Manufacturing of Copper Bond Wire PEMs – Challenges and Mitigation

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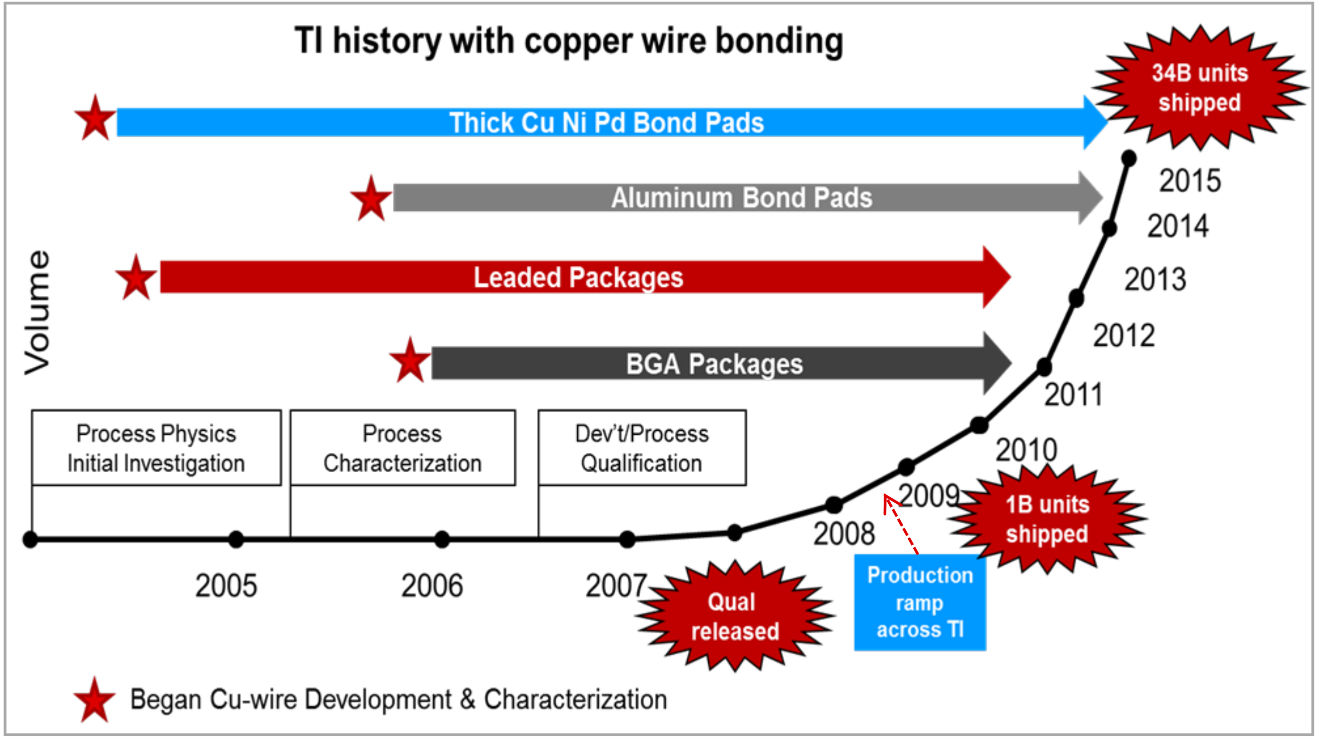
TI Update upto 2015



Applications:
- ➢ Commercial
- ➢ Telecom
- ➢ Industrial
- ➢ Automotive

(safety, powertrain, Infotainment etc)

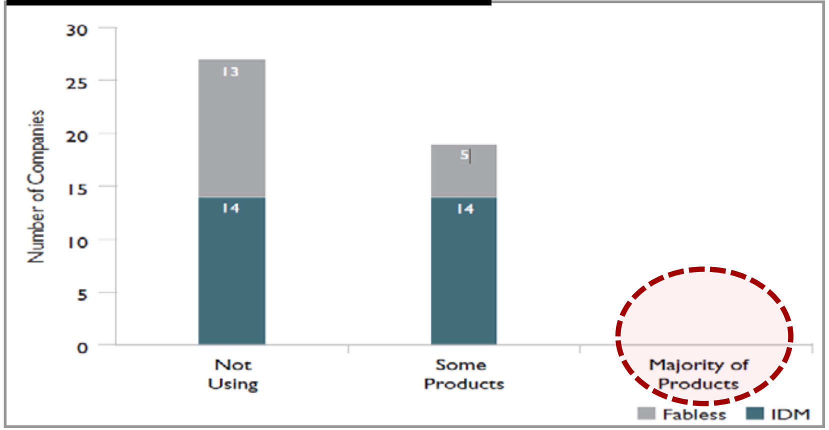
Packages:
All (QFN, QFP, PDIP, SOIC, TSSOP, BGA & others)

AT sites: > 14
(internal & external)

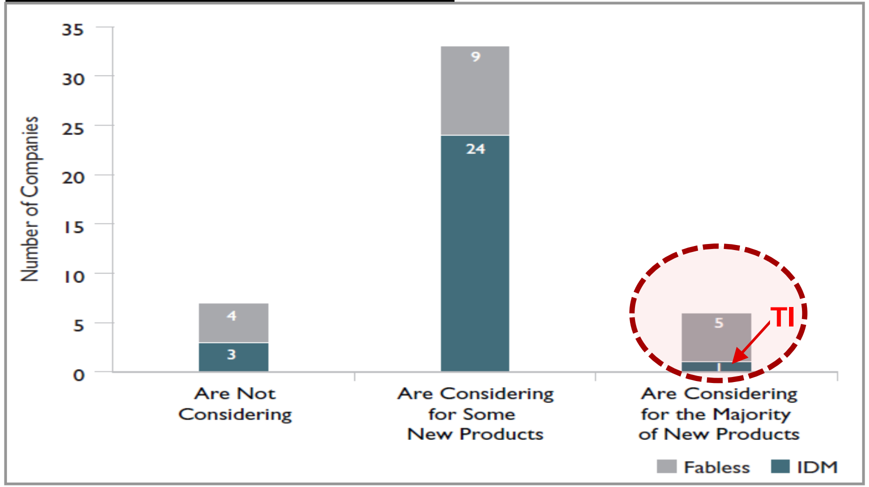
Process Technologies:
50+ from 10+ wafer fabs

Rewind to 2010 - Industry Trends Then

Use in Current (2010) Products



Planned Use over Next 3 yrs



- ➢Limited use in the global SC Industry, but growing.
- ➢**TI was leading the charge in conversion to Cu w/b**.

Outline

Cu-vs-Au Material Properties:
Implications for Manufacturing

Common Challenges in Manufacturing:

- Challenges at First Bond
- Challenges at Second Bond
- Challenges in Failure Analysis
- Key Reliability Challenges

Lessons To Take Forward:

Cu-vs-Au Material Properties:
Implications for Manufacturing

What Can We Expect from Cu-Wire-1

Cost

Lower cost than Gold

- Cost can remain competitive despite need to mitigate unfavorable attributes (hardness, reactivity)

Electrical:

Lower resistivity

- Allows use of thinner wires.
- Favorably affects self-inductance.

Thermal:

*** Similar melting point as Au**

- Use of existing bond processes.
- Similar fusing currents in circuits

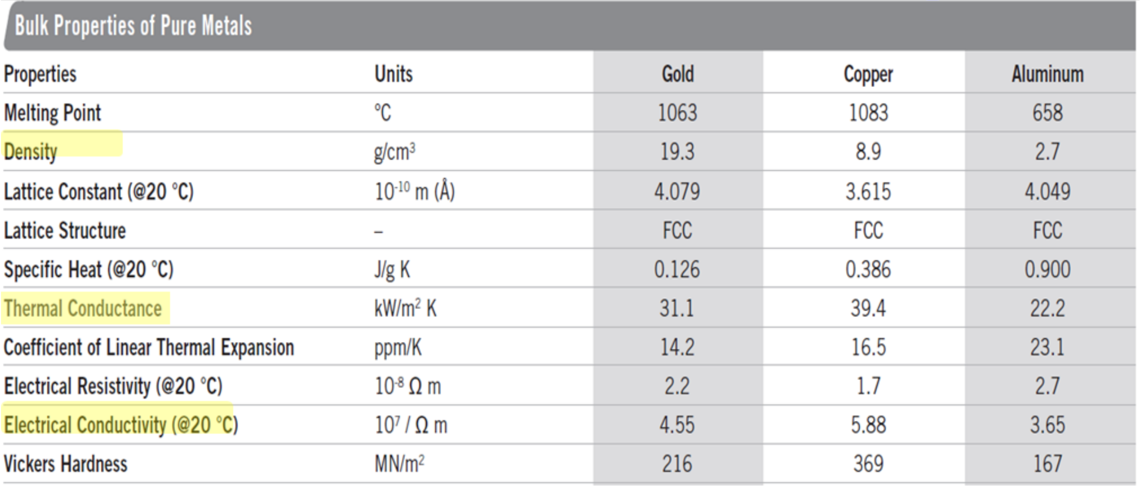
*** 26% higher thermal conductivity**

- May help manage heat in package

***~ 16% higher CTE.**

- No specific issues

Source: Heraeus bonding-wire brochure

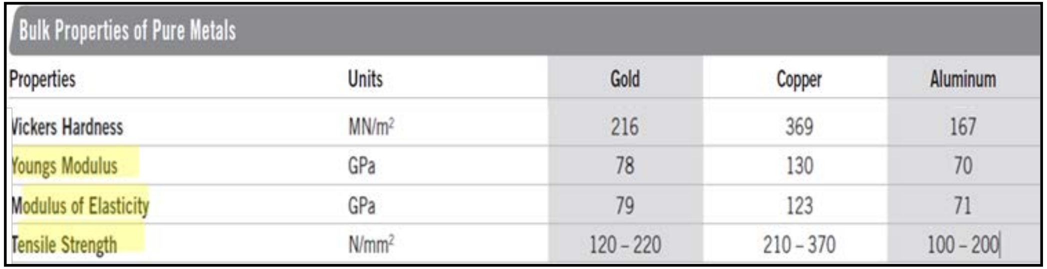


Bulk Properties of Pure Metals

Properties	Units	Gold	Copper	Aluminum
Melting Point	°C	1063	1083	658
Density	g/cm^3	19.3	8.9	2.7
Lattice Constant (@20 °C)	10^{-10} m (Å)	4.079	3.615	4.049
Lattice Structure	–	FCC	FCC	FCC
Specific Heat (@20 °C)	J/g K	0.126	0.386	0.900
Thermal Conductance	kW/m^2 K	31.1	39.4	22.2
Coefficient of Linear Thermal Expansion	ppm/K	14.2	16.5	23.1
Electrical Resistivity (@20 °C)	10^{-8} Ω m	2.2	1.7	2.7
Electrical Conductivity (@20 °C)	10^{7} / Ω m	4.55	5.88	3.65
Vickers Hardness	MN/m^2	216	369	167

What Can We Expect from Cu-Wire - 2

Source: Heraeus bonding-wire brochure



Bulk Properties of Pure Metals

Properties	Units	Gold	Copper	Aluminum
Vickers Hardness	MN/m^2	216	369	167
Youngs Modulus	GPa	78	130	70
Modulus of Elasticity	GPa	79	123	71
Tensile Strength	N/mm^2	120 – 220	210 – 370	100 – 200

Mechanical:
56% higher stiffness; wire-sweep
68-75% higher tensile strength
- ➢ Improve wire-sweep & loop-profiles

70% harder than Au:
- ➢ Increased susceptibility to bond-pad damage.

Lower fatigue resistance
- ➢ Stitch cracks in package, when delaminated.

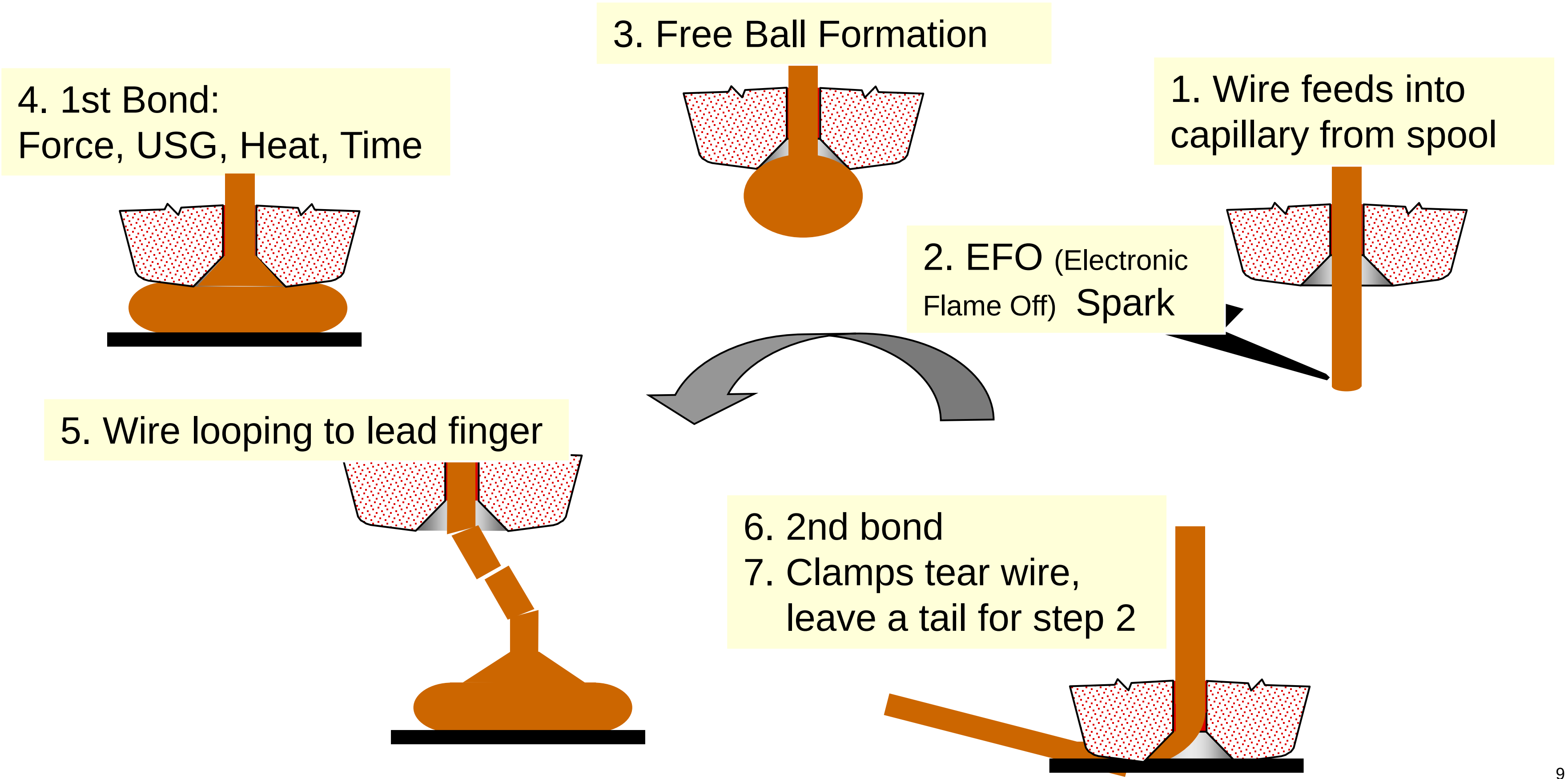
Chemical:
Not a noble metal – oxidation
- ➢ Requires inert atmosphere during bonding

Chemically active - reacts with halides, sulphur etc
- ➢ Susceptible to electro-chemical corrosion

Cu does not diffuse into Al lattice
- ➢ Very Little IMC is formed in wirebond
- ➢ Resistant to Kirkendall voiding

Common Challenges in Manufacturing

Gold Wire Bond Process



3. Free Ball Formation

4. 1st Bond:
Force, USG, Heat, Time

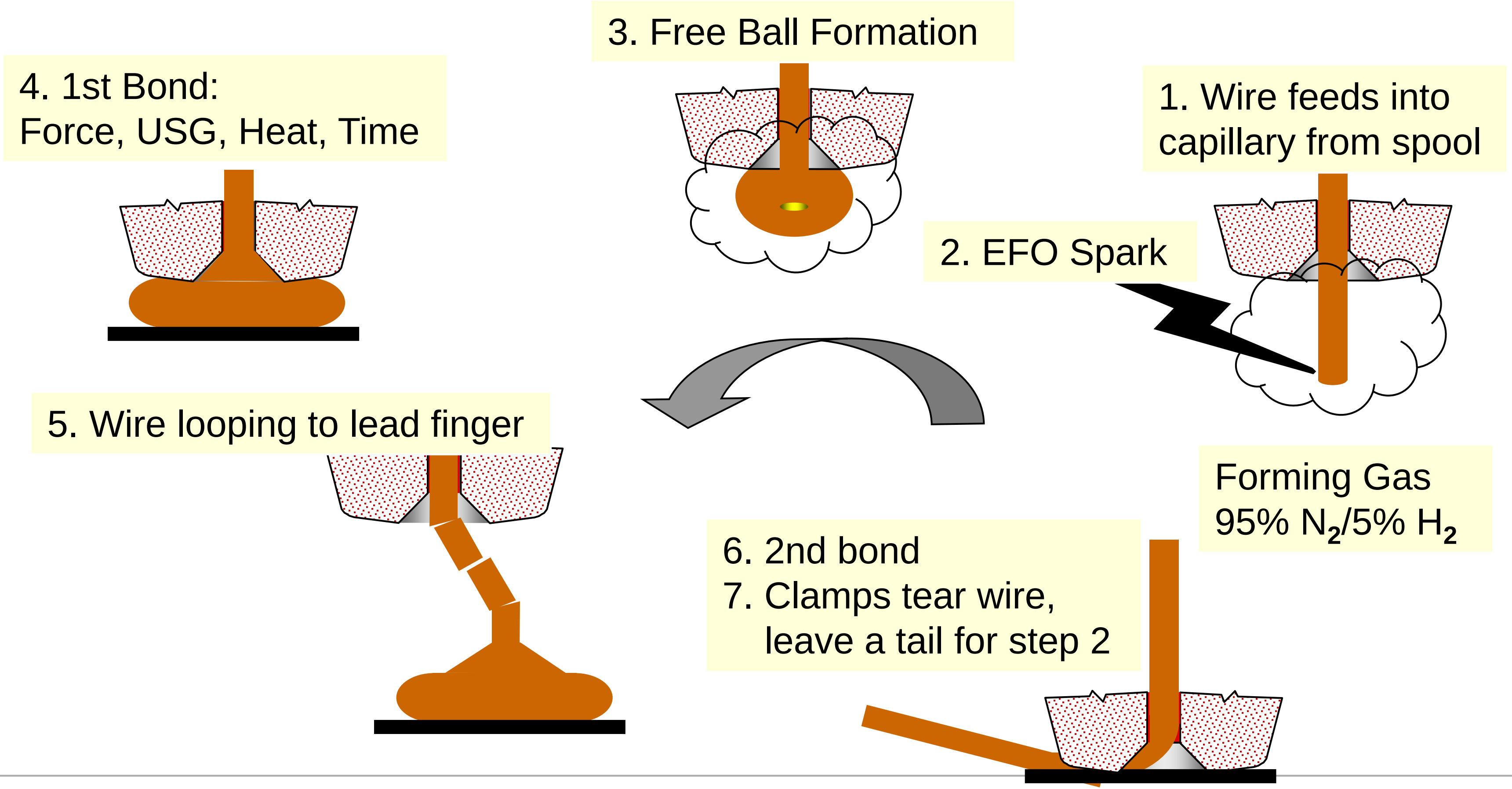
1. Wire feeds into capillary from spool

2. EFO (Electronic Flame Off) Spark

5. Wire looping to lead finger

6. 2nd bond
7. Clamps tear wire,
leave a tail for step 2

Copper Wire Bond Process



1. Wire feeds into capillary from spool

2. EFO Spark

3. Free Ball Formation

4. 1st Bond:
Force, USG, Heat, Time

5. Wire looping to lead finger

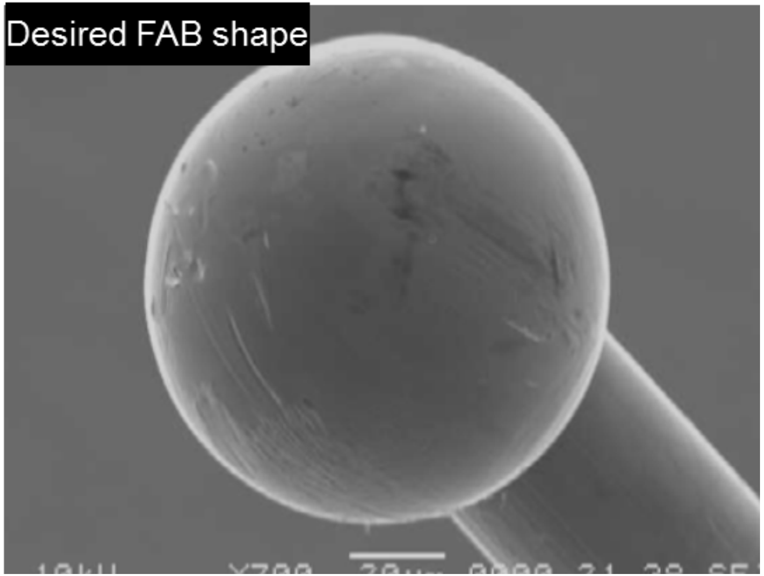
6. 2nd bond

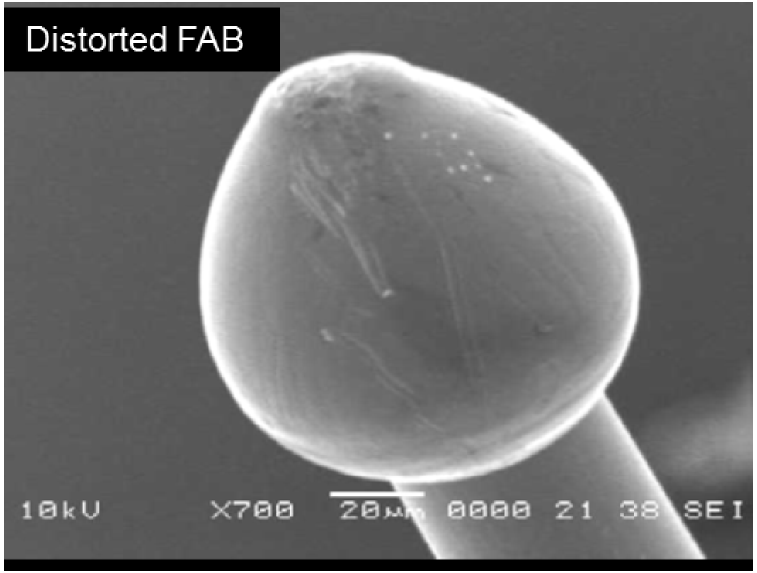
7. Clamps tear wire,
leave a tail for step 2

Forming Gas
95% N_2/5% H_2

Cu Free-Air Ball Formation

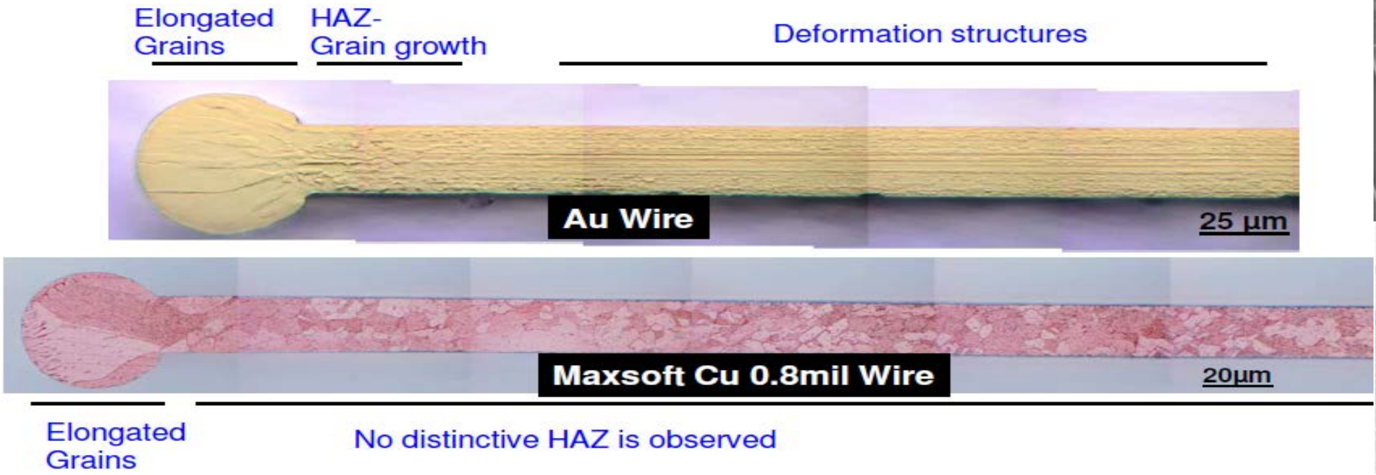
- Cu-oxidation during EFO distorts the ball during cool-down.

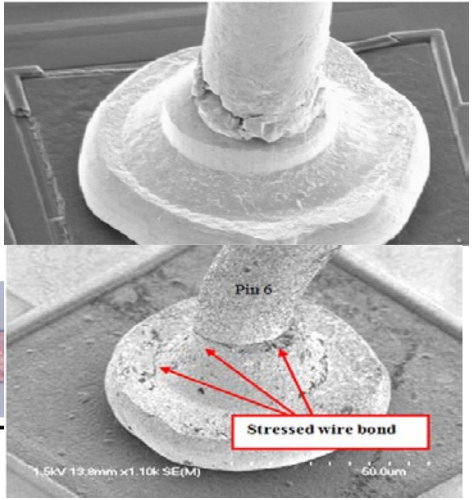

Desired FAB shape


Distorted FAB

- **Oxidized ball presents bonding risks – NSOP or pad-damage.**

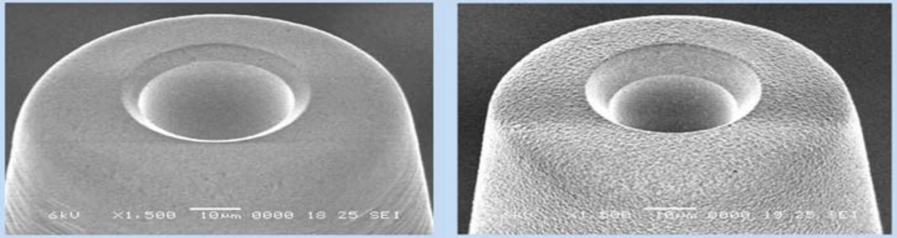
Free-Air Ball Microstructure





- Elongated grain growth in FAB, similar to Au-wire
- Unlike Au, no transitional heat-affected zone (HAZ) characterized by grain-growth in Cu-wire beyond the FAB.
    - Cu wirebond shows more frequent bond-break during wirepull, as a result.
    - Bond fracture can also happen after encapsulation, showing intermittent opens.
    - Handling during assembly and/or jams on Bonder Transport and Mold loaders can also cause this defect.

Capillary Selection



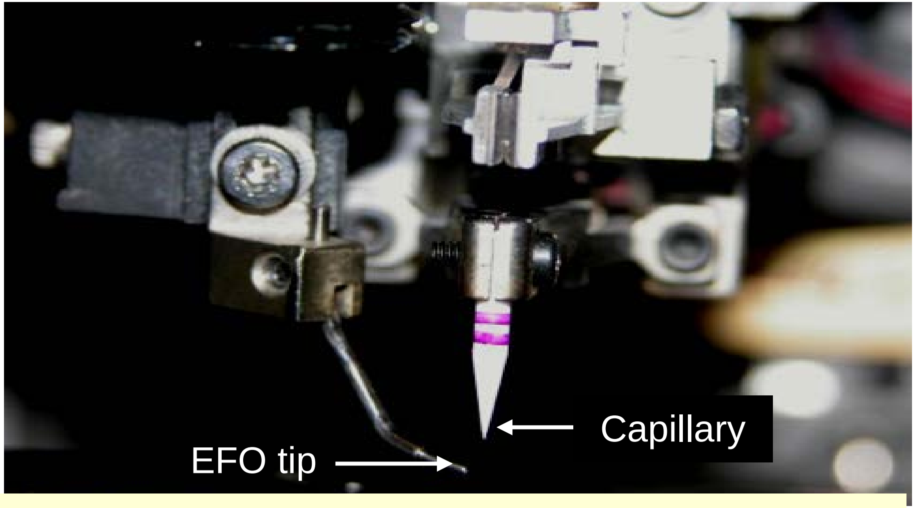
Gold Capillary

Copper Capillary

- Capillary is generally engineered to optimize second-bond process
  - Chamfer diameter, Chamfer Angle, Material Texture are different
  - Rough texture improves gripping between wire & capillary
  - Minimizes wire-slippage during bonding.
- New Capillary must be re-characterized on first-bond process.
- Capillary life is generally reduced relative to Au-wirebond due to wire-hardness and due to use of rough finishes on leadframes.

Preparing For Cu-Wirebond

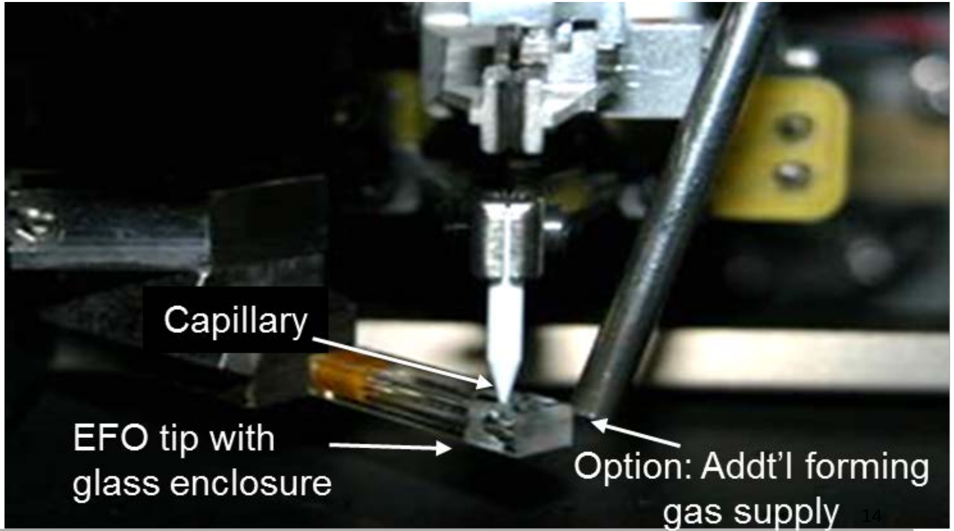
Au Ball Bonding



- Equipment calibrations, maintenance frequencies must be established for Cu-wire
- Consumables (wire, capillaries) storage/use protocols and lifetimes must be established
- Factory personnel must be re-trained for Cu-related protocols and procedures.

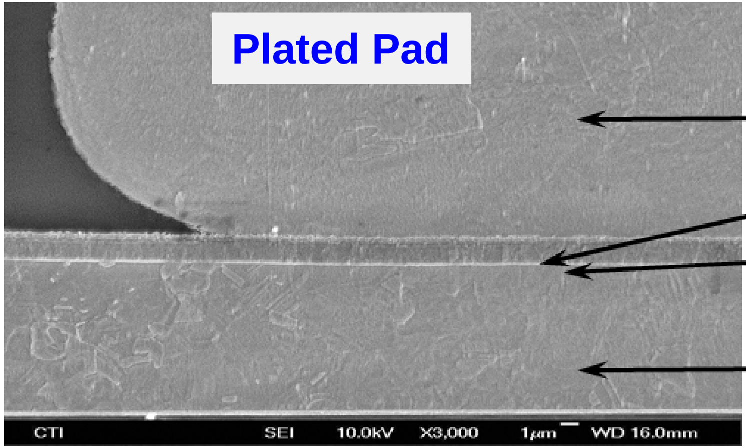
- **A Cu-conversion kit is required for each bonder**
- Factories must add forming gas supply to each bonder location

Cu Ball Bonding

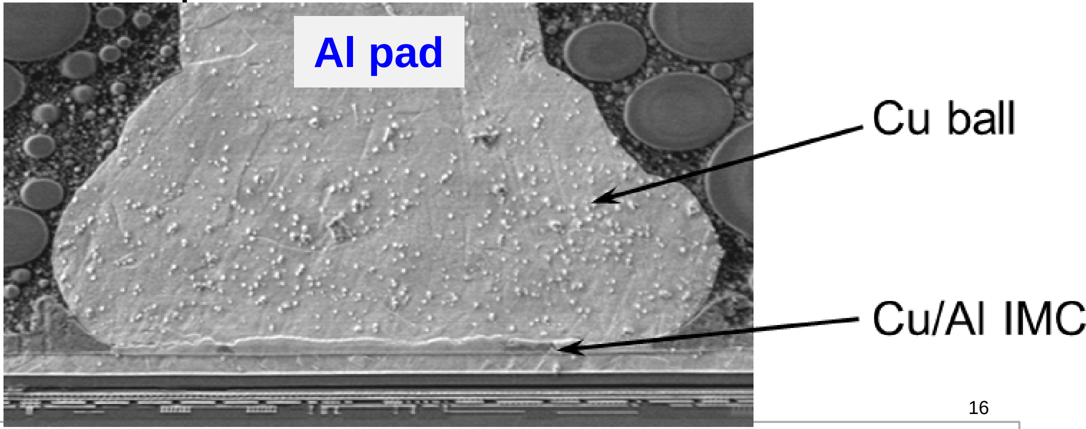


Challenges at First Bond

Types of B/Pad Finishes



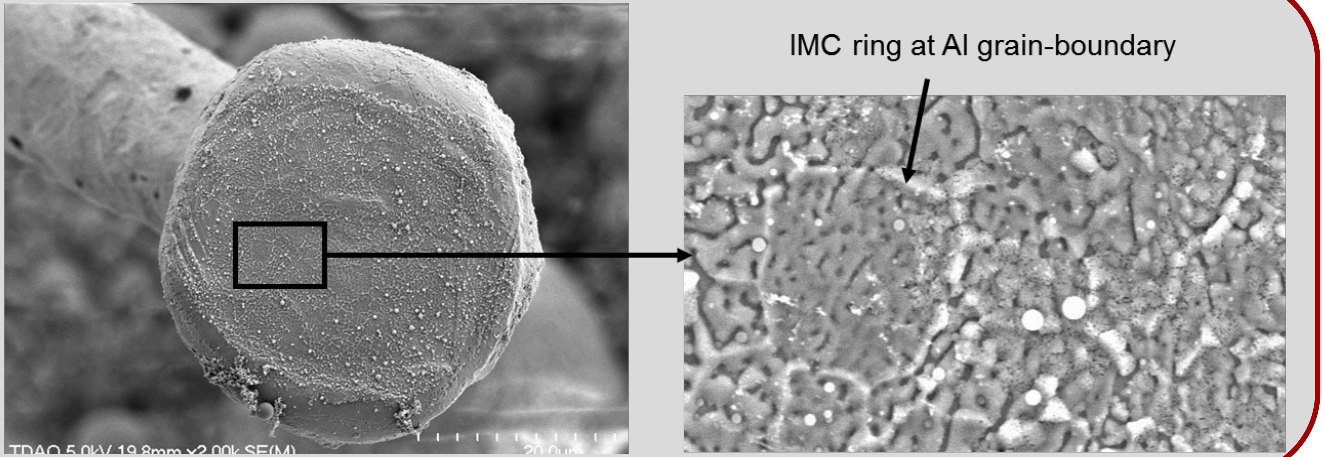
Copper-to-Aluminum, and, Copper-to-Palladium bond-interfaces are very thin compared to Gold on Aluminum.

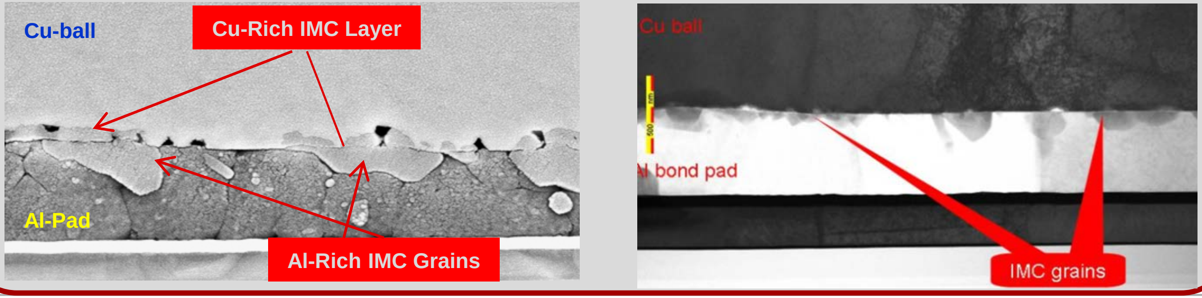


The presentation focuses on wire-bonding of Copper on Aluminum bond-pad

IMC Imaging & Measurement:

Ref: Copeland & Saran, Proc 36th Intern Symp for Test and Fail Analysis, 2010

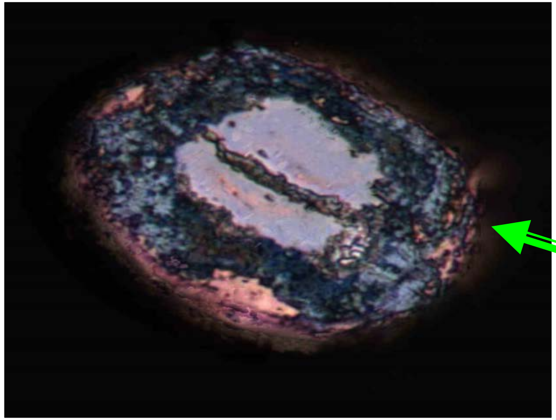


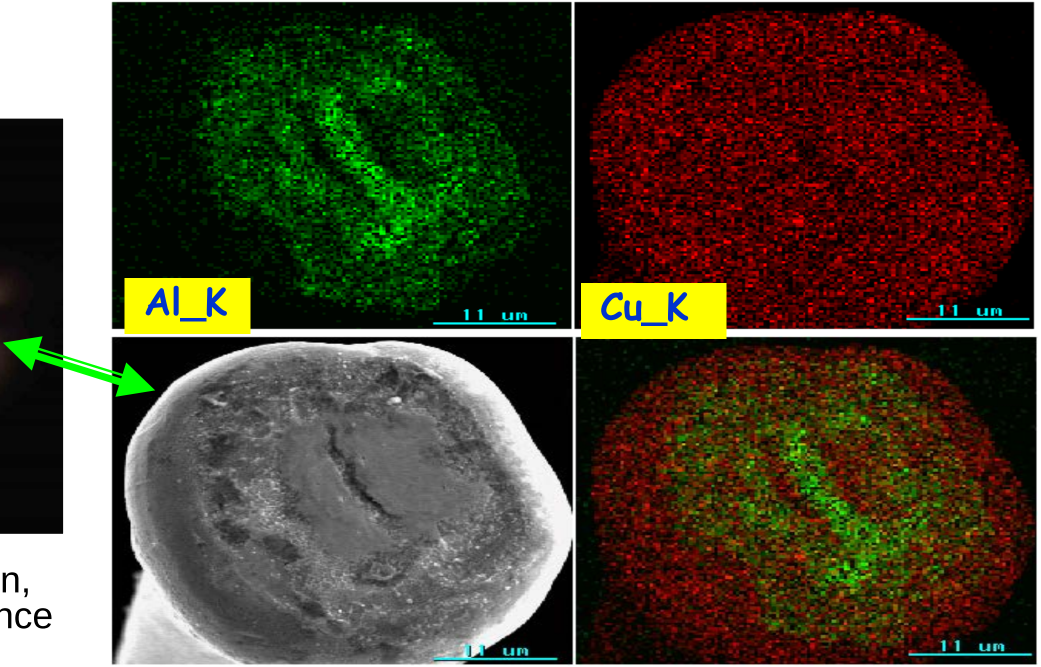


Intermetallic is so thin at wire-bond that monitoring through SEM cross-section imaging is not possible without use of special chemical methods for sample preparation and prior anneal to promote IMC growth.

IMC Imaging: Optical Measurement of Coverage

Post-bake Optical IMC Map

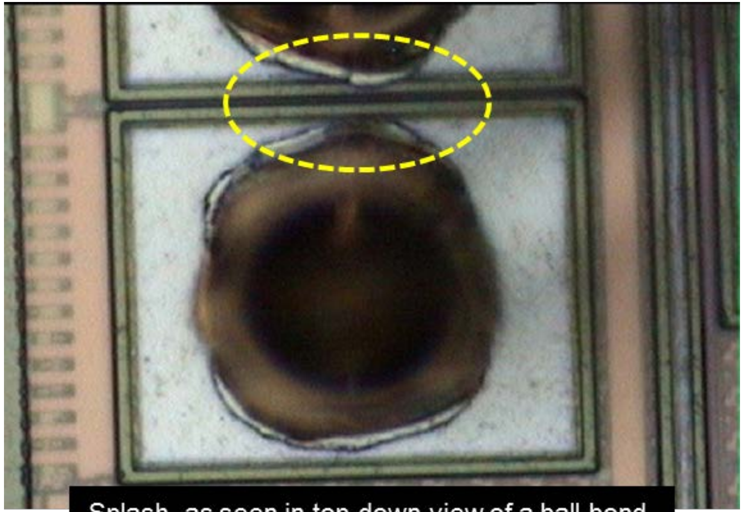




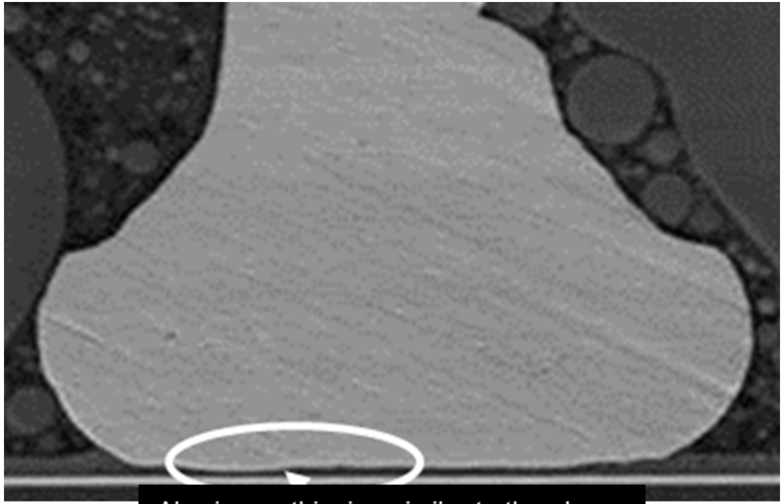
With EDS mapping correlation, the IMC coverage rate tolerance is around 5~10%.

- An optical method to estimate IMC coverage was developed; calibrated to SEM measurement.
- Others have published similar methods more recently.

Al-Splash and Al-Thinning



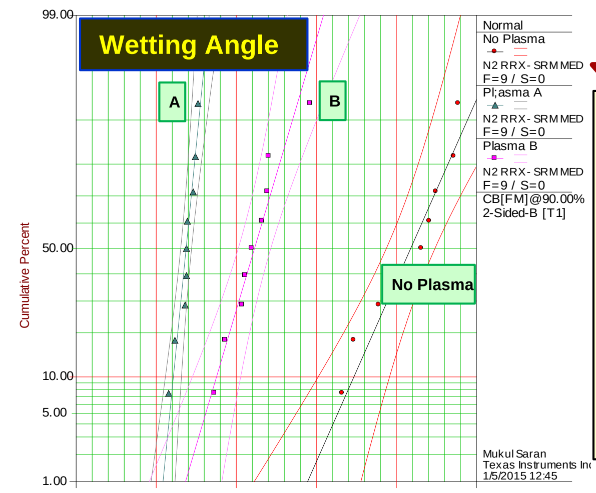
Splash, as seen in top-down view of a ball-bond



Alumimum thinning similar to the above

- Occurs at the edge of ball-bonds on Aluminum pads with Cu-wirebond
- May cause pad-to-pad shorts and Al-thinning under the bond.
- Could potentially lead to de-bonded areas under the ball, if it breaks through the Al-layers (e.g. IMC-to-Barrier debond).
- Mitigated with use of pre-bleed and low-u/s energy during bond and

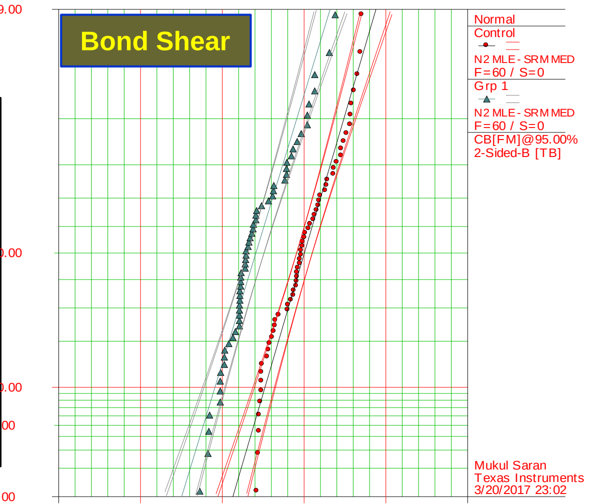
Bonding Yield: Dependance on Surface Cleanliness

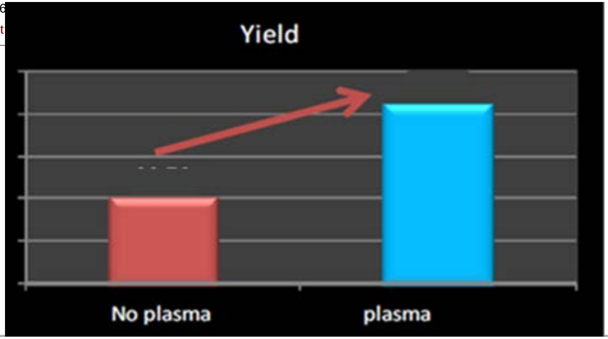


μ1=85.2222, σ1=9.9673, ρ=0.9568
μ2=34.7333, σ2=2.2314, ρ=0.9606
μ3=50.1111, σ3=6.6684, ρ=0.9688

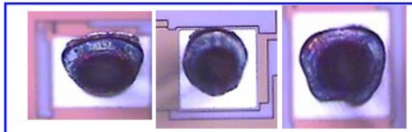
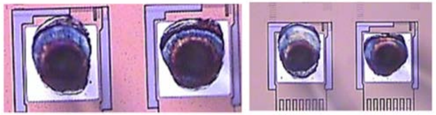
Conclusions:

- ➢ Plasma reduces the wetting angle on bonding surface
- ➢ Longer Power/exposure (A vs B) improves wetting angle
- ➢ Benefits yield, NSOL and NSOP
- ➢ Bond-shear strength increases
- ➢ **Surface cleanliness more critical than Au due to limited IMC growth**





Bond Quality: Dependance on Pad Metallization

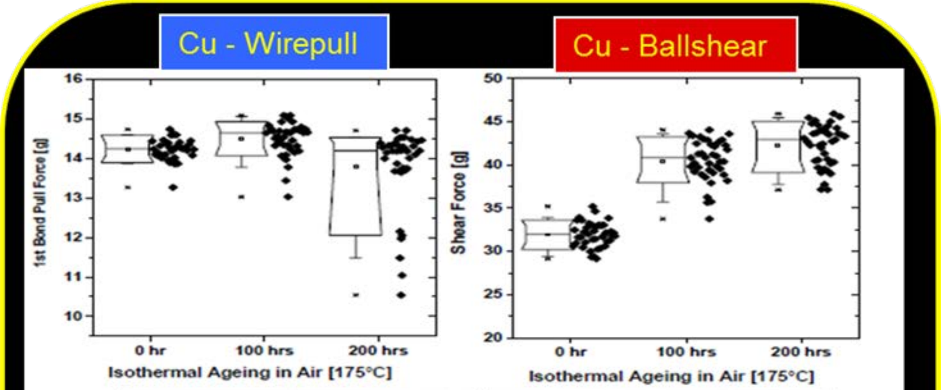
	Al-0.5%Cu	Al-2%Cu
Low-K Dielec Sandwich + Pad Reinforcement	**Abnormal**	 Abnormal ball of Wafer no.05 **Abnormal**
Oxide/SOG Sandwich + No Pad Reinforcement	 Abnormal ball of Wafer no.04 **Abnormal**	**** Bond Parameters Optimized For This Stack up **** **High Bond-Parameters (force/power) were used** **Used the same set on all other stack-ups** **Normal**

- Changing underlying bond-pad structure impacts Wirebond outcomes.

=> Bonding recipes could require optimization for different bond-pad metallizations

Bond-Pad Damage: Cratering

Ref: Wulff et al, Semicon Singapore 2005



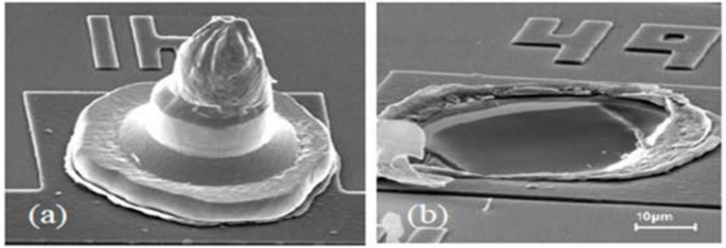
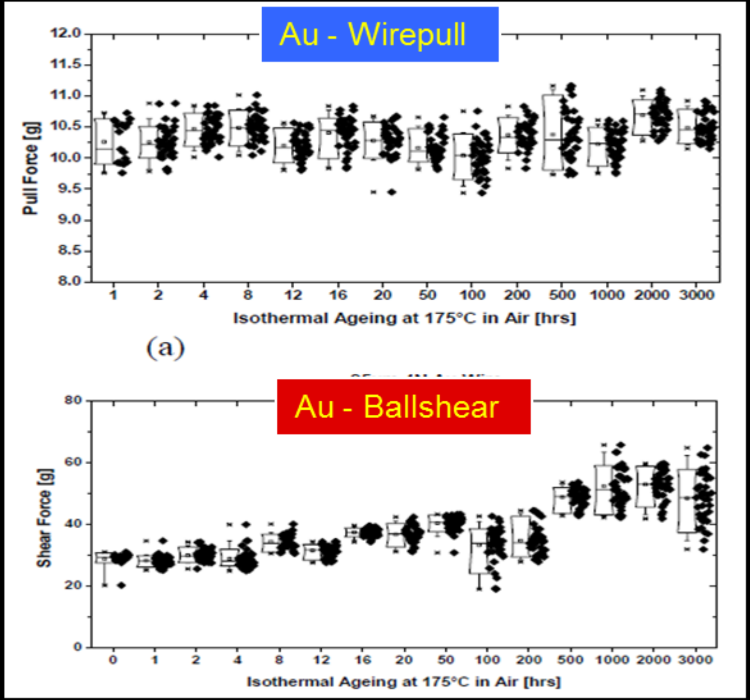


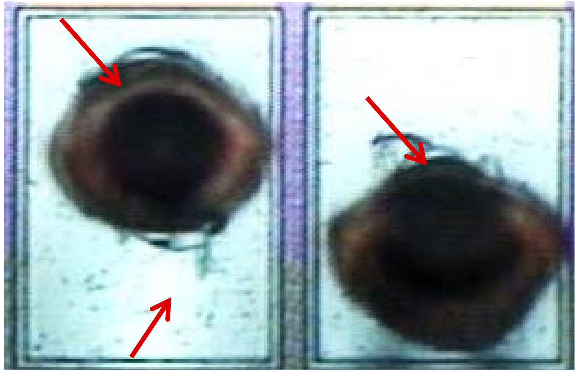
Figure 9. SEM images showing (a) an as-bonded Cu ball without cratering (b) a Cu ball that has cratered after 200 hrs ageing at 175°C



- **Baking Cu-wirebond at 175C can highlight b/pad cratering damage**

Pad-Damage/Lifted Metal (LFML)

Overbonded pads – Optical Images

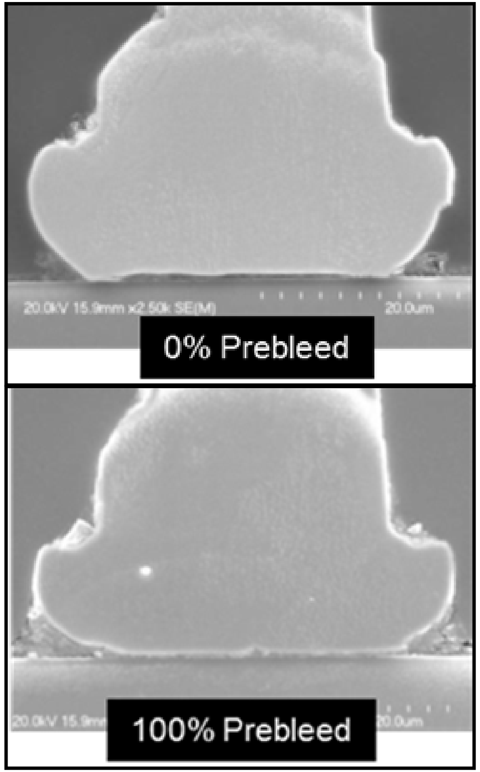


Before Removing Ball-Bond

Arrows point to visible damage around the ball-edges

Lifted Metal Fail in Wirepull

Interconnect layers below the b/pad are visible after LFML fail.



- Pad damage is not unique to Cu, but susceptibility is higher than Au
- Cu-ball does not absorb the impact force on the pad as well as Au-ball.
- Pre-bleed (u/s at ball-impact) flatten the ball-interface profile, reduce pad-damage and Al-splash

Pad-Damage/Lifted Metal (LFML)

Ref: Qin et al, K&S/Univ of Waterloo, EPTC 2009, pp 573-578,

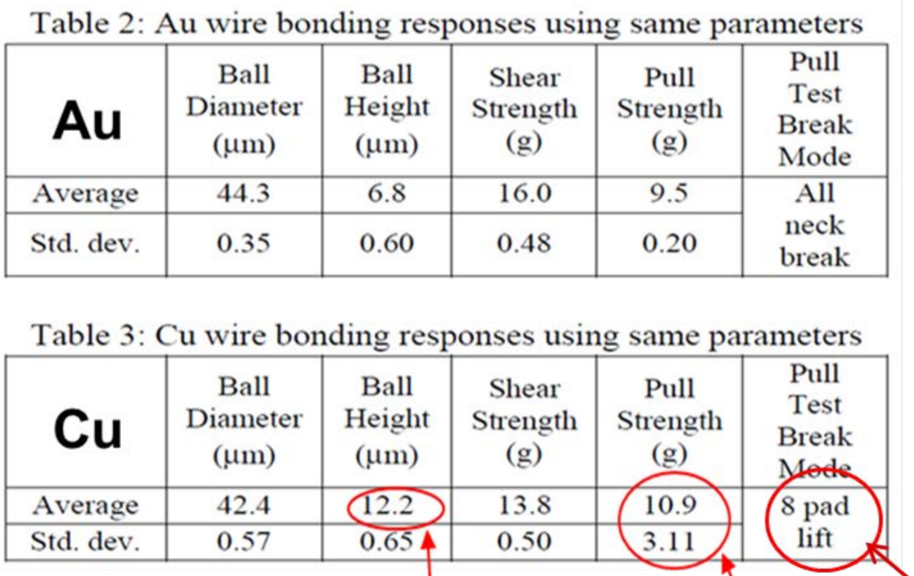


Table 2: Au wire bonding responses using same parameters

Au	Ball Diameter (µm)	Ball Height (µm)	Shear Strength (g)	Pull Strength (g)	Pull Test Break Mode
Average	44.3	6.8	16.0	9.5	All neck break
Std. dev.	0.35	0.60	0.48	0.20	

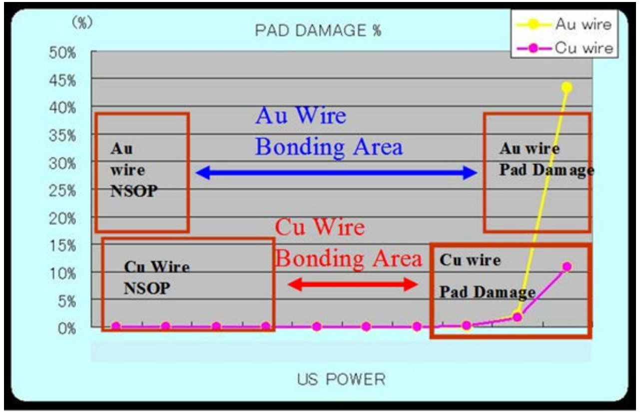
Table 3: Cu wire bonding responses using same parameters

Cu	Ball Diameter (µm)	Ball Height (µm)	Shear Strength (g)	Pull Strength (g)	Pull Test Break Mode
Average	42.4	12.2	13.8	10.9	8 pad lift
Std. dev.	0.57	0.65	0.50	3.11	

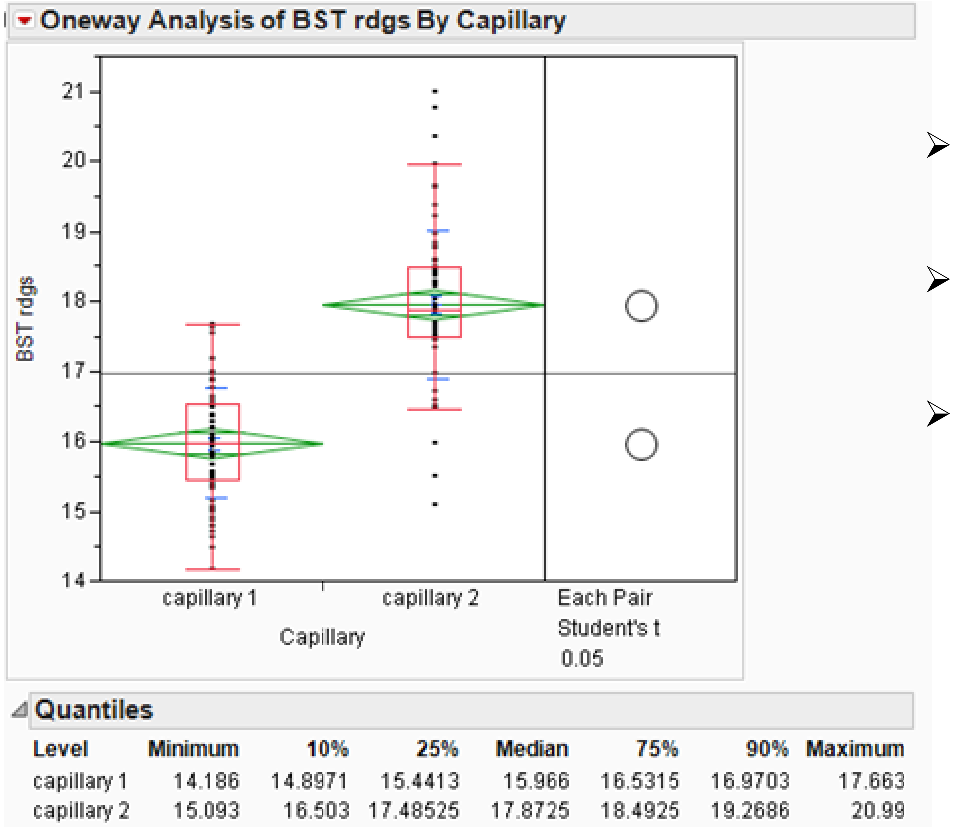
Underbonded

Pad lifts cause high std dev. , Pull strength higher due to higher break-load for Cu wire

- ➢Cu: Pad-damage hidden by normal shear strength
- ➢Bond-shear alone is not a good indicator of bond-quality. Bond-pad damage is seen with high shear values. Optimization must consider both.
- ➢Cu Ball-pull is sensitive to pad damage.
- ➢Au-bond is more forgiving for pad-damage



Ball-Shear: Effect of Capillary

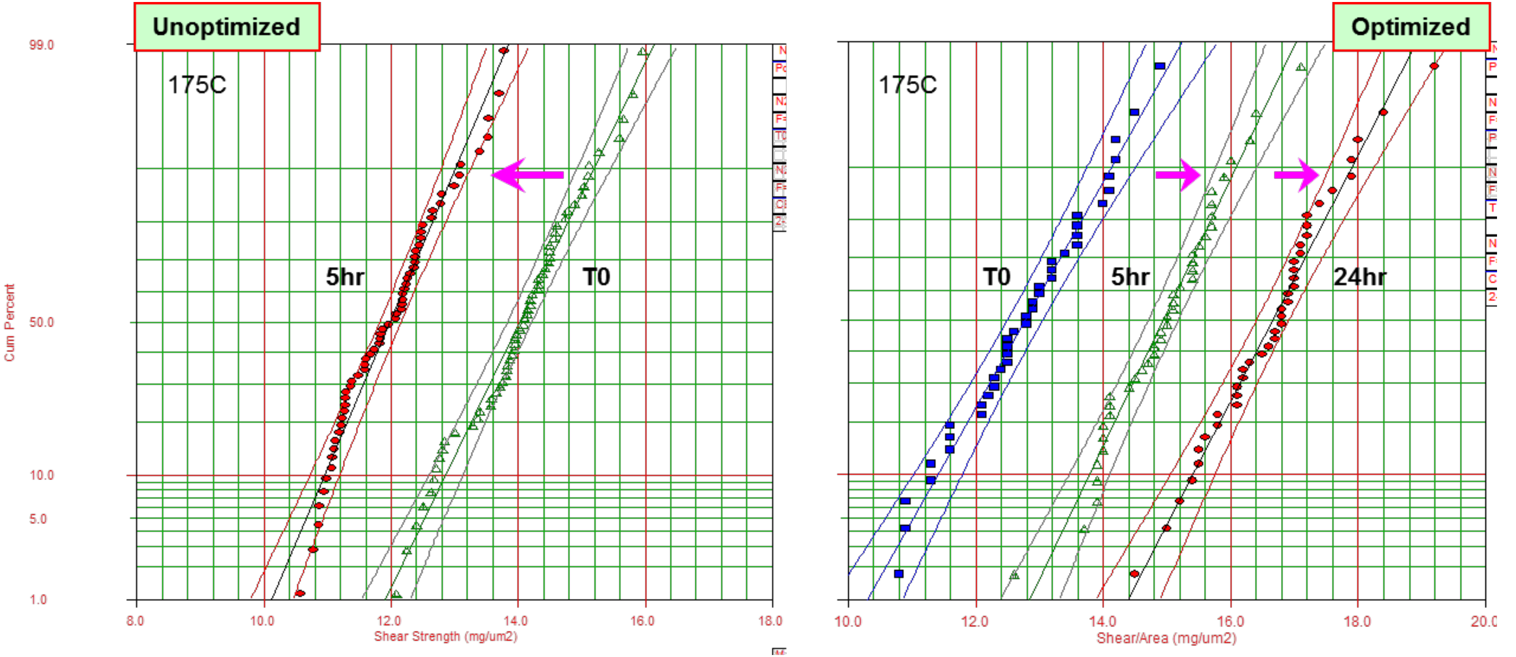


Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
capillary 1	14.186	14.8971	15.4413	15.966	16.5315	16.9703	17.663
capillary 2	15.093	16.503	17.48525	17.8725	18.4925	19.2686	20.99

- Capillary 2 has a larger chamfer diameter than Capillary 1.
- Use of this capillary improves ball-shear and also eliminated lifted-metal (LFML) failures at wirepull.
- LFML is sensitive to process technology and/or bond-pad stackup.

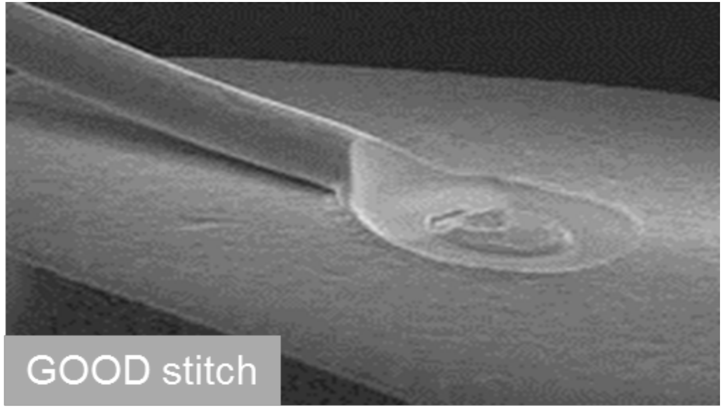
Ball-Shear: Effect of Mold-Cure

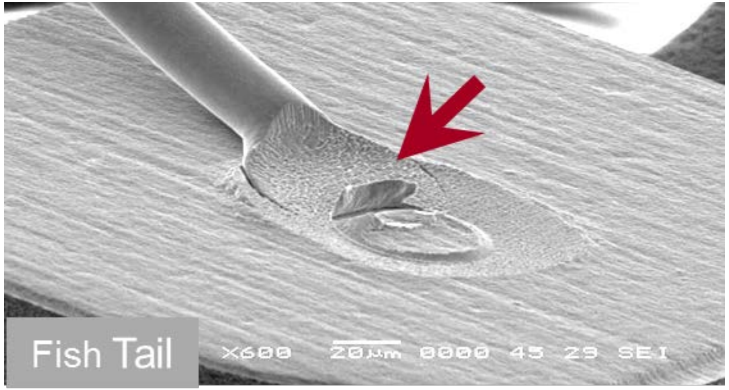


- ➢**Initial bond-strength is not necessarily a good predictor of “bond robustness”.**
- ➢**This observation has been used to establish a robustness check.**

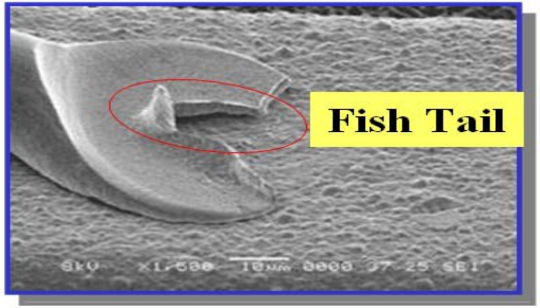
Challenges at Second Bond

Fish-Tail


GOOD stitch

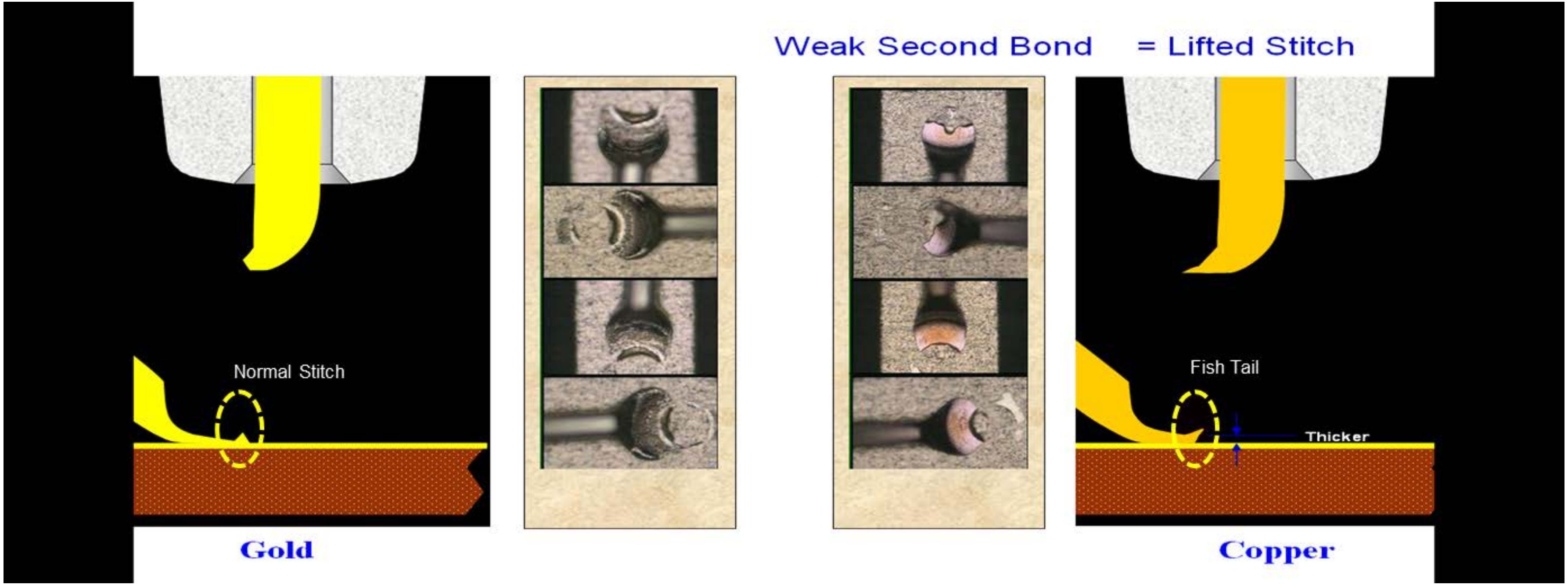

Fish Tail

- **Lifted Stitch/Fish Tail and No tail e**



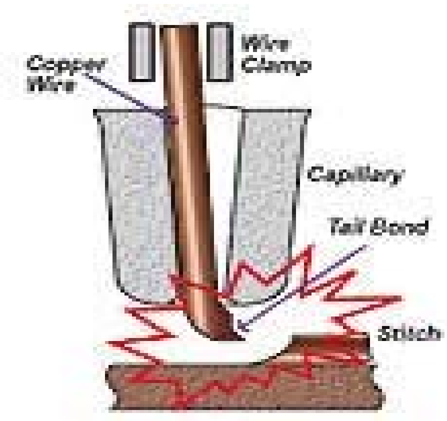
- **3-step/segmented second bond**

Fish Tail

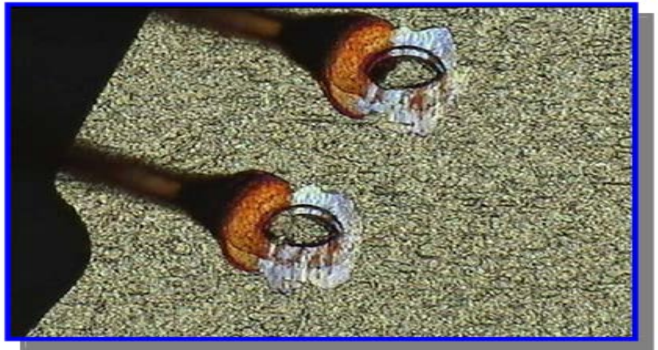


- ➢ Fish-tail occurs due to difficulty in cleanly cutting off the wire after stitchbond

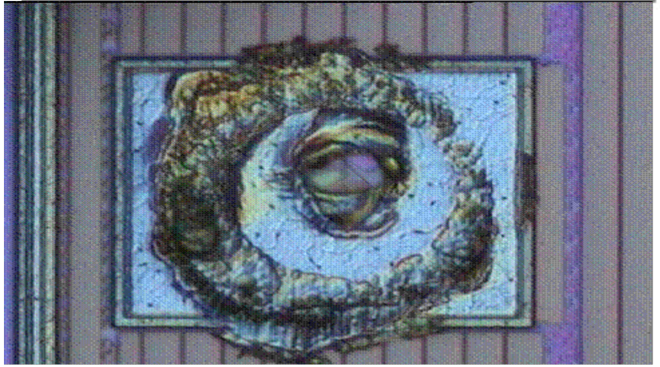
Short-Tail Error



Short Tail



Can result in a cut-stitch bond



Capillary with an inadequate Cu-ball can hit the next bond-pad to leave an imprint without bonding.

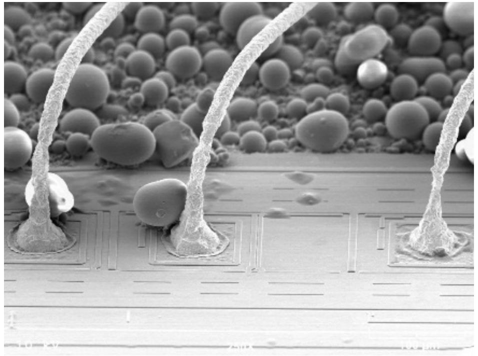
- ➢ Short-Tail results when the Cu-wire is pulled only partially out of a retreating capillary after stich bond, due to a premature cut stitch..

Challenges in Failure Analysis

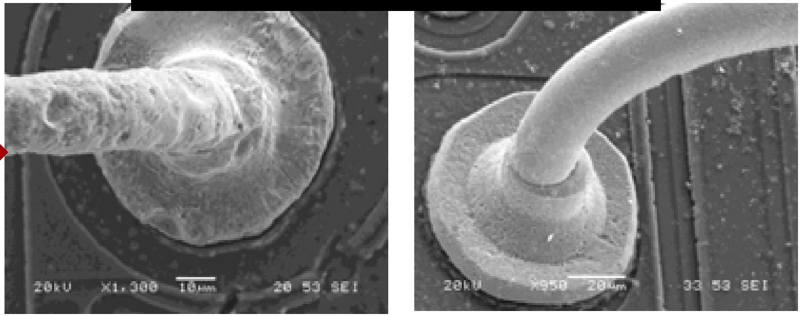
Wet-Decapsulation of Devices with Cu-wires

Au-wirebond devices used Jet-etch techniques using hot fuming nitric acid, or fuming sulphuric acid. Device is held under light vacuum above the area to be decapped. A jet of hot acid is directed at the surface to remove the encapsulation. Hot fuming nitric acid does not attack the Aluminum on the bond-pads or the Au-wire. Hence decapsulation results were generally consistent.

Cu-wire dissolves easily in hot fuming nitric acid. To preserve wire-integrity a mixture of HNO3 & H2SO4 is required. The sulphuric acid forms a protective sheath on the wire-surface and resists attack against the HNO3. A right mixture of the acids, precise timing and temperature are critical to achieve the right outcome.



Improved Wet Chemical Decapsulation



Old etchant

New etchant

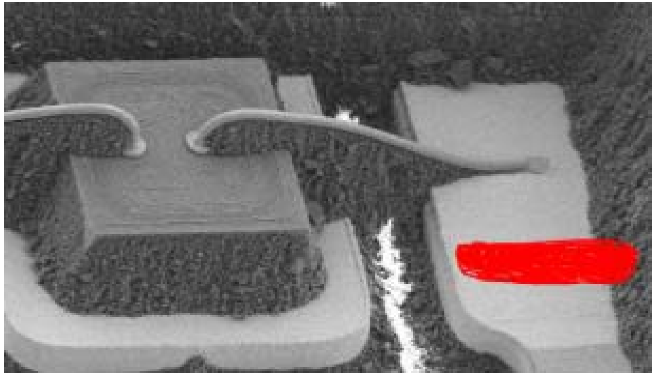
One method that may be used for determining if a wire is over etched is to first perform wire pull. If the pull value is significantly less than the typical value for wire pull of unencapsulated product, then it is very likely that the ball bond has also been damaged due to the etching process. If this does occur then this ‘over etched’ sample should not be used for shear test.

NO visual criteria in JEDEC std to determine ‘good’ or ‘bad’.

Reference -   Annex D: https://www.jedec.org/system/files/docs/22B116B.pdf

Alternative Decapsulation Methods

Laser Ablation (with or w/o wet-etch)**:**



Ref: Annex D: https://www.jedec.org/system/files/docs/22B116B.pdf

Does not require use of acids
Mold-compounds are difficult to clear from under the wires.
Can cause damage to die-surface, as well as Cu-wire
Unsuitable for bond-shear testing, as is
Suited to thermally-aged mold-compounds; wet etch is difficult.

Used effectively **in combination** with wet-chemistries:
Most of the mold-compound is removed by laser ablation leaving a few mils above the die; short wet-etches are used to clear the residual mold-compound.

http://public.hofstragroup.com/3835.pdf

Ref: Failure Analysis of Integrated Circuits: Tools and Techniques; Edited by Larry Wagner, springer 1999

Alternative Decapsulation Methods

Plasma Decapsulation

Does not require use of acids
Uses Microwave plasmas with Oxygen & CF4
Generally requires switching gas-ratios during decapsulation
Conventional RF plasma etch can also be used, but decap times are ~10x longer;
Die-damage due to RF plasma-induced charging, as well as F attack of passivation layers are significant issues.
Can also be used in conjunction with laser ablation.

Thermomechanical Decapsulation

Refers to a variety of techniques used to decapsulate packages without use of acids
Generally include one or more of three elements:

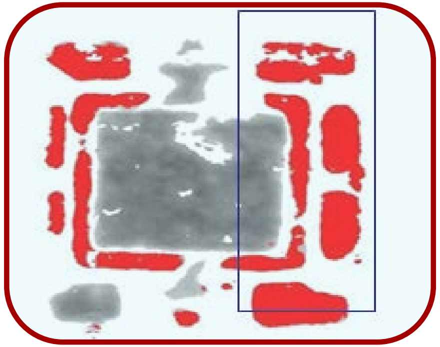
(a) Grinding to reduce mechanical size of the package/mold-compound
(b) Heating the mold-compound to soften
(c) Exerting mechanical force to crack the package or separate materials

Useful to examine corrosion by-products and pathways on leadframe-based packages
Not suitable for electrical isolation of fail sites, since it damages electrical integrity.

Ref: Failure Analysis of Integrated Circuits: Tools and Techniques; Edited by Larry Wagner, springer 1999

Key Reliability Challenges

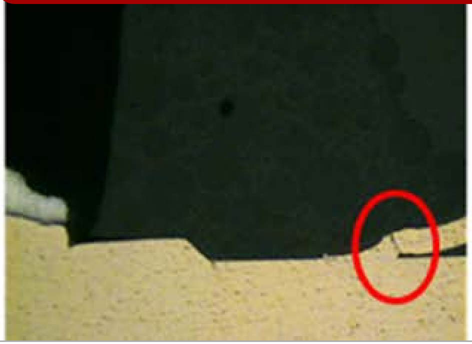
Package Integrity: Mold-Delamination and Post-TC Stitch-Crack

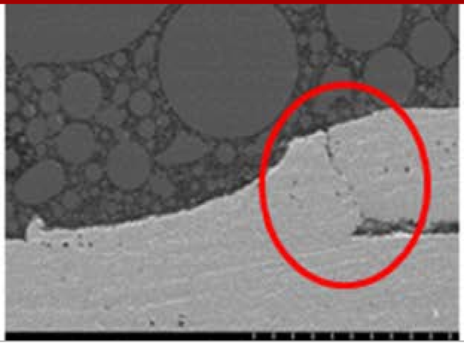


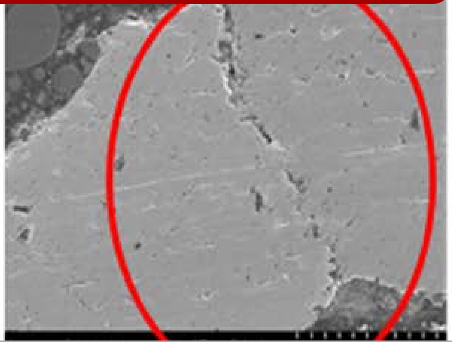
CSAM images show delamination after pre-conditioning in the die attach-pad areas, as well as on leadfinger areas

Post-Reflow package integrity is important for bond-reliability

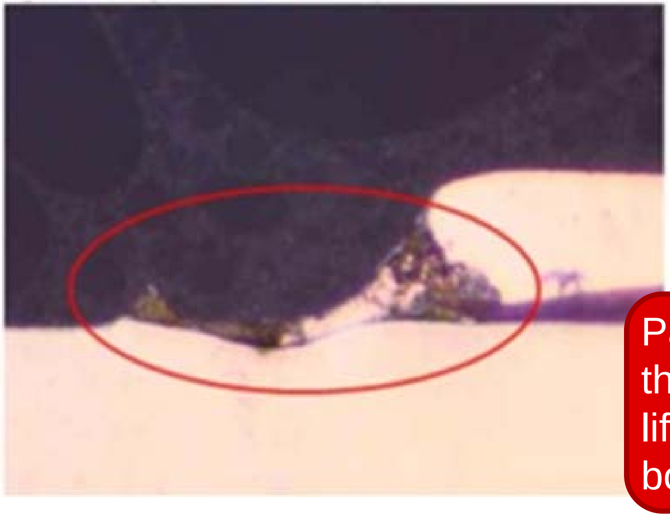
Mold-compound delamination can result in stitch-fracture during Temperature Cycling due to thermo-mechanical fatigue. Copper undergoes work hardening during stitch formation process.





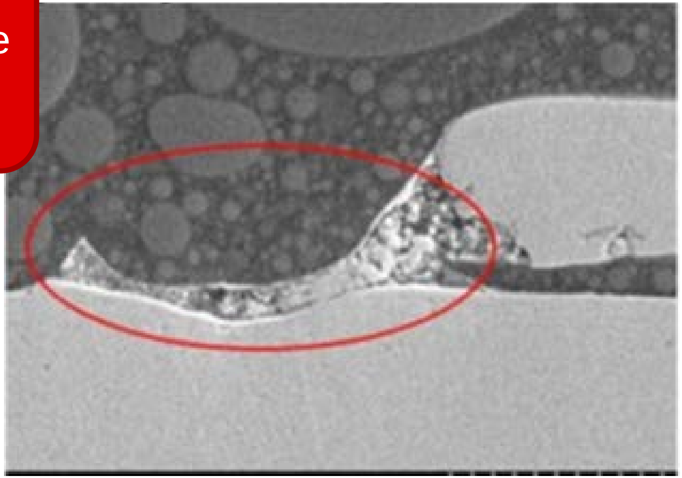


Package Integrity: Chemical Stitch Corrosion



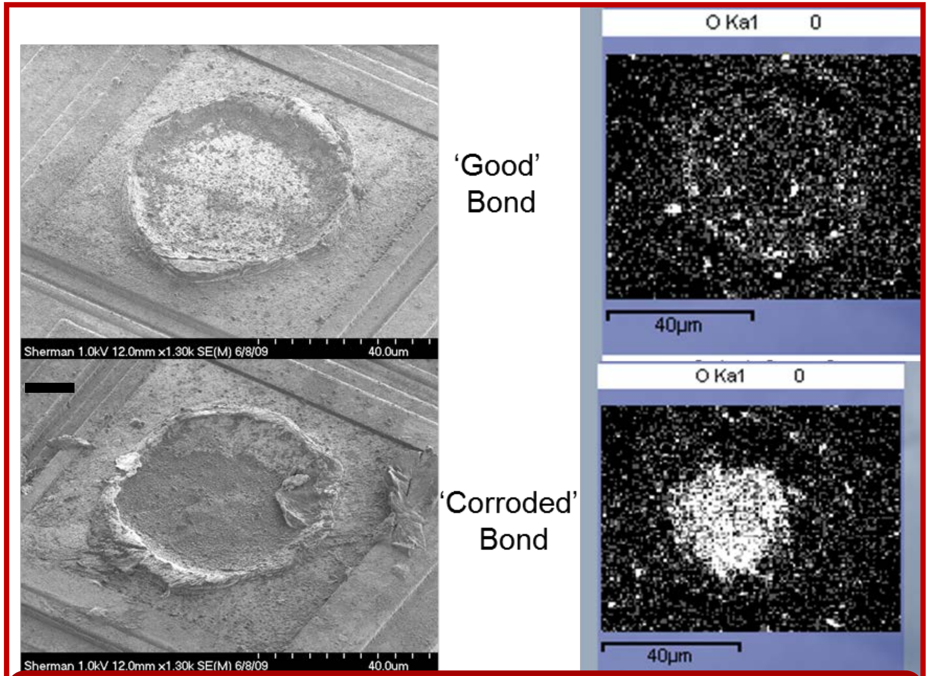
- ***How did the corrosion happen inside***?
  - Time-zero delamination reduces product robustness
  - Post-mold clean chemistry corroded Cu-stitch
  - Au-wire does not corrode

Package integrity throughout package life is important for bond-reliability



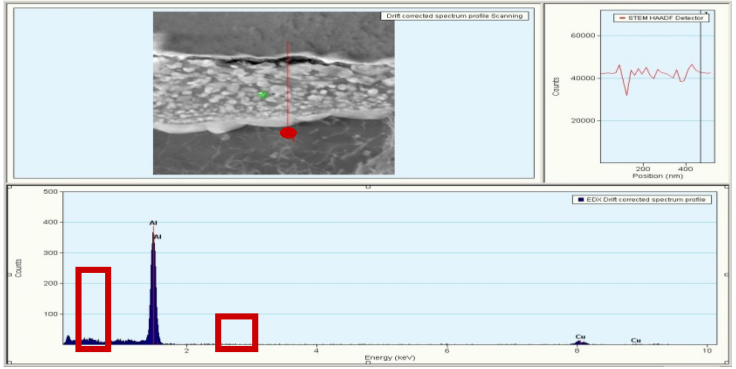
- Initially strong bonds can fail this way
- ***Robustness demands package integrity*** at ‘Time-zero’ and under stress

Humidity: Chlorine-Enhanced Corrosion

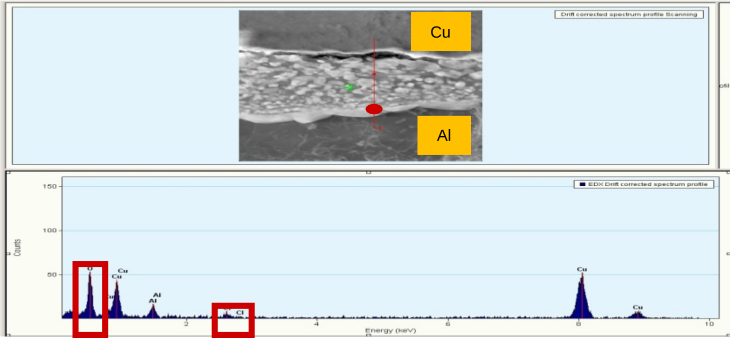


- Trace amounts of Cl are absolutely detrimental if they are attracted towards the bond-interface

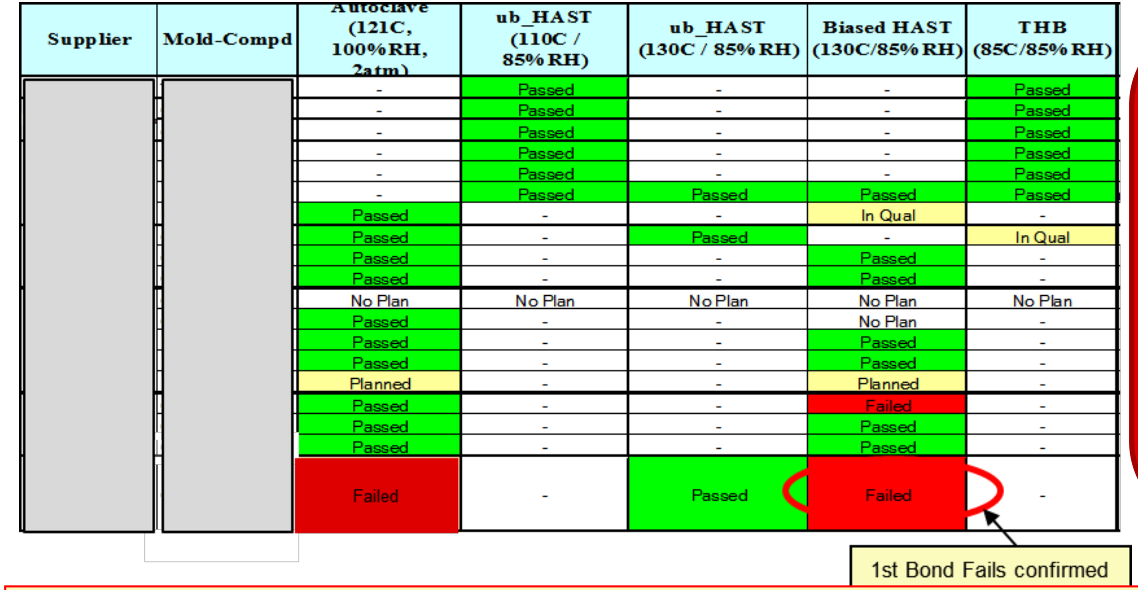
No O or Cl in Aluminum just below the interface.



Cl & O in layer between Al & Cu.



Materials: Mold-Compounds & Chlorine



Supplier	Mold-Compd	Autoclave (121C, 100%RH, 2atm)	ub_HAST (110C / 85%RH)	ub_HAST (130C / 85%RH)	Biased HAST (130C/85%RH)	THB (85C/85%RH)
[redacted]	[redacted]	-	Passed	-	-	Passed
		-	Passed	-	-	Passed
		-	Passed	-	-	Passed
		-	Passed	-	-	Passed
		-	Passed	-	-	Passed
		-	Passed	Passed	Passed	Passed
		Passed	-	-	In Qual	-
		Passed	-	Passed	-	In Qual
		Passed	-	-	Passed	-
		Passed	-	-	Passed	-
		No Plan	No Plan	No Plan	No Plan	No Plan
		Passed	-	-	No Plan	-
		Passed	-	-	Passed	-
		Passed	-	-	Passed	-
		Planned	-	-	Planned	-
		Passed	-	-	Failed	-
		Passed	-	-	Passed	-
		Passed	-	-	Passed	-
		Failed	-	Passed	Failed	-

1st Bond Fails confirmed

Certain mold-compound formulations can contribute to random and/or systematic occurrences of corrosion.

Other assembly processes & materials can also contribute. These are difficult to identify.

TI has made significant advances in this area; it remains an active focus.

- Biased-HAST corrosion is prominent for certain mold-compounds, even if they are 'green'
- Autoclave can also show corrosion without bias.
- Failures do not correlate with residual Cl specs for the mold-compd
- Other sources of Chlorine – Plasma Clean – are also reported ***(e.g. Tai et al, Int Elec Mfg Tech Conf, 2012),***
- Mold-compounds with low pH values protect encapsulated materials against corrosion per Pourbaix diagram.

Lessons To Take Forward

Cu-Wirebonding is not just a material change; it is a mindset change

Development and Qualification:

- √ *Development Process –*
  - √ *engaging the supply chain (engineering/fab/AT/suppliers)*
  - √ *Corner DOE's – making the bonds fail*

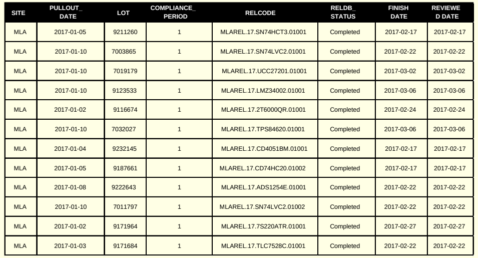
- √ *Reliability/Robustness by Design*
  - √ *Selecting Bill of Materials – mold-compounds, Chlorine, Au/Pd-Coated Cu, Roughened leadframes, capillaries*
  - √ *Bonding-Recipe Development – Process Technology, Device layout, bond-window*
  - √ *Reliability- Relationship to initial bond-strength*
  - √ *Package integrity – delamination in packages – bond-breaks, corrosion*

- √ *Enabling Techniques –*
  - √ *SEM x-sections of IMCs,*
  - √ *laser decapsulation,*
  - √ *Bond-pad IMC mapping,*
  - √ *Rapid in-line bond-inspection for over-bonding checks*
  - √ *Au- vs Cu-identification in encapsulated devices*
  - √ *TEM analysis techniques*

Tight Manufacturing Controls are Essential for Cu-bond Reliability

Maintaining Quality & Reliability

- √ *Assembly process compatibility and integration (die-attach, plasma, trim-n-form, etc)*
- √ *Manufacturing Discipline - Bonder set-ups, bonder-to-bonder matching, handling & cleanliness, across-the-board assembly process controls, preventive maintenance*
- √ *Automation in assembly lines – recipe locks, change control*
- √ *Monitoring:*



SITE	PULLOUT_ DATE	LOT	COMPLIANCE_ PERIOD	RELCODE	RELDB_ STATUS	FINISH DATE	REVIEWE D DATE
MLA	2017-01-05	9211260	1	MLAREL.17.SN74HCT3.01001	Completed	2017-02-17	2017-02-17
MLA	2017-01-10	7003865	1	MLAREL.17.SN74LVC2.01001	Completed	2017-02-22	2017-02-22
MLA	2017-01-10	7019179	1	MLAREL.17.UCC27201.01001	Completed	2017-03-02	2017-03-02
MLA	2017-01-10	9123533	1	MLAREL.17.LMZ34002.01001	Completed	2017-03-06	2017-03-06
MLA	2017-01-02	9116674	1	MLAREL.17.2T6000QR.01001	Completed	2017-02-24	2017-02-24
MLA	2017-01-10	7032027	1	MLAREL.17.TPS84620.01001	Completed	2017-03-06	2017-03-06
MLA	2017-01-04	9232145	1	MLAREL.17.CD4051BM.01001	Completed	2017-02-17	2017-02-17
MLA	2017-01-05	9187661	1	MLAREL.17.CD74HC20.01002	Completed	2017-02-17	2017-02-17
MLA	2017-01-08	9222643	1	MLAREL.17.ADS1254E.01001	Completed	2017-02-22	2017-02-22
MLA	2017-01-10	7011797	1	MLAREL.17.SN74LVC2.01002	Completed	2017-02-22	2017-02-22
MLA	2017-01-02	9171964	1	MLAREL.17.7S220ATR.01001	Completed	2017-02-27	2017-02-27
MLA	2017-01-03	9171684	1	MLAREL.17.TLC7528C.01001	Completed	2017-02-22	2017-02-22

Hunting out the pesky Cu-‘killers’:
Manufacturing materials/environments (consumables, facilities, storage conditions, transportation, floor life, personnel etc)

Navigating to a better place

- *Get a handle on Chlorine*
- *Control Delamination in packages*
- *Identify better material solutions*
- *Decapsulation for wirepull analysis.*

HiRel-Specific Considerations - 1

- **Cu-wirebond is currently restricted in SMDs and VIDs by DLA .**
  - No standard HiRel-focused, Cu-wirebond component qualifications available today

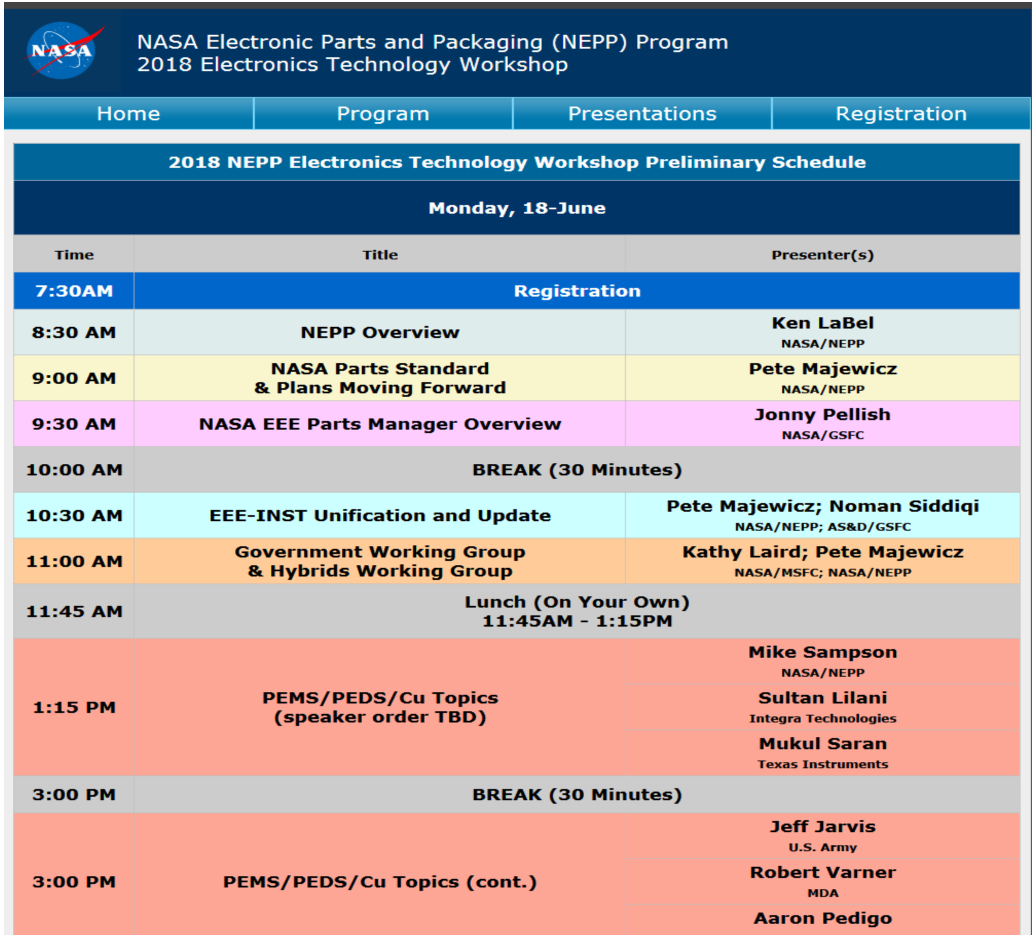
- **Unique stresses in Military & Space applications**
  - Standard component qualification-plans target commercial applications.
  - ***Users must assure suitability for HiRel application.***
  - Long, inactive storage for mission-critical components
  - High-temperature environments
  - Vibration and mechanical shock
  - High radiation environments
  - Sequential-stress qualifications required for space-flows
  - Mission-critical applications demand 100% assurance methodologies

- **Other considerations for HiRel components**
  - Burn-in screening is not a part of the commercial qualification flow
  - 100% Delamination screening by SAM is not a part of the production flows
  - Off-the-shelf commercial parts do not require unique identification for Cu-wirebond; Au and Cu-wirebonded parts may be sold under the same part number.

Points to Remember – Quality & Reliability

- Cu is reliable under standard stress conditions, and can even exceed the minimum if process development is optimized, manufacturing processes/materials/environments are scrupulously and deliberately screened for contaminants, and manufacturing discipline is maintained.
- Cu-wirebond is less forgiving than Au-wirebond in manufacturing. Process optimization, equipment matching, manufacturing discipline, and change control are critical for quality and reliability. Necessary die-level info is not generally available to third-party assembly houses.
- Fabs, technologies, bonder platform & model, bond-process, capillary type, bond-wire material & shelf-life are all important factors.
- Maximizing bond-shear does not assure the best wire-bond quality. An optimization may be necessary
- Bond-Pull can be useful to highlight some b/pad failure mechanisms
- Stitch formation is more difficult than Au-wire and leadfinger surface roughness matters – smoother is better.
- The package must maintain integrity throughout the useful life of the product.
- Random chlorine sources that cause Cu bond corrosion remain an area of focus. The knowledge about potential sources of Chlorine is often privileged and learned by experience.
- Decapsulation of Cu-wirebonds remains challenging despite advances. New ones are on the horizon

END of Presentation



NASA Electronic Parts and Packaging (NEPP) Program
2018 Electronics Technology Workshop

2018 NEPP Electronics Technology Workshop Preliminary Schedule

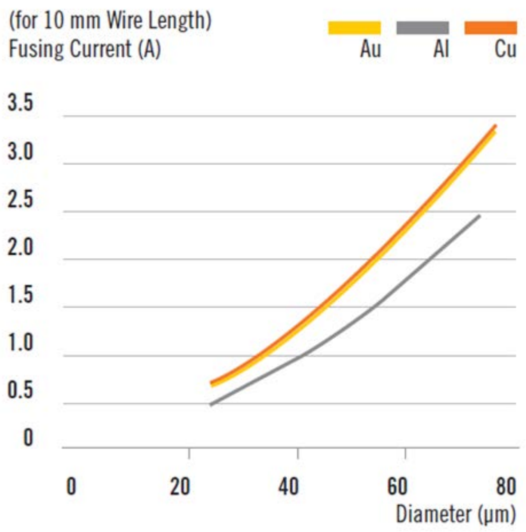
Monday, 18-June

Time	Title	Presenter(s)
7:30AM	**Registration**	
8:30 AM	**NEPP Overview**	**Ken LaBel** NASA/NEPP
9:00 AM	**NASA Parts Standard & Plans Moving Forward**	**Pete Majewicz** NASA/NEPP
9:30 AM	**NASA EEE Parts Manager Overview**	**Jonny Pellish** NASA/GSFC
10:00 AM	**BREAK (30 Minutes)**	
10:30 AM	**EEE-INST Unification and Update**	**Pete Majewicz; Noman Siddiqi** NASA/NEPP; AS&D/GSFC
11:00 AM	**Government Working Group & Hybrids Working Group**	**Kathy Laird; Pete Majewicz** NASA/MSFC; NASA/NEPP
11:45 AM	**Lunch (On Your Own) 11:45AM - 1:15PM**	
1:15 PM	**PEMS/PEDS/Cu Topics (speaker order TBD)**	**Mike Sampson** NASA/NEPP **Sultan Lilani** Integra Technologies **Mukul Saran** Texas Instruments
3:00 PM	**BREAK (30 Minutes)**	
3:00 PM	**PEMS/PEDS/Cu Topics (cont.)**	**Jeff Jarvis** U.S. Army **Robert Varner** MDA **Aaron Pedigo**

Choosing Cu over Au – Fusing Current

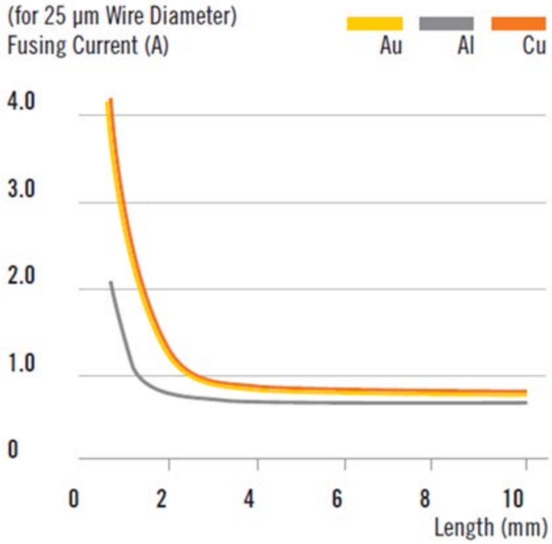
Source: Heraeus bonding-wire brochure

Fusing Current-vs-Wire Diameter



Preece Equation: $I_{fuse} = C * D^{3/2}$
C is a material-dependent constant.

Fusing Current-vs-Wire Length



Short (<3mm) Cu or Au wires can take larger currents before fusing.

Fusing Current –vs- Wire Material

$$I_{Fuse} = \left(\frac{\pi D^2}{4}\right).\sqrt{Ln\left(\frac{(Tmelt-Tamb)}{(234-Tamb)}+1\right)/t} * 33$$

Tmelt -melting temp of wire in deg C
Tambient -ambient temp in deg C
Time -melting time in seconds
Ifuse -fusing current in amps
Area -wire area in circular mils
*Circular Mils = the diameter of the wire in thousandths of an inch (mils) squared. That is, it is the area of a circle 0.001" in diameter. (1 cmil = 0.507E-3 sq mm)
*This equation isn't as valid for non-circular cross sections, or where there isn't free flow of air around the wire.

Source: HM Wire International: (Fusing_Currents_Melting_Temperature_Copper_Aluminum_Magnet_Wire_R2.011609.pdf)

Cu and Au wires are similar in their fusing current capability due to similar melting points.

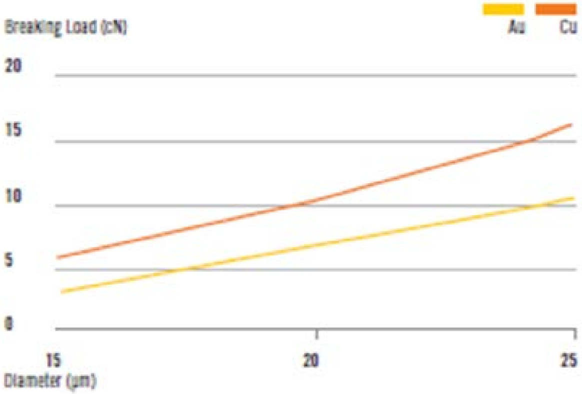
Al fuses at much lower currents for the same wire diameter.

Choosing Cu over Au

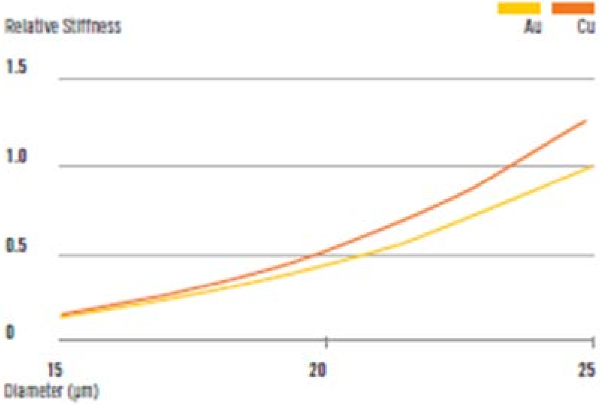
Resistivity-vs-Wire Diameter

Source: Heraeus bonding-wire brochure

Relative Breaking Load-vs-Wire Diameter



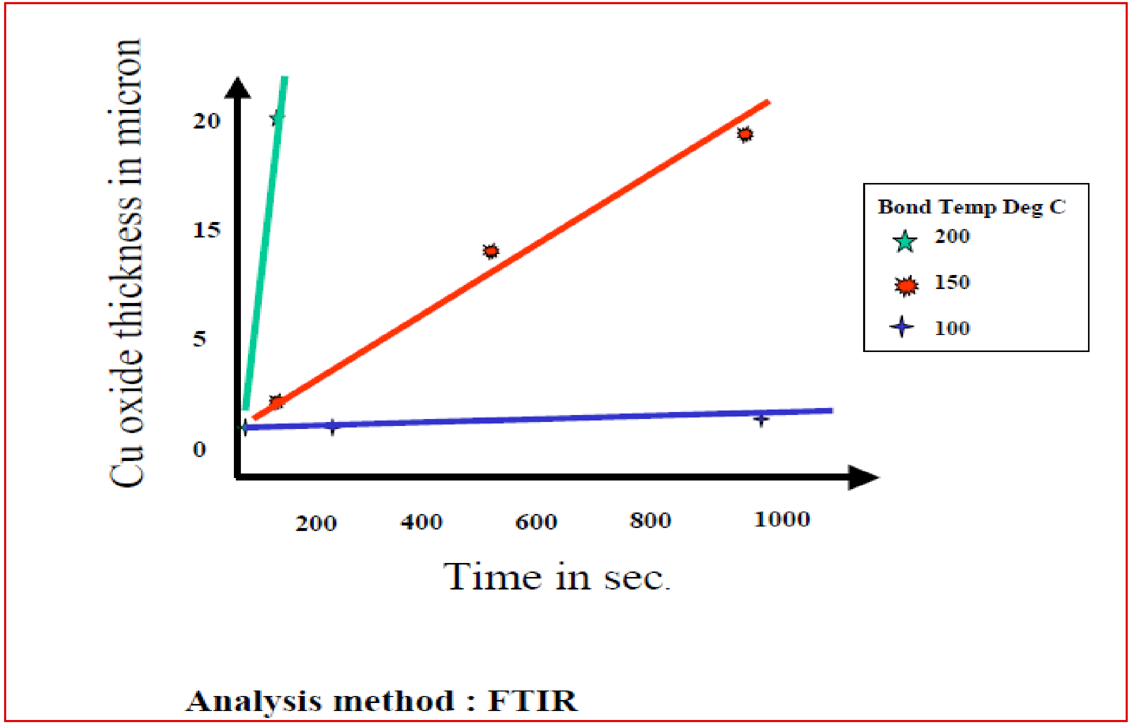
Relative Stiffness-vs-Wire Diameter



Copper exhibits significantly better conductivity than gold or aluminum. Therefore better heat dissipation and increased power ratings are attainable with thinner wire diameters

Copper possesses higher mechanical properties compared to gold. Therefore it displays excellent ball neck strength and high loop-stability during molding or encapsulation.

Copper Oxidation



Sumitomo Metal Mining (SMM) Cu-wire presentation 2007

- ➢EFO temperatures are near the melting point of Cu.
- ➢At high temperatures Cu oxidizes rapidly.
- ➢At very high temperatures, even a short duration in air can oxidize Cu.

➢Therefore, Cu requires use of Forming Gas during wirebond.

Al-Splash – Strain Hardening

Wulff et al, Semicon 2005, Singapore, pp1-10

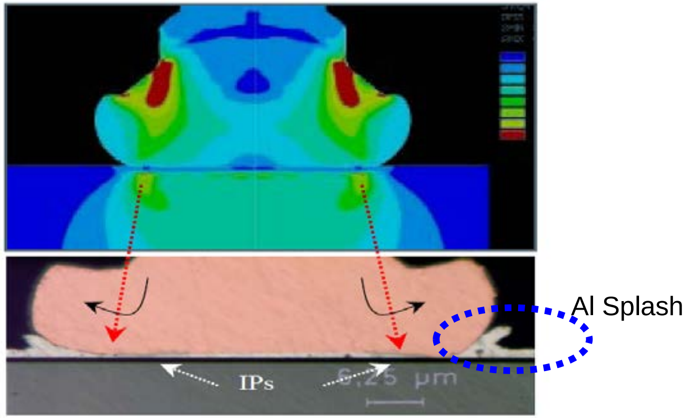


Figure 5. Top image: FEM simulation [20] showing stresses in a bonded ball. Bottom: cross-section of a copper ballbond (4hrs at 250°C) showing deformed Al bondpad and thin Cu-Al phases.

- ➢Bonding causes strain-hardening of the ball due to dislocations
- ➢Edges harden more due to higher strain rates under the capillary. Al-splash occurs from under the edges.

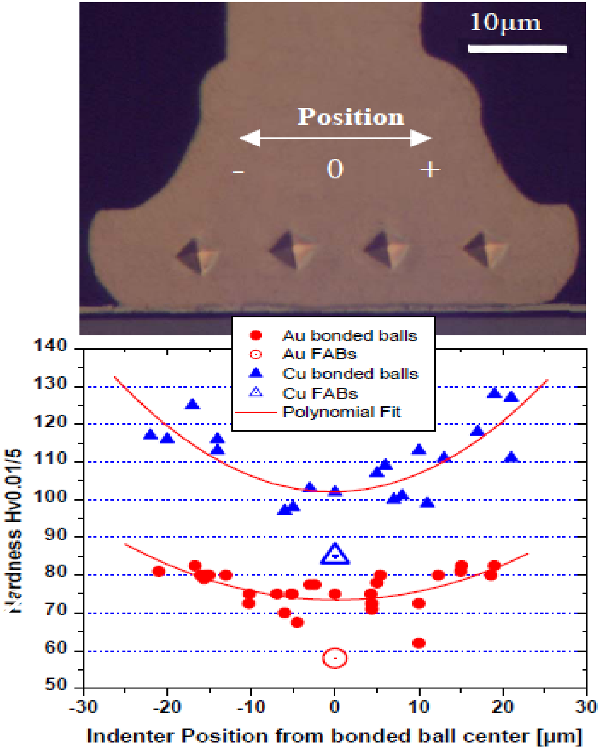
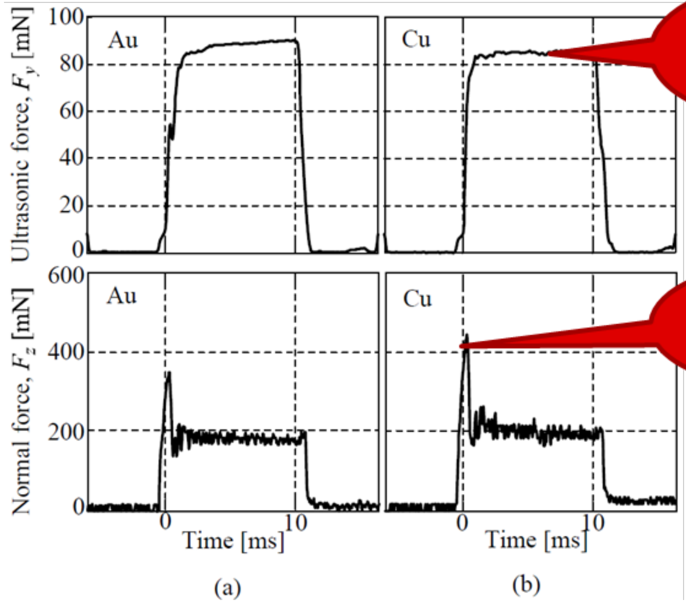


Figure 4. Top: example of a bonded ball with indentations along a centreline across the ball. Bottom: Hardness of Cu and Au ball-bonds as function of position compared with FAB hardness.

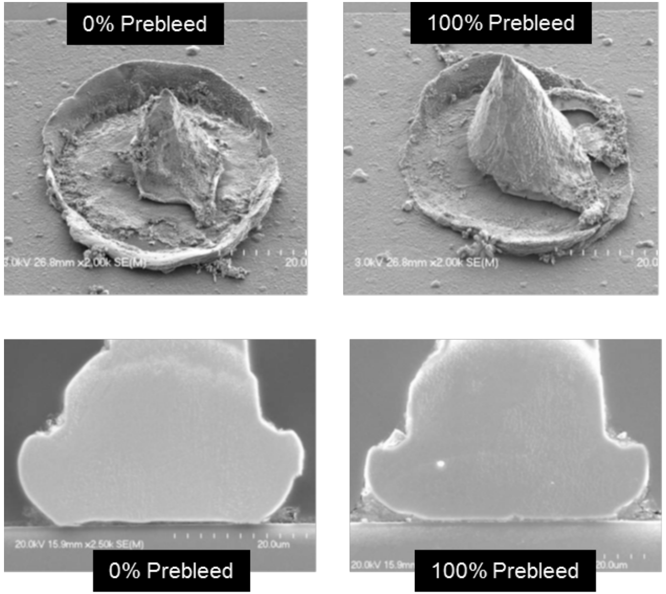
Pad-Damage/Lifted Metal (LFML)

Ref: Qin et al, K&S/Univ of Waterloo, EPTC 2009, pp 573-578



Similar or lower ui/s force measured for Cu than for Au

30% Higher Peak Force than Au.



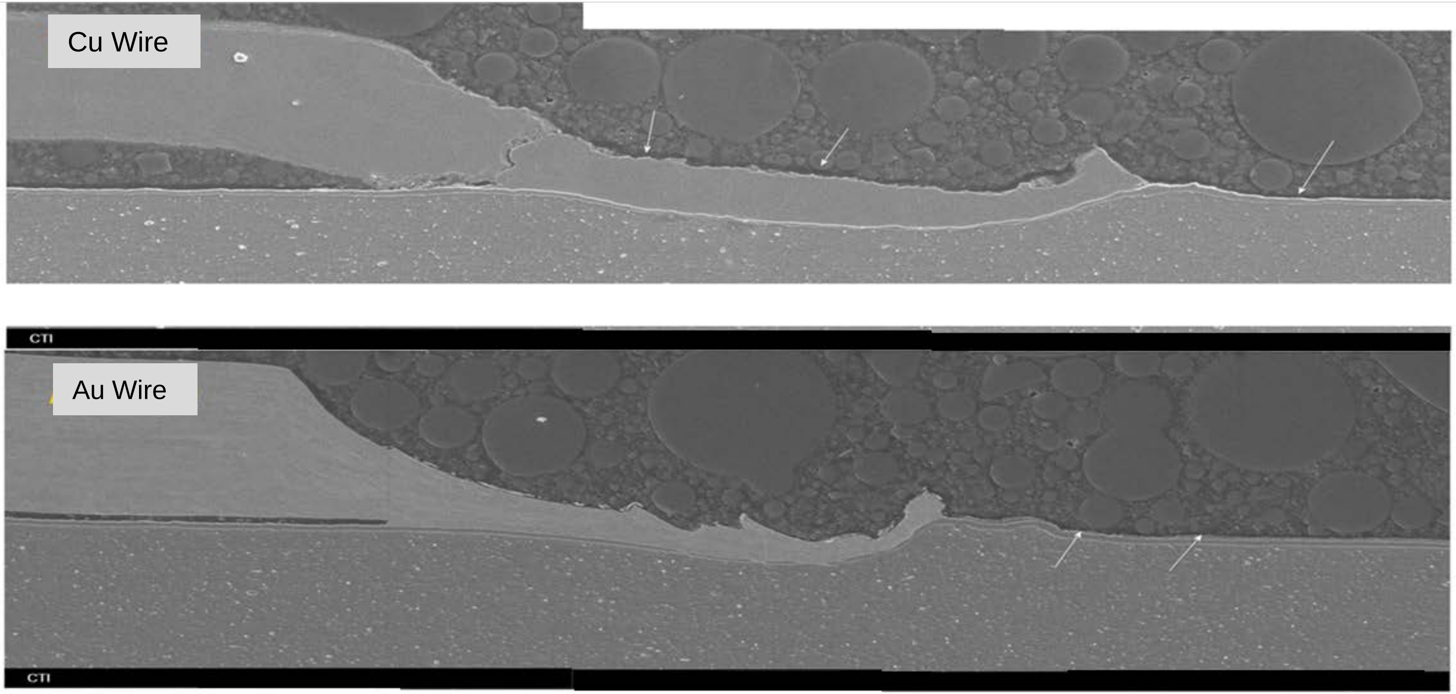
For Cu, U/S force is similar or lower than Au. Also, the Peak normal force during bond is 30% higher, but steady state values are similar.

- **Cu-ball does not absorb impact as well as Au**

- **Use of pre-bleed* reduces, both, b/pad damage at ball-edges & Al-splash. It also flattens the profile**

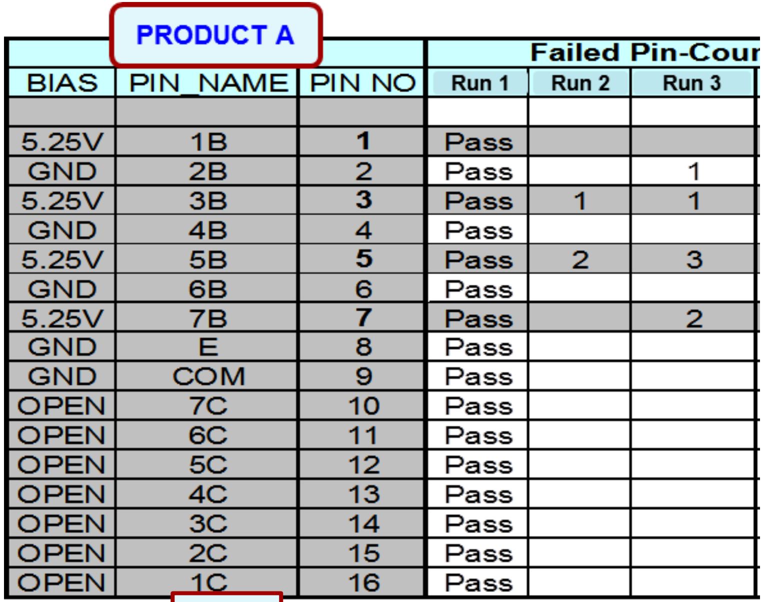
* Pre-bleed refers to application of u/s during ball impact on pad.

Temperature Cycling: Mold-Delamination and Stitch-Crack



Cu Wire –vs- Au Wire Stitch After **1000 T/C**; Au Wire Had No Damage. Both have delamination t0 and after 1000 T/C. Arrows indicate mold-compound delamination

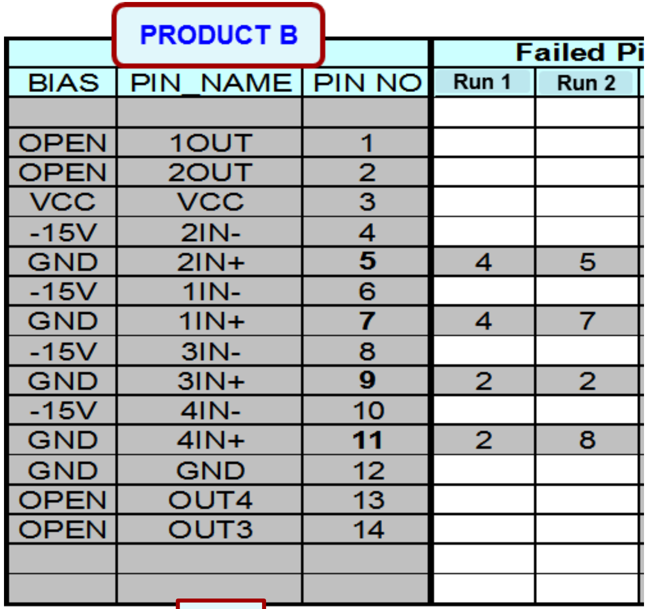
Voltage: Bias-Enhanced Corrosion



PRODUCT A

			Failed Pin-Cour		
BIAS	PIN_NAME	PIN NO	Run 1	Run 2	Run 3
5.25V	1B	**1**	Pass		
GND	2B	2	Pass		1
5.25V	3B	**3**	Pass	1	1
GND	4B	4	Pass		
5.25V	5B	**5**	Pass	2	3
GND	6B	6	Pass		
5.25V	7B	**7**	Pass		2
GND	E	8	Pass		
GND	COM	9	Pass		
OPEN	7C	10	Pass		
OPEN	6C	11	Pass		
OPEN	5C	12	Pass		
OPEN	4C	13	Pass		
OPEN	3C	14	Pass		
OPEN	2C	15	Pass		
OPEN	1C	16	Pass		

5.25V



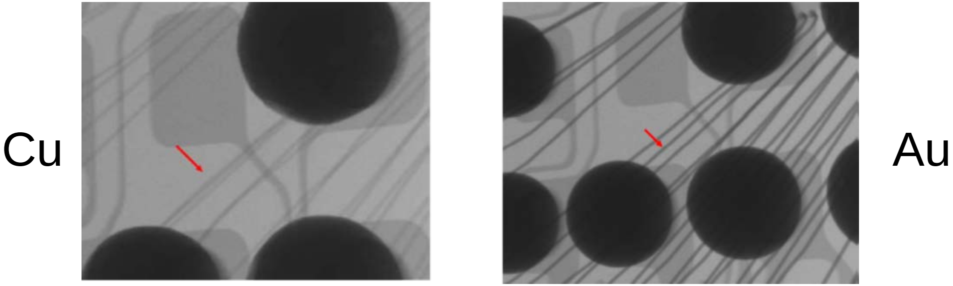
PRODUCT B

			Failed Pi	
BIAS	PIN_NAME	PIN NO	Run 1	Run 2
OPEN	1OUT	1		
OPEN	2OUT	2		
VCC	VCC	3		
-15V	2IN-	4		
GND	2IN+	**5**	4	5
-15V	1IN-	6		
GND	1IN+	**7**	4	7
-15V	3IN-	8		
GND	3IN+	**9**	2	2
-15V	4IN-	10		
GND	4IN+	**11**	2	8
GND	GND	12		
OPEN	OUT4	13		
OPEN	OUT3	14		

15V

- Failures concentrated on biased pins.
- Corrosion signatures identified: oxidation of Cu-Al interface, traces of Cl from mold-compd
- Not all products may show this correlation. It is design-dependent.

HiRel-Specific Qualification Considerations - 2



X-ray contrast against a Au control unit can quickly help identify Cu-wire parts.
The X-ray imprint for Cu is weaker than for Au.

- **Mil-standards are currently being reviewed & updated for Cu-wirebonds.**

Ball-Bond Fail Mitigation Examples

Failure Mechanism	Failure Mode	Risk Mitigation
Bond Pad Cracking	Shorts, leakage, open	Smaller wire-diameter, New advanced bonder
	Shorts, leakage, open	Parameter Optimization. Cratering is caused by High USG with low force
	Opens	Use appropriate barrier metal & Al bond-pad-thickness
	Shorts	Align with bond-pad stack-up design rules (slotting)
Dielectric Cracking	Opens, leakage	Parameter optimization. Align with bond-pad stack-up design rules (vias)
	Opens, Leakage	Ensure minimum remaining Al under ball
	Leakage, Shorts	Use appropriate barrier metal & Al bond-pad-thickness
Bond Pad Corrosion	Opens	Use PCC wire, Improve saw process
Metal Peeling	Opens	Parameter optimization. Ensure minimum remaining Al thickness,
	Opens	Low Frequency USG, Segmented bonding

Stitch-Bond Fail Mitigation Examples

Common Stitch Failure Modes	Usual Corrective Actions/Risk Mitigation
NSOP	Optimize bond parameters:
	NSOP caused by Low force/Low ultrasonic power
	NSOP caused by High force/Low ultrasonic power
Broken Stitch	Mitigate delamination - Roughened LF, Ag-Spot (Matte Sn finish)
	Decouple down-bonds (Wings on pad)
Lifted Stich	Improve LF clamping, Optimize parameters for robust stitch flare
Stitch Corrosion	Identify & remove Cl contamination sources