What The Electronics Industry Missed For 80 Years ...

... Interfacial Void Formation In Solder Joints With Cu Pad Structures During Thermal Aging

Donald W. Henderson*, Peter Borgesen**, Pericles Kondos**
Isabel De Sousa*, Luc Patry* and Liang Yin**

TMS - March 2006

* IBM Corporation
** Universal Instruments Area Array Consortium
Background Information

- Three "Difficulties" – Essentially, Newly Recognized Phenomena Have Been Found In The Investigation Of Soldering Properties Of Plated Cu
  
  1. Highly Variable Cu Consumption Rates During Reflow And Thermal Aging
  2. Solder Joint Fragility Deriving From Solder Joint Interfacial Void Formation
  3. Solder Joint Fragility In The Absence Of Interfacial Void Formation

- Work Continues In Each Of These Areas

- Today's Review Will Focus On The Solder Joint Interfacial Voiding Phenomenon
Today's Review Outlines Two Cases Involving Voiding Phenomena In Solder Joints With Cu Pad Structures

- High Sn Solder Case
  - Sn-Pb Eutectic Alloy (i.e., Sn-37Pb)
  - Pb-Free SAC Alloys (e.g., Sn-3.0Ag-0.5Cu)

- Low Sn Availability Case
  - Low Sn Solders (e.g., Pb-3Sn)
  - Systems With Low Sn Availability

Voiding Phenomena:

- Appear To Be Manifestations Of Interfacial, Reactive, Inter-diffusion Processes
- More Than One Void Formation Mechanism Appears to Be Operative
- Presently, Details Of The Void Formation Mechanisms Are Poorly Understood
Interfacial Structure In Soldering To Cu Pads

Post BGA attachment
245 Peak / 90 sec Dwell

3X Reflow Profile
260 C Peak / 140 s Dwell

Aging 500 hrs / 150 C

Observations:

1. **Post BGA Attachment**: Cu$_3$Sn is present; but, very thin
   Cu$_6$Sn$_5$ is irregular in thickness (scalloped)

2. **3X Reflows**: Presence of Cu$_3$Sn well defined and Cu$_6$Sn$_5$ coarsens and spalls into the solder

3. **Thermal Aging At 150°C**: Cu$_3$Sn layer thickens by solid state diffusion mode, uniform thickness
   Cu$_6$Sn$_5$ phase shows a more uniform thickness at interface.
Interfacial Void Formation With High Sn Solders
An Overview

- Interfacial Void Formation Occurs In Solder Joints With Cu Pad Structures And Sn Based Solders e.g., Sn-Pb Eutectic and SAC Solders

- All Solder Joints With Cu Pad Structures Demonstrate Some Level Of Void Formation

- No Void Formation Typically Manifested Immediately After Initial Solder Joint Reflow

- Interfacial Void Formation Occurs During Thermal Aging

- Void Formation Is A Manifestation Of The "Kirkendall Voiding" Phenomenon
  - Interfacial, Reactive, Inter-diffusion Processes
  - A Coalescence of Atomic Vacancies In Pore Structures By Diffusive Processes
  - Requires A Local Vacancy Supersaturation

- Void Formation, Typically Occurs:
  Within The Cu₃Sn Phase And / Or At The Cu - Cu₃Sn Interface
To Date, Using High Purity, Wrought, Cu, Minimal Void Formation Has Been Found To Result, During Thermal Aging

With Plated Cu Void Growth Rates And Void Spatial Density Can Be Grossly Variable

The Causes Of These Variabilities With Plated Cu -- Are Presently Unknown

In Some Instances With Plated Cu:
Time - Temperature Behavior Of Voiding Phenomenon Can Lead To Severe Solder Joint Fragility At The Temperatures And The Time Frames Associated With Field Applications

Thermal Aging Of Solder Joints Is The Only Methodology, Presently Known, To Detect The Propensity For Severe Voiding In Plated Cu Materials

Propensity For Severe Void Formation In Plated Cu
   - Is Not Rare
   - Has Been Found, At Low Frequency – In Electronics Industry Supply Chain
Recent Literature
Reporting, Newly Found, Solder Joint Embrittlement Phenomenon With High Sn Solders

- 2004 Reports In Literature of Cu Pad Solder Joint Embrittlement Fostered By:
  - Shock Testing Requirements For Hand Held Electronic Equipment
  - Transition To Pb-Free Solders

- Reports Focused On Kirkendall Voiding Mechanism

- TMS March, 2004 Meeting and ECTC - June, 2004 Meeting
  - Texas Instruments ECTC Presentation:
    "Effect of Thermal Aging on Board Level Drop Reliability for Pb-free BGA Packages"
    Cheng Chiu, Kejun Zeng, Roger Stierman, Darvin Edwards, Kazuaki Ano
  - Hitachi - UCLA ECTC Paper:
    "Impact Reliability of Solder Joints"
    M. Date, T. Shoji,* M. Fujiyoshi, K. Sato, and K. N. Tu
Correlation of drop reliability to IMC voids

(From TI's Presentation)
Results Of IBM Testing On Kirkendall Voiding Mechanism Initial IBM BGA Attachment Experiment

- No Severe Kirkendall Voiding Noted In Early Investigations

- New Evaluations Undertaken After Industry Reports

Results From SAC, BGA, Laminate Testing / Evaluation

- Experimental Test Vehicle -- With Plated Cu BGA Pad Structures
- HTS Testing => 150 C For 1000 Hrs.
- 15 Modules Produced From 6 Laminate Lots
  Sectioned After HTS Testing For BGA, Solder Joint Evaluations

- Results => Highly Variable From Lot To Lot After HTS Testing
  - One (1) Laminate Lot Showed Massive Voiding At Cu\textsubscript{3}Sn -- Cu Interfaces
    - 8 BGA Rows From 5 Modules Sectioned For Evaluation
    - Every BGA Site In All Rows Showed Severe Interfacial Voiding
    - However, Significant Variability From Pad To Pad … And Within Pads
  - Five (5) Laminate Lots Showed Minimal / Almost Nonexistent Voiding
    - Multiple Rows Sectioned From Modules From Each Laminate Lot
    - No Significant Voiding Found On Any BGA Pad Site In Any Module
Initial Experiment - HTS Test Results

- SAC - Cu Pad Solder Joint

- The Cu Pad-SAC Interfacial Structure
  - Cu
  - Cu$_3$Sn Layered Interface
  - Cu$_6$Sn$_5$
  - SAC Solder Alloy

- Experimental Test Conditions - 6 Laminate Lots
  - Same Cu Plating Bath - Different Dates
  - Same Solder Ball Lot / Flux Lot
  - Same Oven / Reflow Profile / Assembly Day
  - Same Thermal Aging Test - 1000 Hrs / 150 C
  - IMC Structures Show Identical Thicknesses
  - Only 1 Plating Lot In 6 Showed Significant Voiding
  - Solder Joint, Pull Test Results, Showed Decline

- Additional Thermal Aging Testing
  - Of ~ 35 Subsequent Lots Showed No Evidence Of Excessive Voiding
  - One Additional Laminate Lot Showed Mild Propensity For Void Formation
IBM Testing On Kirkendall Voiding Mechanism
Vendor “A” Laminate Test Results

- Worst Case Section Of BGA Solder Joint Interface After 1000 Hours At 150 C

  - Central Pad Region

  - Voiding Levels Low at Pad Periphery -- For This Particular Pad
  - Void Formation Variable From Pad To Pad ..... And Within Pads
Analytical Work Undertaken To Determine Cause Of Voiding

- All Samples From Test Bath 1 “Good” Lots And Single, “Bad” Lot

- SIMS Compositional Depth Profiles
  - “As Plated” Cu + Solder Joints, Including Intermetallic Compounds And Interfaces
  - Cs Sputtering Beam => Concentration Differences In C, O, S, and Cl Examined
  - No Significant Cu Bulk Compositional Differences Found
  - Concentrations of C,O,S, and Cl => Typical Of Plated Cu
  - Evidence Of Interconnected Porosity In Severely Voided Cases
  - Indication Of Increased Cu Surface Roughness In Samples With Severe Voiding
  - Surface Concentrations / Roughness Effects Required Great Depth For Stabilization
  - Work Continues In This Area

- TEM Analysis
  - Cu and Cu₃Sn Phases And Interfaces Examined
  - No Compositional Differences Or Segregation Found At Interfaces Or Grain Boundaries
  - Cu₃Sn Phase In Both Sample Types => Marked By Small Grain Size … ~ < 1 u
  - Evidence Of Later Stage Columnar Grain Growth In Cu₃Sn Phase On Cu₆Sn₅ Side.
  - No Significant Microstructural Differences Found Between “Good” and “Bad” Samples

- NET => No “Smoking Gun” Found … But, More Work Underway … New Samples
Analytical Work
Undertaken To Determine Possible Cause Of Voiding

• GDMS Compositional Evaluations
  – Examination Of Electroplated Plated Cu Foils
  – Highly Voiding And Minimally Voiding Foils Analyzed For 72 Elements
  – No High Level Metallic Impurities Found - Typically < 5 ppm
  – Cl ~ 10 to 40ppm / S ~ < 1ppm to 20ppm /
  – No Clear Correlation Found Between Voiding Propensity and Composition

• Carbon Compositional Analysis
  Leeco Carbon Determination Technique

<table>
<thead>
<tr>
<th>Sample</th>
<th>Carbon in ppm</th>
<th>Sulfur in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Foil CF3</td>
<td>26</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Good Foil CF7</td>
<td>33</td>
<td>21</td>
</tr>
<tr>
<td>Good Foil CF14</td>
<td>55</td>
<td>13</td>
</tr>
<tr>
<td>Bad Foil CF2</td>
<td>29</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Bad Foil CF11</td>
<td>67</td>
<td>25</td>
</tr>
<tr>
<td>Bad Foil CF17</td>
<td>41</td>
<td>3</td>
</tr>
</tbody>
</table>
Universal Instruments Consortium Testing

- UIC Has Undertaken A "Random" Industry Sampling Of:

  - Approximately 40 Sources Of Electrolytically Plated Cu In Laminate Structures
  - Approximately 10 Sources Of Electrolytically Plated Cu Foil Material With Several Samples, Each, From These Foil Producers
  - Sampling Primarily Focused On US and European Suppliers
  - Sampling Emphasized "High Quality" Producers
  - Work Focused On High Sn Solders
Universal Instruments Consortium Findings

- All Cu Plated Material Shows Some Level Of Interfacial Voiding After HTS Testing

- Cu Appears To Be The Dominant Diffusing Species In Cu₃Sn At Temperatures Examined
  
  => Based On Using Voids In Cu₃Sn As "Kirkendall Markers"

- Significant Interfacial Void Formation Does Not Occur In Solder Joints
  
  → Using High Purity Wrought Cu Test Samples
  
  → Confirmed By IBM and Univ. Of Illinois Experiments

- Individual Void Growth Rates / Interfacial Volume Of Voids
  
  Can Vary Markedly Between Cu Plating Samples

- In Cu Samples Demonstrating High Interfacial Voiding Rates
  
  Increase In Pore Nucleation Rate Accompanied By Increased Pore Growth Rates
  
  (Consistent With Independent IBM Findings)

- Voiding Behavior Not Affected By:
  
  Flux, Surface Finish, Reflow Profile or Solder Alloy -- Consistent With IBM Findings

- Annealing Of Plated Cu Foils at ~ 650 C, Eliminates The Propensity For Voiding
  
  In Material With An Originally High Propensity For Void Formation

- Approximately 5 to 10 % Of The Cu Plating Samples => Laminates And Foils
  
  Show Structurally Significant Voiding In The Aging Of Solder Joints
Examples Of Extreme Voiding Behavior
In Industry Supply Chain
Universal Instruments Consortium Finding (continued)

- Arrhenius Extrapolation Of Voiding Growth Rates To Low Temperatures => Can Fail

  Extrapolation Of TI Data To Field Conditions By Cisco Systems, ECTC 2005
  - Z. Mei, M. Ahmad, M. Hu and G. Ramakrishna, ECTC (2005) p. 415
  - Arrhenius Plot Of TI Voiding Data Indicated:
    • Arrhenius Behavior Found In TI Measurement Range -- 100C to 175 C
    • Extrapolation Indicated:
      • 25 % Interfacial Voiding in 4.1 Yrs at 50 C
      • 50 % Interfacial voiding in 16.5 Yrs at 50 C
      • Implies Voiding Phenomenon Not a Significant Problem In Most Applications
      • Implication Is Incorrect

  Extrapolation Of UIC Data And Comparison To Experiments
  Showed Much Different Results - In Some Instances
  - Arrhenius Behavior Found In Samples From One Plating Source
    But, 25 % interfacial Voiding Occurred in 3 Months – At 70 C
  - Another Source Showed An Arrhenius Behavior in The 100 to 175 C Temperature Range
    • Extrapolation To 70 C Indicated 25% Interfacial Void Formation Would Occur At 6.5 Yrs
    • Experimental Evaluation Showed 25 % Interfacial Void Formation At 70 C In 3 Months

- Experimental Findings Demonstrate That Structurally Significant Void Formation Can Occur Under Field Conditions In Short Time Frames --- At Least In Some Cases
Voids As Kirkendall Markers
And The Question Of Sn Diffusion In Cu₃Sn
Aging 1 Week At 150 C
Voids As Kirkendall Markers
And The Question Of Sn Diffusion In Cu₃Sn

Potential Void Motion With Growth At The Cu-Cu₃Sn Interface

![Graph showing frequency per unit length vs distance of void from Cu/Cu₃Sn interface. The x-axis represents distance in micrometers (µm), and the y-axis represents frequency per unit length.]
Voids As Kirkendall Markers And The Question Of Sn Diffusion In Cu$_3$Sn Aging At 150 C

Constant Void Distribution Indicates Minimal Sn Diffusion
Comparison With Previous Work

• Knowledge Of The Growth Kinetics Of Cu3Sn Phase Is Important In Understanding Origins Of Void Formation.
  – Voids Almost Certainly Generated At Or Very Near Cu – Cu3Sn Or Cu3Sn – Cu6Sn5 Interfaces
  – Understanding Which Interfaces Are Involved Requires Knowledge Of The Growth Kinetics

• Previous Papers Of Note:

• Experiments Undertaken Include Sn-Cu and Cu – Cu6Sn5 Diffusion Couples With Inert, Kirkendall, Markers
  – Diffusion Experiments Undertaken At Higher Aging Temperatures
  – Previous Results Indicate That Sn Diffusion In Cu3Sn Is Significant
  – Paul, et. al., Results: \( J_{Sn} / J_{Cu} = 0.9 \) ( 215 C )
  – Pore Based Evaluation At UIC, In Present Work \( \Rightarrow J_{Sn} / J_{Cu} =< 0.1 \) ( 150 C )
  – Paul, et. al., Finding \( \Rightarrow \) Growth Of Cu3Sn, Phase, Only At Cu Interface
  – Present Investigation \( \Rightarrow \) Growth Of Cu3Sn, Phase, Substantially, At Cu6Sn5 Interface

• Previous Results Seem Inconsistent With Constancy of Pore Spatial Distribution In Solder Joints At Lower Aging Temperatures

• Cause For Differences In Behavior, Presently Unclear
  – Temperature ?
  – Microstructure ?
Speculative Hypothesis For Interfacial Void Formation

- **Hypothesis For Cu$_3$Sn Phase Interfacial Voiding**
  - Vacancy Diffusion Mechanism For Cu => In Cu$_3$Sn Phase
  - Cu Significant Diffusing Species In Cu$_3$Sn
  - Cu Diffusive Flux Accompanied By Corresponding - Counter - Vacancy Flux
  - In Reactive Inter-diffusion With Vacancy Diffusion
    - Interfaces Must Act As Vacancy Sources or Sinks
    - Applies to Cu – Cu$_3$Sn Interface and Cu$_3$Sn – Cu$_6$Sn$_5$ Interface
      - van Loo (1990)
  - Supersaturation of Cu Vacancies Created By Vacancy Flux Near Cu Interface Region
  - Supersaturations Of Vacancies -- Believed To Be Low ~ A Few Percent - At Most
    - Where Vacancy "Sinks" Readily Available
      - Bardeen and Herring (1952); Seitz (1953); Balluffi (1954)
  - At Cu – Cu$_3$Sn Interface => Interfacial Misfit Dislocations Most Probable Interfacial Sinks
    - Hirth (1995)
  - In Some Cases Sinks Could Be “Disabled”
  - Preexisting Cu – Cu$_3$Sn Interfacial Pores Will Also Act As Vacancy Sinks (Source Of Pores?)
  - Growth Of Cu3Sn Phase Occurs Principally At Cu3Sn - Cu6Sn5 Interface
    - (Based On Pores Motion, As Kirkendall Marker)
  - Pores Within Cu$_3$Sn Created By Growth Processes At Cu3Sn–Cu6Sn5 Interface – And Left Behind
  - Nucleation Of Voids By Atomic Vacancy Coalescence
    - Homogeneous Nucleation Assessed As Very Improbable - Sietz (1952)
    - Heterogeneous Nucleation Almost Certainly Required With Low Supersaturations
      - Resnick and Seigle (1957)
    - Possible Nucleation Processes At Cu – Cu3Sn and Cu3Sn – Cu6Sn5 Interfaces => Unclear
Limiting Pore Formation Behaviors

-Same Thermal Aging Condition
  150 C For 1000 Hours

-Note Pore Size Difference

-Pore formation
  At Cu – Cu₃Sn Interface
  =>
  Pores Nucleated / Grow
  Principally At Cu₃Sn Interface

-Pore formation
  Throughout Cu₃Sn Phase
  =>
  -Hypothesis:
    Pores Left Behind By Cu₃Sn Growth Process At Cu₃Sn – Cu₆Sn₅ Interface
Why Do Have Such Large Variations In Voiding?

• Possible Mechanisms In High Sn Solders -- Cu Pad System, causing Increased Voiding:
  
  – Increased Nucleation Site Density -- Reduced Activation Energy Barrier (Inconsistent With Increase In Nucleation And Growth Rates)
  
  – Increased Diffusion Rates (Inconsistent With Measured IMC Growth Rates And Cu Consumption Rates)
  
  – Dilatory Stress Fields Augmenting Both Nucleation And Growth Could Vary (Would Require Dramatic Stress Increase In Samples With High Voiding Rates)
  
  – Heterogeneous Pore Nucleation At “Time-Zero” During Wetting (Would apply solely to Cu₃Sn – Cu Interface)
  
  – Reduced Vacancy Sink Efficiencies => Raising Vacancy Supersaturation And Nucleation Rate (Possible Explanation In Some Instances)
Demonstration Of Segregant Induced Interfacial Void Formation In Sn-Cu System


- High Sn Solders Used => Sn-Bi And Sn-Pb, Eutectic Solders In Forming Solder Joint With High Purity Cu

- Bi Found Segregated To Cu-Cu3Sn Interface, Using Sn-Bi Solder
  - Approximately 1 Monolayer Of Bi Found At Interface In 7 Days At 120 C
  - Void Formation At Cu - Cu3Sn Interface => Found Only In Association With Sn-Bi Solder
  - Significant Void Formation Found In 30 Days Of Aging At 120 C

- Authors Suggest Bi Pins Interfacial Dislocations And Disrupts Vacancy Sinking Processes

![Aged Solder Joint](image1)

- Sn-Pb Solder
- Cu6Sn5
- Cu3Sn
- Cu

![Aged Solder Joint](image2)

- Sn-Bi Solder
- Cu3Sn
- Cu
Zn Doping Of High Sn Solder Alloys
IBM - UIC Collaboration

- Zn Additions To Sn Based Solders
  - Are Known To Modify Interfacial Intermetallic Compound Structures
  - Low Level Additions (~ 0.5 wt %) Inhibit Cu3Sn Phase Formation (IBM Research)

- Low Level Zn Additions (~0.5 wt %) Appear To Eliminate Void Formation In “Worst Case”, Cu Plating, Samples, Using SAC Alloy

- Cu Diffusion Through IMC Layers
  - Dramatically Reduced With Zn Addition, As Demonstrated By Cu Consumption Rate
  - Reduced Cu Diffusion Rate Reduces Rate Of Vacancy Diffusion To Cu-Cu3Sn Interface

- HTS Results For “Worst Case”, Plated Cu, Sample, Shown Below, For SAC Alloys Using Sn-3.0Ag-0.5Cu Alloy With and Without 0.6 wt.% Zn Addition -- Aged For 750 Hours At 175 C
So, Where Are We, re: High Sn Solders?

- All Solder Joints With Cu Pad Structures Demonstrate Some Level Of Interfacial Void Formation With Thermal Aging

- The Void Formation Process Is A Vacancy Coalescence Process -- Driven By A Local Supersaturation Of Vacancies -- And Is Known As Kirkendall Voiding

- Thermal Aging Of Solder Joints With High Purity, Wrought, Cu, Produce Levels Of Voiding Which Do Not Represent A Long Term Reliability Risk

- Interfacial Voiding In Solder Joints -- With High Sn Solders And Plated Cu Pad Structures Is A Potential Reliability Problem, Which The Electronics Industry Faces In Its Supply Chain
  - 5 to 10 % Of The Plated Cu, Supplied To The Industry, Demonstrates Severe Voiding Behavior
  - Severe Void Formation Can Occur In Short Time Frames In Real Field Application Conditions

- The Voiding Phenomena Have Not Been Widely Recognized By The Electronics Industry
  - Problem Probably Existent From The Initial Use Of Cu Plated Cu Structures
  - Problem Still Not Widely Recognized By The Electronics Industry
The Question Of
Low Sn Solder - Cu Pad Solder Joints

- Work Initially On This Type Of System
  By Michael Sullivan, et. al., 1979, IBM, Early, C4 Development Efforts

- Characterization Of Voiding Behavior Found By Sullivan, et. al., @ 1979

  - High Purity Evaporated BLM Structures
  - Significant Voiding Found If Thick Final Cu BLM Layer Used In BLM Structure
  - Primarily Cu₃Sn Layer Formation During Reflow
  - Cu₃Sn More Fully Developed During Reflow Than For High Sn Solders
  - Voiding Found Immediately After Reflow (360 C)
  - NO AGING Required to Initiate Void Formation
  - Little Or No Voiding Within Cu₃Sn Phase
  - Significant Voiding At Cu-Cu₃Sn Interface And Within Cu, Near Interface
  - Many Voids Filled With Solder Below The Cu₃Sn Phase
  - Void Formation Attributed To Vacancy Coalescence ("Kirkendall Voiding")

- Recent Experiments With Electroplated Cu + Pb-3Sn Solder
  - Plated Cu Thickness ~ 5 u
  - Pb-3Sn Overplate ~ 80 u
  - Results By Sullivan, et. al., -- Found, Again
The Question Of Low Sn Solder - Cu Pad Solder Joints

- Sections Shown Immediately After Wafer Fabrication
- Comparison Between Optical And SEM images - Same Field Showing That Many Of The "Void" Structures Are Filled With Solder
- Interfacial Intermetallic Compound Comprised Substantially Of Cu₃Sn
- No Voiding Within The Cu₃Sn Phase
- Some Voids Within Cu Phase In, Near Interface, Region
- Voiding Disappears With 2µ layer of Sn Interposed Between Cu And Pb-3Sn
The Question Of
Low Sn Solder - Cu Pad Solder Joints

- Experiments Undertaken With In High Purity System
  - 99.9999 % Pure, Wrought, Cu
  - High Purity - Pb-3.5Sn Solder
  - Reflowed Using Alpha 102-1500 Rosin Flux
  - Single Reflow
  - Peak Temperature 360 C
  - Approximately 2 Minute Dwell Above Melting Point
The Question Of
Low Sn Solder - Cu Pad Solder Joints

- Results of High Purity, Pb-3.5Sn, Solder Reflowed On 99.9999 % Pure Cu:
  - Predominant Interfacial Phase Formed Was Cu3Sn
  - Voiding Found Between Cu3Sn and Cu Phases, Immediately After Reflow
  - No Aging Required To Produce Void Formation
  - No Voids Found Within Cu3Sn
  - Most Voids Were Filled With High Pb Solder.
  - Some Voids Were Found To Be Unfilled. -- Filled Voids May Reflect Smearing
  - Smaller Void Size May Reflect Single Reflow
The Question Of
Low Sn Availability - Cu Pad Solder Joints

- "Sn Starved" Case -- In High Sn Solder (SAC – Sn-3.0Ag-0.5Cu) Application
  - SAC BGA Solder Ball Attached To Cu Pad With Central "Flux " Void".
  - Sn Access To Central Void Region By Surface Migration Or Thru Flux Residue

- Optical Sections Shown After 1000 DTC Cycles
The Question Of
Low Sn Availability - Cu Pad Solder Joints

- Sn "Starved" Condition After 1000 Cycles of DTC
- Sn Access To Central Via Region, Limited
- Only Cu3Sn Interfacial Phase Forms In Central Via Region
The Question Of Low Sn Availability - Cu Pad Solder Joints

- Sn "Starved" Case After 3X Reflow + 1000 DTC Cycles + 1000 Hours At 150°C
- SAC BGA Shown Attached To Cu Pad Structure With Central Via, "Flux", Void
  - Sn Access To Central Region Via Surface Diffusion Or Through Flux Residue
  - Only Cu₃Sn Phase Formed At Interface Under Central "Flux" Void
  - Sn "Starved" Condition In Via Region
  - Extensive Voiding At Cu-Cu₃Sn Interface
  - No / Few Voids Found Within Cu₃Sn Phase
  - Voids End, Where Cu₆Sn₅ Overlayer Begins And Sn "Starvation" Terminated
The Question Of
Low Sn Availability - Cu Pad Solder Joints

**Conclusions:**

- Interfacial void formation is intrinsic to the use of high Pb - low Sn solders on Cu pad structures.

- The void formation behavior is NOT attributable to the specific use of plated Cu pad structures. Phenomenon found with:
  - Evaporated Cu
  - Plated Cu
  - High Purity Wrought Cu

- Void formation / growth is attributable to atomic vacancy coalescence, resulting from the reactive interdiffusion of Sn and Cu.

- This type of void formation appears to be critically associated with low Sn availability in the Sn-Cu diffusion couple and the resulting control of the interdiffusion process by the interfacial Cu$_3$Sn phase.

- Absence of Cu$_3$Sn - Cu$_6$Sn$_5$ interface, during growth, *may* be associated with the notable absence of void formation within the Cu$_3$Sn phase.