Fine Pitch Probing and Wire Bonding and Reliability of Aluminum Cap Copper Bond Pads

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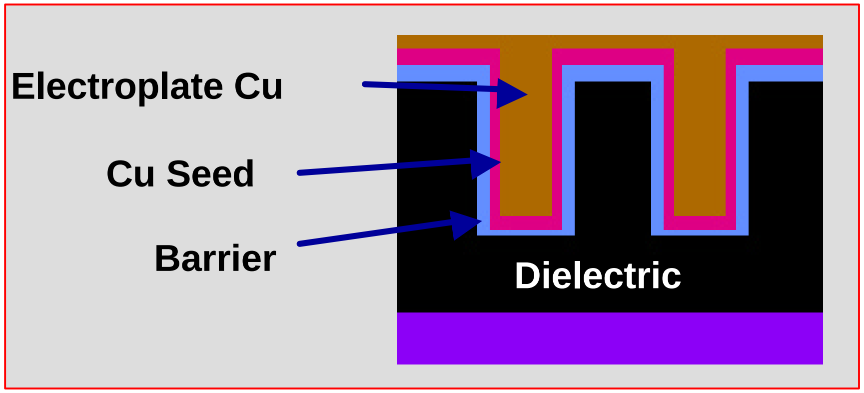

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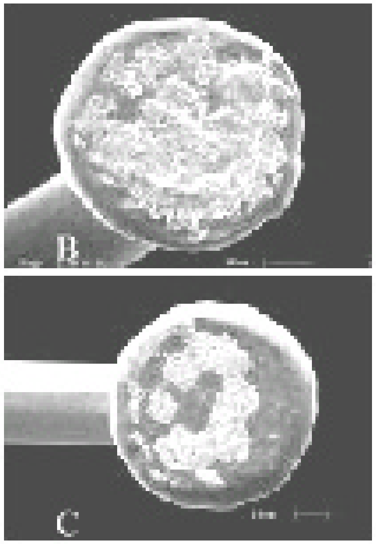
Topics to be Covered

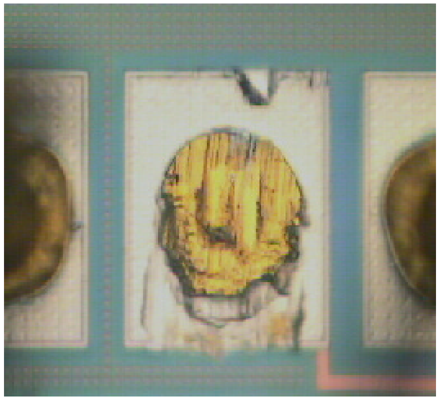
- Criteria for Reliable Ball Bonds
- Inspection Criteria for Probe Mark Damage
- Impact of Probe Marks to Wire Bonding in Al Technology:
  - 43µm Ball Bond
- Back-end Challenges in Cu Technology
- Impact of Probe Marks to Wire Bonding in Cu Technology:
  - 70 and 60µm Ball Bonds
  - Multiple metal layers
  - Probe conditions
- Conclusions and Recommendations

Criteria for Reliable Ball Bonds

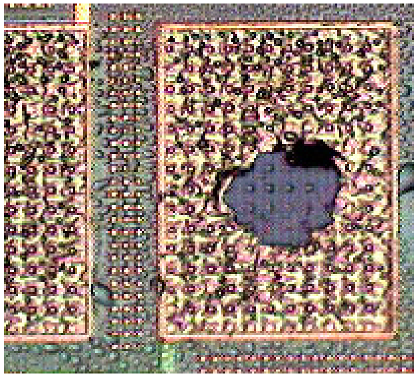
100% On-bonding



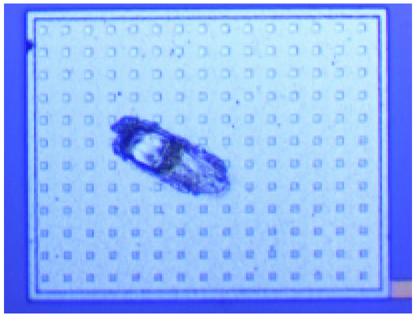
Au-Al Intermetallic Coverage of >70%



Ball Shear Strength/Area = 5.5gf/mil^2



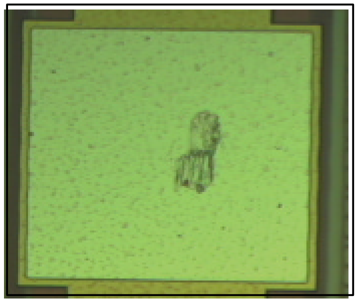
No Pad Cratering after KOH



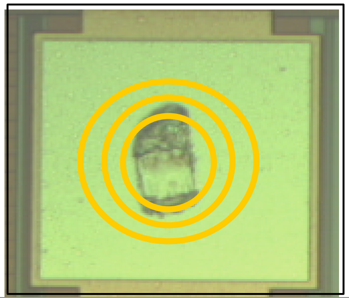
No Non-stick

No Pad Lift

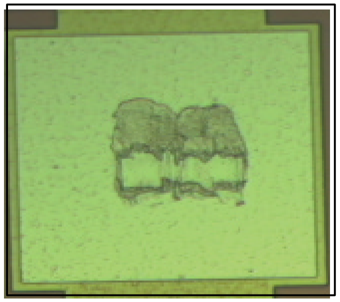
Inspection Criteria for Probe Mark Damage



1X Light - 22x28mm

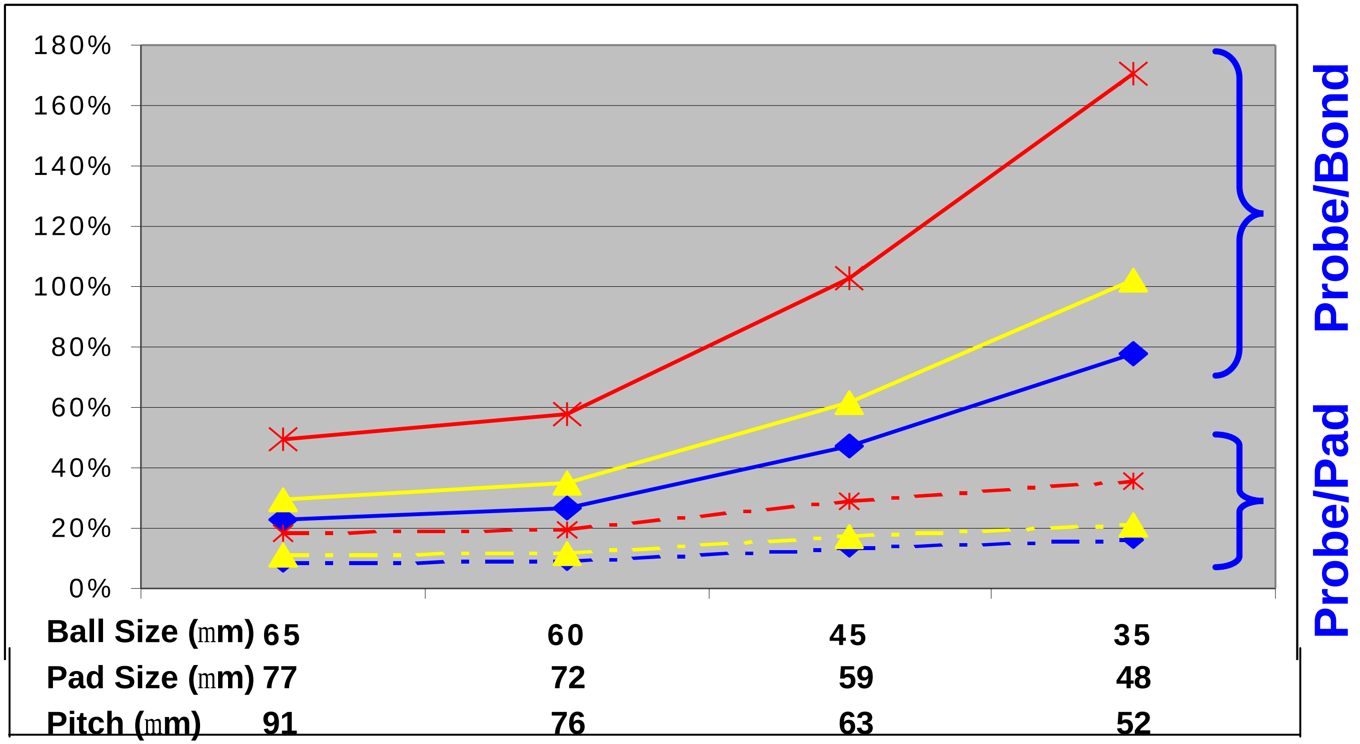


1X Heavy - 20x40mm



2X Heavy - 27x49mm

Data Courtesy of Fuaida Harun



Loose criteria for inspecting probe mark damage on pad:

- No exposed oxide, no cracked glass
- Max 25% probe/pad ratio
- **Probe/ball bond ratio is NOT specified!!**

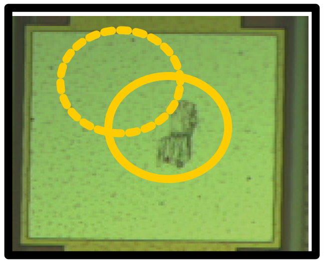
Large variation in probe mark sizes:

- Tends to magnify at finer pitch and smaller ball bonds

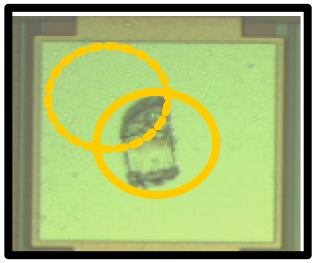
Impact of Probe Mark to Wire Bonding

43mm Ball Bond on Al Technology

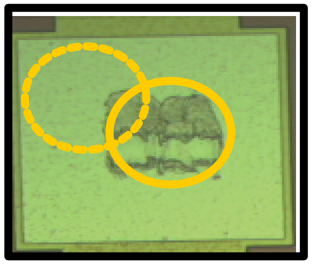
1XL



1XH



2XH



Data Courtesy of Fuaida Harun

	NSOP		*Lifted Metal*	
	Center Probe	Offset Probe	Center Probe	Offset Probe
1 X Light	0%	0%	0%	0%
1 X Heavy	0%	0%	1.17%	0%
2 X Heavy	12%	0.13%	1.95%	0.19%

Non-stick on Pad(NSOP):

- Very significant NSOP rate for Center Probe compared Offset Probe in 2XH

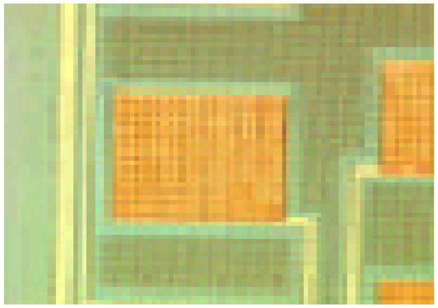
Lifted Metal after wire bonding:

- Both Heavy probe marks experience Lifted Metal for Center of Probe with higher rate for 2XH
- Lifted metal also experienced for the Offset Probe (no space)

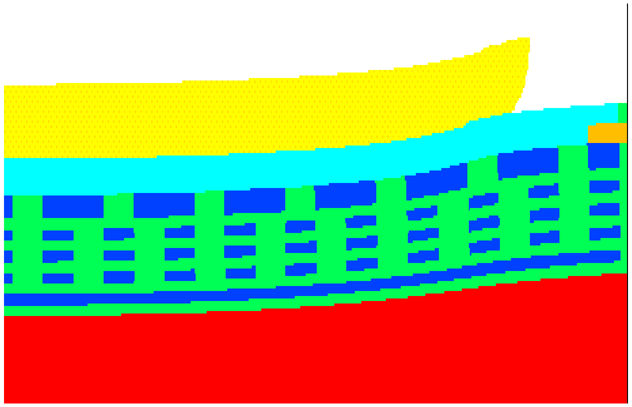
– Large probe marks decrease Au-Al intermetallics coverage and increase bond non-sticks and pad lifts.

– Must control to < 60% probe/ball bond ratio

Back-end Challenges in Cu Technology

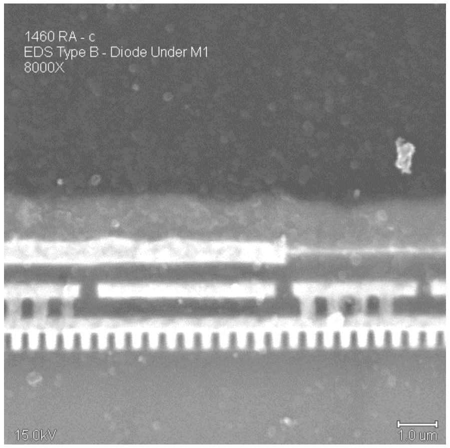


Cu Bond Pad
➡ Oxidation

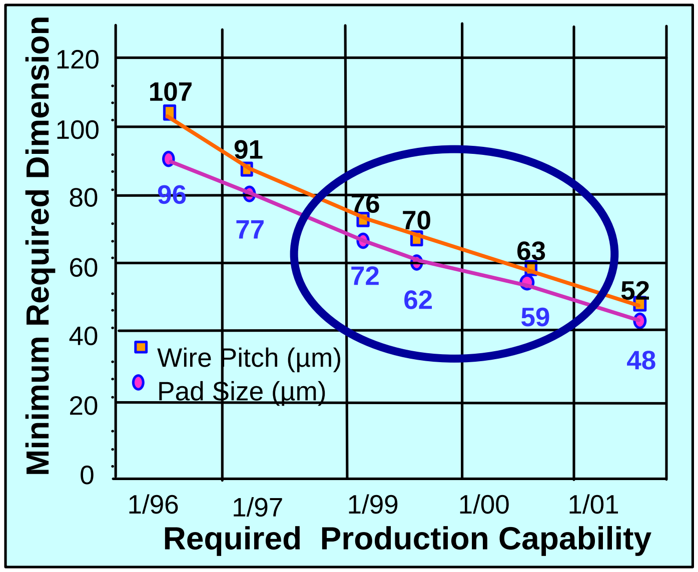


Thin Top Metal
➡ Pad Cupping

Multiple Metal Layers
➡ Pad Sinking

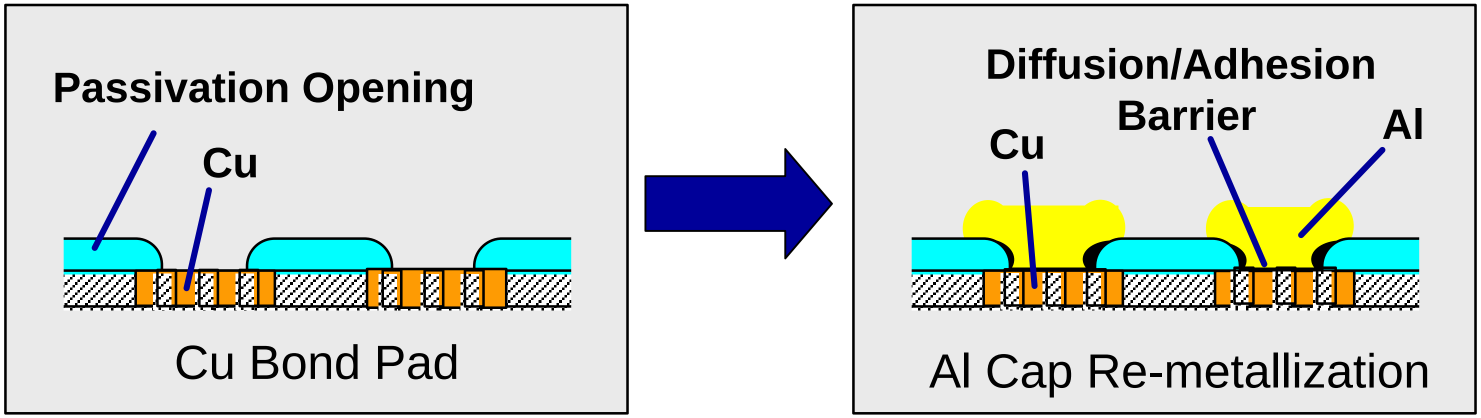


Active Circuitry Under Pads
➡ Circuitry Damage



Fine Pitch Geometry
➡ Probe and Wire Bond Capabilities

Back-end Approach



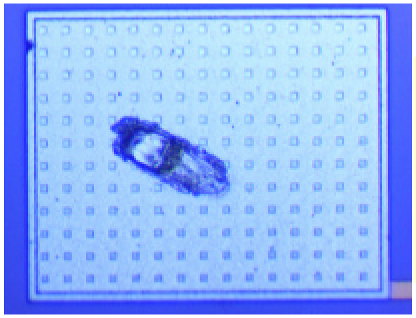
Advantages:

- Existing Al fab equipment/process/tooling
- Re-metallization is performed in fab, thereby reducing cycle time
- Fine pitch capability due to photo lithography
- Existing know-how in probe and assembly on Al bond pads

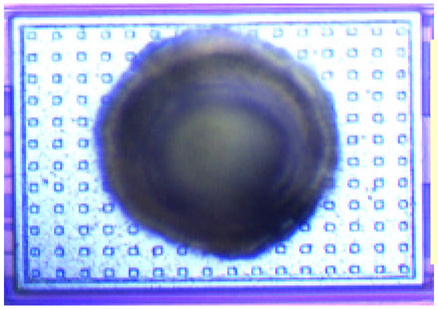
Approach:

- Developed 76µm pitch probe and wire bond capability (60 µm Ball ∅) on thin Cu layer
- Al Cap Cu wire bond process window is narrower and shifted to the right compared to standard Al process.

Experiment Flow



1-metal device
6.7 x 6.7mm
230 pads
256 17x17 BGA



3-metal device
4.2 x 4.7mm
174 pads
196 15x15 BGA

Fabrication → **Probe** → **Assembly**

Variables
- ☐ 1-Metal
- ☐ 3-Metal

Variables
- ☐ Tip Diameter - 1 mil
- ☐ Overdrive - 60µm (k=1.5gf/mil)
- ☐ Probe Passes - 6 max

Variables
- ☐ Ball Bond Size - 70 and 60µm

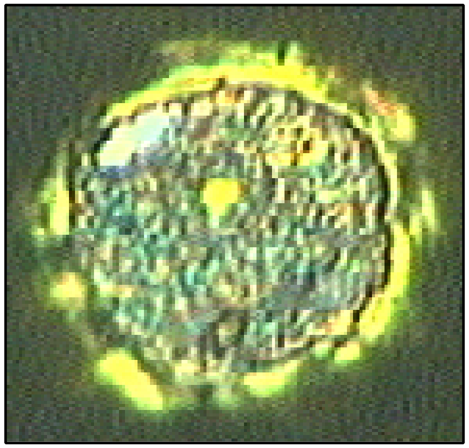
Responses/Analysis

Structural Integrity - Thermal Age Study (175ºC; 0, 5, 24, 100, 200, 500, 1000 hrs)
- ☐ Ball Shear & Failure Mode
- ☐ Rip Test & Failure Mode

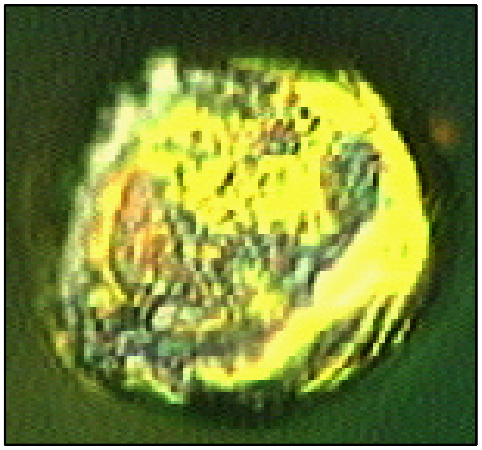
Reliability
- ☐ MSL 3 + Temp Cycle (-65 to 150ºC) - 0, 500, 1000 cycles
- ☐ MSL 3 + Autoclave - 0, 96, 144 hrs

Evaluate Effects of:
- Ball Sizes - 70 and 60 µm
- Multiple Layers - 1 and 3
- Probe Conditions - up to 6 touches

Au-Al Intermetallics Coverage %

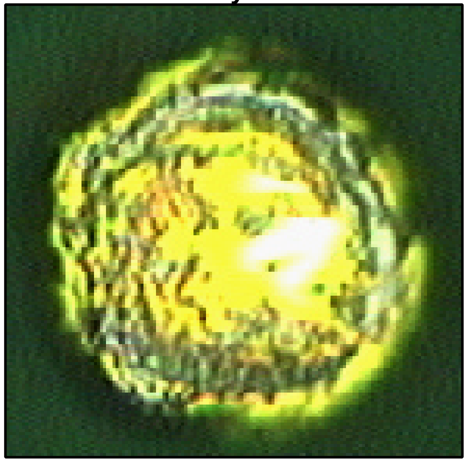


Un-probed Pad
90%



Pad Probed 4-6x
75%

Photo Courtesy of Fuaida Harun

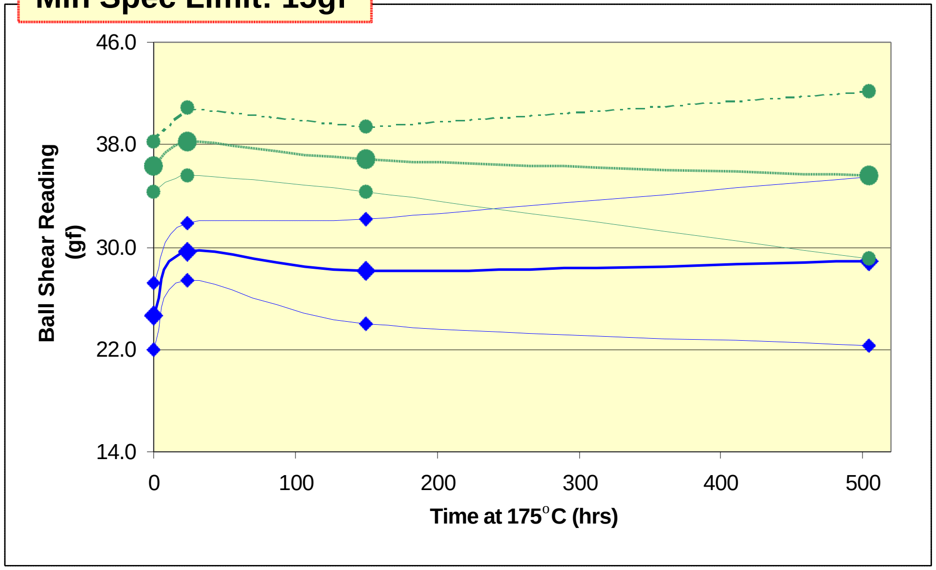


Pad Probed 8x
25%

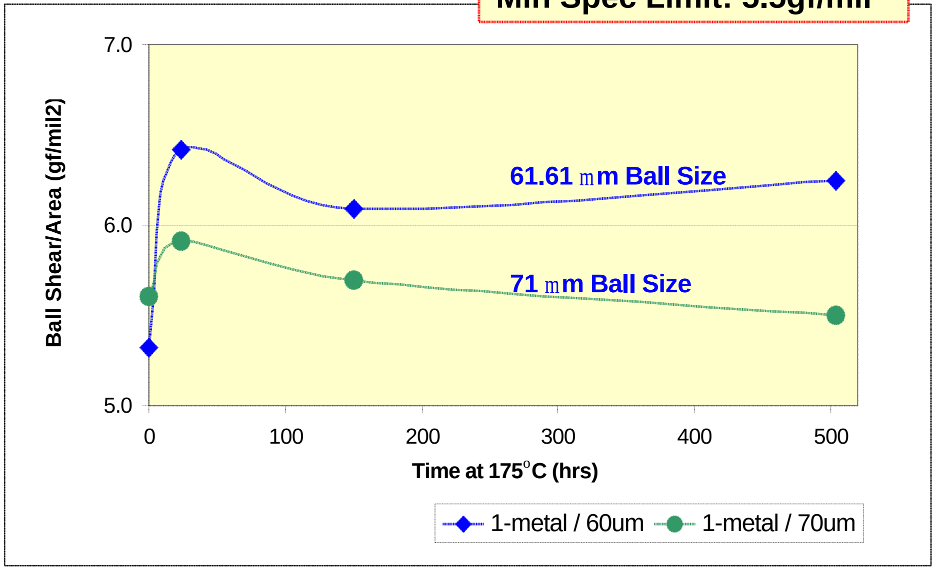
Effects of Smaller Bond Sizes - Ball Shear Results

1-metal Device, Probed 6x, Ball Bonds 70 and 60mm

Min Spec Limit: 15gf



Min Spec Limit: 5.5gf/mil^2

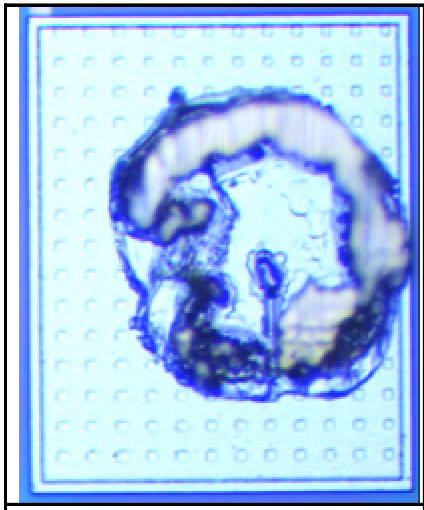
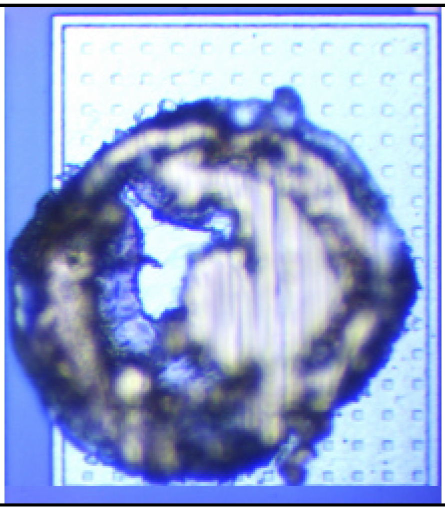
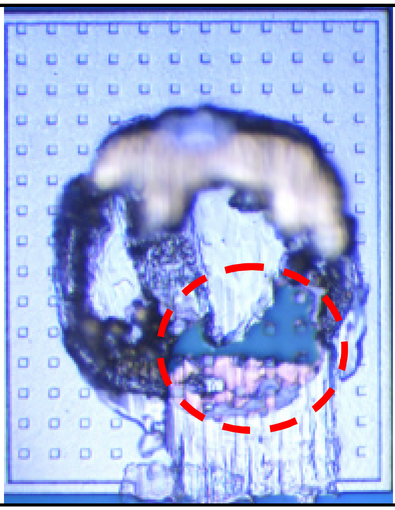
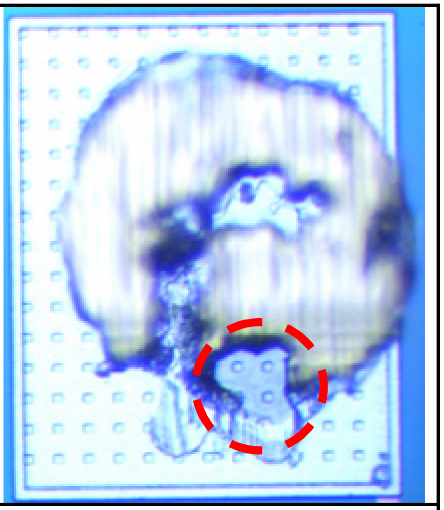


Effect of smaller bond sizes:

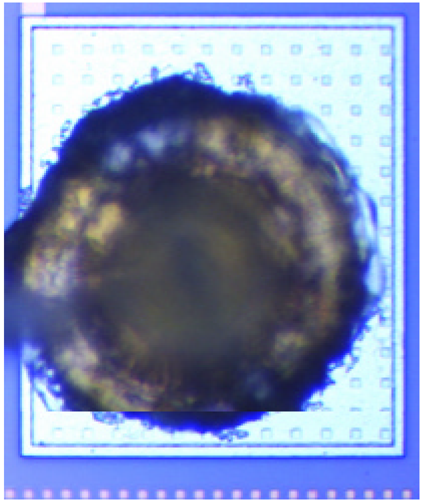
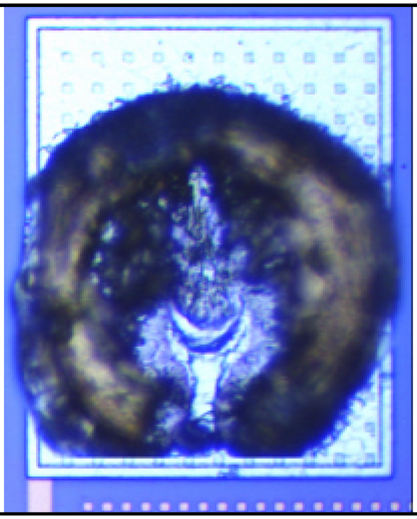
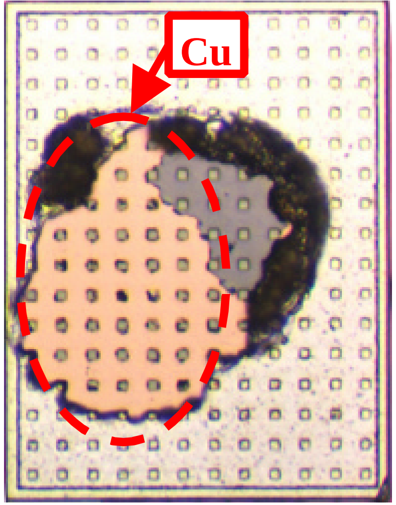
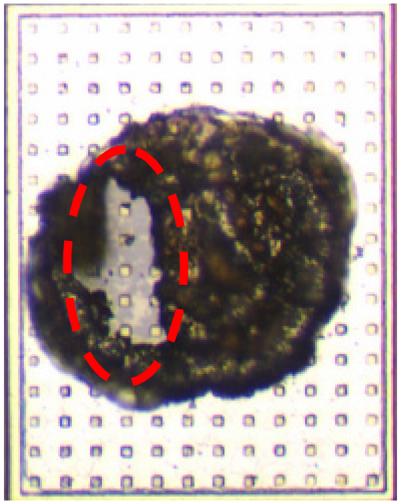
- Different bond sizes yielded similar ball shear/area with optimized wire bond processes.

Sample Size/cell :
16 balls/unit x 5 units = 80 balls

Ball Shear Failure Modes

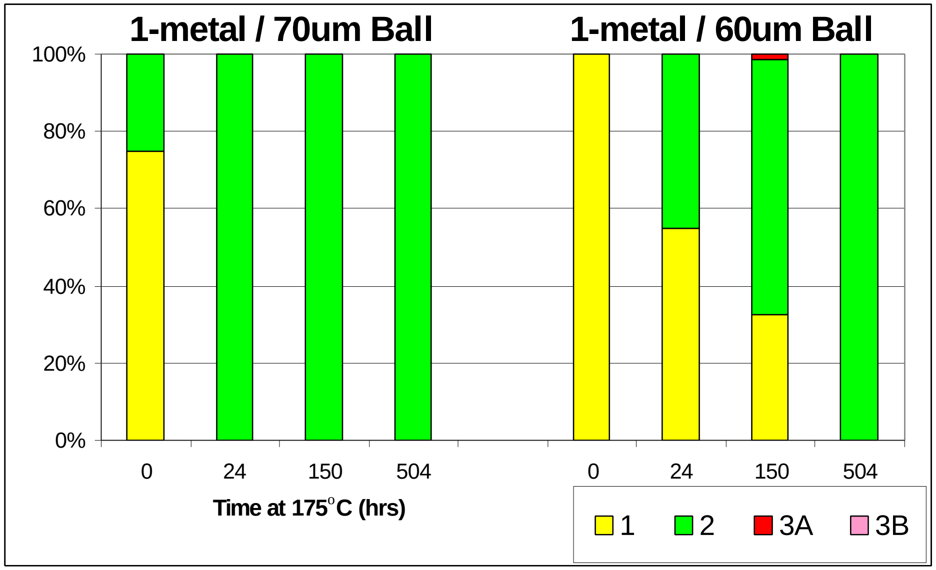
			
Mode 1 Less than 25% gold left on pad	**Mode 2** More than 25% gold left on pad	**Mode 3A** Pad lift below barrier exposed Cu or oxide	**Mode 3B** Pad lift at barrier

Wire Rip Failure Modes

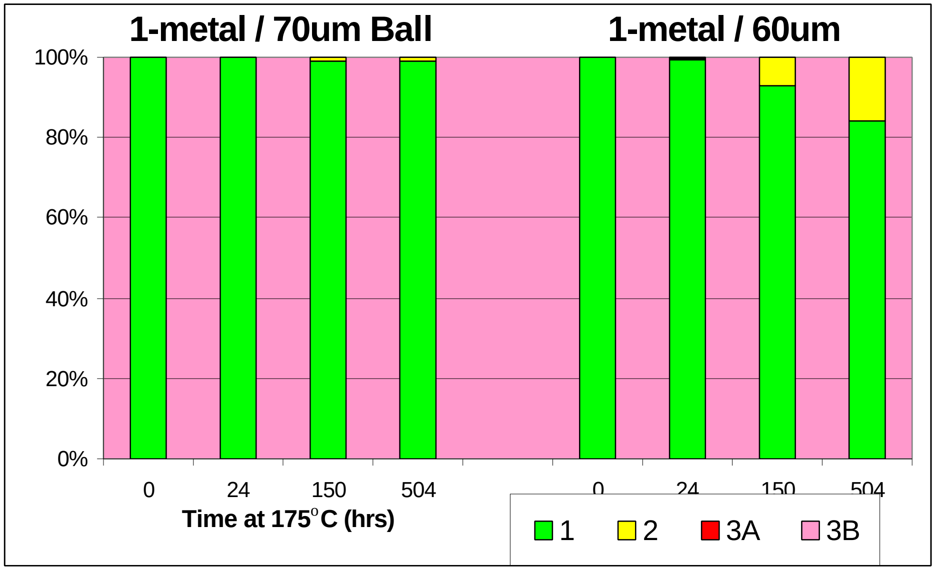
			
Mode 1 Gold wire breaks at neck	**Mode 2** Ball lifts pad remains intact	**Mode 3A** Pad lift below barrier exposed Cu or oxide	**Mode 3B** Pad lift at barrier

Failure Mode Results

1-metal Device, Probed 6x, Ball Bonds 70 and 60mm



Ball Shear



Wire Rip

Effect of Smaller Ball Bond:

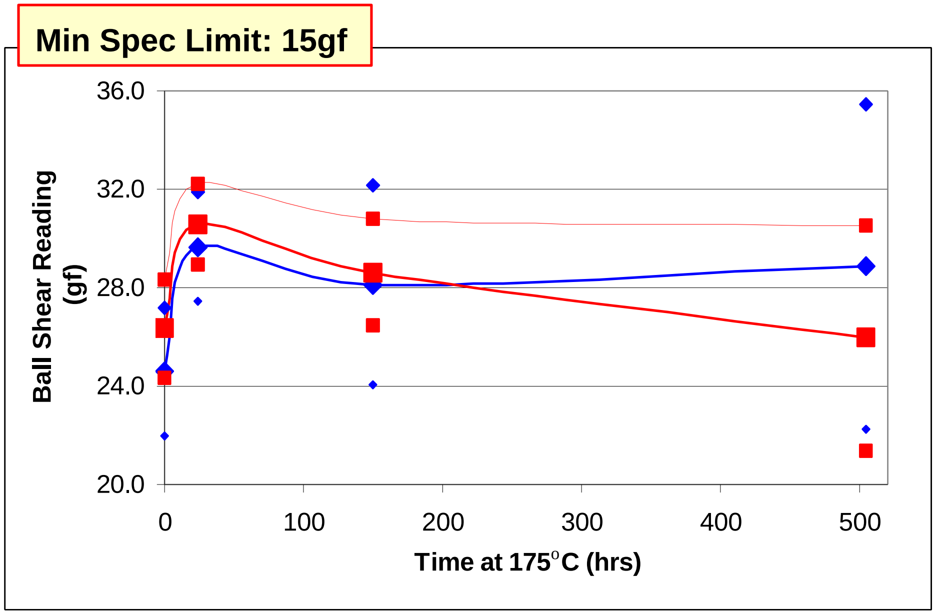
- Increasing mode 2s (Break through Au-Al intermetallics) with increasing thermal age indicates weakening bonds.
- Smaller bonds weakened earlier than larger bonds.

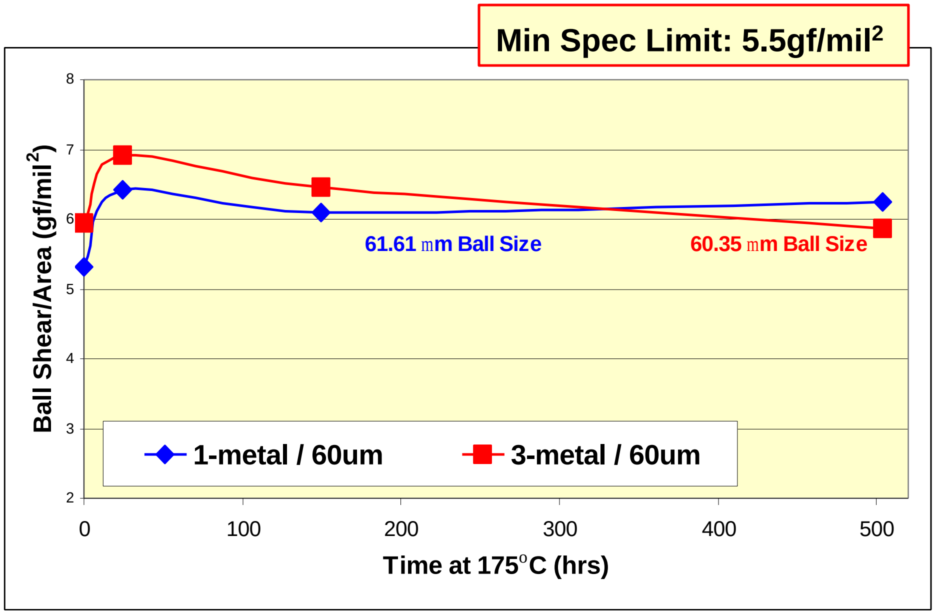
Sample Size/cell :
16 balls/unit x 5 units = 80 balls
173 wires/unit x 2 units = 346 wires

Semiconductor Products Sector

Effects of Multi-layer Structure - Ball Shear Results

1-metal and 3-metal Devices, Probed 6x, Ball Bonds 60mm



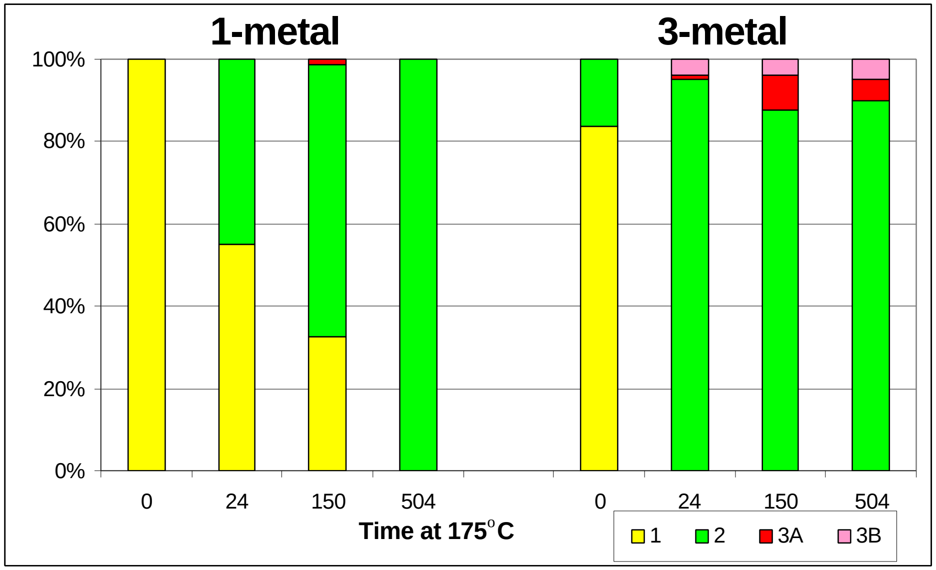


Effect of Multi-layer Structure:

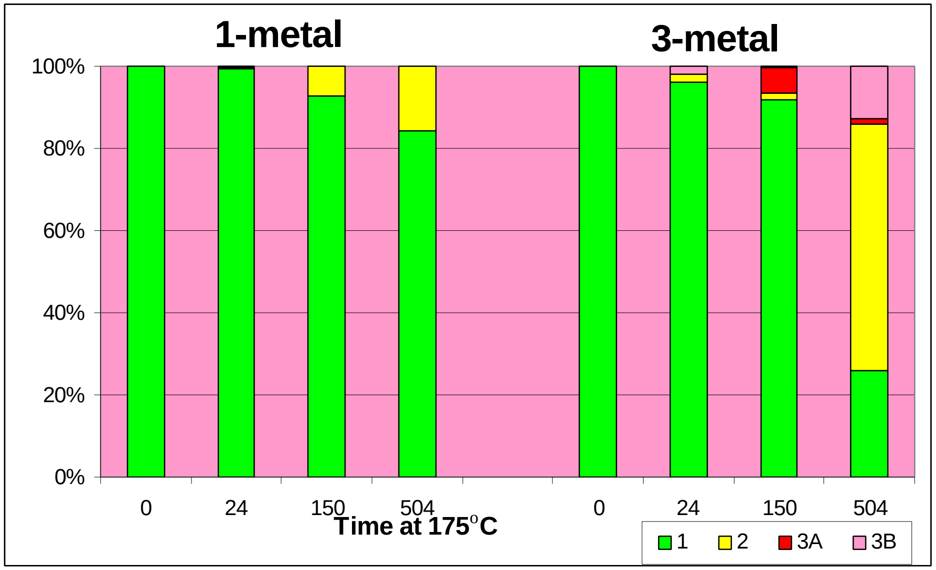
- Slight degradation in ball shear strength for 3-metal device compared to 1-metal device.

Failure Mode Results

1-metal and 3-metal Devices, Probed 6x, Ball Bonds 60mm



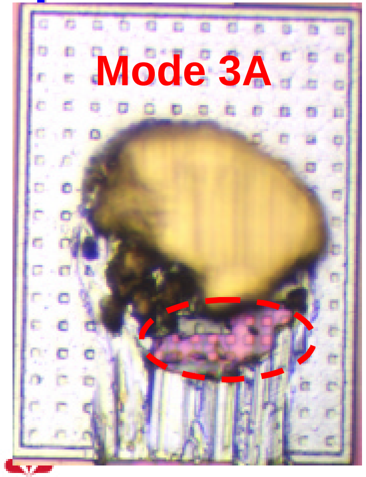
Ball Shear



Wire Rip

Effect of Multi-layer Structure:

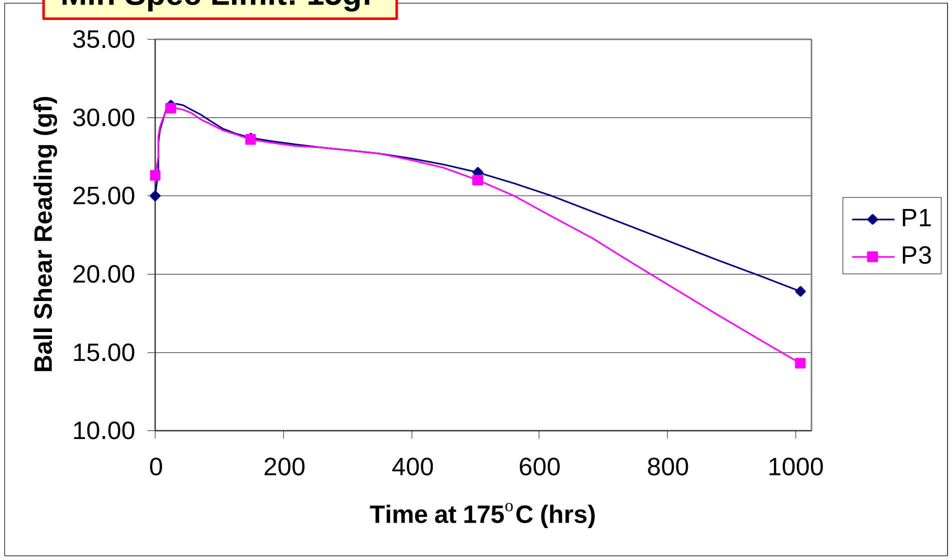
- More mode 3s was observed on 3-metal device.
- When evaluating failure mode with ball shear strength, mode 3s are not indicative of a problem.
  - High shear strength indicates that a robust Au-Al intermetallic formation is stronger than the Al cap interfacial strength.
- Bonding onto 3-metal device weakened faster than on 1-metal device.



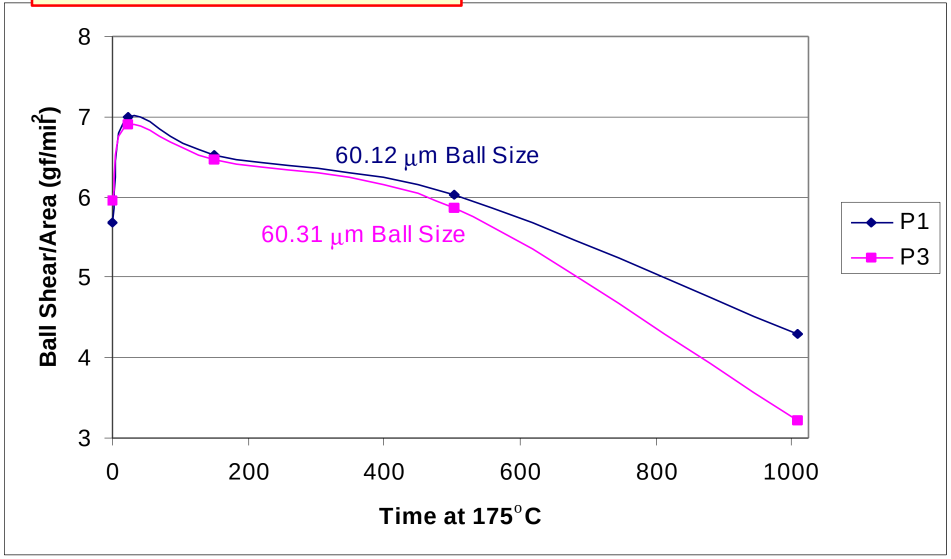
Effects of Probe Conditions - Ball Shear Results

3-metal Device, Probed 1x and 3x, Ball Bonds 60mm

Min Spec Limit: 15gf



Min Spec Limit: 5.5gf/mil^2

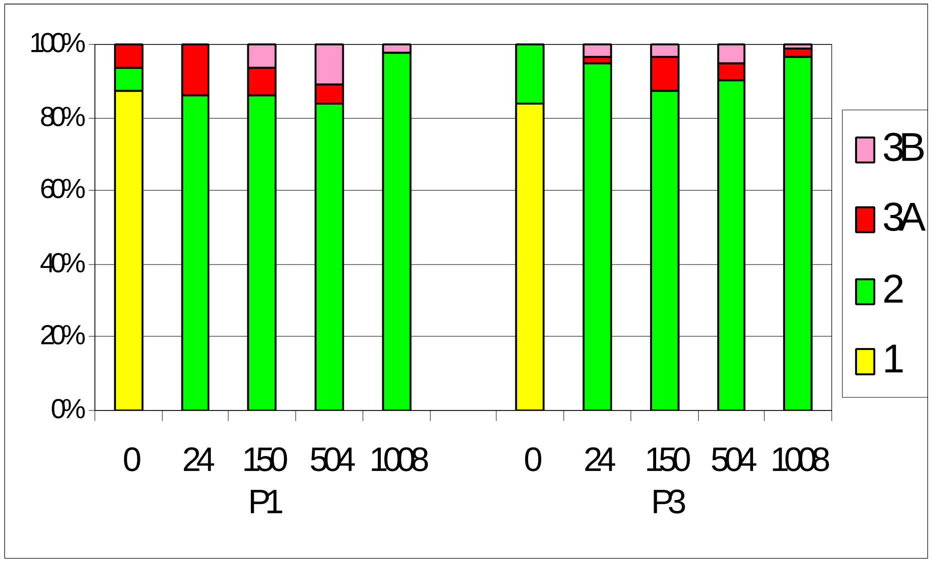


Effect of probe conditions:

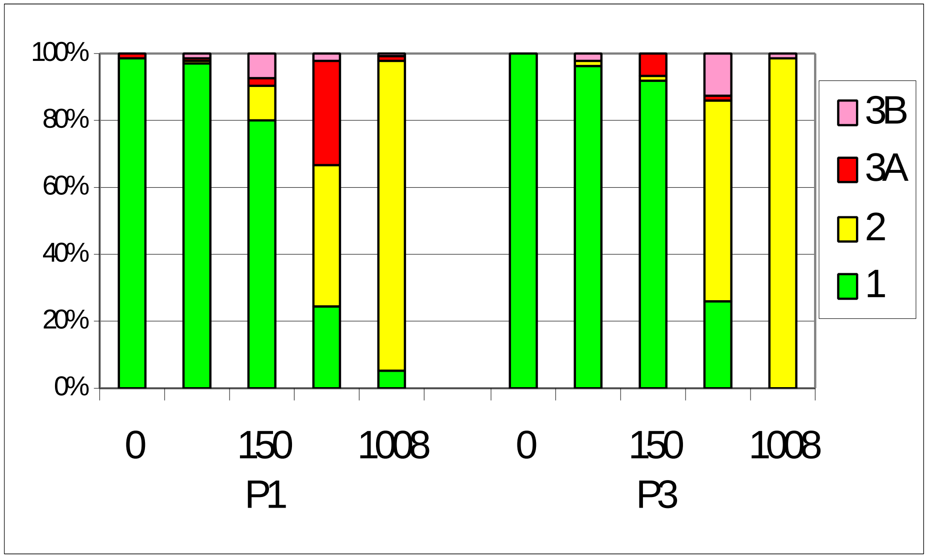
- Beyond t(504 hrs) P3 ball shear strength deteriorates more rapidly than the P1 ball shear strength.

Ball Shear Failure Mode Results

3-metal Device, Probed 1x and 3x, Ball Bonds 60mm



Ball Shear



Wire Rip

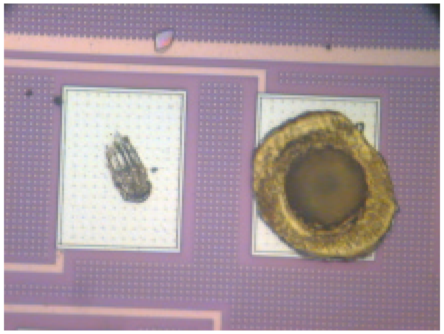
Ball shear failure modes evaluated in conjunction with relatively stable shear strength readings indicate:

- Mode 3s are not indicative of a problem. Shear strength of a robust Au-Al intermetallic formation is stronger than the Al cap interfacial strength.
- Decrease in mode 3s and increase in mode 2 at t(1008 hrs) points to a weakening bond.
- P1 bonds are more robust than P3 bonds (more mode 3s).

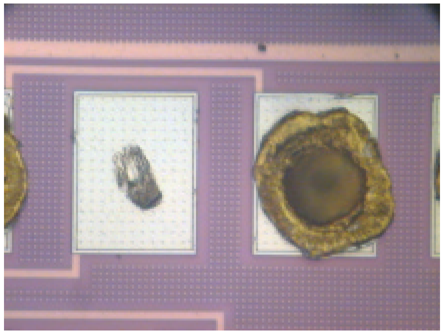
Wire rip: P1 bonds are more robust than P3 bonds (less mode 2s).

Probe Effects on Wire Bondability

High Condition:
1 mil tip (k=1.5gf/mil),
60um OD,
3 Double-touch Passes
Size: 18 x 36 µm
Probe/Bond: 28%



O hrs



24 hrs

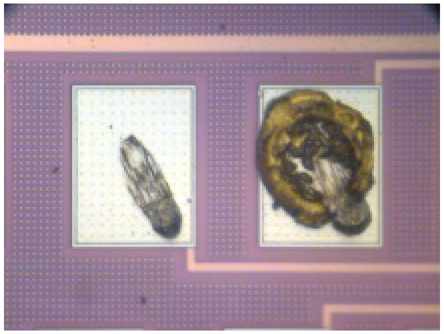
200 hrs

Worst Condition:
1 mil tip (k=1.5gf/mil),
80um OD,
4 Double-touch Passes
Size: 22 x 72 µm
Probe/Bond: 70%

NOT RECOMMENDED

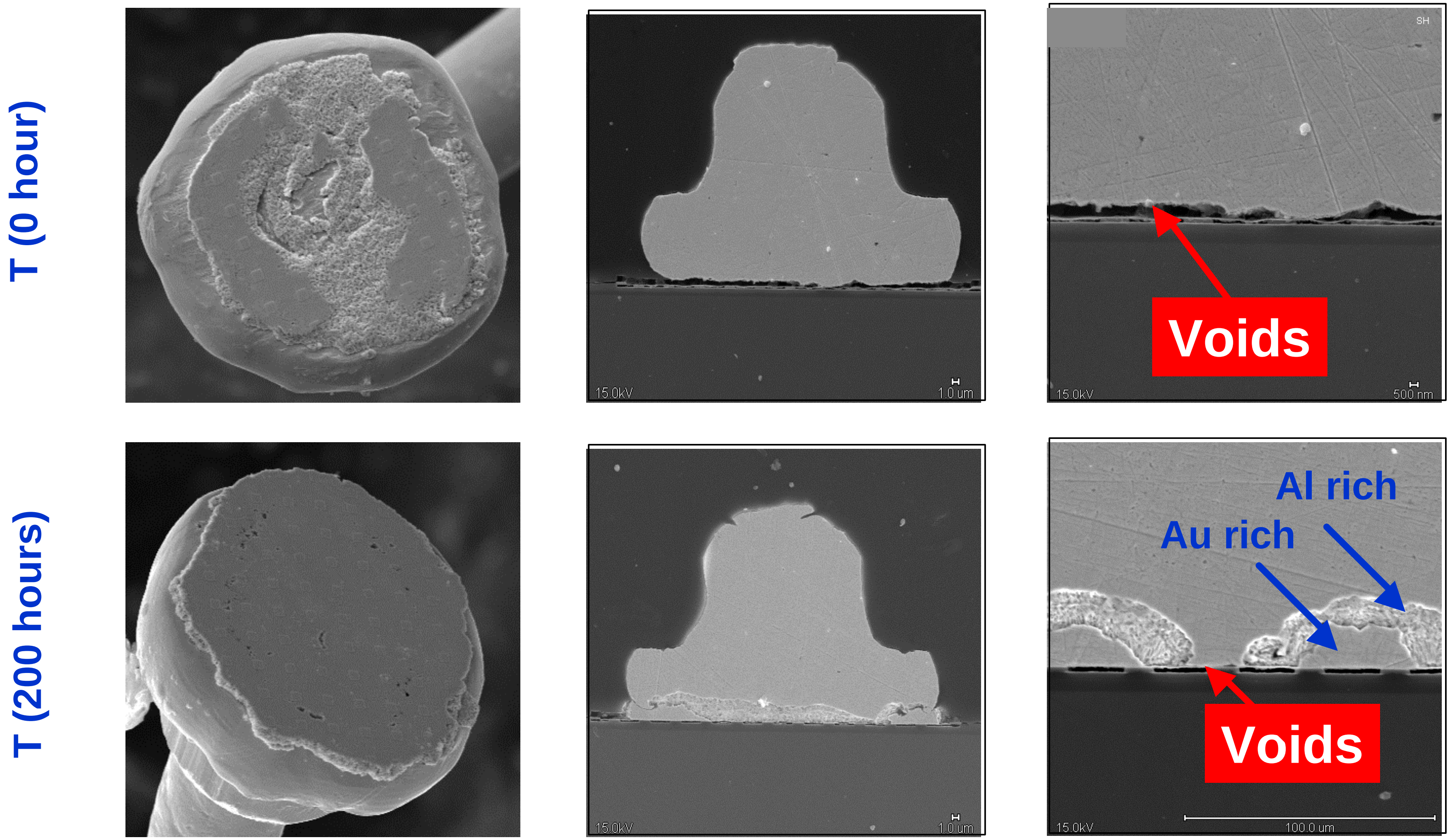
O hrs

24 hrs



200 hrs

Cross-sections



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3-metal Reliability Results

MSL3 Pre-conditioning
0 / 180

Air-to-Air Temperature Cycling -65C to 150C	
500 Cycles	1000 Cycles
0/90	0/90

Autoclave, 121C / 100%RH / 15PSIG	
96 hours	144 hours
0/90	1/90 (1)

(1) 1 failure is acceptable.

Wafers probed at
1mil tip/50mm OD/6 touches

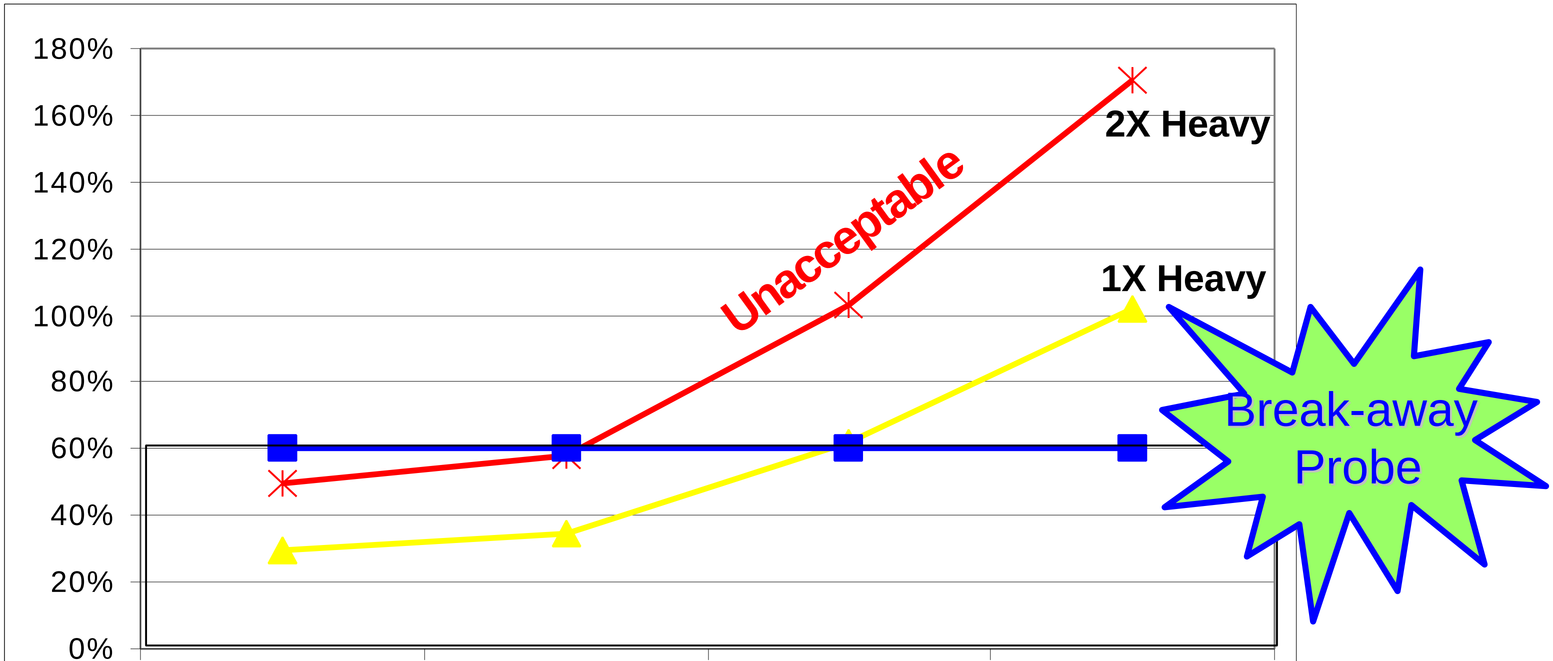
Dice probed 6 times passed reliability testing.

Conclusions and Recommendations

- 3-Cu-layer pad structure is more "sensitive" than 1-layer structure.
  - Narrower wire bond process window than Al technology's
  - Slight ball shear degradation
  - More prone to failure mode 3s
  - **3-metal devices probed 6 times passed package reliability evaluations.**
- Probe affects wire bonding.
  - Large probe marks create greater voids that:
    - Reduce Au-Al intermetallic formation
    - Increase bond non-sticks and pad lifts
    - Degrade ball shear strength faster at t(1000 hours)
  - Probe mark variation is large and its impact is magnified at finer pitch.
  - 1 mil probe tip (k=1.5gf/mil^2) / 60µm OD / 6x max is recommended for 76µm pitch and 72µm pad opening.
  - **Heavier overdrive and excessive probing is strongly discouraged.**
- Better probe characterization, control and in-process inspection is required.
  - Use wire bondability as one probe response

➡Probe and assembly must work together to ensure highest system yield.

Looking out to Finer Pitch ...



Ball Size (mm)	65	60	45	35
Pad Size (mm)	77	72	59	48
Pitch (mm)	91	76	63	52

Break-away probe technology with less force contact and minimal pad damage.

- Maintain max 60% probe/ball bond ratio
- At 45µm ball bond, probe size is 20x40µm
- At 35µm ball bond, probe size is 15x30µm

Is it possible?

Thank You!

Die Design
Substrate Design

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