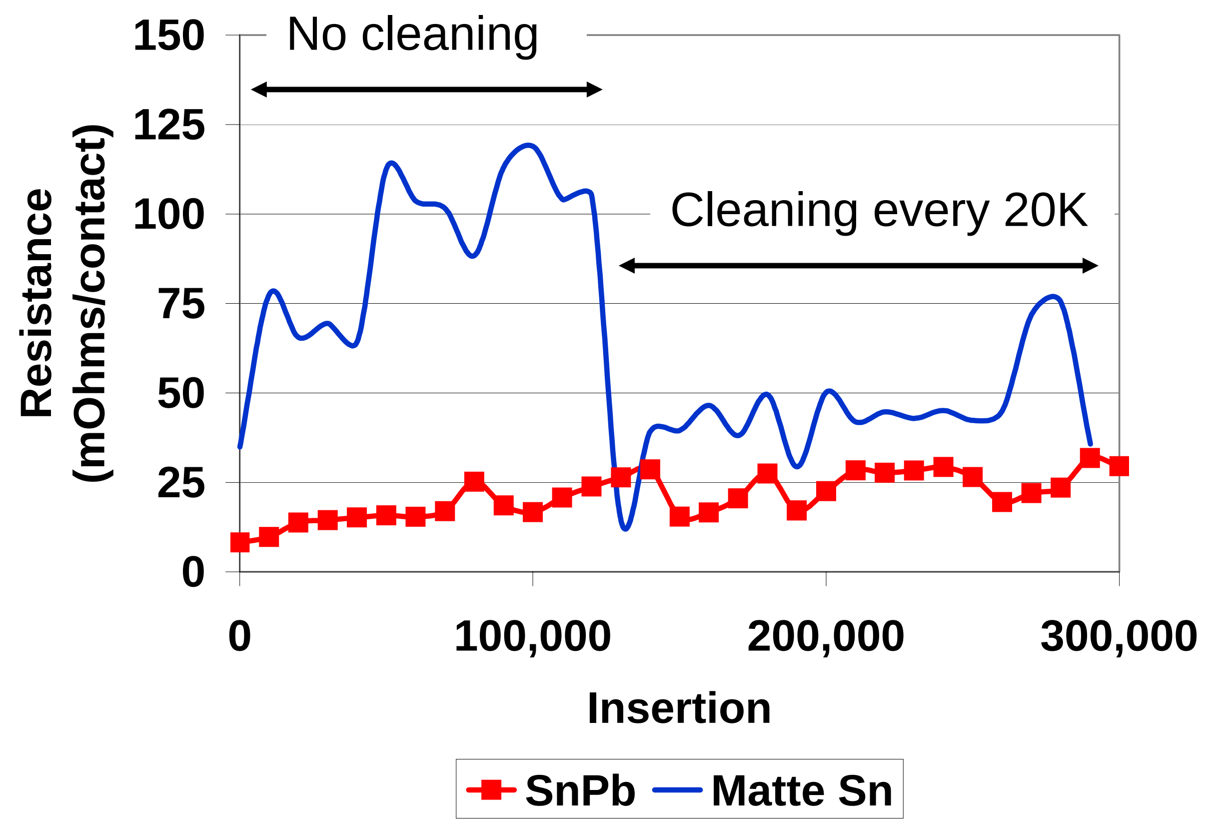
Matte Sn and NiPdAu Qualification Pad ROL200 Design

- **Utilizes non-plated contact of hardness >350 Vickers, with two elastomers to create device and load board bias.**
- **Tangential scrub action on the device. Contact rolling action on the load board.**
- **Manufactured for testing with:**
  - 48QFN07-0.50



*Data from this design will be discussed within this presentation

SnPb vs. Matte Sn Pad ROL200 Resistance Performance



Sn: No Clean

Avg = 92mΩ

Stdev = 43mΩ

Sn: Clean @ 20K

Avg = 48mΩ

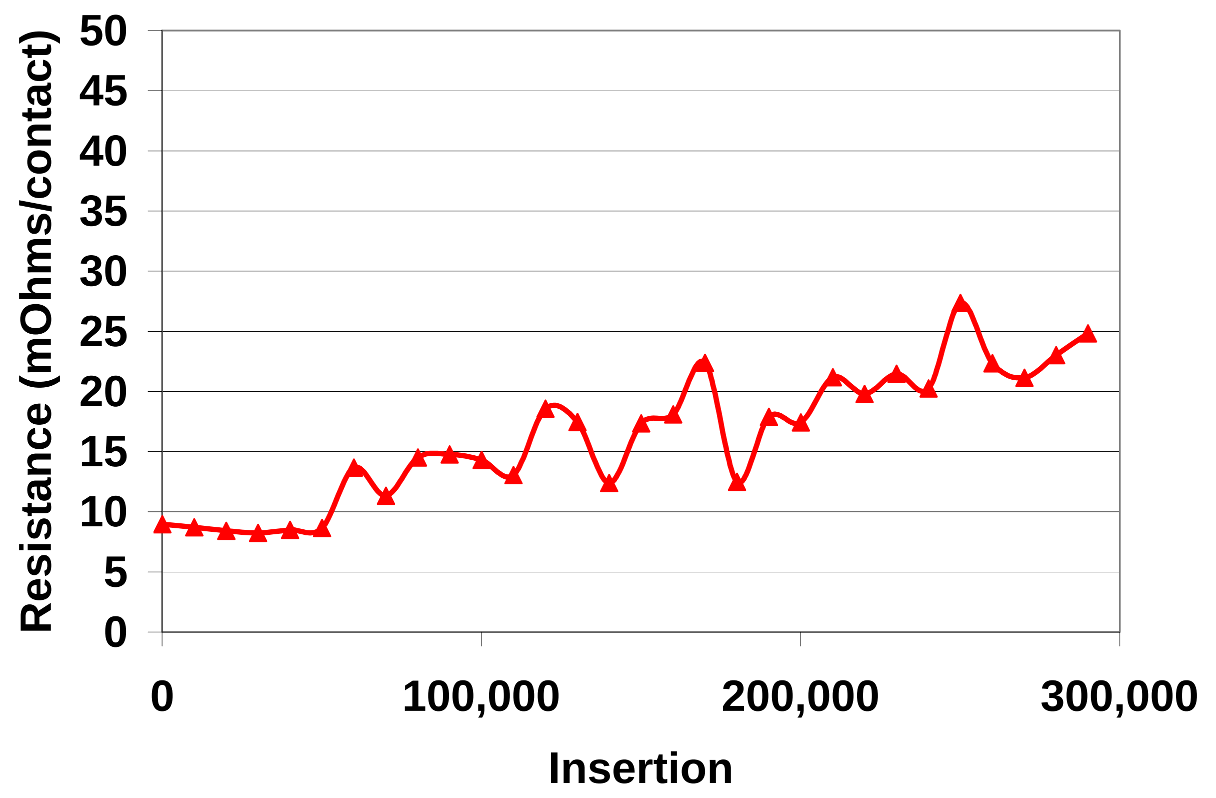
Stdev = 35mΩ

SnPb - No Clean

Avg = 28mΩ

Stdev = 5mΩ

NiPdAu Pad ROL200 Resistance Performance



<u>NiPdAu</u>

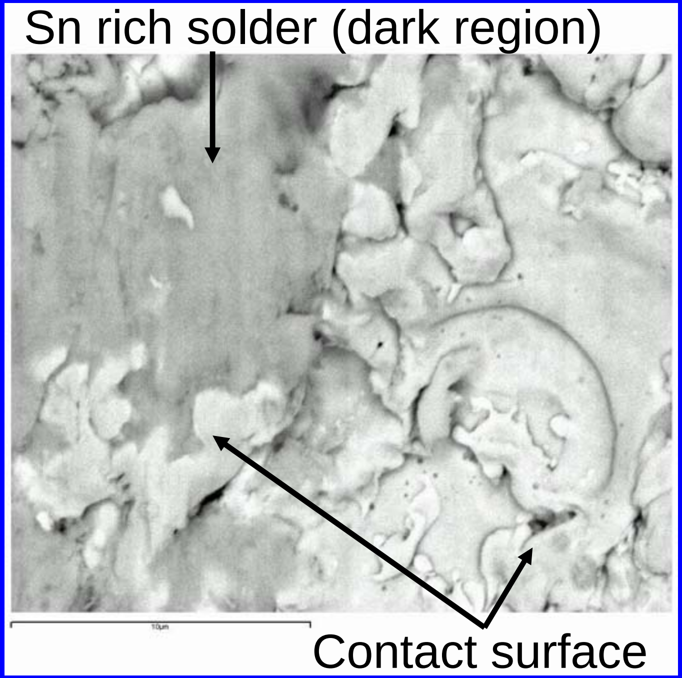
Avg = 16mΩ

Stdev = 12mΩ

Conclusions

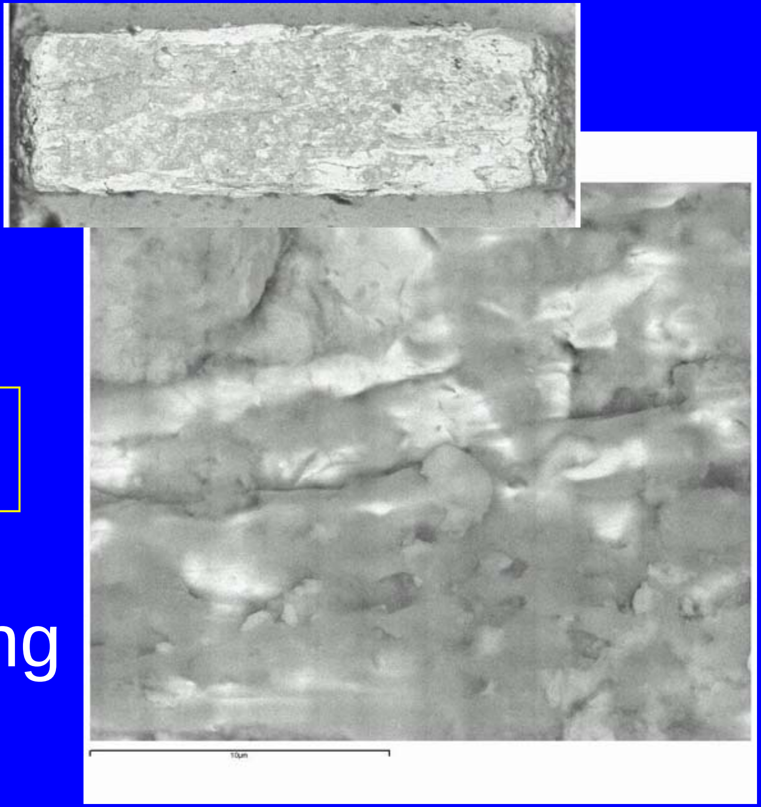
- **SnAgCu Evaluation**
  - Sn rich solder smears in the contact surface over insertion, creating resistance rise.

$$\boxed{R_{film} >> R_C}$$



  - Increase in force, combined with a self-cleaning function aids in maintaining of nominal resistance performance.

Conclusions



- **Matte Sn Evaluation**
  - Pure Sn tend to smear and cover the contact surface.
  - A prescribed cleaning cycle aids in maintaining low resistance values, while promoting long contact life.

$R_{film} >> R_C$

Conclusions

- **NiPdAu Evaluation**
  - Debris/oxide presence was not detected and does not pose a problem to resistance performance. Cleaning wasn't necessary during this test.
  - Wear on un-plated contacts will reduce the force over insertion, thus increasing the variation in contact resistance.

$$\boxed{R_c \propto F^{-1/2}}$$

Proposition for Interconnect Success

- **SnAgCu and Matte Sn (Maintain Low R)**
  - The right combination of force and self-cleaning scrub eliminate Sn build-up on the contacts which will reduce cleaning frequency. (Reduce down time)
- **NiPdAu (Promoting Long Life)**
  - Un-plated contacts with material hardness of >350 (Vickers) to ensure improved contact life.

Future Work
Understanding Sn

- The mechanism for the increase in resistance due to the matte Sn pads and SnAgCu balls needs to be understood.
- An increase in force may reduce the need to clean as frequently, but also may reduce contact life.

Application of Socket Cleaning and Contact Restoration to Reduce Burn-In, Test & Device Programming Cost

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Erik Orwoll - Nu Signal LLC
Jason Hughes - IBM Microelectronics

Interconnect Restoration

- ❖*Solder Contamination*
- ❖*Interconnect Failure*
- ❖*Yield & Capacity (Production) Loss*
- ❖*Restoration Process & Results*

Interconnect Restoration

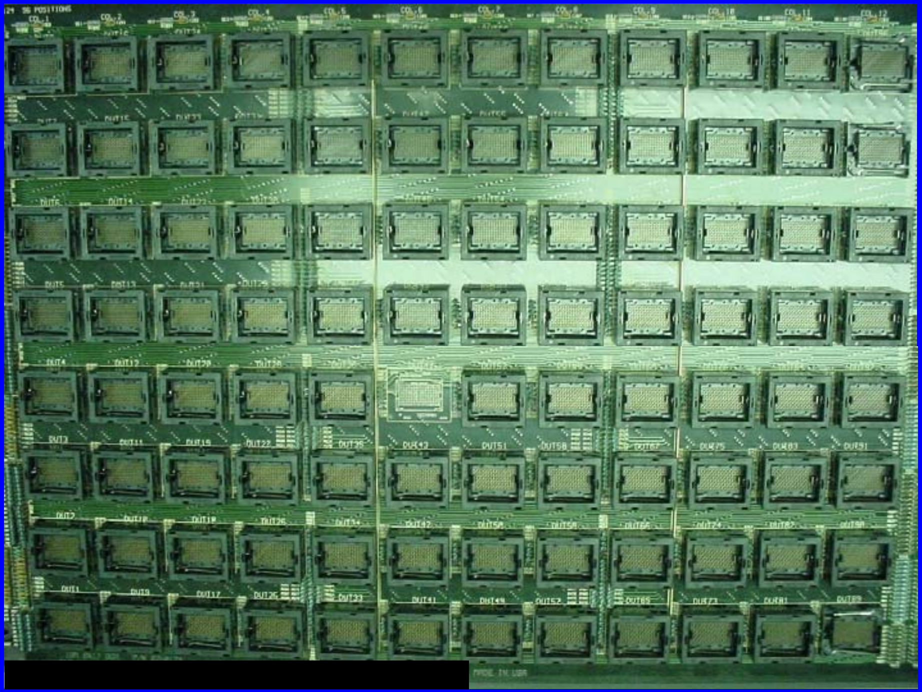
Process Applied To

Burn-In Boards

Test Sockets: Pogo Pins (Spring Probes)

Programming Sockets

Burn-In



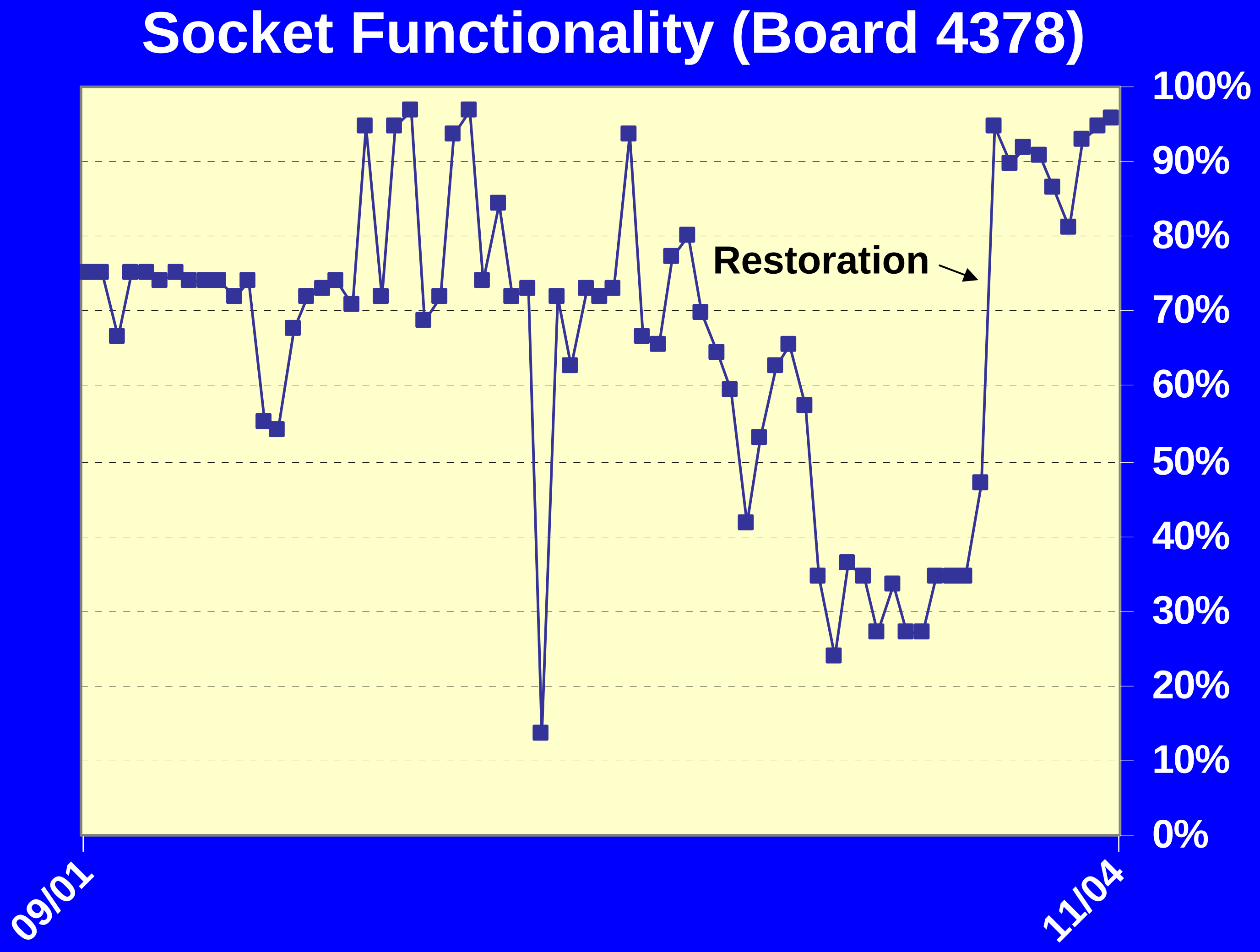
[redacted]

Board Stats:

- **96 Socket Positions**
- **153 Pin BGA**
- **Pinch Style Contact**
- **Auto Load – Open Top**

Burn-In: Solder Contamination

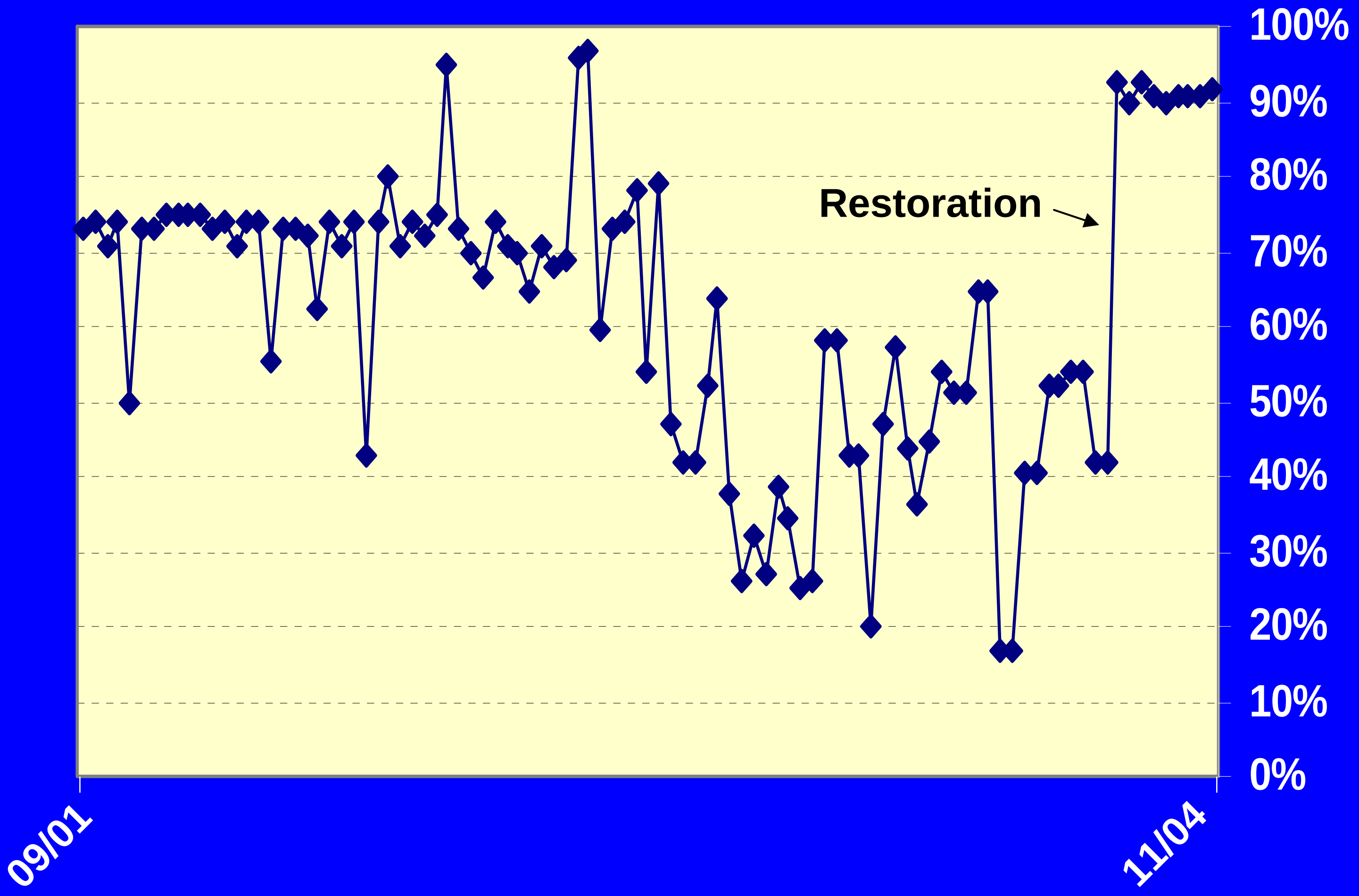
Burn-In



Socket Functionality (Board 4378)
Restoration
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
09/01
11/04

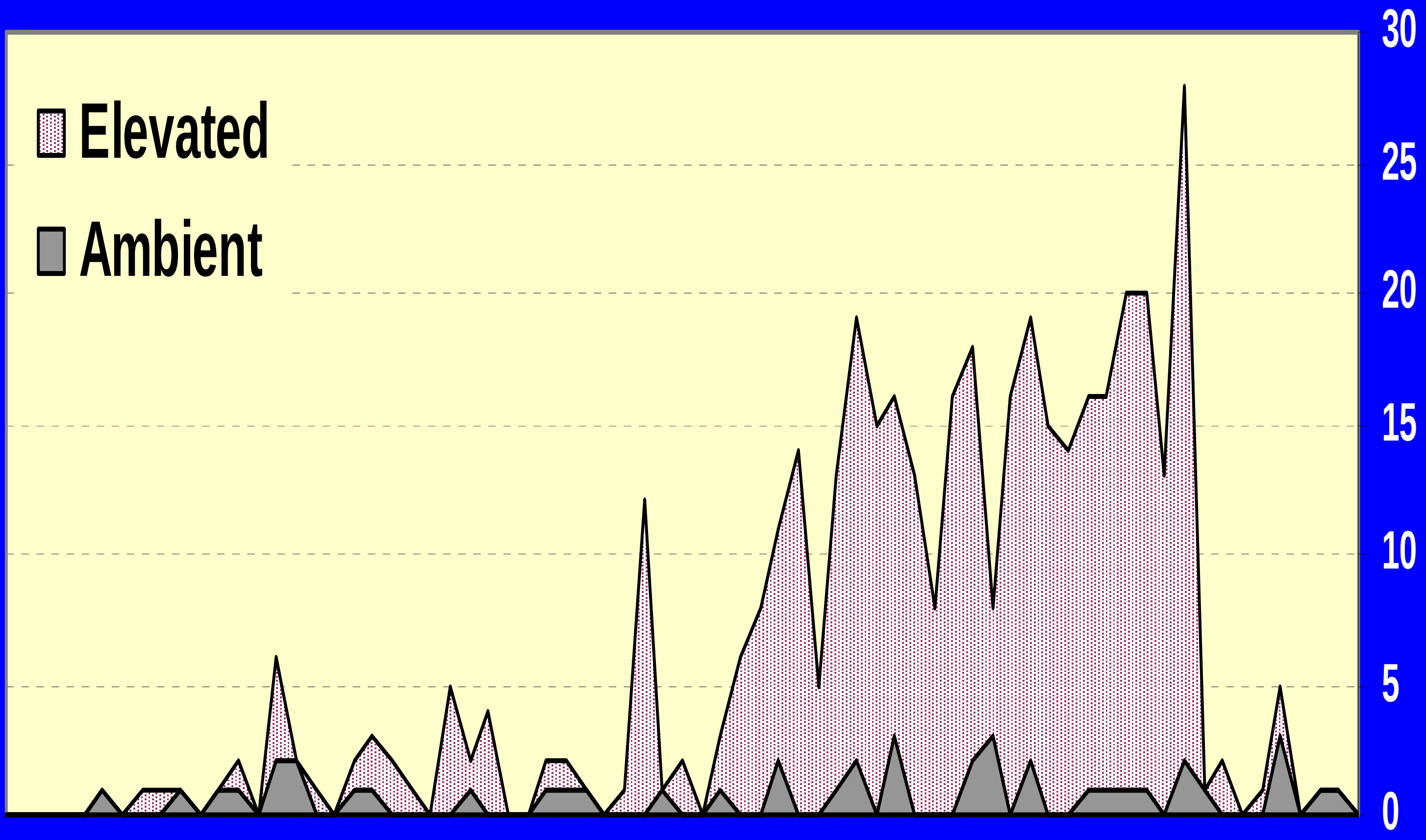
Burn-In

Socket Functionality (Board 434C)

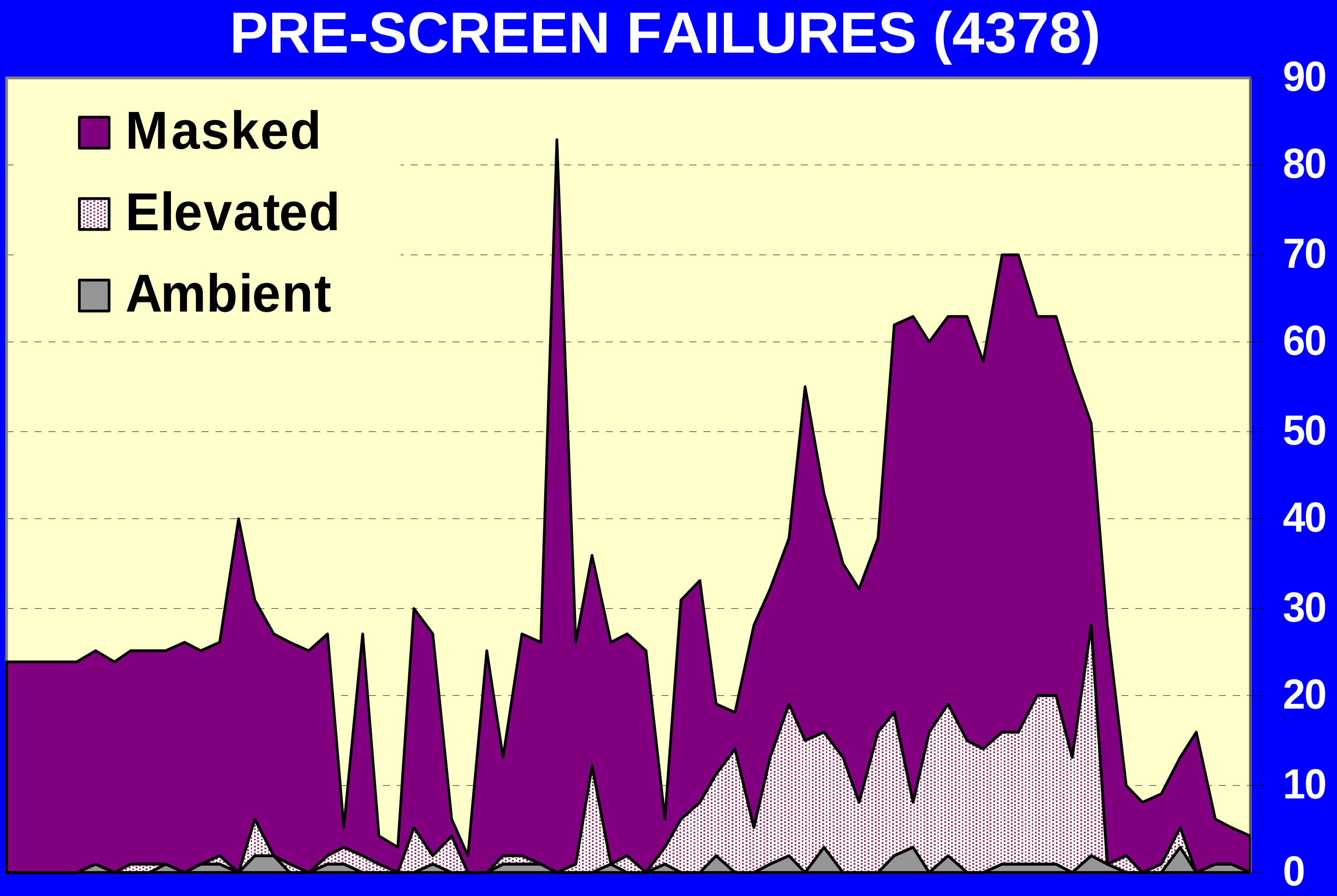


Burn-In

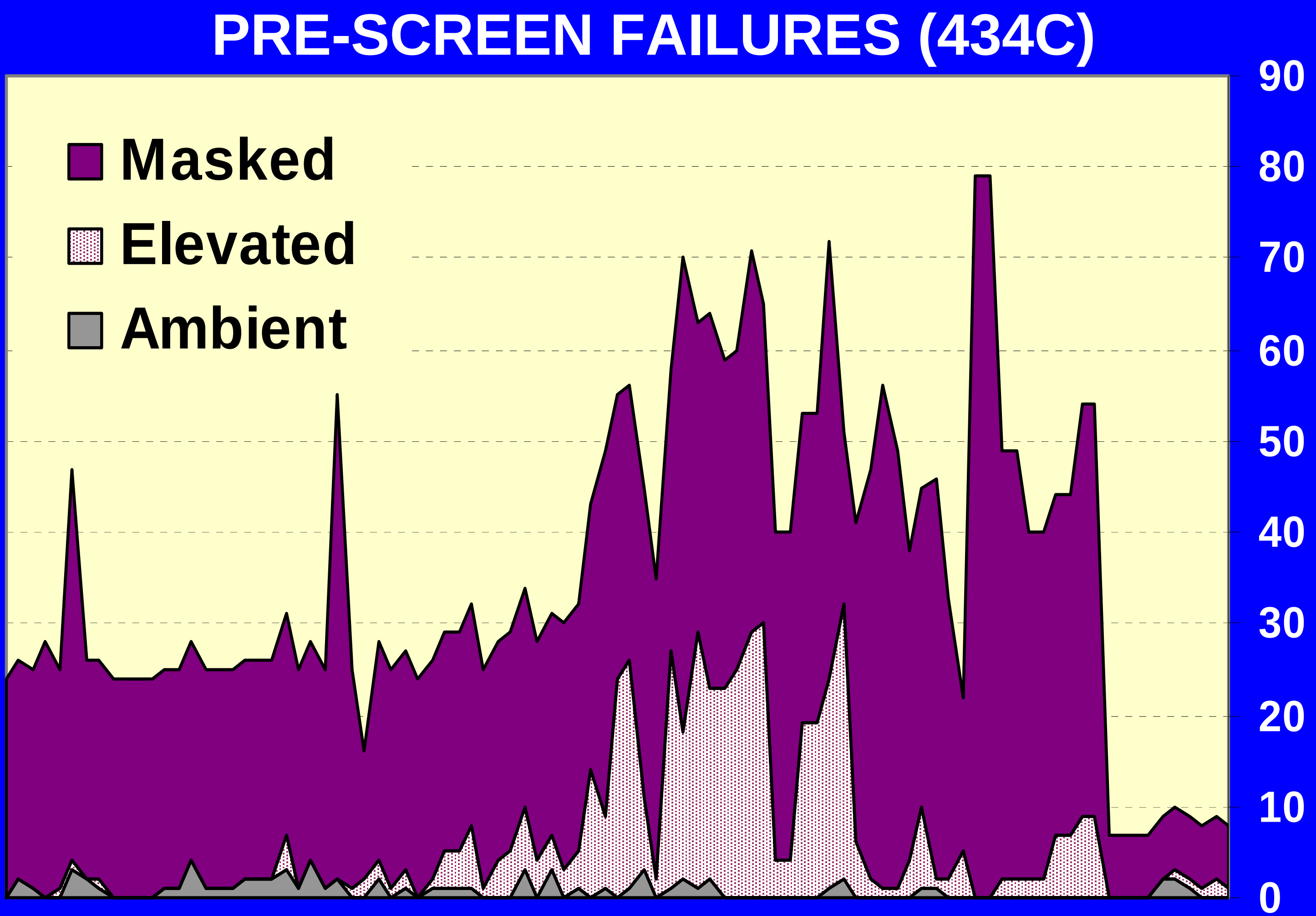
PRE-SCREEN FAILURES (4378)
Masked Sockets Excluded



Burn-In: Contact Failure at Temp



Burn-In: Contact Failure at Temp



Burn-In: Benefits Summary

- Reduces/Eliminates Board Replacement Cost
- Reduces Labor: Board Handling & Pre-Screen
- Increases Oven Space Utilization
- Decreases Facility Power Consumption
- Increases Production Capacity (+112%)

Test

POGO PIN / SPRING PROBE RESTORATION

Test

- Spring Probe (Pogo Pin) Socket
- 144 Pin BGA Device
- 53K Initial Use Cycle Count
- 45K Post Process (Average)

Test

FAILED SOCKET - CONTACT RESISTANCE

MAX 12022 / MIN 118 / AVG 1558 / STD DEV 2338 (milliohm)

	A	B	C	D	E	F	G	H	J	K	L	M
1	*8243*	*1404*	*695*	*1201*	203	298	*6248*	*535*	*835*	389	*598*	*511*
2	*1352*	*2224*	*4121*	432	*3405*	*11186*	172	151	*503*	*2421*	175	*1268*
3	*691*	*2735*	298	*584*	*2221*	*6852*	*581*	*701*	382	304	*1591*	217
4	268	426	*1317*	*638*	*2854*	*6690*	*1192*	*696*	132	193	1854	916
5	*6195*	301	*1687*	*6124*	*3451*	*1949*	198	198	*1249*	*902*	*583*	*583*
6	197	*2081*	*896*	397	*1511*	121	147	*528*	182	*1114*	194	*653*
7	427	263	269	*2625*	118	182	168	182	*593*	*714*	*9883*	176
8	*581*	*5113*	402	447	237	*506*	*504*	165	346	184	*645*	288
9	*2325*	*534*	*1108*	*1474*	225	137	*1233*	*6824*	*674*	119	*958*	*571*
10	174	*1105*	126	*8483*	480	*4868*	*518*	149	143	*1502*	*6987*	*2644*
11	*927*	138	*970*	199	*675*	*522*	*9286*	*12022*	*618*	185	*1227*	*812*
12	141	*4003*	382	142	*542*	*1867*	*1962*	234	254	*963*	*2718*	*905*

Test

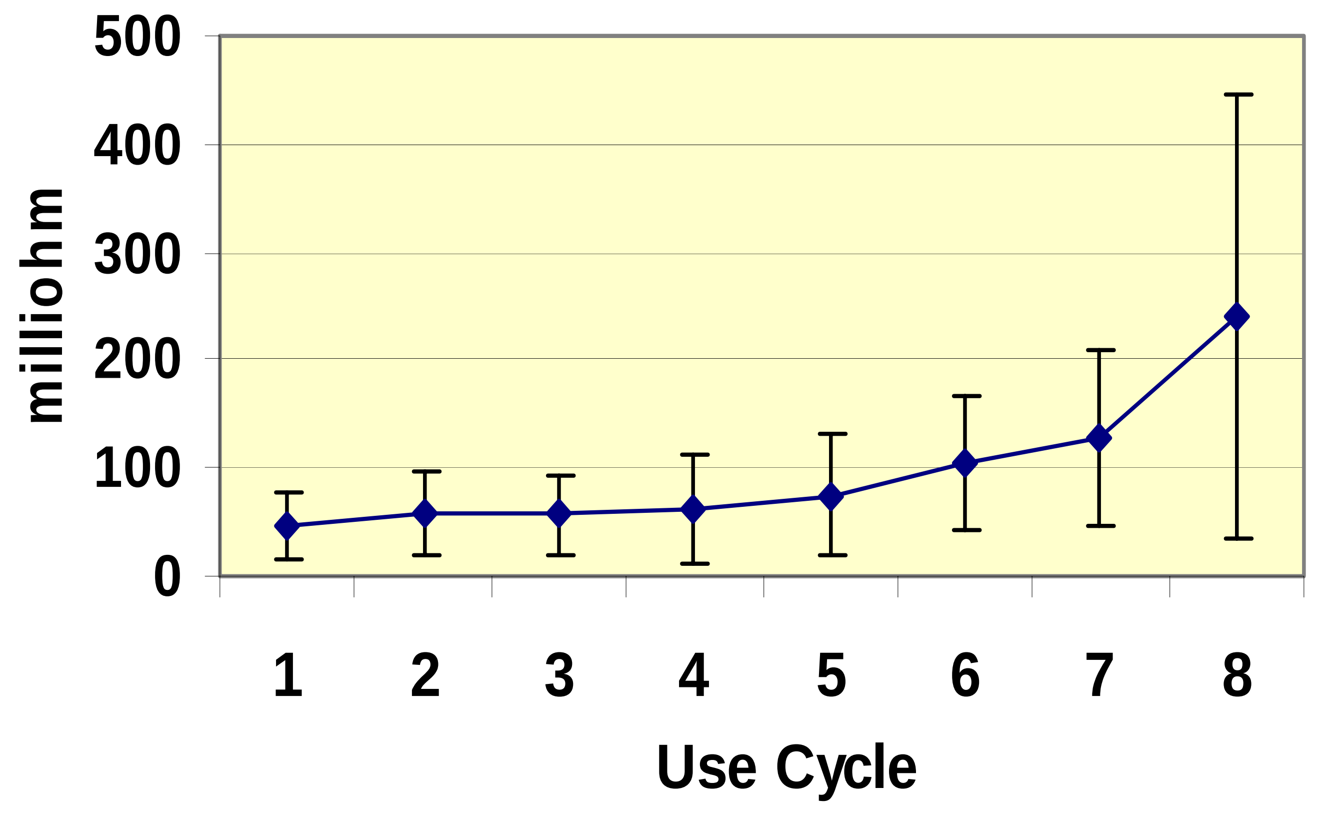
RESTORED SOCKET - CONTACT RESISTANCE

MAX 385 / MIN 31 / AVG 59 / STD DEV 40 (milliohm)

	A	B	C	D	E	F	G	H	J	K	L	M
1	42.4	31.2	39.4	41.1	47.4	88.9	34.8	45.8	47.1	102.3	56.4	35.1
2	63.6	54.8	49.5	58	60.4	34.7	40.7	59	42.8	61	50.8	40.3
3	48	39.7	61.4	49.5	52.9	44	57.3	54.5	45.2	54.4	74.9	57.5
4	42.9	47.5	44.4	385.1	334	48.2	103.6	66.2	49.7	56.8	54	67.8
5	46.7	53.1	57.8	42.8	58.8	42.7	44.3	56.1	77.4	47.1	51.4	42.3
6	44.3	42.4	49.4	70	42.7	55.2	35.7	59.1	187	64.9	42.3	57.4
7	40.1	45.6	52.3	57.3	41.4	50.5	55.7	64.1	45.7	41.1	54.5	68.3
8	47.6	57.1	54.7	48	45.2	40.3	44.8	47.7	76	51.9	64.2	92.9
9	55.6	56.9	67.8	45.2	52.8	43.6	46.2	60	44.5	57.1	47.7	39.9
10	51	52.9	49.1	69.6	45.8	78	53.3	55.6	76.4	51	64.8	41
11	77.6	75.7	48.1	45.1	63.8	46.5	83.9	43.4	107.9	48	56.4	42.9
12	55	63.2	44.1	59.5	65.2	51.3	77.2	49.8	46.7	42.5	62.3	46.3

Test

POGO PIN CONTACT RESISTANCE

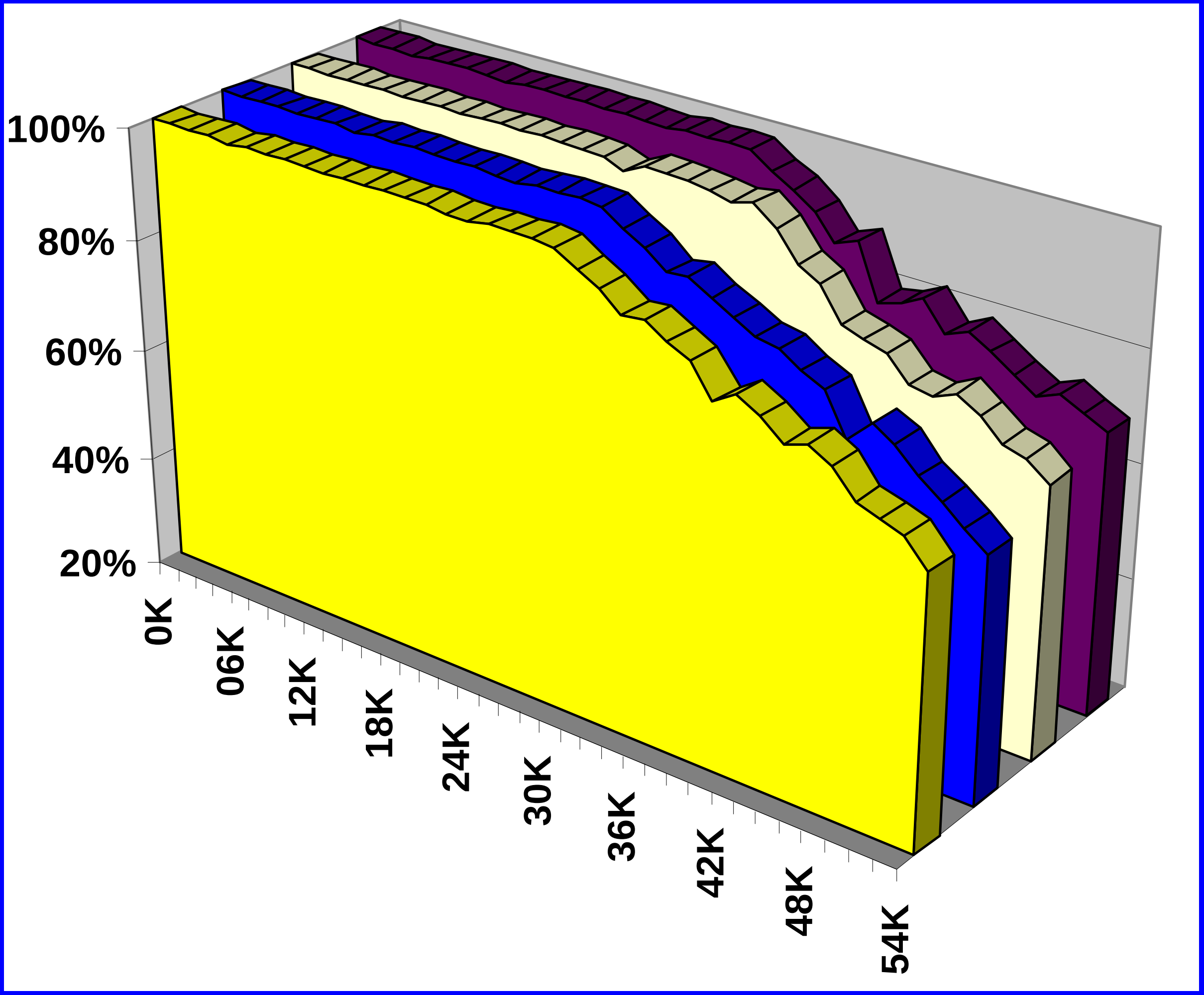


Device Programming

- Programming Yield
- Solder Contamination → Reduced Yield
- Yield Restoration
- Production Results

Device Programming

YIELD VS. DEVICES PROGRAMMED (Typical)

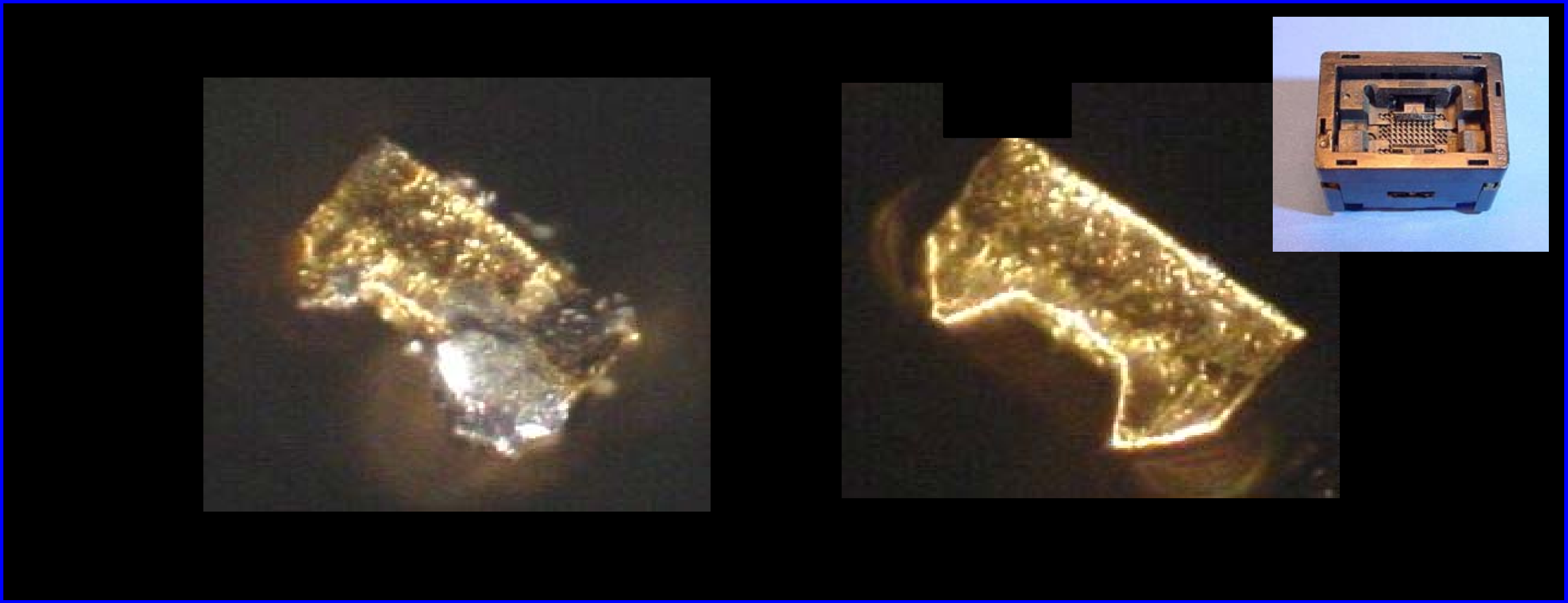


Device Programming

Solder Contamination

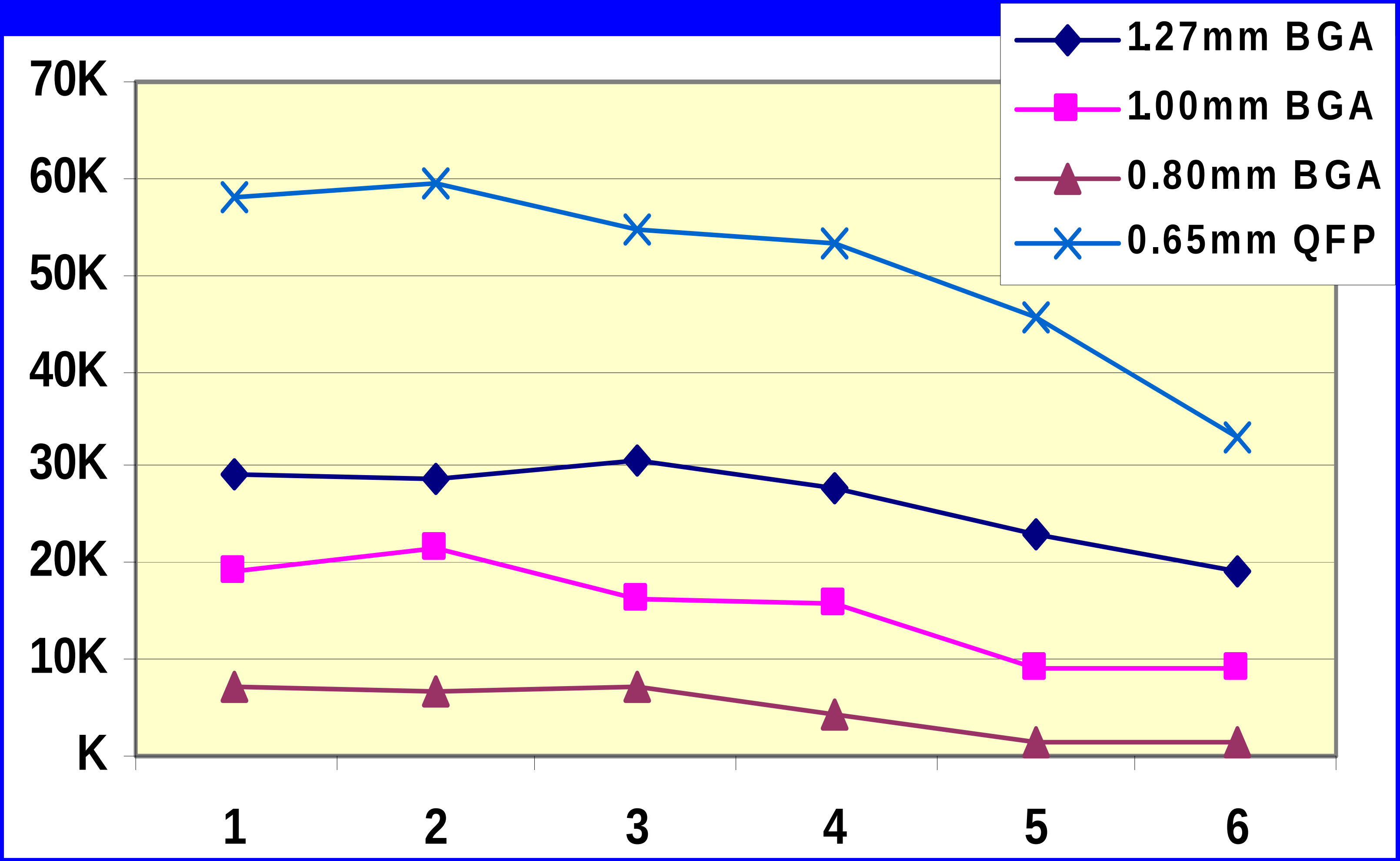
Increased Contact Resistance

Reduced Yield



Device Programming

Socket Restoration



Thank You!