

ENGINEERING PRACTICE STUDY

TITLE: Copper (Cu) wire bond test methodology development for microcircuit, hybrid and semiconductor devices

FINAL REPORT

STUDY PROJECT 5962-2017-002

September 20, 2017

**Study Conducted by DLA Land and Maritime
Document Standardization Division (VA)**

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- I. OBJECTIVE: The purpose of this Engineering Practice (EP) Study is to obtain input from the military services, microcircuit manufacturers, and user community through survey responses concerning Cu wire bonding. The DLA goal is to use this survey information as a basis to then test and analyze Cu wire bonded devices for the development of Cu wire bond test methodologies for military test method standards. This will include defining criteria for Cu wire bond pull testing, shear testing, common wire diameters, Cu wire alloys, and Cu wire coatings. The resulting developed criteria, tests, and requirements, will then be proposed for inclusion into military test standards MIL-STD-883 and MIL-STD-750, and the proposed specification requirements into MIL-PRF-38535, MIL-PRF-38534, and MIL-PRF-19500.
- II. BACKGROUND: Copper wire bonding refers to the wire bonding process that employs copper wires for interconnection, instead of the gold (Au) and aluminum (Al) wires traditionally used in military and space level microcircuit, hybrid, and semiconductor devices. The use of Cu wire bonds in military and space level devices are cause for reliability concerns due to the non-availability of Cu wire bond pull and shear test methods in MIL-STD-883 and MIL-STD-750.
Currently, some QML manufacturers are adopting or switching their wire bonding process technology to Cu wire bonding from their commercial product lines. These manufacturers are proposing that in the near future they will introduce Cu wire bonding into military products. DLA is looking to mitigate the Cu wire bonding issues/concerns by developing a test methodology and working other issues with manufacturers to improve the Cu wire bonding process.
DLA Land and Maritime-VA has launched a project for Copper (Cu) wire bond test methodology development for microcircuit, hybrid, and semiconductor devices. DLA requested the manufacturers, assembly houses, and users of Cu wire bonded devices to provide Cu wire bonding information by responding to the survey questionnaire.
- III. RESULTS: The EP study initial draft posted on the web and distributed to military services, microcircuit manufacturers, original equipment manufacturers, and user communities on March 13, 2017 for review and comments. DLA Land and Maritime-VA has received comments/responses from five different leading Cu wire bond devices manufacturers/assembly/test laboratory. All comments/responses along with DLA Land and Maritime-VA's findings (see attachment # 1) were discussed at the Cu wire task group teleconference meetings as well as JEDEC JC-13.7 Cu wire bond task group meeting in Columbus, Ohio, on September 12, 2017. The findings of this Cu wire bond EP study were sufficient to move forward for developing a Cu wire pull test method into TM2011 of MIL-STD-883, and need to be developed a Ball bond shear force test method TM XXXX into MIL-STD-883. Since Cu wire bond process required rigorous process control monitoring system, therefore some reliability performance test need to be incorporated into the controlling specification for Cu wire bond qualification process.
- IV. CONCLUSIONS: DLA Land and Maritime-VA will continue working with Cu wire bond device manufacturers and user's communities to develop Cu wire pull test method into TM2011 of MIL-STD-883, and new Ball bond shear force test method TM XXXX into MIL-STD-883 as well as reliability performance requirements for Cu wire bond devices.

DEFENSE LOGISTICS AGENCY

AMERICA'S COMBAT LOGISTICS SUPPORT AGENCY



Attachment # 1

EP Study Report

on

Cu wire bond

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DLA Land and Maritime-VA
September 2017



Goal of Cu wire bond EP study

- ❖ The DLA goal is to use this EP Study to collect information and then test and analyze Cu wire bonded devices for the development of Cu wire bond test methodologies for military test method standards. This includes defining criteria for Cu wire bond pull testing, shear testing, common wire diameters, Cu wire alloys, and Cu wire coatings.



Background of Cu wire bond EP study

- ❖ Copper wire bonding refers to the [wire bonding](#) process that employs copper wires for interconnection instead of the gold (Au) and aluminum (Al) wires traditionally used in microcircuit, hybrid, and semiconductor packaging. Cu wire bonded devices have some concerns related to reliability issues due to non-availability of Cu wire bond pull and shear test methods in MIL-STD-883 and MIL-STD-750.
- ❖ Currently, some QML manufacturers are adopting their wire bonding process technology to Cu wire bonding from their commercial products and are proposing that in the near future they will introduce Cu wire bonds in military products. DLA is looking to mitigate Cu wire bonding issues/concerns by developing a test methodology and working other issues with manufacturers to improve the Cu wire bonding process.
- ❖ DLA Land and Maritime has launched a project for Copper (Cu) wire bond test methodology development for microcircuit, hybrid, and semiconductor devices and request manufacturers and assembly houses provide Cu wire bonding information by responding to the EP study questionnaire.



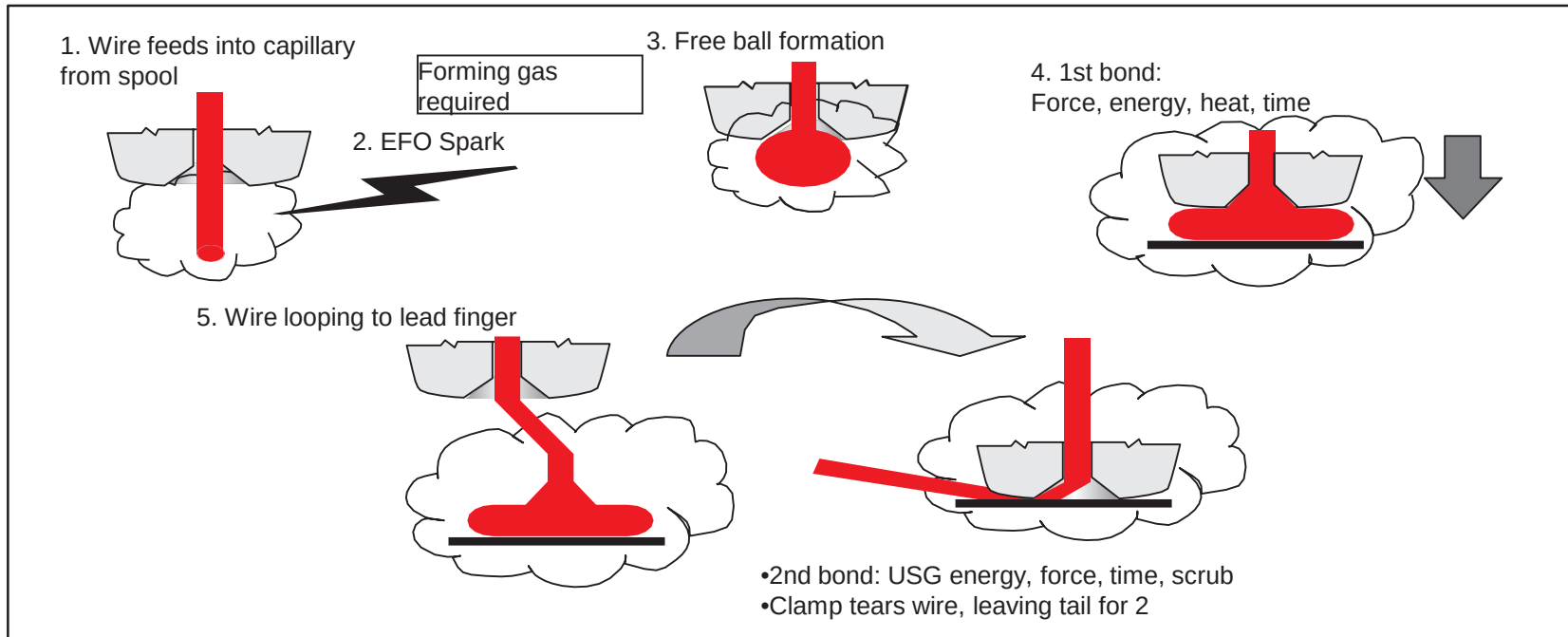
Cu wire bond Challenges

- ❖ **Oxidation:** Copper oxides quickly and easily, because of this it is hard to form a good bonding process in a FAB. Inter metallic growth (IMC) corrosion can easily occur at the Cu bond and the Aluminum interface.
- ❖ **Hardness:** Copper wire [Copper hardness (~80Hv) and Au hardness ~60Hv] bonding is harder than gold bonding. Applying excessive force and ultrasonic energy could damage the silicon substrates under the bond pad, cause metal lift, or worse, silicon damage during wire bonding process.
- ❖ **Reliability:** The copper wire bonding failure rate is higher compared to gold. One reason for this is that it is difficult to get a good contrast to distinguish copper lead frame from copper wires.
- ❖ **Cratering:** Cratering (i.e. cracking) failure often occurs at the glass layers underlying the bond pad because of excessive bond power/force during the wire bond process.
- ❖ **Latent Cratering (LC):** Latent cratering develops after high temperature storage during ball pull testing at 100 hrs.
- ❖ **Decapsulation** with copper wire bonds is more challenging than decapsulating with aluminum wire bonds. Copper reacts with acid easily and corrodes together with the molding compound. Gold in comparison is resistant to corrosion.
- ❖ **Cu wire bond pull and shear test:** Currently MIL-STD-883 test method TM 2011 wire bond pull strength test discusses only Au and Al wire diameter (condition C or D) and its related pull forces. No Cu wire diameter or pull strength is mentioned in TM2011. JESD 22-B116 discusses ball bond shear forces (referred JESD22-B16) but needs updating.



Cu wire bond process

Process improvement: Copper wire bonding can use the same infrastructure as gold wire bonding, provided the equipment can be retrofitted with a forming gas supply, and the electronic flame-off (EFO) current supply is adequate for forming free air ball (FAB). Standard bonding tools or capillary can be used for copper wire bond process.





Questionnaire and response:

- ❖ What are your general comments/views concerning Cu wire bond reliability in military devices?
- ❖ XX : Cu-wire bond in plastic packages can meet or exceed usual JEDEC standards for commercial applications and Q006 standards for automotive applications with appropriate care in design & development, in manufacturing and in the logistic processes involved during their production cycle. The Cu-wire bond reliability for military applications has not been tested by XX. The application-specific stresses and their suitability for the application will need to be determined by the customer.
- ❖ YY: No production concern in military devices with Cu wire bond due to there are MP experience in SPIL Besides, the reliability results of Cu wire (0.8mil) in military devices are passed so far.

Reliability Test Conditions
Unbiased HAST: 110°C, 85%RH, 264hrs
Biased HAST: 110°C, 85%RH, 264hrs
TCB: -55~125°C, 1000cycles
HTST: 150°C, 1000hrs
- ❖ PP: PP semiconductor does not manufacture any military grade product with Cu wire. PP Semiconductor has no plans to offer military grade product with Cu wire at this time. No guarantee is made for any military fitness of use of Cu bonded product from PP Semiconductor.
- ❖ ZZ: It is our understanding that sale of raw copper wire has already exceeded the sales of Gold (Au) and Aluminum (AL) wire sales. It is only inevitable that copper wire based bonding will start to be incorporated into military devices in the near future. There are some process related questions that each manufacturer will need to overcome when processing Copper wire in integrated circuits. ZZ also emphasizes that Cu wire is typically used for large volume integrated circuit applications (such as plastic commercial applications) where material cost savings is an important factor when producing integrated circuits. In addition it is our understanding that most military integrated circuits are extremely low volume and the high reliability of the parts that are produced is significantly more important than any small material cost savings that may be attributed to the change to Cu wire



Questionnaire and response:

Would you be interested in participating with DLA in the initial Cu wire bond project by providing Cu wire bond information?

- ❖ XX will support the effort to the extent possible and within limitations of sharing confidential and proprietary information
- ❖ ZZ would be interested in participating in the initial Cu wire bond project.
- ❖ YY has interested in participating with DLA.
- ❖ PP Semiconductor is not interested in participating at this time.



Questionnaire and response:

Are you currently producing Cu wire bond devices? If yes, please provide following information:

During characterization of Cu wire bond properties, what are the following factors you consider?

(i) Wire geometry:

Manufacturers	XX	YY	ZZ	MM
Is wire metallization bare/pure Cu?	Not always	The core material is pure Cu	Yes 99% bare Cu	yes
What are the Cu with alloy compound?	No alloys	No alloy compound	no	na
What type of Cu wire coating materials?	Pd	Au and Pd	no	n/a
What is the shape of the Cu wire ?	Cylindrical for ICs	Cylindrical	Cylindrical	Cylindrical



Questionnaire and response:

Wire bond types

Manufacturers	XX		YY		ZZ		MM	
Bond type	On Cu/Al/Au package post	On Al-Pad CuNiPd bond pad	On Cu/Al/Au package post	On Au-Pd Cu bond pad	On Cu/Al/Au package post	On Al bond pad	On Cu/Al/Au package post	On Al bond pad
Do you use ball bond?		Ball Bond		Ball Bond	Ball Bond	Ball Bond		Ball Bond
Do you use a wedge / stitch bond?	Stitch		Stitch		No	no	Stitch	
Any other type of bond?		N/A		No	no	no		No



Questionnaire and response:

Performing the Cu wire bond process:

Manufacturers	XX	YY	ZZ	MM
Do you use ultrasonic bonding process?	No	No	No	no
Do you use thermosonic bonding process?	Yes	Yes	Yes	yes
Do you use another type of process? N/A	n/a	No	No	n/a



Questionnaire and response:

- Performing Cu wire bond tests:

Manufacturers	XX	YY	ZZ	MM
Bond pull test –Mid span/STP(pre seal)	Yes Cpk ≥ 1.66	Yes	Yes	yes
Bond shear test (pre seal)	Yes Cpk ≥ 1.66	Yes	Yes	yes
Any other test?	None in production	IMC coverage test, cratering test	No	n/a



Questionnaire and response:

❖ Cu wire bond test results:

Manufacturers	XX		YY		ZZ		MM	
Test type	Cu wire diameter	gram-force	Cu wire diameter	gram - force	Cu wire diameter	Gram-force	Cu wire diameter	Gram- force
Bond pull test Mid span/STP(pre seal)	0.7- 2.0 mils	2.0 -7.7	0.8 mils	4.0	1.0 mils	8.0-15.0	0.7 mils 0.8 mils 0.9 mils 1.0 mils	3.0 4.0 5.0 6.0
Bond shear test (pre seal)	0.7 – 2.0 mils	6.2-9.3 mg/um2	0.8 mils	10.0			0.7 mils 0.8 mils 0.9 mils 1.0 mils	3.0 5-6 7-9 25-31
Any other test?	No	no	no	no	no	no	no	no



Questionnaire and response:

- ❖ Decapsulation with copper wire bonds is more challenging than decapsulation with aluminum wire bonds as copper reacts with acid easily and corrodes, unlike gold, which is resistant to corrosion. What type of acid/solution or plasma do you use for package decapsulation?
 - **XX** uses laser ablation process in conjunction with common wet-chemical deprocessing methods to decapsulate Cu-wire bonded devices.
 - **YY**: laser decap + chemical decap with mix acid ($\text{H}_2\text{SO}_4 + \text{HNO}_3$)
 - **ZZ** uses the standard fuming nitric acid.



Questionnaire and response:

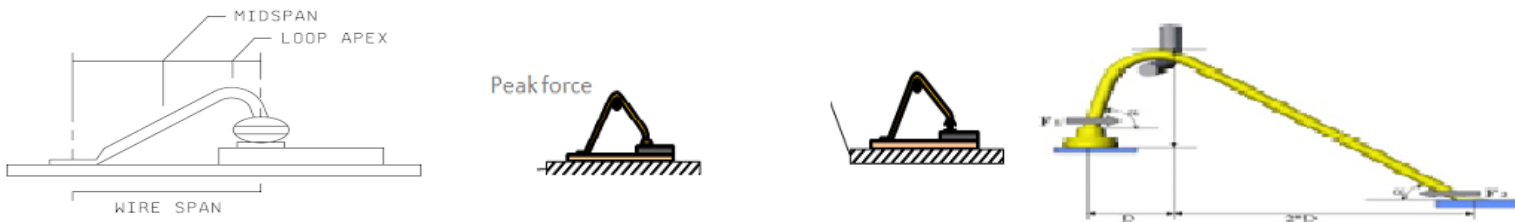
❖ **Do you have any technical suggestions for Cu wire bonded devices? Please provide your comments.**

- **XX :** Cu wirebond reliability cannot be assured by testing alone. Attention is required towards developing a robust bonding process, maintaining package integrity in assembly and in stress. Post-decap wirepull results are dependent on operator decap skill/experience, even when using laser-ablation.
- **YY:** For military devices, suggest to use high reliability AuPdCu wire to make the robust reliability test pass
- **ZZ:** There are a number of technical processing issues that need to be addressed with copper wire. • Pure copper may be considered better than gold wire but an additional processing requirement is needed to form the wire bonds. If you are using a coated Cu wire a different set of parameters will be needed. • As for the actual wire bond, the bond on the package posts should not have any adherence issue. However the bond on the die pad side (interface) will need to have a suitable bonding pad material that adheres well to the Cu wire and can resist the mashed ball interface on the die pad opening. Based upon previously qualified packages, AL wire to AL die pad and AU wire to AL die pad have both been accepted. It is not determined if there are any issues with a Cu to AL die pad. • In ceramic qualification testing (MIL-STD-883 TM 5005, Group D6, TM 1018), the internal cavity can have up to 5,000 PPM internal cavity moisture. With the addition of Cu wire, the added moisture may or may not have an affect the Cu wire performance of the integrated circuit.
- **PP:** Copper bonding considerations, reliability tests, decapsulation, and technical suggestions. PP Semiconductor has developed Cu wire process procedures and controls that meet the JESD22 and AEC Q006 standards. We will continue to use these processes, however; if something should change with the wire pull conditions of MIL 883, Method 2011 in the future we will review it then.

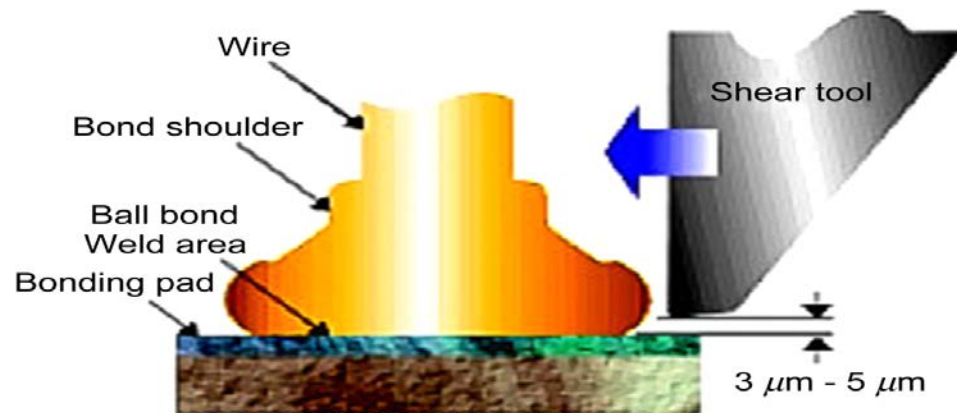


Findings of Cu wire bond process and reliability

- ❖ Numerous presentations and comments were received from the EP study resulting in the following issues to be discussed:
- ❖ Cu wire pull Mid span vs Peak force when hook placement is a factor to wire break.



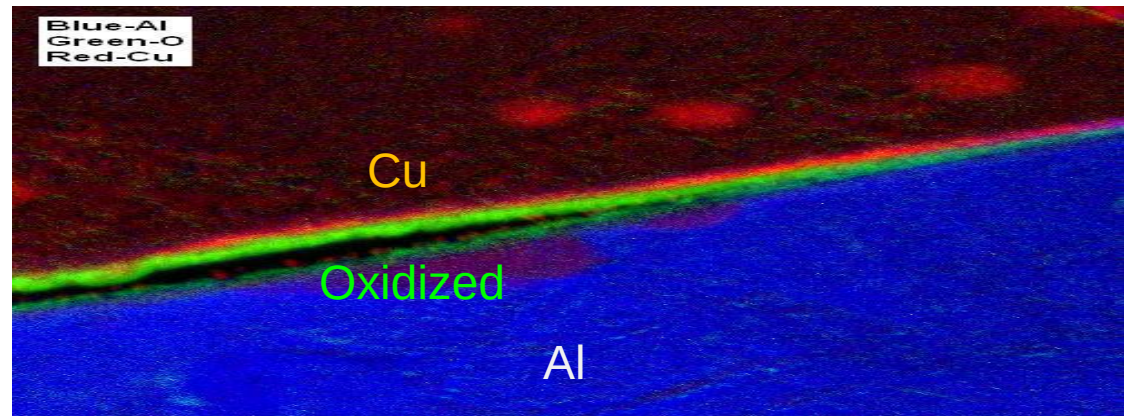
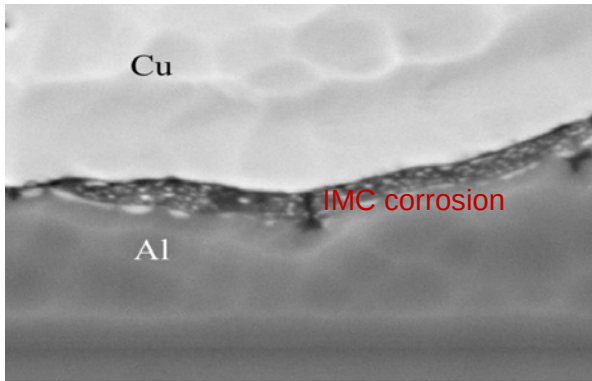
- ❖ Cu wire Ball bond shear force measurement development TMXXX /883





Findings of Cu wire bond process and reliability

- ❖ Numerous presentations and comments were received from the EP study resulting in the following issues to be discussed:



Courtesy : TI presentation at JEDEC

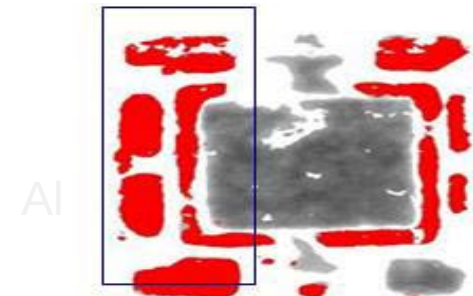
Corrosion of Cu-Al Bonds shown at Post HAST test:

- ❖ Cu bond interface corrodes by oxidation of the Cu/Al interface.
- ❖ Separation occurs in the oxidized IMC layer towards the interface with Al
- ❖ Separation can occur even in regions which may have previously grown an IMC.
- ❖ A well-formed bond with high bond-strength can fail easily due to corrosion

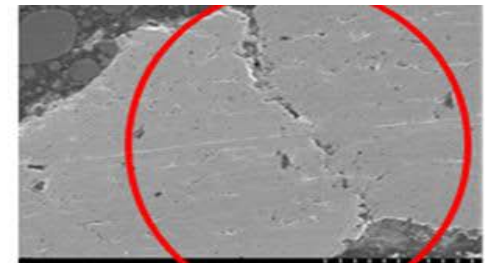
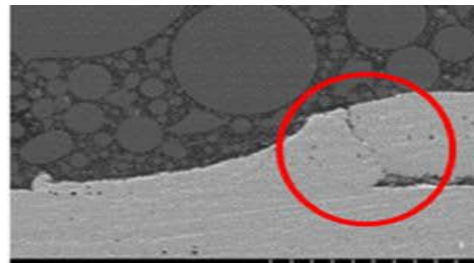
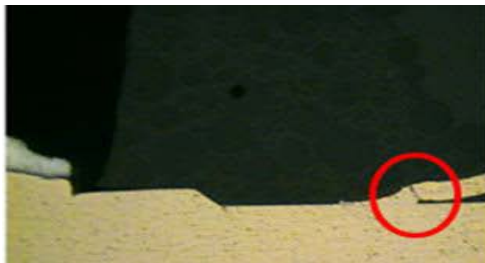


Findings of Cu wire bond process and reliability

- ❖ Numerous presentations and comments were received from the EP study resulting in the following issues to be discussed:
- ❖ **Delamination – Stitch bond Cracks** : Corrosion at stitch-bonds due to moisture/solvent ingress in conjunction with delamination (not seen with Au wire)
- ❖ **CSAM images show delamination after pre-conditioning in the die attach-pad areas, as well as on leadfinger areas**



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

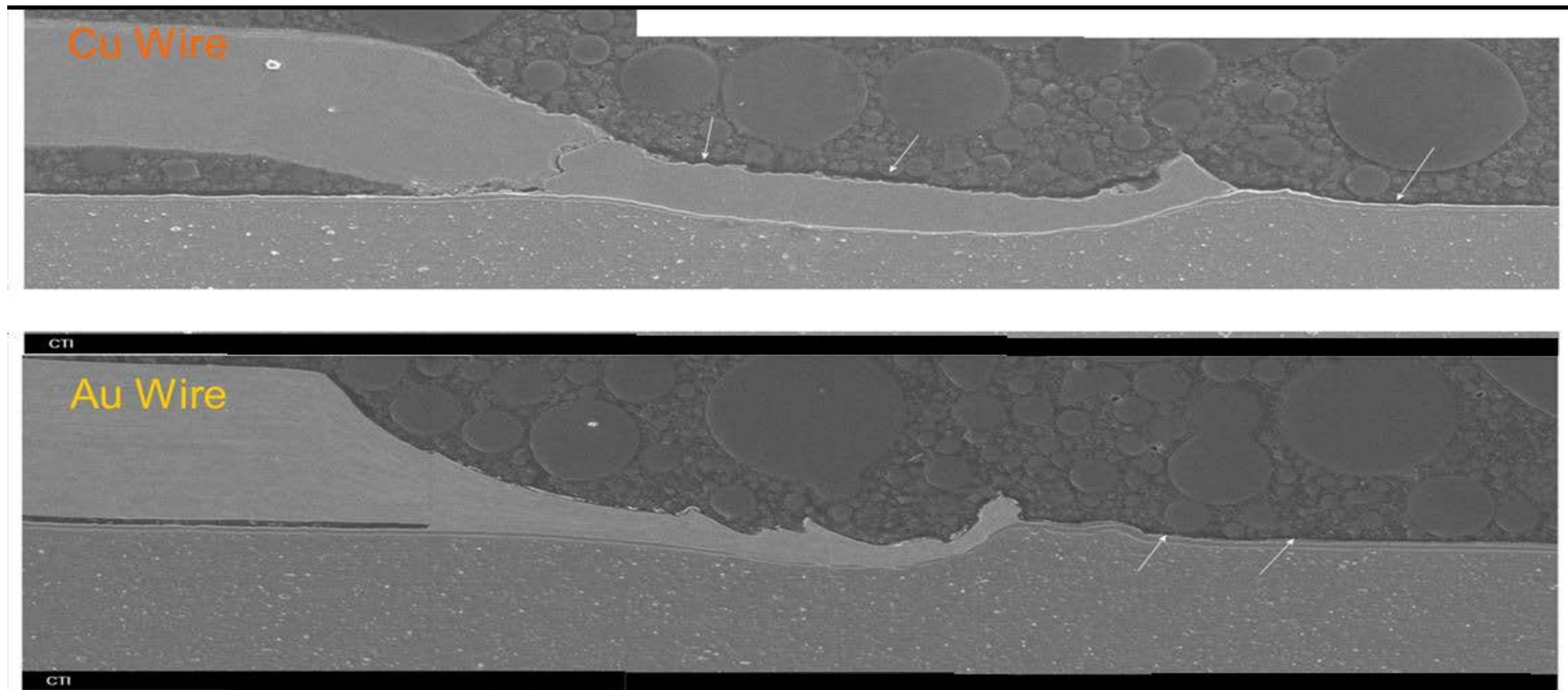




Findings of Cu wire bond process and reliability

- ❖ Numerous presentations and comments were received from the EP study resulting in the following issues to be discussed:

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





Findings of Cu wire bond process and reliability

- ❖ All Cu wire bond process related issues/challenges appropriate steps (i.e. Bills of materials selection, oxidation, IMC corrosion, cratering, hardness and decapsulation) shall be specified in the manufacturers QM plan/product data sheet/product development plan.
- ❖ **For reliability concerns of Cu wire bond test shall be specified in the controlling performance specification and standard .**
- ❖ For controlling performance specification: A separate section shall be inserted for Cu wire bond devices wherein all reliability performance requirement shall be specified :
 1. **Unbiased HAST (130C/85% RH) at 264 hrs.**
 2. **Biased HAST (110C/85% RH) at 264 hrs.**
 3. **Temperature Cycling : -55 C to 125°C, 1000 cycles**
 4. **Thermal shock : -55 C to 125°C, 2000 cycles**
 5. **High temperature storage test : 150°C, 1000 hrs**
- ❖ For measurement of Cu wire pull strength, test method TM 2011 of MIL-STD-883 shall be specified specific Cu wire diameters wrt pull forces.
- ❖ For measurement of Cu wire bond shear strength, New ball bond shear test method TM XXX of MIL-STD-883 shall be developed or modified JESD22-B116 (note current JESD22-B116 need clarification with individual bond shear vs average shear force)



Findings of Cu wire bond process and reliability

❖ Proposed TM 2011 wire pull force (gram-force) table: For an example

Test condition TM2011/883 (C wire pull single bond) (D wire pull double bond)	Wire materials	Wire diameter	Minimum Bond strength Pre seal (gram force)	Comments	Discussion for pull and shear force
C or D	Aluminum (Al)	0.0007 Inch	1.5	If we consider average tensile strength of Aluminum wire 120 MPa then pull force should be at least 3.0 gram-force. Current pull force=1.5 gm-f is low as tensile strength is 59 MPa.	2.0
	Gold (Au)	0.0007 Inch	2.0	If we consider average tensile strength of Gold wire 174 MPa then pull force should be at least 4.0 gram-force. Current pull force= 2.0 gm-f is low as tensile strength is 79 MPa.	2.5
	Copper (Cu)	0.0007 Inch	4.0	If we consider average tensile strength of Copper wire 220 MPa then pull force should be at least 5.0 gram-force.	



Findings of Cu wire bond process and reliability

❖ Proposed TM XXX ball bond shear force (gram-force) table: An example

Wire bond diameter	Minimum individual Shear force reading per JESD22 B116 (gram force)	Minimum shear force average reading per JESD22-B116 (gram-force)	Calculation of Shear force for Ball bond (gram-force)	Comments
2.0 mil (0.002 inch 0.0508 mm)		12.6		Shear force 4000 psi is required to bond fail. Considering JESD 22-B116 bond diameter start with 2.0 mils (50 micrometer)
2.5 mil (0.002 inch 0.0508 mm)				
3.0 mil (0.002 inch 0.0508 mm)	21.1	30.8		
3.5 mil (0.002 inch 0.0508 mm)		43.4		
4.0 mil (0.002 inch 0.0508 mm)		58.3		
4.5 mil (0.002 inch 0.0508 mm)	59.0	75.6		



**For Question/Concerns on this EP study
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