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Session 7
Wednesday 3/05/03 8:00AM

Contact Technology

“Electroplated Palladium-Cobalt On Test Probe Plungers: An Improved Method For Reducing Solder Adhesion”
  Therese Souza – Rika Denshi America, Inc.
  Larre Nelson – Rika Denshi America, Inc.

“Contact Technology For 0.5mm Pitch And Below”
  Prasanth Ambady – Texas Instruments
  James Forster – Texas Instruments
  Jason Cullen – Texas Instruments

“High Frequency Performance Of Various Test Contactor Geometries - 0.8mm Pitch”
  Eric Fachon – QA Technology, Inc.
Electroplated Palladium-Cobalt on Test Probe Plungers

An Improved Method For Reducing Solder Adhesion

Authors:
Therese Souza, Rika Denshi America
Larre Nelson, Rika Denshi America

BiTS Workshop 2003
Outline

• Problem description
• Potential solutions
• PdCo as a novel surface finish
• Experiment description
• Conclusions / references
Problem Description

Solder sticks to contact area of test probe plunger

- Decreased yield
- Variability in resistance
- Open circuit condition
- Reduced life
- Increased maintenance
- Increased down time
Mechanism of Solder Contamination

- Solder transferred to plunger during use
- Solder bonds to gold
  - Intermetallics
  - Solder Oxides
- Contact area become contaminated
- Intermetallics / oxides have poor conductivity
Au-Sn Phase Diagram

Temperature (Celsius)

Weight Percent Tin

(Au)

(Liquid)

(Sn)

Au-Sn

Phase

Diagram
Repair/Prevent Options for Contaminated Plungers

- Mechanical abrasion (scrubbing)
- Chemical cleaning
- Tip Design – self-cleaning
- Replaceable tips
- Other plated finishes
Palladium-Cobalt
Novel Test Probe Finish

• Palladium–Cobalt
  – Both are elements combined thru plating
  – Semi–noble plated finish

• Pd alloys
  – Commonly used on separable connectors & lead frames

• Properties
## Why Palladium Cobalt Makes A Difference

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>WHY THIS IS GOOD FOR A TEST PROBE</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PdCo is very hard</td>
<td>A hard surface finish decreases wear and increases durability</td>
<td>Hard Gold hardness: Knoop 130–200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo hardness: Knoop 600–650</td>
</tr>
<tr>
<td>PdCo is slippery</td>
<td>A low coefficient of friction makes the plunger motion smoother and makes it easier for foreign matter to slide off the surface of the plunger</td>
<td>Hard Gold coefficient of friction: .60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo coefficient of friction: .43</td>
</tr>
<tr>
<td>PdCo has a small grain size</td>
<td>It is less likely that a small grain size material will allow diffusion and the formation of intermetallic compounds</td>
<td>Hard Au grain size: 200–250 Angstroms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo grain size: 50–150 Angstroms</td>
</tr>
<tr>
<td>PdCo has low porosity</td>
<td>Low porosity does not allow corrosion to penetrate the plating and damage the base metal</td>
<td>Hard Gold porosity index: 3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo porosity index: 0.2</td>
</tr>
<tr>
<td>PdCo has good ductility</td>
<td>A ductile plated surface is less likely to crack under mechanical stresses</td>
<td>Hard Gold: &lt;3% elongation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo: 3–7% elongation</td>
</tr>
<tr>
<td>PdCo is thermally stable</td>
<td>When exposed to elevated temperatures over time, the contact resistance stays consistent</td>
<td>Hard Gold: up to 150°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo: up to 395°C</td>
</tr>
<tr>
<td>Pd and Co have high melting points</td>
<td>A plating material with a high melting point will inhibit diffusion and the formation of intermetallic compounds</td>
<td>Gold melting point: 1,064°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Palladium melting point: 1,554°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cobalt melting point: 1,495°C</td>
</tr>
<tr>
<td>PdCo is an alloy</td>
<td>Alloys are good barriers to diffusion</td>
<td>Hard Gold chemistry: almost 100% Au</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PdCo chemistry: 80% Pd / 25% Co</td>
</tr>
<tr>
<td>PdCo has surface oxides</td>
<td>Surface oxides help deter solder adherence</td>
<td>To be determined</td>
</tr>
</tbody>
</table>
PdCo Studies

- Life Cycle Resistance Study
- Solder Ball Cycling Study
- Life Cycle Against Pure Tin
- Solder Dip Test Comparison Study
1. Life Cycle Resistance Study

- Test probe design (0.162” x 0.0138”): double ended plunger, movable conical tip and stationary four point crown

- Comparison of Hard Gold plate vs. PdCo plate

- 500,000 cycles against gold surface
Cycle Tester
Life Cycle Resistance Study

Gold vs. PdCo Resistance Readings

<table>
<thead>
<tr>
<th>Average Resistance +/- Std Dev (milliohms)</th>
<th>Hard Gold</th>
<th>PdCo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>79 +/- 8</td>
<td>113 +/- 10</td>
</tr>
</tbody>
</table>

Graph showing resistance measurements over cycles with Gold and PdCo datasets.
2. Solder Ball Cycling Study

- Cycle to a 60/40 solder ball
- 50,000 cycles
- Ambient temperature
- PdCo vs. Hard Gold
Solder Ball Cycling Study

Hard Gold

492 +/- 87 mΩ
Solder Ball Cycling Study

PdCo

421 +/- 92 mΩ

Resistance mΩ vs. Cycles
3. Life Cycle Against Pure Tin

- Spherical plunger cycled against pure electroplated tin
- Tin contact resurfaced every 5,000 – 10,000 cycles
- Hard gold vs PdCo
- Multiple tests conducted
- Cycled 150–200 k
- Contact force 40/80 grams
- Plunger tips frequently examined for transferred tin
Observations

- Plunger force deformed tin on contact surface
- Tin build-up on gold more obvious

Dimple in Tin
Palladium-Cobalt

Post Plating Treatment

Options

Palladium–Cobalt can be treated
  • To provide increased protection from solder sticking
  • To increase hardness of deposit
  • To increases ductility
  • May alter other properties
4. Solder Dip Comparison Study

- Test samples prepared from copper foil and preplated with electroless nickel
- Post plating treatment
- 20–30 microinches PdCo
- Solder dip using 60/40 solder & 5 second dwell time
Solder Dip Comparison Study
Conclusions

• PdCo can be used as a test probe finish
  – Alternative to gold
  – Consistent resistance readings when mated against tin
  – A reduced tendency to form adhesions to solder

• PdCo has the potential for increased contact resistance
References


• Kudrak, Abys, Chinchankar, Maisano, *Porosity Evaluation of Composite Palladium, PdNi and Gold Electrodeposits*, AT&T Bell Laboratories,


• http://klara.met.kth.se/pd/element/Au–Sn.html
Contact Technology For 0.5 mm Pitch and Below

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Attleboro, MA

REV 1.2
INTRODUCTION
The Communications Age

The ability to communicate is changing the way we live, our freedoms, and making the world a smaller place.
OVERVIEW

• Introduction To Different Contact Technologies
• Discussion Of Currently Available Technologies
• Design Issues With Current Technology
• Future Design/Cost Challenges
BURN-IN SOCKET REQUIREMENTS

- Temperature: Up To 150 °C
- Life: 4,000 to 10,000 Cycles
- Hand Loading/ Auto Loading Capabilities
- Insulation: 500 V DC, 1000 M Ohms Between Pins
- Resistance: Less Than 1 Ohm Per Pin
- Acceptable Capacitance & Inductance
Through Hole Sockets:
Sockets Mounted By Soldering
The Contact Leads Through A Plated Hole In The Board.

Surface Mount Sockets:
Sockets Mounted By Soldering
The Lead To A Pad On The Board.

Compression Mount Sockets:
Socket Contact Lead Presses Vertically Against The Board.
Spring Force Provides Interconnection between The Pad And The Contact
CONTACT OPTIONS

a) Metal Pinch Contact
b) Metal ‘Y’ Contact
c) Conductive Polymer
d) Coil Spring
e) Pogo Pin
f) Metal Probe - Buckling Beam
CONTACT TYPES
HORIZONTALLY ACTUATED

Dual Pinch Style

Single Beam Style

ACTUATION

ACTUATION
CONTACT TYPES

VERTICALLY ACTUATED

Helical Coil Spring

ACTUATION

Buckling Beam

ACTUATION
SOLDER BALL - CONTACT INTERFACE
PINCH STYLE

Dual Beam Pinch Style Witness Marks

- Location of witness marks
- Ball deformation

Example of Witness Mark - Dual Pinch Contact - 140° C for 12hr
0.4mm Dia Ball, 0.75mm Pitch. Typical of 1.00mm to 0.5mm pitch
SOLDER BALL - CONTACT INTERFACE
BUCKLING BEAM STYLE

Example of Witness Mark - Buckling Beam Contact - 140° C for 12hr
0.3mm Dia Ball, 0.50mm Pitch.
FINE PITCH DUAL PINCH CONTACT

Issue

• Make a mechanical contact with metal less than 0.12 mm thick

Pitch: 0.50mm;  
Ball Diameter: 0.30mm  
Available Space: 0.17 mm

• As pitches shrink below 0.5mm, the space for the arms of a pinch style contact is limited.

• Solutions favor single beam, buckling beam or pogo pin for pitches less than 0.5mm.

Contact Technology for 0.5 mm Pitch and Below – Ambady et al.  
BiTS Workshop 2003, March 2-5, 2003
FINE PITCH - MOLDED COMPONENTS

- Tooling Difficulties For Fine Pitch Core Pin Arrays.
- Longer Lead Times For Tool Qualification.
- Uniform Fill And Mold Stability.
- Cost.
ASSEMBLY ISSUES

- Automation
- Handling Of Small Components
- Contact Loading
- Time For Assembly: Cost Of Labor
- Increase with Higher I/O Sockets
DESIGN ISSUE: CONTACT TIP GEOMETRY

Witness Marks And Contact Resistance: Trade Off

A Sharper Contact Tip Allows Better Penetration Of The Oxide Layer And Lower Contact Resistance ..... But Increases The Solder Ball Witness Mark Size.

Less contact tip area: Higher resistance Small witness mark

More contact tip area: Lower resistance Large witness mark
DESIGN ISSUE: CONTACT TIP GEOMETRY

Sharp Tip With Aggressive Bite - Suitable For Short Burn In Time And Programming Applications

Blunt Tip With Softer Bite - Suitable For Longer Burn In Time And Hast Applications.
BIB MOUNTING

Fan Out Interposer Allows BIB To Be Drilled At Pitches Of 1.27 or 1.00 mm – Lower Overall Cost

- Concept Works Well For 0.75mm Pitch
- Being Applied to 0.5mm Pitch
COMPRESSION MOUNTING OF SOCKETS

• Spring Loaded Contact Tail - Eliminates Problems Drilling Fine Pitch Holes.

• Concern - Reliable Interconnect In Harsh Testing Conditions Esp. BIB To Contact .

• Possibility Of Contamination - Can Increase Overall Resistance
FINE PITCH LIMITATIONS

• As Pitches Go Below 0.5 mm, The Ball Diameter And Ball Height Are Also Reduced.

• Poses Difficulties When Targeting Specific Areas Of The Solder Ball Where The Contact Can Touch.

• Smaller Metal Contacts Have Lower Fatigue Life And Are More Difficult To Manufacture.

• Tighter Package Tolerances Are Required. Critical Dimension On Molded Plastic Parts Can Be Held Within +/-0.01mm (0.0004”) In Production.
CONTACT RESISTANCE

Contact Resistance As A Function # Of Cycles

- Increases With Socket Actuations: Solder Buildup, Contact Wear Etc.
- Increase As Contact Size Decreases For Fine Pitch Applications.

Contact Technology for 0.5 mm Pitch and Below – Ambady et al.
BiTS Workshop 2003, March 2 - 5, 2003
FUTURE DESIGN CHALLENGES

- Emergence Of Low Profile Bumps As An Alternative To Solder Balls.
- LGA Compression Style Contacts Have To Be Used.
- Requires Large Latching Force And Bigger Socket Sizes
- Witness Marks On Sides - Bottom Of Ball Not Compromised.

SOLDER BUMPS

Contact Technology for 0.5 mm Pitch and Below – Ambady et al.
BiTS Workshop 2003, March 2 - 5, 2003
FUTURE DESIGN CHALLENGES

• Low Cost And Reliable Contacts For 0.4mm & 0.3mm Pitch.
• Small Open Top Socket Outline.
• Contact Life.
• Manufacturability Of Fine Pitch Sockets.
• Handling Of Multiple Solder Ball Profiles.
• Moldability Issues Of Plastic Parts For Fine Pitch.
ACKNOWLEDGEMENTS

• Work presented here was the result of much effort by many people - especially the following: ........
  
• Design Team in Japan
• Design Team in Korea
• WW Manufacturing Team
• Technical Services Lab
DISCUSSION
High Frequency Performance of Various Test Contactor Geometries

0.8 mm Pitch

Eric Fachon
QA Technology, Inc.
BiTS Workshop, March 2003
Test System

- Hewlett Packard: 8720ES Vector Network Analyzer, 50MHz-20GHz
- GigaTest Labs: GTL 4040 Wide Area Probing Station & Custom Test Fixture
- GGB Industries: Microwave Probes and Calibration Substrate
Test System
Custom Test Fixture

- Designed by GigaTest Labs
- Allows the use of a simple, symmetrical surrogate contactor
- Provides for Open, Short and Loop-thru measurements
- Allows measurements of different pin locations
- Provides for measurements on various pitches
Test Fixture

- Test arrays for probe pitches of:

  1.0 mm
  0.8 mm
  0.75 mm
  0.65 mm
  0.5 mm
Test Fixture

- Top board
- Surrogate package
Test Fixture

- Top board
- Surrogate package
Test Fixture: Surrogate Contactor

- Torlon 4203
- 10 x 10 Array
Test Fixture: Loop-thru

- Round trip through two adjacent probes and surrogate package
- Surrounding probes are grounded
Test System Repeatability

Insertion Loss ($S_{21}$)

Composite of Five Data Sets

$S_{11}$ Open

$S_{11}$ Short
Early Contactor Repeatability

Insertion Loss ($S_{21}$)

Selected Data

$S_{11}$ Open

$S_{11}$ Short
General Test Methodology:

- Fabricate surrogate contactor
- Perform system calibration (SOLT)
- Make Open/Short/Thru measurements for all four probe pair locations
- Repeat for each of four contactor orientations
- Import measurement data to Excel
- Generate Smith Charts and Bandwidth Plots
- Generate averaged S-parameter data for model extraction by GigaTest
Our earliest surrogate contactors were of a simple one piece design. Subsequent versions captured the probe via a two piece design. Clearances were varied in these later designs to evaluate the effect on high frequency performance.
Contactor Geometry Variants

- Minor Diameter x Major Diameter
- Probe: \(0.0166\)" x \(0.0224\)"
- Tight Clearance: \(0.018\)” x \(0.024\)”
- Medium Clearance: \(0.021\)” x \(0.026\)”
- Loose Clearance: \(0.021\)” x \(0.028\)”
S-Parameter Measurements

- Tight Clearance
- -1db at 3.7 GHz

Insertion Loss ($S_{21}$)

S11 Open

S11 Short
S-Parameter Measurements

- Medium Clearance
- -1db at 10.0 GHz

Insertion Loss ($S_{21}$)

- $S_{11}$ Open
- $S_{11}$ Short
S-Parameter Measurements

- Loose Clearance
- -1db at >10.05 GHz

Insertion Loss ($S_{21}$)

S11 Open

S11 Short
S-Parameter Measurements

- Loose Clearance
- -1db at 12.25 GHz

Insertion Loss ($S_{21}$)

S11 Open

S11 Short
S-Parameter Measurements

- Tight Clearance
- Crosstalk

**S₂₁ Open**

Slide 19
S-Parameter Measurements

- Medium Clearance
- Crosstalk

**S\textsubscript{21} Open**

Slide 20
S-Parameter Measurements

- Loose Clearance
- Crosstalk

![Graph showing S21 Open](image)

**S21 Open**
Time Domain Measurements

- Close Clearance
- Loop-thru

- Rise Time = 53 ps
- ½ Delay = 40 ps

TDR

TDT
Time Domain Measurements

- Medium Clearance
- Loop-thru

- Rise Time = 38 ps
- \(\frac{1}{2}\) Delay = 35 ps

TDR

TDT

Slide 23
Time Domain Measurements

- Loose Clearance
- Loop-thru
- Rise Time = 37 ps
- ½ Delay = 33 ps

**TDR**

**TDT**
Equivalent-circuit Model Extraction

- Model data extracted by GigaTest Labs

- L1, L2: pin self inductance
- M21: mutual inductance between adjacent pins
- R1, R2: shunt resistance of inductors L1 and L2
- C21a: mutual capacitance between pins (PCB side)
- C21b: mutual capacitance between pins (BGA side)
Model Data Comparison

- **Self Inductance (nH)**
  - Tight
  - Medium
  - Loose

- **Mutual Capacitance (pF)**
  - Tight
  - Medium
  - Loose

- **-1db Bandwidth (GHz)**
  - Tight
  - Medium
  - Loose
Alternate Material: Torlon 5530

- Medium Clearance
- -1db at 10.0 GHz

Insertion Loss ($S_{21}$)

$S_{11}$ Open

$S_{11}$ Short
Alternate Material: Torlon 5530

- Medium Clearance
- Crosstalk

S21 Open

Slide 28
Alternate Material: Torlon 5530

- Medium Clearance
- Loop-thru

- Rise Time = 39 ps
- $\frac{1}{2}$ Delay = 35 ps

TDR

\[\text{Ohms} \]
\[\text{Time (ps)}\]

TDT

\[\text{rho} \]
\[\text{Time (ps)}\]
Alternate Material: Model Data

**Self Inductance (nH)**

**Mutual Capacitance (pF)**

-1db Bandwidth (GHz)
Conclusions

- Contactor housing geometry plays a significant role in the high frequency performance of a test contactor.
- Small variations in geometry can have a large effect on loop-thru bandwidth, a popular figure of merit for contactors.
- Probe contact consistency is a vital contributor to repeatable high frequency performance (and DC performance as well).