Raytheon

3.3 Assessment Of Copper Bond Wire For Use In Long Term Military Applications

Integrated Defense Systems

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Potential Failure Modes / Risks

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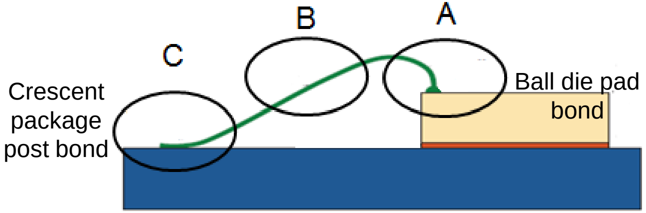
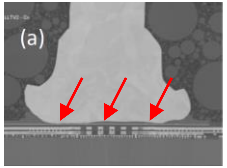
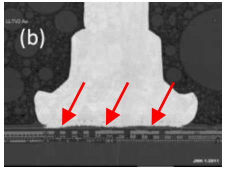
Failure Modes	Reliability Risks
1) Corrosion	Loss of electrical connection over time, with humidity
2) Intermetallic growth	Loss of electrical connection over time, with temperature
3) Process variability – bondability from copper oxidation	Potential loss of bond integrity
4) No standard test method or requirements for copper – Military Standard Au / Al	This could lead to variability in manufacturer quality and inconsistent results from destructive physical analysis (DPA) assessment
5) Susceptibility to cleaning process chemicals	Commercial grade component intended for "no clean" SMT could be put at risk when processed in a DoD application requiring post solder cleaning
6) Epoxy compounds such as flame retardants have been shown to increase susceptibility of copper to corrosion	Impact of encapsulant chemistry: Transition to copper without assessing package material could impact long term life of copper wire integrity (Bromines, etc.)
7) Package removal methods may affect copper wire and impact follow on assessment	Standard DPA plastic removal processes required to insure Cu wire integrity is maintained for follow on mechanical integrity and inter-metallic assessment
8) Bonding with copper wire requires greater strike force due to material hardness	Potential damage to die and circuitry under the pad may require design modification to pad & metallization effecting performance
9) Change in electrical performance	Change from Al to Cu in RF IC's are subject to parametric shifts and potential noise susceptibility
10) Some commercial suppliers transitioned to copper without changing part number or adding an identifier	Loss of technology traceability potentially obscures performance failure issues in legacy designs

Potential failure points
A) Ball bond
B) Wire
C) Wedge bond





Copper / Aluminum Bond Intermetallic Region



Gold / Aluminum Bond Intermetallic Region

Copper wire assembly, electrical performance & reliability presents significant reliability risks compared to legacy gold wire

Photos of Copper Wire Failures

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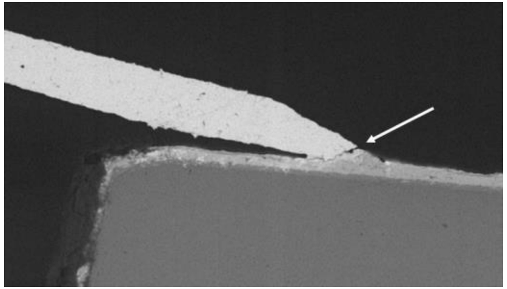
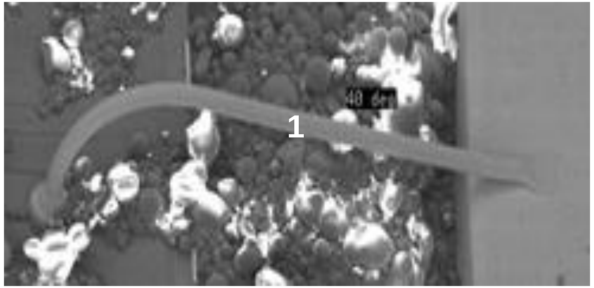
Limited reliability data is available for copper wire in plastic encapsulated packages. However, some field reports have indicated failures associated with die ball bond and stitch bond fractures. Examples are shown below:

(1) Crack through stitch bond

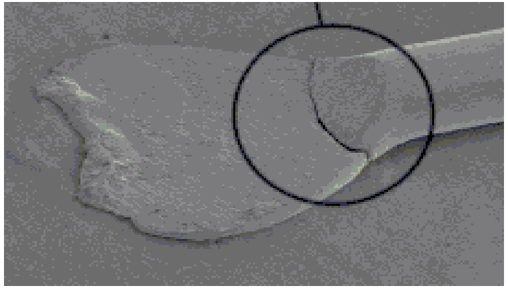


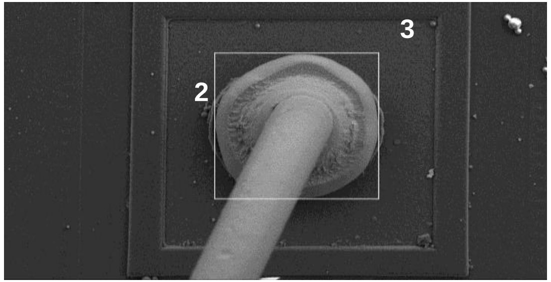


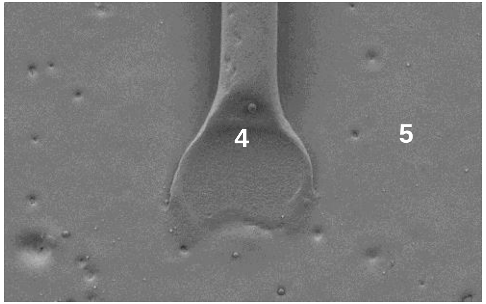
Potential failure points:

1. Failure in wire
2. Break at neck down point
3. Failure at wire to die pad interface
4. Failure at wire to lead frame bond
5. Lifted metallization from substrate pad

(2) Break in wire at stitch bond







DPA Wire Bond Assessment Test Plan

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1. X-ray
2. CSAM – IPC/JEDEC J-STD-035 Acoustic Microscopy for Non-Hermetic Encapsulated Electronic Components
3. Electrical Continuity - I/O’s with respect to Power & Ground pins
4. Environmental conditioning per J-STD-020
   a) Bake the sample for 24 hours minimum at 125 +5 / -0 °C, per J-STD-020, Section 5.4.
      This step is intended to remove moisture from the package so that it will be ‘‘dry.’’
   b) Devices placed in a clean, dry, shallow container so that the package bodies do not touch or overlap each other.
      Samples subjected to 168 +5/-0 hours of 85 °C/85% RH environmental conditioning, per J-STD-020, Section 5.5
   c) 100 temperature cycles, Condition B, JEDEC JESD22-A104 -55C / +125C. Minimum 10 min. soak @ max. & min. temperatures
   d) 3 cycles SMT solder reflow per paragraph 5.6 and Table 5-2 of J-STD-020. Reflow performed 15 min. - 4 hours after removal from temperature/humidity chamber
5. De-cap - Laser ablation followed by microwave plasma oxygen etch
6. Bond visual inspection
7. Bond integrity – per gold wire limits
   a) Destructive wire bond pull per MIL-STD-883 Method 2011
   b) Destructive ball shear per JEDEC JESD22-B116
8. Bond cross sectioning & material analysis
   a) Ball to die pad bond
   b) Crescent to package post bond

Summary of DPA Assessment

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Description	Wire Dia	Die Bond	Lead Frame Base	Lead Frame Pad	Package type	Temperature range
Complex Programmable Logic Device	20.4 um	Aluminum	Cu on pwb	Au flash/Ni 8um	Plastic 324 Pin BGA	-40C to +100C
4 Output Clock Driver	19.2 um	Aluminum	Cu 96.2 % Ni 3.4 % Si 0.4 % by wt	4.3 um Ag on Cu	8 Pin SOIC	-40C to 85C
Ethernet Transceiver	35.5 um	Aluminum	Cu	Cu 62.9 % Pd 37.1 % by wt	Plastic 117 Pin BGA	-40C to 85C
Power Rectifier	Paddle	NA	Cu 98.0 Fe 2.0 % by wt	Sn – 14.7 um	2 Pin J Lead	operating junction -55C to 150C
Schottky Diode	20.2 um	Aluminum	Fe 5.08 % Ni 41.2 % Mn 0.8 % by wt	Cu- 5.7 um	3 pin SOT-23	operating junction -55C to 150C
N Channel Power MOSFET	19.2 um	Aluminum	Fe 58.0 % Ni 40.1 % Mn 1.1 % by wt	Cu – 4.9 um	3 pin SOT-23	operating junction -55C to 150C
N Channel Power MOSFET	19.5 um	Aluminum	Fe 58.0 % Ni 41.0 %, Mn 0.65 % by wt	Cu – 3.1 um	3 pin SOT-23	operating junction -55C to 150C
N Channel Power MOSFET	19.8 um	Aluminum	Fe 58.7 % Ni 40.5 % Mn 0.7 % by wt	Cu – 4.4 um	3 Pin SOT-23	operating junction -55C to 150C
N Channel Power MOSFET	20.5 um	Aluminum	Fe 58.8 % Ni 40.6 % Mn 0.5 % by wt	Cu 4.4 um	3 pin SOT-23	operating junction -65C to 175C
N-Channel power MOSFET	21.6 um	Aluminum	Fe 59.6 % Ni 39.6 % Mn 0.8 % by wt	Cu - 4.7 um	3 lead plastic SMT	-55C to 150C
Schottky Diode	19.4 um	Aluminum	Fe/Ni	Cu – 5.2 um	SOT-23 (TO-236AB)	operating junction -55C to 150C
Buffer Receiver tri-state	24.4 um	Aluminum	Cu 92.8 % Fe 2.2 % by wt	0.9 um Ni	48 Pin SOIC	operating junction -40C to 150C
MOSFET Driver	25.4 um	Aluminum	Cu 97.1 % Ni 2.5 % by wt	Au/Pd/Ag – 200 nm over Ni 500nm	8 Pin SOIC	operating junction -40°C to +105°C
MOSFET Driver	25.4 um	Aluminum	Cu 97.3 % Ni 2.4 % by wt	Au/Pd/Ag 200 nm over Nickel – 0.5 um (500 nm)	8 Pin SOIC	operating junction -40°C to +105°C
MOSFET Driver	25.4 um	Aluminum	Cu 97.5 % Ni 2.5 % by wt	Ni 0.9 um	8 Pin SOIC	operating junction -40°C to +105°C
Quadruple differential line receiver	27.2 um	Aluminum	Cu 97.7 % Fe 2.3 % by wt.	Ni: 1.0 um	16 lead plastic SMT	-40C to 85C
16 Bit Buffer Driver tri-state	24.1 um	Aluminum	Cu 97.7 % Fe 2.3 % by wt	Au / Pd / Nickel 1 um	48 Pin TSSOP	-40C to 85C
Quad bus buffer gates with 3-state outputs	25.6 um	Aluminum	Cu 97.8 % Fe 2.2 % by wt	Au/Pd flash over 1.0 um Ni	14 lead plastic SMT	-40C to 85C
RS232 Line Driver / Receiver	26.0 um	Aluminum	Cu 97.8 % Fe 2.2 % by wt	<200 nm Au/Pd over 700 nm Ni	20 Pin SOIC	-40C to 85C
Quadruple differential line receivers	26.5 um	Aluminum	Cu 97.8 % Fe 2.2 % by wt	Au-Pd flash over 1.2 um Ni	16 lead plastic SMT	-40C to 85C
Quad Differential Line Receiver tri-state	24.8 um	Aluminum	Cu 97.9 % Fe 2.1 % by wt	Au/Pd flash over 0.7 um Ni	16 Pin SOIC	operating junction -55C to 150C
Differential Line receiver tri-state	24.2 um	Aluminum	Cu 97.9 % Fe 2.1 % by wt	1.0 um Ni	16 Pin SOIC	-40C to 85C
Quad Differential Line receiver tri-state	22.3 um	Aluminum	Cu 97.9 %Fe 2.1 % by wt.	Au/Pd flash over 1.0 um Ni	16 Pin gull wing SOIC	-40C to 85C
Quad Differential Line Receiver tri-state	25.4 um	Aluminum	Cu 98.0 % Fe 2.0 % by wt	Au/Pd flash over 1.0 um Ni	16 Pin SOIC	-40C to 85C
16 Bit Buffer Driver tri-state	24.6 um	Aluminum	Cu 98.2 % Fe 1.8 % by wt	Au/Pd – 100 nm over Ni – 700 nm	48 Pin SOIC	operating junction -40C to 150C
Quad Differential Line Receiver tri-state	23.4 um	Aluminum	Cu 98.3 % Fe 1.7 % by wt	Au/Pd – 350 nm over Ni – 1.3 um	16 Pin SOIC	-40C to 85C
Quadruple differential line receiver	25.8 um	Aluminum	Cu 98.56 % Fe 1.44 % by wt.	Ni 1.3 um	16 lead plastic SMT	-40C to 85C
Adjustable negative voltage regulator	33.9 um	Aluminum	Cu 99.8 % Si 0.2 % by wt	Cu	Plastic 5 lead TO-263	-40C to 125C
Complex Programmable Logic Device	21.3 um	Aluminum	Not Recorded	Cu	324 lead BGA plastic SMT	-40C to 85C

Note: Temperature range taken from manufacturer’s datasheet

Bond Pad Material Summary

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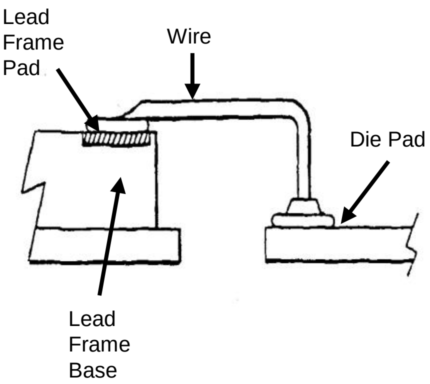
Over 23 part types from 5 different suppliers, more than 240 parts with copper wire analyzed

Wire Dia	Die Pad	Lead Frame Base	Lead Frame Pad
20.4 um	Aluminum	Cu on pwb	Au flash/Ni 8um
19.2 um	Aluminum	Cu 96.2 % Ni 3.4 % Si 0.4 % by wt	4.3 um Ag on Cu
35.5 um	Aluminum	Cu	Cu 62.9 % Pd 37.1 % by wt
Paddle	NA	Cu 98.0 Fe 2.0 % by wt	Sn – 14.7 um
20.2 um	Aluminum	Fe 58.0 % Ni 41.2 % Mn 0.8 % by wt	Cu- 5.7 um
19.4 um	Aluminum	Fe/Ni	Cu – 5.2 um
24.4 um	Aluminum	Cu 92.8 % Fe 2.2 % by wt	Ni 0.9 um
24.8 um	Aluminum	Cu 97.9 % Fe 2.1 % by wt	Au/Pd flash over 0.7 um Ni
24.2 um	Aluminum	Cu 97.9 % Fe 2.1 % by wt	1.0 um Ni
24.6 um	Aluminum	Cu 98.2 % Fe 1.8 % by wt	Au/Pd – 100 nm over Ni – 700 nm
25.8 um	Aluminum	Cu 98.56 % Fe 1.44 % by wt.	Ni 1.3 um
33.9 um	Aluminum	Cu 99.8 % Si 0.2 % by wt	Cu



Palladium plating on bond wire:

- Some manufacturers state that their copper wires are plated with Palladium to increase the integrity of the bond wire
- Only one instance of Palladium has been observed in the SEM (200nm Pd over Cu)

Ball Bond Interface: Unstressed vs. Stressed

- Samples that were stressed by the environmental conditioning mentioned in the previous slide were compared to unstressed samples in the SEM
- Diffusion between Cu and AL results in an intermetallic phase between the two materials
- For stressed and unstressed samples, AL layers were identified that exhibited signs of cracking and voiding
- Appears environmental conditioning has negligible effects on the composition of the individual layers

Ball Bond Interface: Unstressed vs. Stressed

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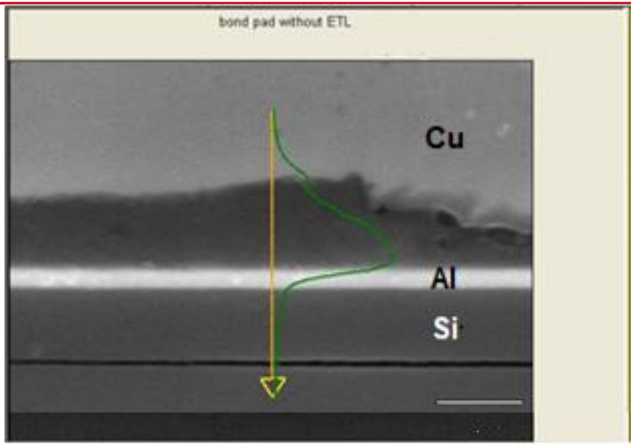
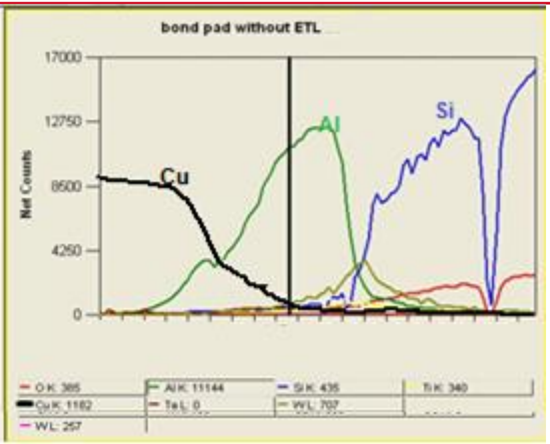
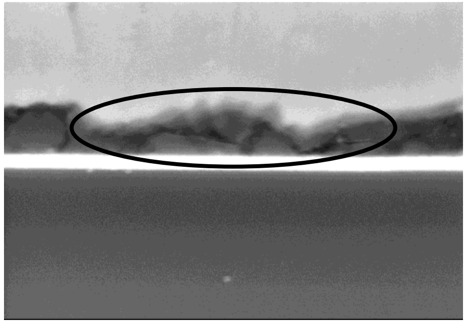
Unstressed Sample:

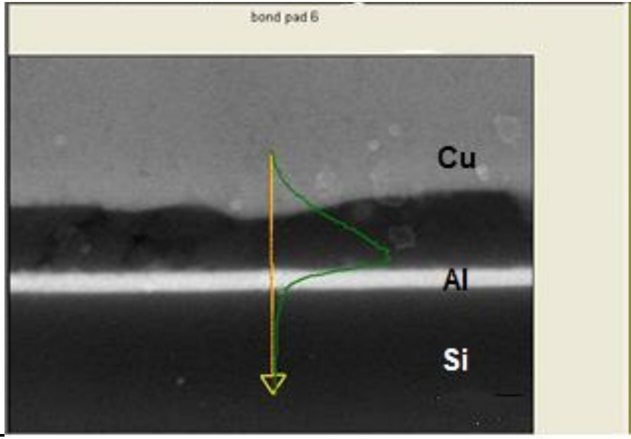


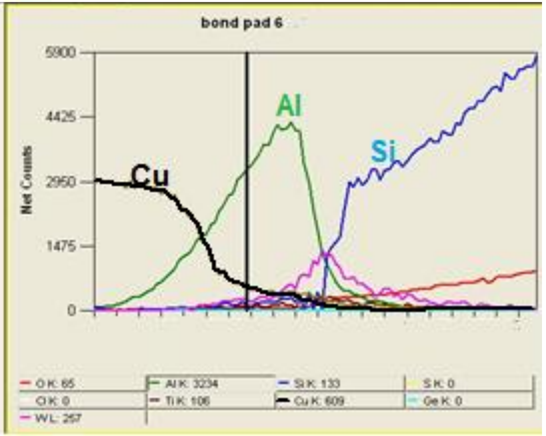


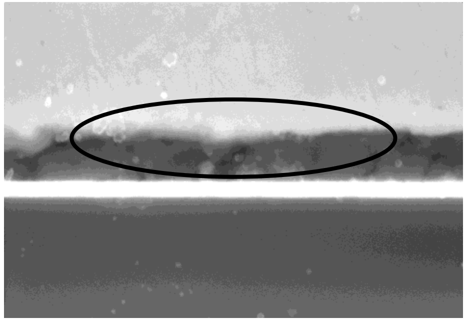


Al layer cracking and voiding in unstressed sample

Stressed Sample:





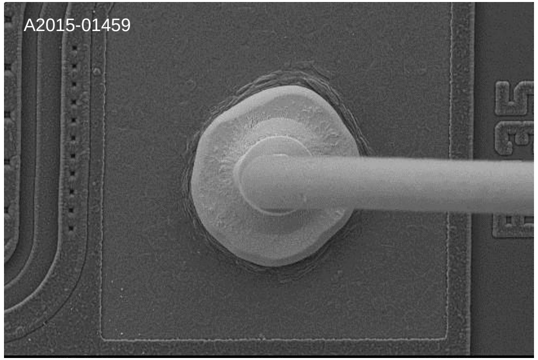


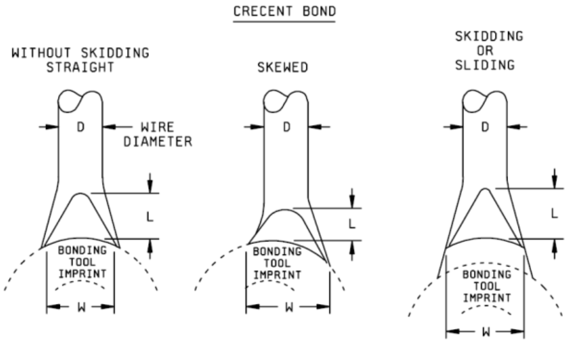
Al layer cracking and voiding in stressed sample

Ball to pad

3.2.1.1 Gold ball bonds. No devices shall be acceptable that exhibits:

a. Gold ball bonds on the die or package post wherein the ball bond diameter is less than 2.0 times or greater than 5.0 times the wire diameter.
b. Gold ball bonds where the wire exit is not completely within the periphery of the ball.
c. Gold ball bonds where the wire center exit is not within the boundaries of the unglassivated bonding pad area.

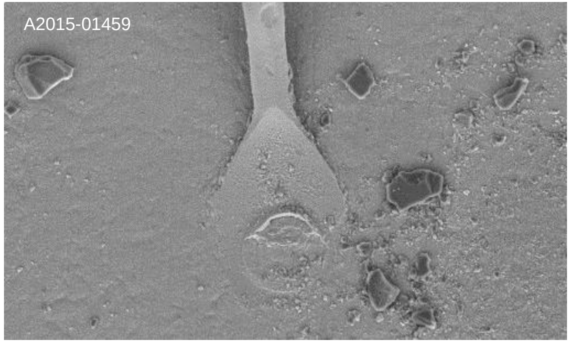




Crescent to post

3.2.1.3 Tailless bonds (crescent, terminating capillary bond). No device shall be acceptable that exhibits:

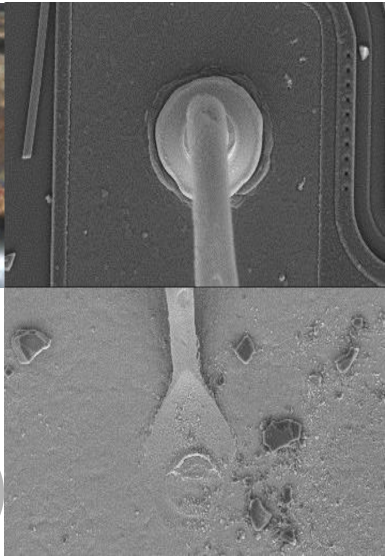
a. Tailless bonds on the die or package post that are less than 1.2 times or more than 5.0 times the wire diameter in width, or are less than 0.5 times or more than 3.0 times the wire diameter in length.
b. Tailless bonds where tool impression does not cover the entire width of the wire.



Samples inspected to MIL-STD-883G requirements for gold wire since no industry or military standard exists for copper - conformed as specified

MIL-STD-883G METHOD 2011 BOND STRENGTH (DESTRUCTIVE BOND PULL TEST)

3.2 Failure criteria. Any bond pull which results in separation under an applied stress less than that indicated in Table I as the required minimum bond strength for the indicated test condition, composition, and construction shall constitute a failure.



Typical Bond Integrity Results	
Bond Pulls	53
Average	11.519
Std.	1.849
Max.	14.241
Min.	2.885

Note: single low pull of 2.885 grams force

Minimum strength for gold – 2.4 gram force

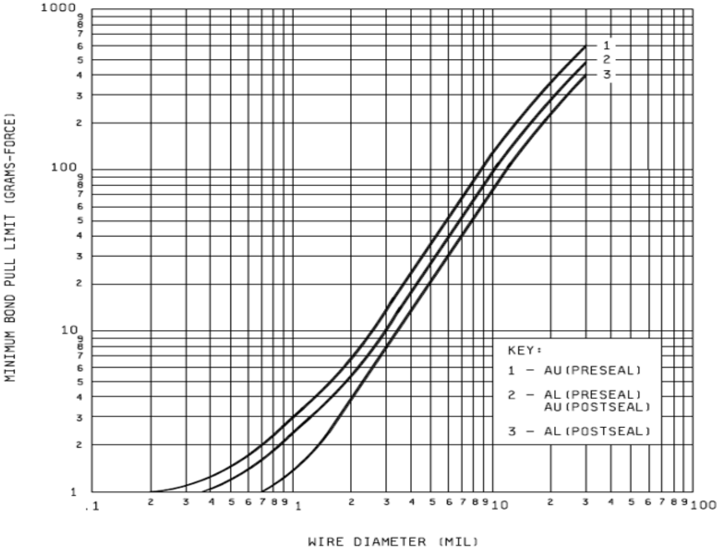


Figure 1. Minimum Bond Pull Limit Graph from MIL-STD-883, Method 2011

Note: No minimum bond strength specified for copper – use gold specification for worst case

Samples inspected to MIL-STD-883G requirements for gold wire since no industry or military standard exists for copper - conformed as specified

JEDEC Wire Bond Shear Test Method JESD22-B116A

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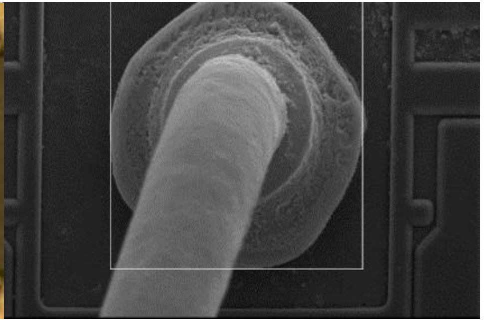

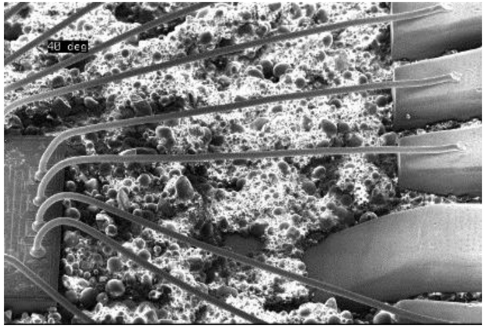

Typical Ball Shear Results	
Ball Shears	49
Average	55.860
Std.	12.374
Max.	94.164
Min.	39.958

Minimum shear average – 24.4 grams
Minimum individual shear – 15.6 grams

This test provides a means for determining the strength of a gold ball bond to a die bonding surface or an aluminum wedge or stitch bond to a die or package bonding surface, and may be performed on pre-encapsulation or post-encapsulation parts. This measure of bond strength is extremely important in determining two features:

1) the integrity of the metallurgical bond which has been formed.
2) the quality of gold and aluminum wire bonds to die or package bonding surfaces.

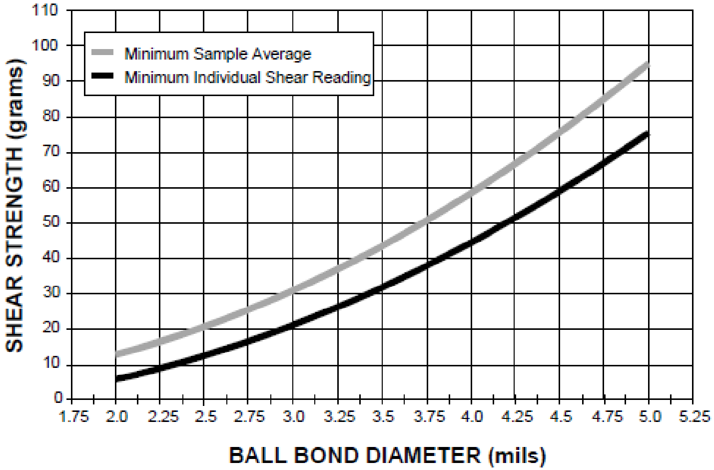

Figure 1. Minimum Shear Values Graph from JESD22-B116A, Section 4.4

Note: No minimum ball shear strength specified for copper – use gold specification for worst case

Samples inspected to MIL-STD-883G requirements for gold wire since no industry or military standard exists for copper - conformed as specified

Supplier Info: SN74ABT125D 14 Pin SOIC Available with Both Gold & Copper Wire not Reflected in Part Number

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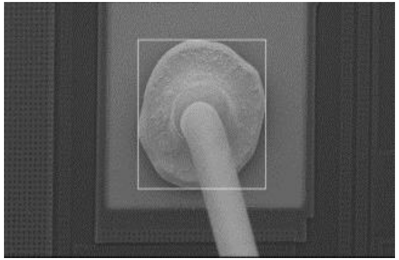
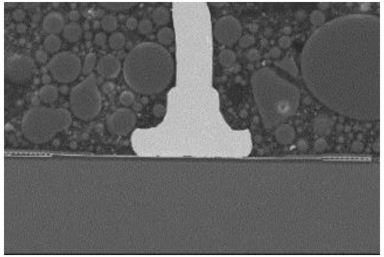
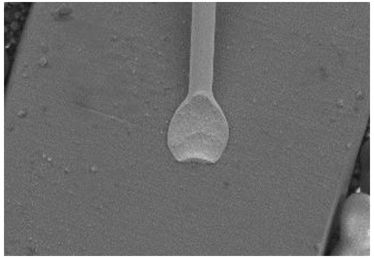
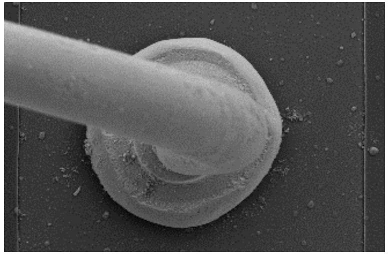
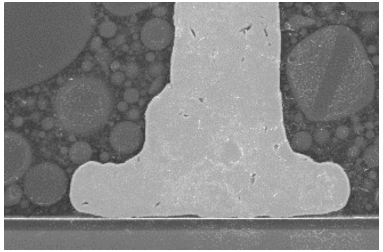
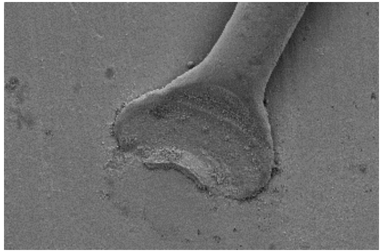




Bond wire diameter: 19.4 um
Bond wire material: gold

Bond wire diameter: 19.0um
Bond wire material: copper

Gold http://www.ti.com/quality/docs/materialcontentsearch.tsp?PCID=41342&OPN=SN74ABT125D#resultstable

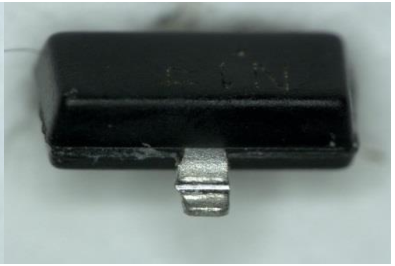
Copper http://www.ti.com/quality/docs/materialcontentsearch.tsp?PCID=41343&OPN=SN74ABT125D#resultstable

The difference is not reflected in the procurable part number.

Supplier Info: Supplier Transitioned SOT-23 Package to Copper 5/26/2009

material breakdown	Mold Compound						Leadframe					Plating			Die		Wire Bond	
	Ortho Cresol Novolac Resin	Phenolic Resin	Fused silica	AlHydroxide	Carbon black	Weight	Cu	Fe	Ni	Ag	Weight	Sn	Pb	Weight	Si	Weight	Cu	Weight
Part Number	[%]	[%]	[%]	[%]	[%]	[mg]	[%]	[%]	[%]	[%]	[mg]	[%]	[%]	[mg]	[%]	[mg]	[%]	[mg]
MMBF0201NLT1G	10.00	10.00	65.00	14.50	0.50	4.90	13.50	50.20	36.30		2.92	100		0.14	100	0.05	100	0.01

Product Change Notification	
Change Notification #	16257
Change Title	***Copper Wire replacing Gold Wire in the SOT23 Package for MOSFET Products***
Issue Date	5/26/2009
Description	Supplier is notifying customers of its use of Copper Wire (in place of Gold Wire) for their SOT23 Packaged Products assembled with MOSFET Die. SOT23 Products built with Planar and Trench MOSFET platforms are represented by this Process Change Notice. Reliability Qualification and full electrical characterization over temperature has been performed.
Key Items Affected by Change	SOT23 Assembly Areas – Wire Bond
Effective Date:	***8/25/2009***
Possible Replacements	N/A



Copper wire required wire bonding process changes resulting in parametric shifts and noise susceptibility that did not impact manufacturer's data sheet performance specifications. It DID effect legacy design performance as compared to devices with gold wire

Conclusions

- Over 40 DPA's (>240 parts) performed on commercial grade plastic encapsulated semiconductors & suppliers without any failures relating to bond integrity, ball shear or bond inspection conditioned as follows:
  a) 24 hours at 125 +5 / -0 °C, per J-STD-020, Section 5.4
  b) 168 hours of 85 °C/85% RH, per J-STD-020, Section 5.5
  c) 100 cycles -55 °C / +125 °C 10 minute dwell time, per Condition B, JEDEC JESD22-A104
  d) 3 cycles SMT solder reflow per paragraph 5.6 and Table 5-2 of J-STD-020
- No released specification for copper wire – USE requirements for gold wire, per MIL-STD-883, Method 2011
- Several OCM's transitioning from gold to copper without reflecting change in part number or ordering information
- Semiconductor manufacturers are reluctant to release long term storage or life reliability test results

Moving Forward…

- Increase stress levels during copper bond wire conditioning
  – Extended life testing
- Get clarification from suppliers on which parts have copper bond wires
- Consider Spec. update to Include copper wirebond pull & sheer limits
- Consider additional assessment / handling measures for long term storage / use bare copper wire bonded IC's

References

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2. Growth behavior of Cu/Al intermetallic compounds and cracks in copper ball bonds during isothermal aging
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5. Body of Knowledge (BOK) for Copper Wire Bonds E. Rutkowski 1 and M. J. Sampson
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Abstract

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For years semiconductor manufacturers have used gold wire to connect the semiconductor die to the lead frames and external pins. However, rising gold prices are driving manufacturers towards less expensive alternative materials such as copper for use in high volume commercial plastic package devices. Military standards such as MIL- STD-883 do not have requirements for copper bond wire and therefore manufacturers are using qualification and process monitoring developed for gold wire to qualify the copper bond wire technology. Although copper bond wire designs are moving forward for commercial applications, there are concerns with quality and reliability for use of copper bond wire in high reliability military electronics with long mission life.

This presentation will review findings from the destructive physical analysis (DPA) testing performed on a number of standard commercial plastic encapsulated microcircuits (PEMs) used on ground-based systems. This presentation will focus on the die ball bond and lead frame crescent bond metallurgical structures, mechanical bond strength, wire composition, and manufacturing bonding process workmanship & overall quality.

Based on the DPA findings, potential risks will be defined along with recommendations to the qualification program of PEMs with copper bond wire for use in harsh environments and long term high reliability military programs.