BiTS™

Burn-in & Test
Socket Workshop

March 7 - 10, 2004
Hilton Phoenix East / Mesa Hotel
Mesa, Arizona

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Session 7
Wednesday 3/10/04 8:00AM

DEFORMATION AND CONTAMINATION

“Effects Of Contaminants On Test Pad Surfaces”
 Therese Souza – Rika Denshi America, Inc.

“Effects Of Solder Ball Deformation On Interconnect Quality And Reliability”
 John Caldwell – Micron Technology, Inc.

“Testing Of VQFN With Palladium Cobalt Pogo Pin”
 Thuan-Lian Chua – Infineon Technologies
 Jayachandrian – Infineon Technologies  Dieter Schuetz – Infineon Technologies
Effects of Contaminants on Test Pad Surfaces

Identifying A Potential for Yield Loss

Author:

Therese Souza, Rika Denshi America

BiTS Workshop 2004
Historical

• Contamination recognized as a problem by Bell Labs
  – Problem identified in assembled products
• Separable connectors and wiping effectiveness
  – Displacing contamination
  – Complicates contact design
• A real & serious problem for microelectronics
Possible Contaminants

- Handling – skin oils, flakes of skin, smoke, dust
- Packaging – residues from plastic bags
- Process chemicals – plating residues, solder flux, tap water, cleaners, oils, outgassing from plastic fixtures
- Storage & environmental gases - hydrocarbons, sulfides
Challenge for Contactors

Smaller test probes have decreased surface area, normal force, and operating/testing voltages.

These factors lead to:

  Increase in sensitivity to surface contamination
Symptoms of Contamination

• Failure or erratic data at electrical testing
• May pass initial testing but fail at a later date
  Note: In each case the product passes tests after cleaning

Example using resistance measurements:
• Initial resistance is high or erratic – decreases with cycling or with increased normal force
Yield Loss, 0.1%

Opportunity lost per 1,000,000 devices tested

<table>
<thead>
<tr>
<th>Cost of Device, $</th>
<th>Opportunity Lost, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>750</td>
<td>750,000</td>
</tr>
<tr>
<td>500</td>
<td>500,000</td>
</tr>
<tr>
<td>100</td>
<td>100,000</td>
</tr>
</tbody>
</table>
**Experiment**

- 50 test probes
- 50 cycles per test
- 7 test samples (blocks)
- Resistance before and after contaminating test samples
- Contact force 62 grams
- Plunger tips cleaned
- Based on ASTM B667-97
- Cannot prevent vibrations
ASTM B667-97

- 4-wire contact resistance method
- Effects of films on conductive surfaces
- No wipe or vibrations
- Produce normal force vs. resistance curve
Cycle Tester
Selected Contaminants
Applied to Test Surface (Block)

Test Surface has a copper base plated with 1 micron of nickel then .75 micron of hard gold.

1. Tap Water
2. Skin Oils
3. Dust
4. Storage in Plastic Bag, 24 hours, 100 °F
5. No Clean Flux (ORL-O), 250 °C, 5 minutes
6. Cigarette Smoke
7. Control – not contaminated
Before Contamination

Initial Resistance Readings at Start

Probe Number

MilliOhms

Probe Number

1 5 13 17 21 25 29 33 37 41 45 49
After Contamination

Resistance After Contamination

Plunger Number

MilliOhms

0 20 40 60 80 100 120 140 160

1 5 9 1 31 72 12 52 93 33 74 14 54 9

Legend:
- 1
- 2
- 3
- 4
- 5
- 6
- 7
After Contamination

Comparison Average Resistance Readings

- Std Dev between 0.72-2.05 MilliOhms
- Open Circuit on one contact with dust

MilliOhms

tap water, skin oils, dust, plastic bag, flux, smoke, control

Before, After
Cleaning

• Identify the contaminant
  – ESCA, Auger… etc

• Test several cleaners or processes.
  – Do not assume that a cleaner is “safe” and will not leave contaminants

• Plasma cleaning

• Vacuum instead of high pressure air
Contamination Prevention

- Prevention is better than repair
- Program that:
  - Identifies potential sources of contamination
  - Includes process steps that prevent or repair contamination
  - Routine testing for clean surface
    - UV lights
    - Ionic contamination testing
Conclusions

- Surface contamination can affect electrical testing
- Potential contaminants can be identified
- Contamination can be prevented with a proactive plan
- Repair is possible with the right process
References


• *Outgassing of Engineering Plastics In High-Vacuum Applications*, http://www.boedeker.com/outgas.htm

References

• T. F. Egan, *Ionic Contamination*, Plating, April 1973

• *Rinsewater Quality....Hard Data*, http://www.pcbfab.com/rinsew.html

Effects of Grid Array Ball Deformation on Solder Joint Quality and Reliability

2004 Burn-In and Test Socket Workshop
March 7–10, 2004

John Caldwell
Test R&D Engineer
Micron Technology, Inc.
Agenda

► Industry concerns & opposing arguments
► The “No Contact Zone”
► Design of experiment
► Device coplanarity
► Solder joint quality and reliability
► Follow-on research
► Q&A
Background

► Industry concerns
  - Entrapped flux and contaminates may cause voids in the BGA solder joint during SMT reflow
  - Deformation on the upper hemisphere of the solder ball may cause coplanarity error
  - Cosmetics (??)

► Opposing arguments
  - Solder ball contamination/residual flux, PCB land contamination, reflow oven profile, and solder paste/flux chemistry have a profound impact on voiding [1]
  - Voided solder joints have been shown to perform better during reliability testing [2]

► Bottom line: The surface mount process MUST be done right
Some semiconductor producers adhere to a “no contact zone” policy

- Require test socket suppliers to provide alternate solution
- Semiconductor producers may address within their own process (i.e. post electrical test reflow)

Is this really necessary?
Design of Experiment

► SDRAM devices contacted repeatedly, then segregated into “damage level” groups
  ▪ Sample set = 300 SDRAM fBGA’s per damage group
  ▪ One “contact” = One insertion into each of the three contact styles (crown, cup, pincher)

► Device packages laser scanned for packaged component dimensions (coplanarity, etc.)

► Damage level groups randomized and assembled onto dual in-line memory modules (DIMM)

► Initial module failures investigated for possible correlation to preexisting solder damage

► Passing modules reliability tested up to 3,250 temperature cycles

► Failure verification post temperature cycle
## Materials & Process

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device Size (mm):</td>
<td>8 x 16</td>
</tr>
<tr>
<td>Solder Balls:</td>
<td>60</td>
</tr>
<tr>
<td>Pitch:</td>
<td>0.8mm</td>
</tr>
<tr>
<td>Device Package:</td>
<td>Board-on-Chip (BOC)</td>
</tr>
<tr>
<td>Solder Ball Diameter:</td>
<td>0.40mm</td>
</tr>
<tr>
<td>Land Pad Diameter:</td>
<td>0.33mm</td>
</tr>
<tr>
<td>Solder Composition:</td>
<td>63% Tin/37% Lead</td>
</tr>
<tr>
<td>PCB Attach Medium:</td>
<td>Eutectic Solder Paste</td>
</tr>
<tr>
<td>Reflow Profile:</td>
<td>Standard (215°C peak)</td>
</tr>
</tbody>
</table>
Build & Test Parameters

► Memory module
  ▪ 8-component DIMM
  ▪ 6-layer FR4
  ▪ PCB thickness = 1.27mm
  ▪ PCB length = 133.35mm
  ▪ PCB height = 31.75mm

► System level motherboard test to gauge time-zero module quality

► Reliability test
  ▪ -40°C to +85°C, air-to-air, two cycles per hour
Excessive Solder Deformation?
Levels of Deformation

- Low: control
- Medium: up to 24 insertions
- High: up to 50 insertions
Device Coplanarity

- Laser scan data analyzed statistically
- No adverse impact

<table>
<thead>
<tr>
<th>Level</th>
<th>Number</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err Mean</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1_LOW</td>
<td>3000</td>
<td>0.019930</td>
<td>0.011334</td>
<td>0.00021</td>
<td>0.01952</td>
<td>0.02034</td>
</tr>
<tr>
<td>2_MED</td>
<td>3000</td>
<td>0.018553</td>
<td>0.010636</td>
<td>0.00019</td>
<td>0.01817</td>
<td>0.01893</td>
</tr>
<tr>
<td>3_HIGH</td>
<td>3000</td>
<td>0.016877</td>
<td>0.009727</td>
<td>0.00018</td>
<td>0.01653</td>
<td>0.01723</td>
</tr>
</tbody>
</table>
Time-Zero Module Quality

► 6 component failures
  ▪ Internal component degradation
  ▪ Consistent with silicon level defects

► 2 component failures
  ▪ Poor solder joint geometry
  ▪ Low volume solder interconnect
  ▪ No voids

► X-ray, x-section, electrical failure analysis to verify failure modes

► Time-zero module fails not related to solder damage/voids
Solder Joint Reliability (-40°C to +85°C)

Probability - Weibull

Unreliability, $F(t)$

Thermal Cycles, $(t)$

$\beta_1=6.3121$, $\eta_1=3477.0726$, $\rho=0.9878$
$\beta_2=7.5691$, $\eta_2=3309.2888$, $\rho=0.9882$
$\beta_3=6.4851$, $\eta_3=3417.0370$, $\rho=0.9874$

Source: Micron Technology, Inc.
Conclusion

► Surface mount process maturity and monitoring is VERY important
  - X-ray (void volume & frequency)
  - X-section (standoff height measurements)
  - Reflow oven profile
  - Solder paste/flux chemistry
  - Clean BGA solder alloys & PCB land pads

► No correlation between degree of solder ball damage and -
  - Component coplanarity degradation
  - Time-zero solder interconnect quality
  - Solder joint reliability (SJR)
Follow-on Research

- 96.5Sn/3.0Ag/0.5Cu (lead-free) versus 62Sn/36Pb/2.0Ag
  - Daisy chain WLCSP’s
  - In-situ solder joint monitoring

- Results → April 2004
Acknowledgements & Sources

► Special thanks to:
  William Casey, Mike Morrison, John Odle, Faye Sinclair, Rich Mansfield, David Sammons, Glen Watson, Gregory Barnett, Ismat Sulaivany, Syed Ahmad, Ken Eytchison, Von Sorenson, Arlene Haugse

► Effects of solder joint voiding on plastic ball grid array reliability
  Donald R. Banks, et al.
  Motorola Semiconductor Products Sector

► Reduction of voiding in eutectic ball grid array solder joints
  William Casey
  Micron Technology, Inc.
Testing of VQFN with Palladium-Cobalt Pogo Pin

Chua Thuan Lian
Jayachandrian
Schuetz Dieter
Contents

Background

Problem

Target

Introduction to Testing of VQFN Package

Study the Poor Performance of the Gold Pogo Pins

Pogo Pins Selection and Study

Result of the Performance of the PdCo Pogo Pins

Benifits of Introduction of PdCo Pogo Pins
Low Production Output Capacity
High Invalid Test Failures
High Tester/Handler Downtime due to frequent cleaning of contactors
High Consumption of Pogo Pins
1. Short life-span of pogo pins due to deposition of solder on the pin (<12k insertions).

2. High downtime due to regular cleaning of pogo-pins.

3. High % of invalid parametric failures (12% ~ 40%).
Testing of VQFN with Palladium-Cobalt Pogo Pin

Reduce Downtime of Equipment by 50%

Improve Contactor Performance by 50%

Improves Production Output Capacity by 50%

Reduction in Production Cost by 50%
Introduction to Testing of VQFN Package
Introduction to Very thin Quad Flat Non Leaded Package (VQFN)

<table>
<thead>
<tr>
<th>Package</th>
<th>Body size (mm)</th>
<th>Package thickness (mm)</th>
<th>Terminal pitch (mm)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>VQFN 48</td>
<td>7 x 7</td>
<td></td>
<td></td>
<td>In production</td>
</tr>
<tr>
<td>VQFN 40</td>
<td>5.5 x 6.5</td>
<td>0.9</td>
<td>0.5</td>
<td>In production</td>
</tr>
<tr>
<td>VQFN 32</td>
<td>4.5 x 5.5</td>
<td></td>
<td></td>
<td>Q4/ 2004</td>
</tr>
<tr>
<td>VQFN 24</td>
<td>3.5 x 4.5</td>
<td></td>
<td></td>
<td>Q2/ 2004</td>
</tr>
<tr>
<td>VQFN 20</td>
<td>3.5 x 3.5</td>
<td></td>
<td></td>
<td>In production</td>
</tr>
</tbody>
</table>
Test Contacting Methodology

Leaded Package

Ball Grid Array Package

VQFN Package
VQFN package contact element

Pogo-pins are used as contacting elements between device and DUT board.

IC Contact pad

Pogo pins

size of pad

0.55

0.5

0.25

0.25
Test Handling Technology

Gravity handlers are used to test VQFN 48-1 packages by means of pogo pin contactors.

The initial pogo pin design used was the crown tip pogo pins.

Crown tip pogo pins from RXX
Study the Poor Performance of the Gold Pogo Pins
Gold Plated Pogo Pins

• Study of the gold plated pogo pin from different supplier.
• Solder deposit were confirmed on all evaluated gold plated plate.
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Testing of VQFN with Palladium-Cobalt Pogo Pin

Gold Plated Pogo Pins

- Study of the electrical impact on the solder deposit on the tip surface.
- Increase of resistance is observed as early after 1K insertion. And worst at 10K

New Pogo pin

Pogo pin at 100K insert
Gold Plated Pogo Pins

Experiments show that as solder deposition increases, the contact resistance will also increase.

Increase in contact resistance of pogo pins will lead to high % of invalid parametric failures.
Gold Plated Pogo Pins

- Study of the impact of cleaning on gold plated pogo pin.
- Solder deposit was able to be removed after cleaning.
- Pogo pin based was exposed after frequent cleaning.

Pogo pin before cleaning  Pogo pin after cleaning
Gold Plated Pogo Pins

- Study of the mode of the gold plating removal.
- Adhesive effect of gold plating removal was observed after frequent cleaning.
Attached are the SEM picture (showing adhesive failure) and EDX revealing the base material (steel).
Finding of the problem

• The solder deposit, which has an adhesive effect on the pogo pins, has caused an increase in the contact resistance of the pins.

• The same adhesive effect was observed in the various types of pogo pins used for the VQFN packages.

• Cleaning is needed to remove the solder deposit from the pogo pins, but this will cause a deterioration in the life-span of the pogo pins.
Pogo Pin Selection and Study
Selection criteria and Study Method

Main criteria for the selection of test contactor

- Reliable and Good Electromechanical Performance
- Long Life-span, >500k Insertions
- Robust Housing, >1 million insertions
- Modular Design for Ease of Maintenance
- Low Cost

Test contactor qualification test

- Mechanical life cycle test (Contact element life)
- Electrical performance (True test monitoring)
- Mechanical performance (Test pad protection, DUT board)
- Mechanical requirements (Cleaning, contact replacement)
Selection criteria and Study Method

- Look into different material or plating with better solder resistance property
- Conduct cycle test to check on insertion life cycle vs resistance
- Conduct contact housing evaluation with actual production loading
- To compare the Operating mechanism of pogo pin
Cycle Testing
Life Cycle Resistance Study

Gold Pin

- 8020SnPb_standard_AUpin
- 8020_SnPb_reflow_Au_Pin
- 100Sn_standard_Au_Pin
- 100Sn_shiny_Au_Pin
- 98_2SnBi_Au_Pin

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Testing of VQFN with Palladium-Cobalt Pogo Pin
Life Cycle Resistance Study

Ni_Pin_on 80_20SnPb_Standard

resistance (ohms)

# touchdowns

8020_SnPb_standard_Ni_Pin
80_20SnPb_Standard_Synergetix_Ni_Pin
Life Cycle Resistance Study

![Graph showing resistance study of PdCo Pin over the number of touchdowns.](chart.png)
Life Cycle Resistance Study

Contact resistance vs Standard and reflow

![Graph showing contact resistance vs number of touchdowns for different conditions](image-url)
Testing of VQFN with Palladium-Cobalt Pogo Pin

Life Cycle Resistance Study

Contact resistance Pogo-Pins vs. Leadframe with different Platings

- 80/20 SnPb standard (PdCo Pin)
- 80/20 SnPb standard (Au-Pin)
- 80/20 SnPb reflow (Au-Pin)
- 80/20 SnPb reflow (PdCo Pin)
- 80/20 SnPb standard (Ni-Pin)
- 100 Sn standard (Au-Pin)
- 100 Sn standard (PdCo-Pin)
- 100 Sn shiny (Au-Pin)
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Testing of VQFN with Palladium-Cobalt Pogo Pin  

**Contactor Evaluation Matrix**

<table>
<thead>
<tr>
<th>Handler Type</th>
<th>Pin Type</th>
<th>Housing</th>
<th>Result</th>
<th>Cleaning Freq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multitest</td>
<td>“X” Source (250K)</td>
<td>Multitest</td>
<td>High Parametric Failures when reaching end of life span</td>
<td>3</td>
</tr>
<tr>
<td>Multitest</td>
<td>“X” Source (250K)</td>
<td>*SNR</td>
<td>High Parametric Failures when reaching end of life span</td>
<td>3</td>
</tr>
<tr>
<td>Multitest</td>
<td>K&amp;S (500K)</td>
<td>*K&amp;S</td>
<td>Good Elect. Yield. Life Span &gt;500K</td>
<td>1</td>
</tr>
<tr>
<td>Rasco</td>
<td>“X” Source (250K)</td>
<td>Rasco</td>
<td>Good Elect. Yield. Life Span ~200K.</td>
<td>2</td>
</tr>
<tr>
<td>Rasco</td>
<td>K&amp;S (500K)</td>
<td>*K&amp;S</td>
<td>Good Elect. Yield. Life Span &gt;500K</td>
<td>1</td>
</tr>
</tbody>
</table>

Note:  
1. * denotes design based on Infineon Outline.  
2. Material used for pogo pins is Palladium Cobalt.
Comparison of “X” Source and K&S Pogo-pin Operating Mechanism

“X” source Pogo pin (Single Acting)

- Only DUT-end spring loaded (Spring force 19g)
- The Plunger and the barrel moves together when device is plunged

K&S Pogo pin (Double Acting)

- Both ends spring loaded (reciprocating) (Spring Force 42g)
- 0.3mm pre-load
- Pre-load ensures good continuity between DUT board and pins, reduces damage to test pads
- Only the plunger-tip moves when device is plunged
- Higher contact force on package pads improves electrical performance
- Less friction during reciprocating action
Summary of the Study of PdCo

• The PdCo plated pogo pin has longer insertion life-span and minimum change in contact resistance, relative to large number of insertions.

• PdCo plating exhibits low coefficient of friction and makes it easier for foreign matter to slide along the surface of the plunger and prevents solder deposition.

• Contactor design also plays a key role in the insertion life cycle performance.

• Contactor with Pre-load design also reduces damage to test pads through good continuity between DUT board and pins.

• Minimum cleaning frequency during production is achieved.

• PdCo plated pogo pins are suitable for testing of VQFN package.
Result of the Performance of the PdCo Pogo Pin
Fus18/16/18 Test performance

Actual Production Monitoring

- Ni plated pins
- PdCo plated pins (K&S)

Cleaning Frequency

Output (K)

Invalid Fails (%)
## Monitoring Results

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Gold plated pogo-pins</th>
<th>(PdCo) plated pogo-pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-Span (No. of insertions)</td>
<td>50,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Vendor’s Spec.</td>
<td>100,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Cleaning Freq./Day</td>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td>% Invalid Test Failures</td>
<td>&lt; 5%</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Avg 1st Pass Yield</td>
<td>70 - 95%</td>
<td>90 - 94%</td>
</tr>
<tr>
<td>Avg Daily Production Output</td>
<td>7,000</td>
<td>14,000</td>
</tr>
</tbody>
</table>
Benefits of Introduction of PdCo Pogo Pin
### 2004 Burn-in and Test Socket Workshop

**Testing of VQFN with Palladium-Cobalt Pogo Pin**

#### Results (Quantifiable)

**Reduction in Pogo-Pin Consumption**

<table>
<thead>
<tr>
<th>Cost of Pogo-pins</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel plated pins: S$ XX.XX</td>
<td>Output / day: 14,000</td>
</tr>
<tr>
<td>Palladium Plated pins: S$ YY.YY</td>
<td>Package: VQFN 48 (48 pins/set-up)</td>
</tr>
</tbody>
</table>

#### Cost Savings/set-up

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Gold plated pogo-pins</th>
<th>Palladium Cobalt plated pogo-pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-Span (No. of insertions)</td>
<td>50,000</td>
<td>250,000</td>
</tr>
<tr>
<td>Cost of pins consumed /month</td>
<td>S$7,344</td>
<td>S$974</td>
</tr>
<tr>
<td>Cost of pins Consumed/Yr</td>
<td>S$88,128 (S$7,344 x 12mths)</td>
<td>S$11,688 (S$974 x 12mths)</td>
</tr>
</tbody>
</table>

**Savings per year**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Savings per year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S$76,440 (S$88,128 - S$11,688)</td>
</tr>
</tbody>
</table>

**86% Savings**
### Results (Quantifiable)

Reduction in Tester and handler downtime (Due to frequent cleaning of pogo-pins)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Palladium Cobalt plated pogo-pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cleaning/day</td>
<td>2</td>
</tr>
<tr>
<td>Down Time/day</td>
<td>10 mins</td>
</tr>
<tr>
<td>Due to cleaning</td>
<td>[2 x 5mins]</td>
</tr>
<tr>
<td>Cost impact on handler</td>
<td>S$8,294</td>
</tr>
<tr>
<td>Downtime/per year</td>
<td>S$2,527</td>
</tr>
<tr>
<td>Cost impact on tester</td>
<td>S$199,065</td>
</tr>
<tr>
<td>Downtime/per year</td>
<td>S$60,652</td>
</tr>
<tr>
<td>Cost savings</td>
<td>S$248,900</td>
</tr>
<tr>
<td>(199065 + 60652) - (8294 + 2527)</td>
<td></td>
</tr>
<tr>
<td>Savings per year</td>
<td>SGD 325,340</td>
</tr>
</tbody>
</table>

**Total savings per year**

SGD 325,340

95% Savings

**PER SETUP!!**
Benefits

- Reduction in Downtime of Equipment
- Increased in Production output
- Increased in Contactor performance
- Reduction in Production Cost

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