Challenges of Contacting Lead-Free Devices

2005 Burn-in and Test Socket Workshop

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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

- **<u>Contactor Designs</u>**
- **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

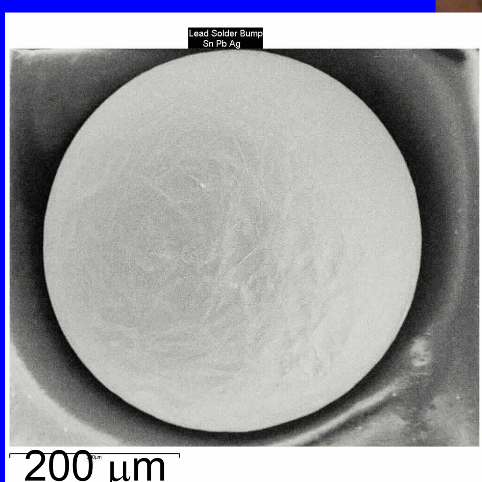
- Contacts were populated into a contactor and mounted to a test board.
- Force Testing: Contact force was measured in real-time as devices were inserted into the contactor.
- Resistance Testing: The test board and devices were designed so that four-point Kelvin resistance measurements were made across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

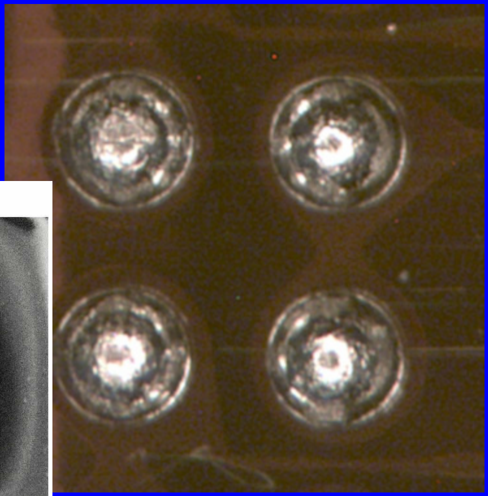
Qualification of Interconnect Success

- **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.

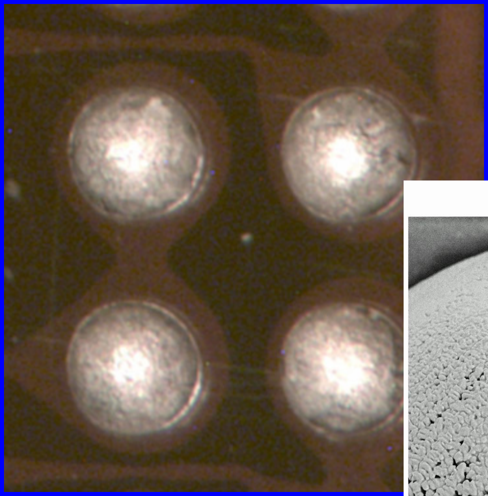
SnAgCu Balls
Physical Appearance

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

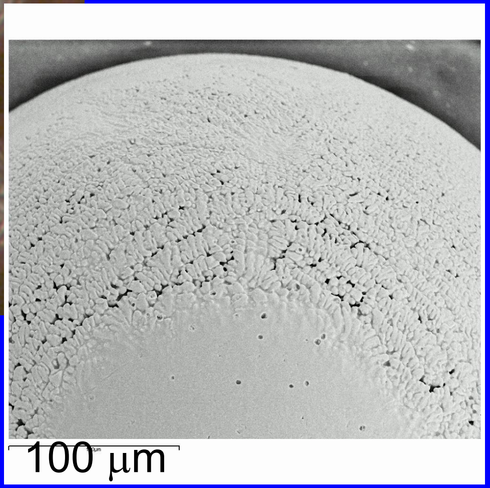




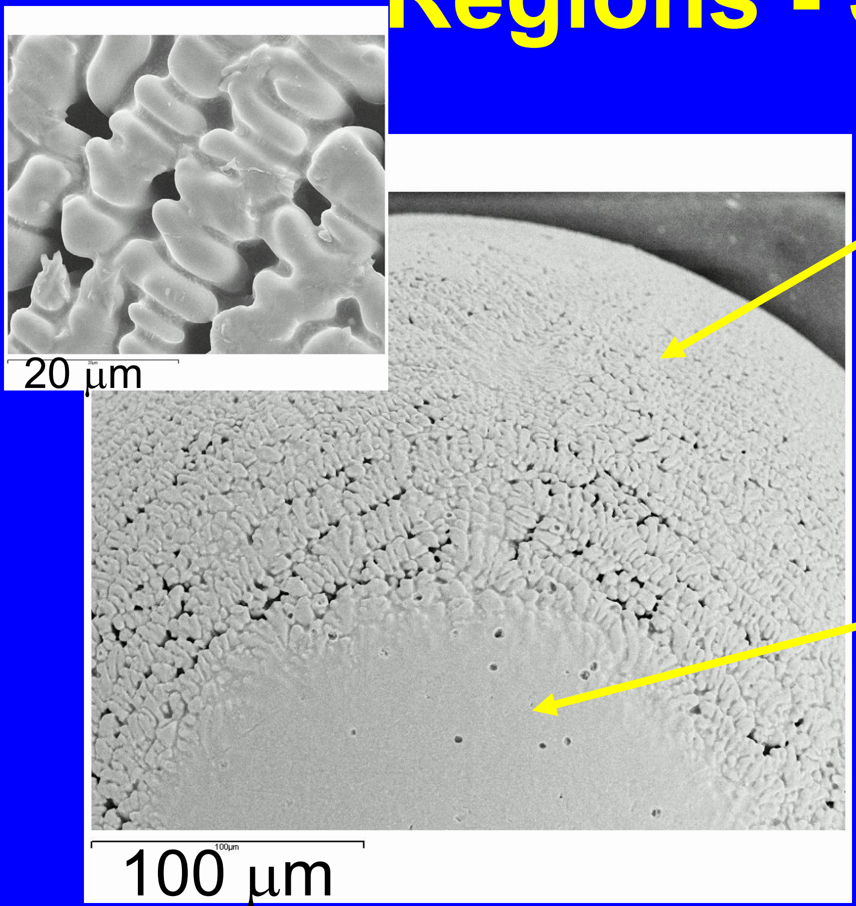
SnPb



SnAgCu



EDS Spectrum of Dendrite Rich Regions - SnAgCu Balls



Average composition in dendritic rich region

Sn	99.8%
Cu	0.2%
Ag	<0.1%

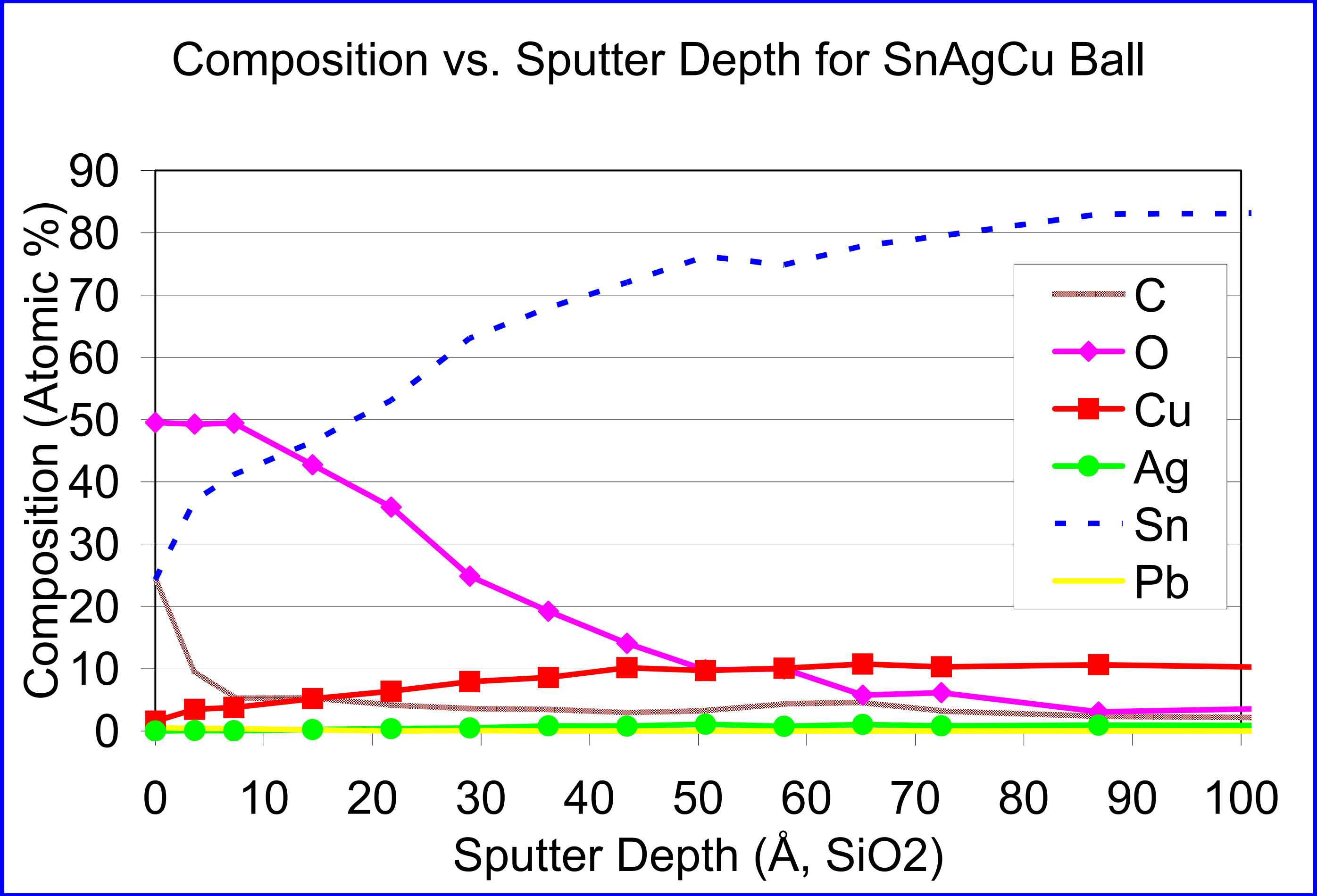
Average composition in non-dendritic region

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}

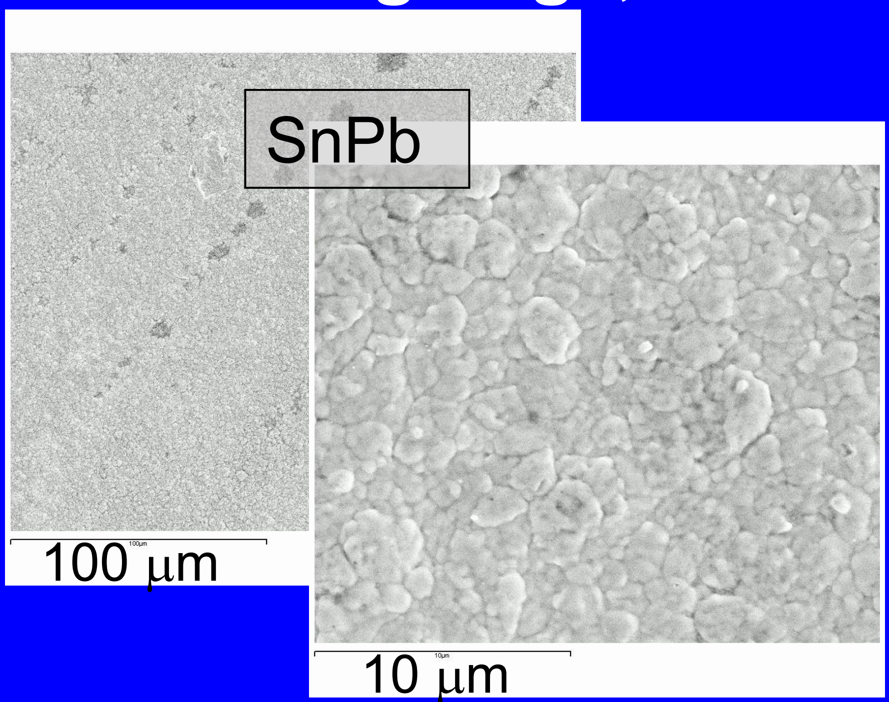
angstrom

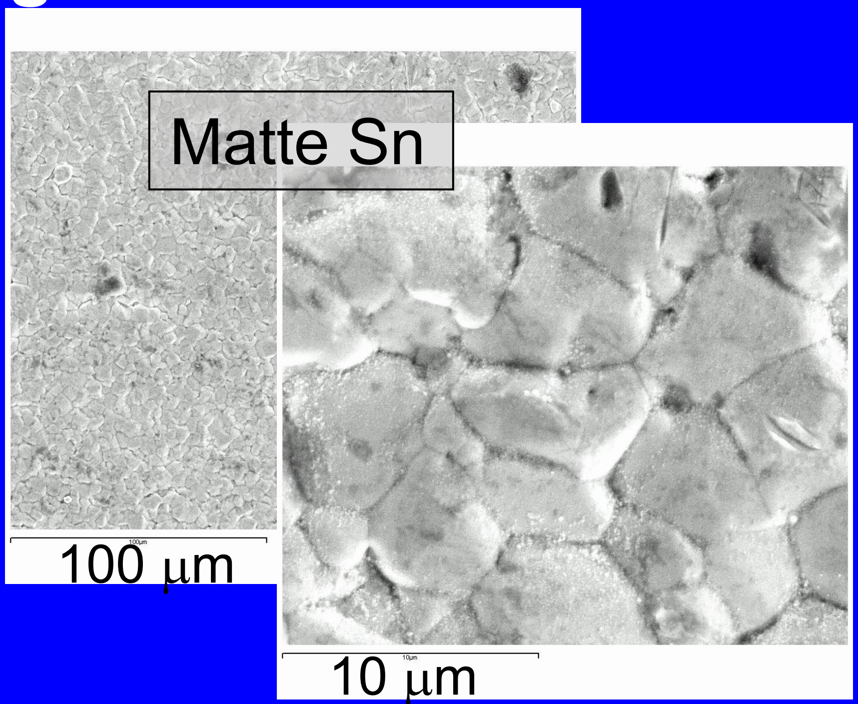
XPS/SEM Analysis of SnPb and SnAgCu Balls

- **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

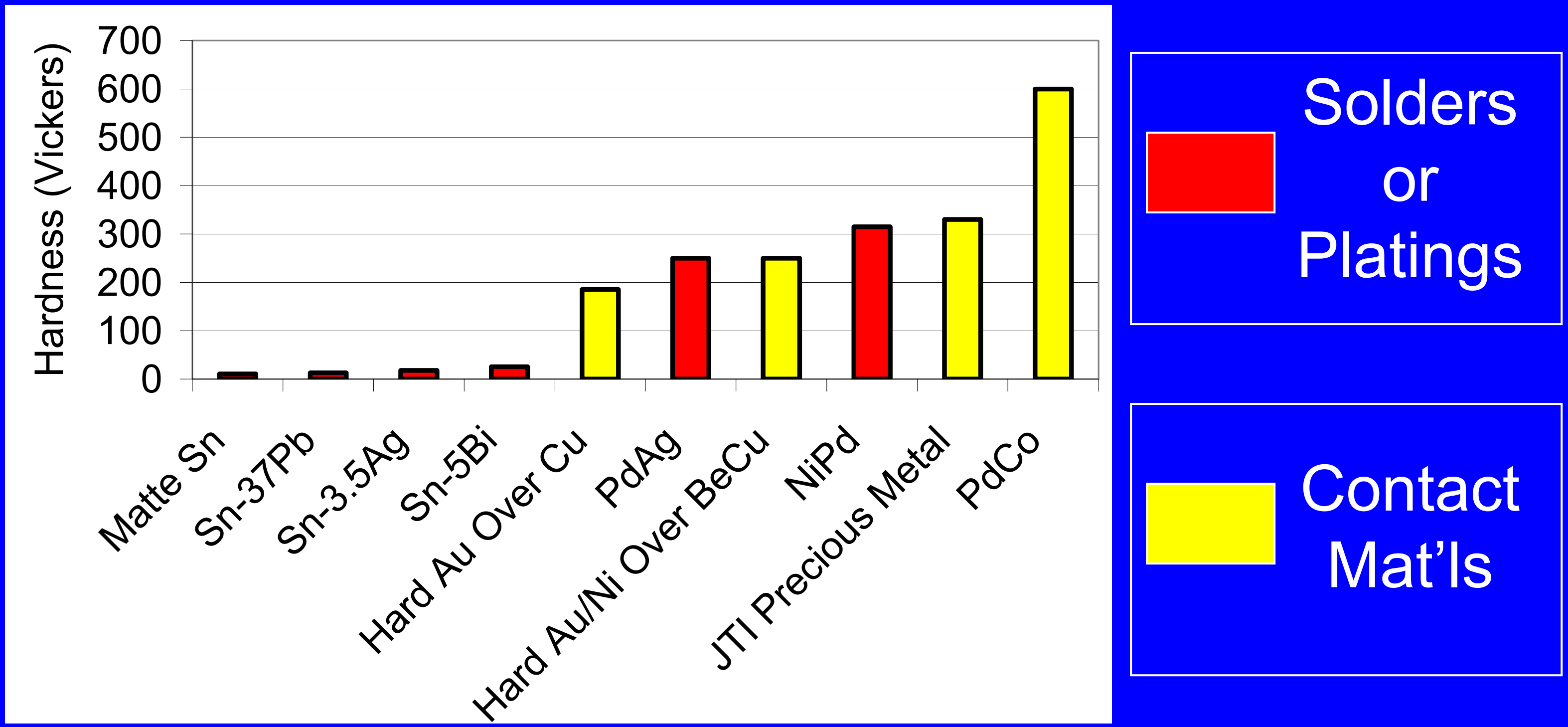
- **Matte Sn pad surfaces were observed having large, Sn-rich grains.**



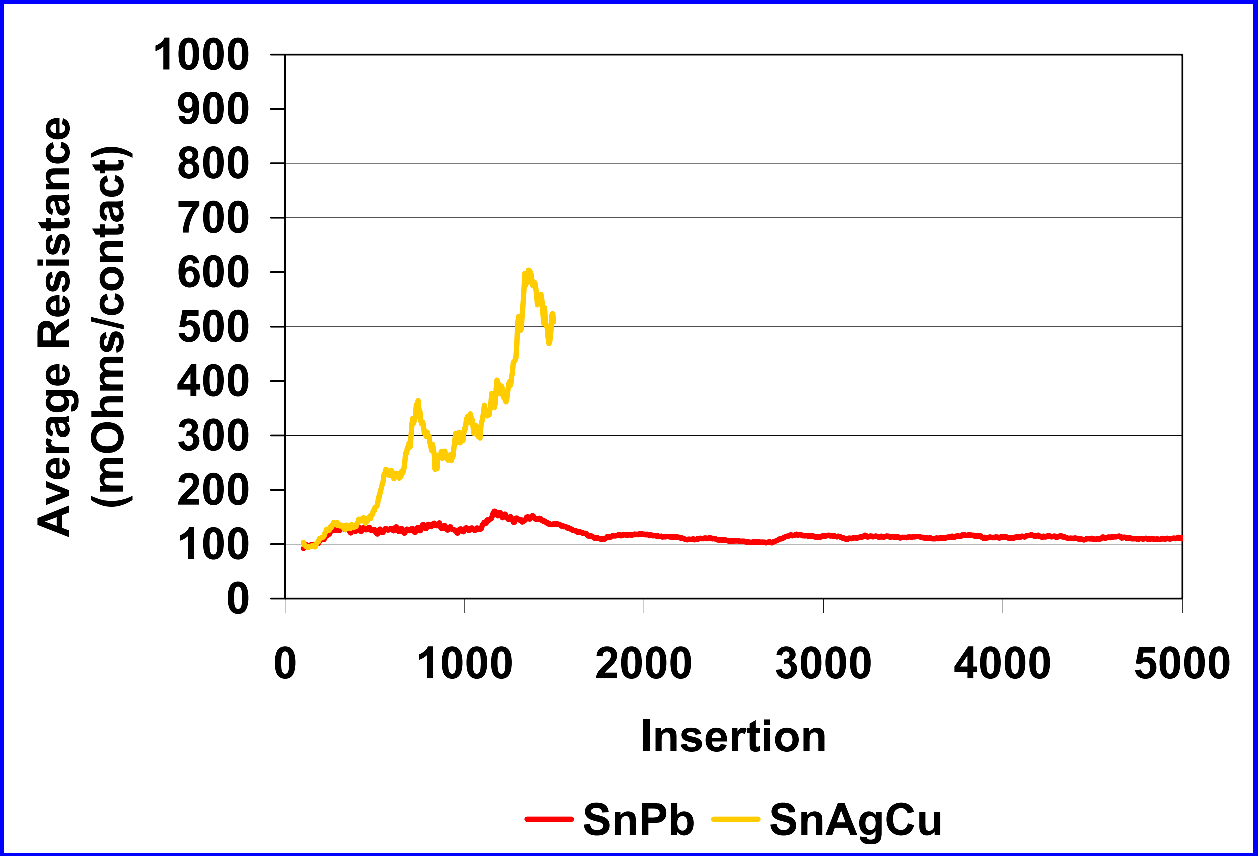


NiPdAu Pad Properties

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



SnPb vs. SnAgCu BGA Resistance Performance



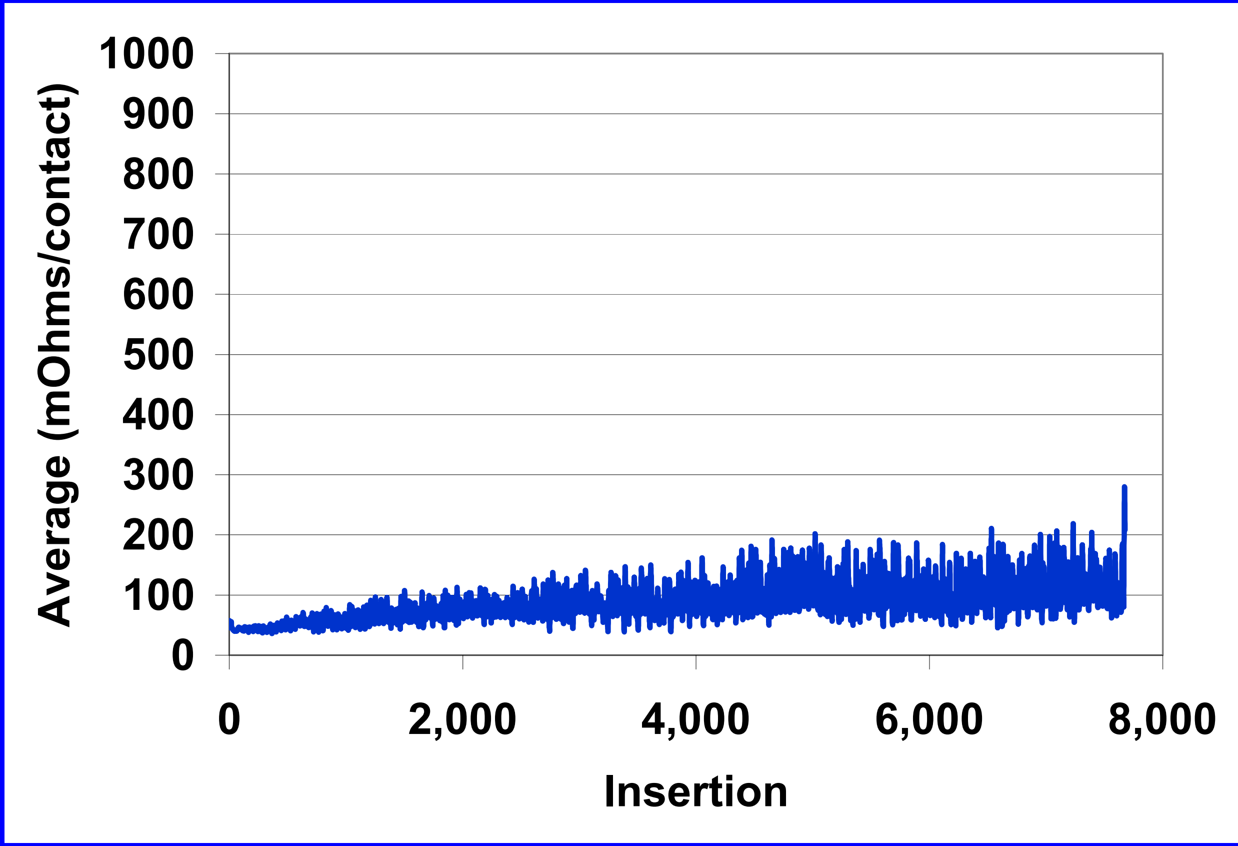
Approximate

Force = 17gm

SnPb
Avg = 118mΩ
Stdev = 43mΩ

SnAgCu
Avg = 389mΩ
Stdev = 490mΩ

Increased Force BGA SnAgCu Resistance Performance



Approximate

Force = 50gm

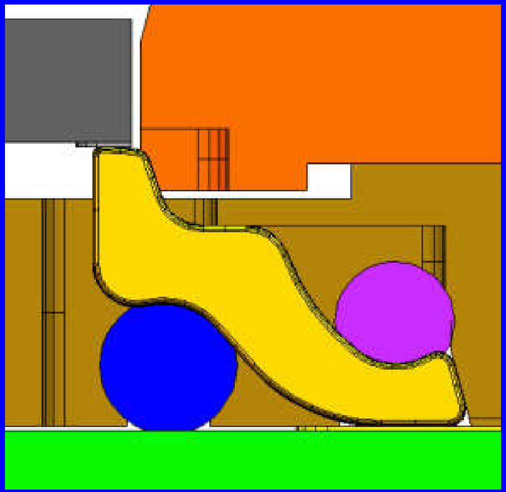
SnAgCu

Avg = 91mΩ

Stdev = 47mΩ

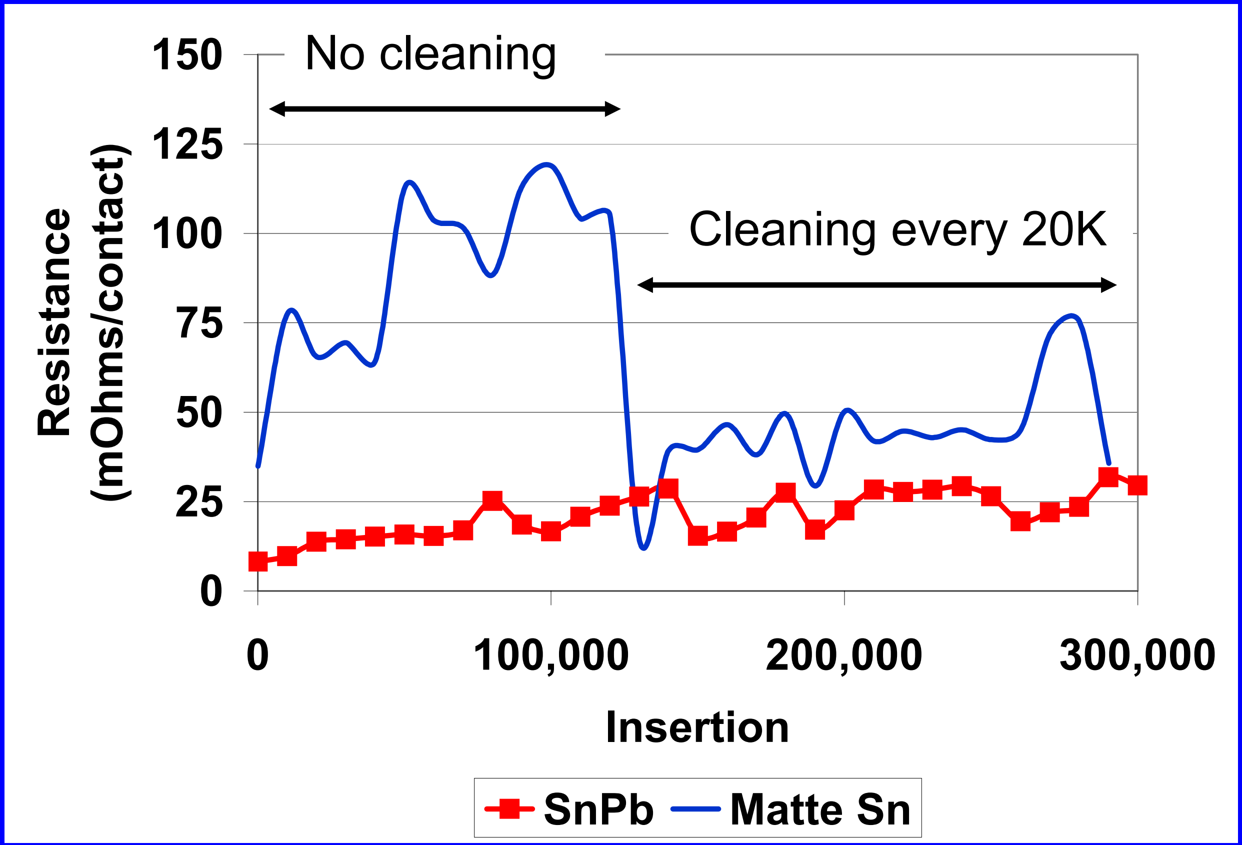
Matte Sn and NiPdAu Qualification Pad ROL200 Design

- **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

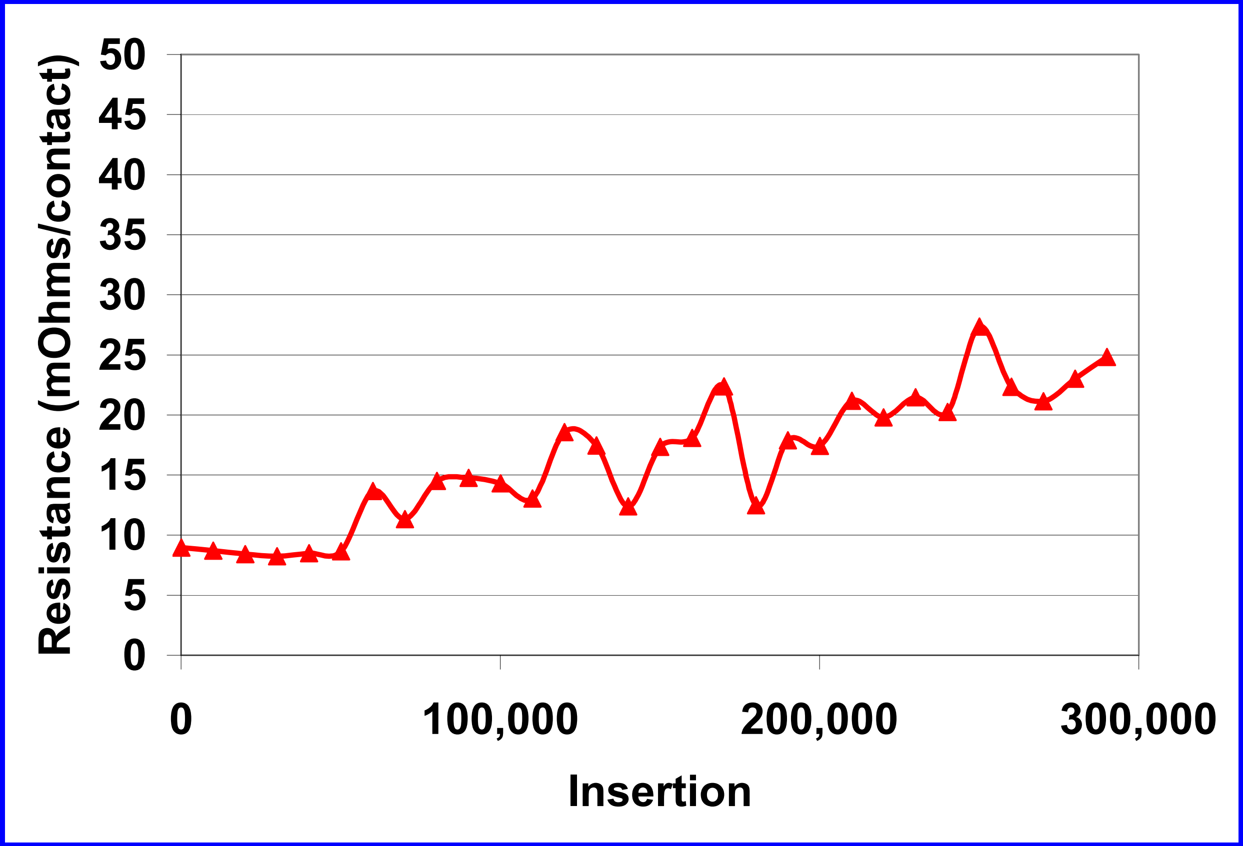
Stdev = 35mΩ

SnPb - No Clean

Avg = 28mΩ

Stdev = 5mΩ

NiPdAu Pad ROL200 Resistance Performance



NiPdAu

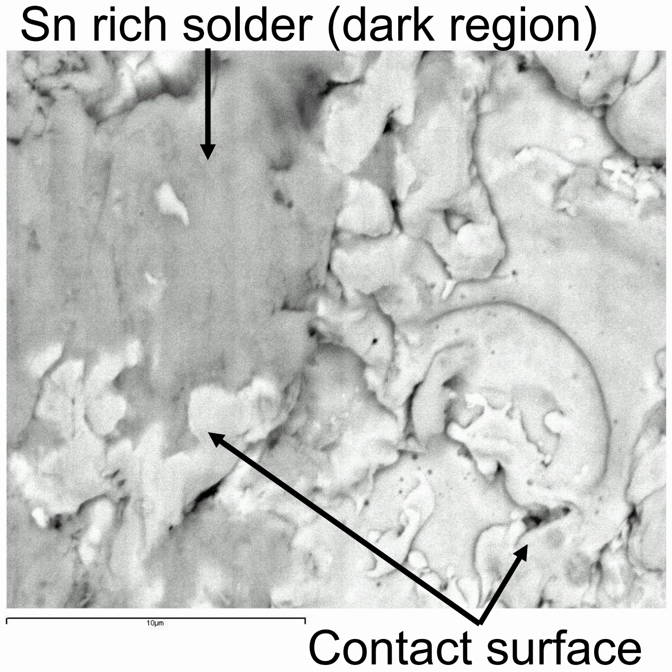
Avg = 16mΩ

Stdev = 12mΩ

Conclusions

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

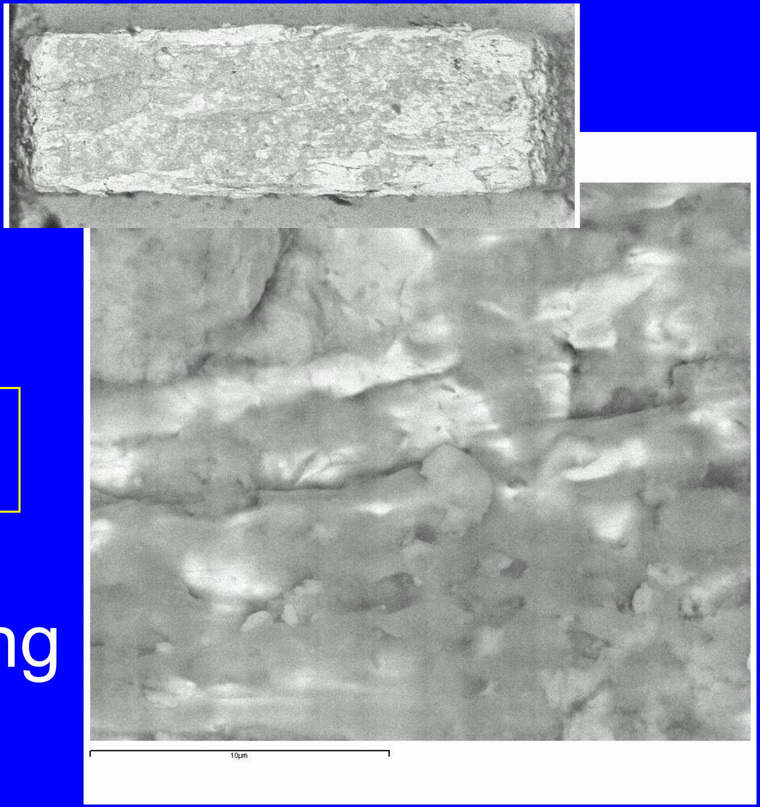
$$\boxed{R_{film} >> R_C}$$



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

Conclusions

- **<u>Matte Sn Evaluation</u>**
  - <u>Pure Sn</u> tend to smear and cover the contact surface. $\boxed{R_{film} \gg R_C}$
  - A prescribed cleaning cycle aids in maintaining low resistance values, while promoting long contact life.



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.