Freescale Copper Wire - Analysis, Results and Implementation

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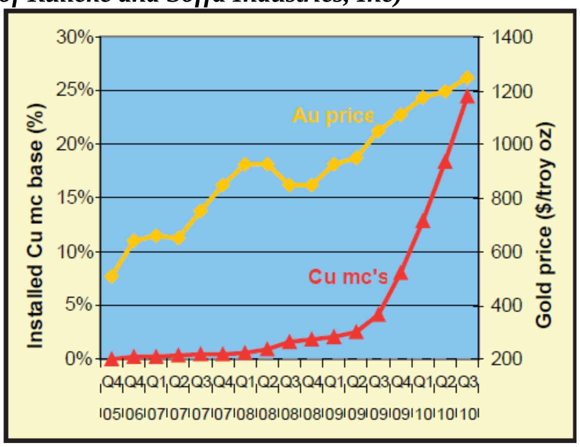
Introduction

Since the end of 2009, the semiconductor industry has seen a sharp increase in the use of copper as a bonding wire. By the end of 2010, the installed base of copper wire capable bonders approached 25% of the total installed fine-pitch wirebonder base [1]. This increased from under 5% at the beginning of 2009. Freescale Semiconductor is currently supplying wirebond packaged products with copper wire.

Figure 1. Installed base of Cu wire bonding machines as a percentage of total installed and gold prices for 2005 – 2010 (Reprinted with permission of Kulicke and Soffa Industries, Inc)



Packaging devices with copper wire does require changes to the wirebond process and package deprocessing. Higher Free-Air-Ball hardness and relatively low oxidation temperature of the copper require special copper wirebond process parameters. And the chemicals traditionally used to remove the mold compound in package deprocessing will attack the copper wire. However, regardless of wire composition, these products are designed to meet the same high quality and reliability standards expected from Freescale Semiconductor. Freescale data has shown no material performance, quality or reliability difference between products packaged with copper or gold wire.

Table 1. Comparison of copper and gold wire physical properties [Compiled from commonly available published sources]

Property	Units	Wire Type		
		4N Gold	2N Gold	Copper
Resistivity	µOhms-cm	2.2 - 2.4	3	1.7
Elastic Modulus	Gpa	80 - 95	85 - 100	60 - 90
Tensile Strength	N/mm^2	> 240	> 260	160 - 220
Elongation	%	2 - 6	2 - 6	7 - 15
Break Load	cN	> 3	6 - 12	4 - 10

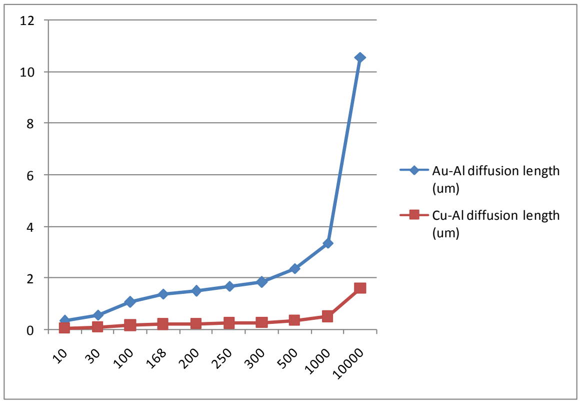
Copper Wirebond Characteristics

Products packaged with both copper and gold wire are qualified to the same quality, reliability and performance standards regardless of wire type. These parts are completely interchangeable in the customer's process and final application.

While the end customer should see no difference in product performance, a construction analysis of the part will show differing characteristics of copper versus gold wirebonds on an aluminum bond pad.

First, the intermetallic formed in a copper-aluminum bond is much smaller than that formed with a gold-aluminum bond. This is the result of a much lower diffusion rate of the copper-aluminum system compared to the gold-aluminum system (figure 2).

Figure 2. Inter-diffusion rate comparison: Au-Al vs. Cu-Al based on vacancy diffusion control mechanism (fcc structure)[2]



While much smaller, the copper-aluminum intermetallic layer is much more robust and stable than gold-aluminum. As a result, the aluminum consumption and voiding growth in the bond seen with gold wirebonds during aging is not observed with copper wirebonds.

Figure 3 shows a comparison of gold and copper wire bonded to an aluminum pad with no aging. Note that a distinct copper-aluminum intermetallic phase is not visible at this magnification, while a 1-2µm gold-aluminum phase is clearly visible.

Figure 3. Copper-aluminum (a) and gold-aluminum (b) wirebonds with no aging.

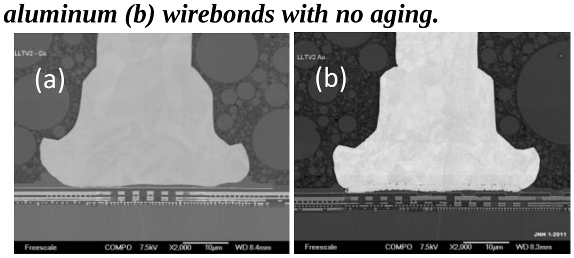


Figure 4 shows higher magnification images of the intermetallic region of the same bonds. Note at this magnification, a very thin copper-aluminum intermetallic is barely visible. In figure 5, a very high magnification image shows the copper-aluminum intermetallic phases.

Figure 4. Higher magnification images of intermetallic regions of same bonds in figure 3.

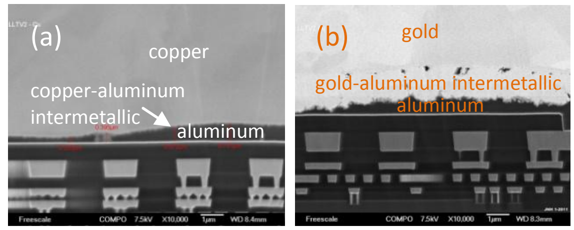
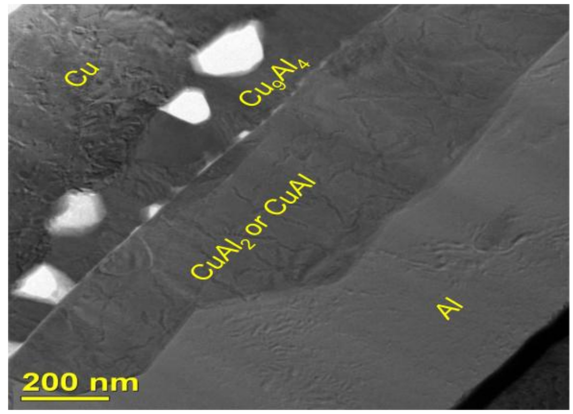


Figure 5. Copper-aluminum intermetallic phases.



Figures 6 and 7 compare the gold and copper bonds after aging. It can be seen that the copper-aluminum intermetallic has grown after 2016 hours at 150°C compared to samples with no aging, but the aluminum is still not completely consumed. The interconnect is solid with minimal voiding. The gold-aluminum intermetallic, on the other hand, has grown to consume the entire thickness of the aluminum pad. Furthermore, large voids have formed within the intermetallic region.

Figure 6. Copper-aluminum (a) and gold-aluminum (b) wirebonds after 2016 and 554 hours at 150°C.

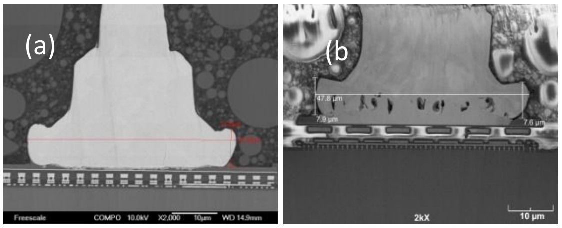
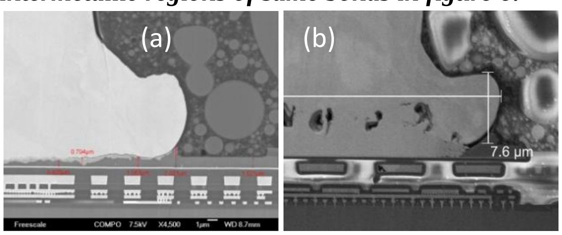


Figure 7. Higher magnification images of intermetallic regions of same bonds in figure 6.

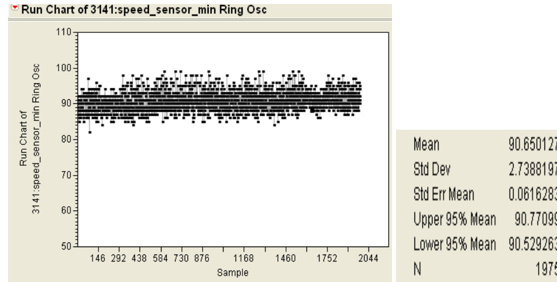


Electrical Performance with Copper Wire.

The end user should see no difference in electrical specifications for Freescale products packaged with copper and gold wire. The critical electrical parameters of speed and power of Au and Cu bonded devices were compared. Production test data for each material was analyzed for the device Speed Sensor and IDD dynamic current of the VDDD supply. Scatter plots, mean, and standard deviation were collected for each. Results indicate that Cu wire bond material has equivalent performance of the Au wire bonded material. Results are shown in Figures 8 and 9.

Figure 8. Ring oscillator speed.

(a) Copper wire



(b) Gold wire

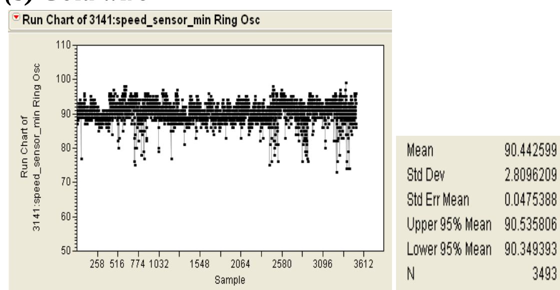
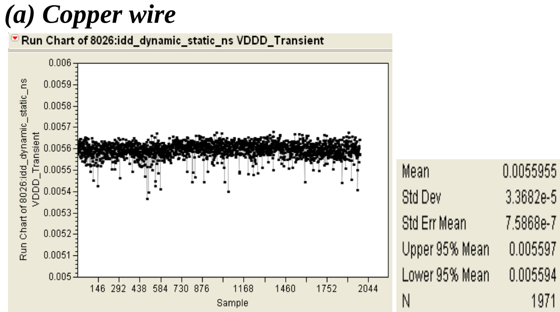
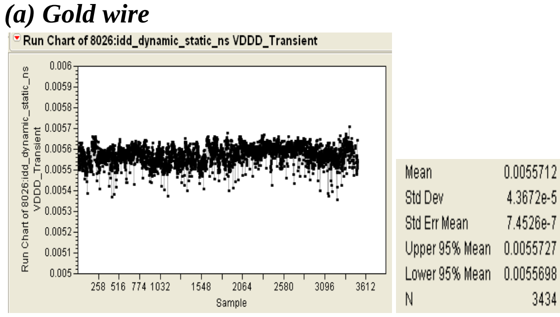


Figure 9. IDD dynamic current of VDDD supply.

(a) Copper wire



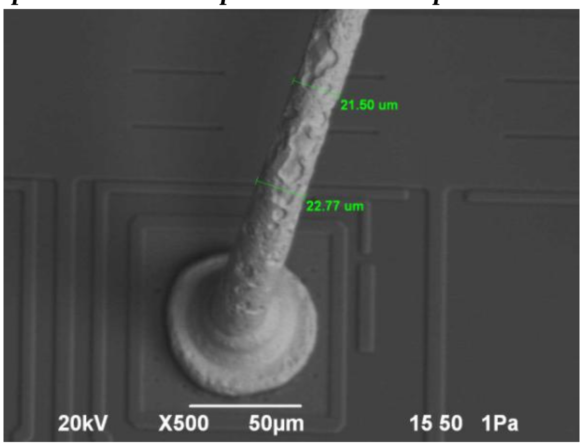
(a) Gold wire



Deprocessing Copper Wire Packages

During chemical deprocessing of copper wirebonded parts, care must be taken to minimize chemical attack of the copper wire which, if left unchecked could completely remove the wires or significantly reduce wire diameter. Most traditional methods used with gold are not compatible with copper wire, and show results similar to Figure 10.

Figure 10. Severe attack of copper wire from non-optimized mold-compound removal recipe.



Freescale has found a recipe where careful control of temperature and the acid mixture is able to best preserve the bond pad and copper wire (figure 11). However, some removal of the copper does occur – affecting both pull strength and failure mode. For instance, the break during wire-pull testing sometimes occurs further from the neck than typically seen with gold wire. Additionally, elongation of the copper wire at the hook placement site is observed (figure 12). This can be attributed to the higher elongation to break for copper (7-15%) compared to gold (2-6%)

Figure 11. Copper wirebond after improved mold-compound removal recipe.

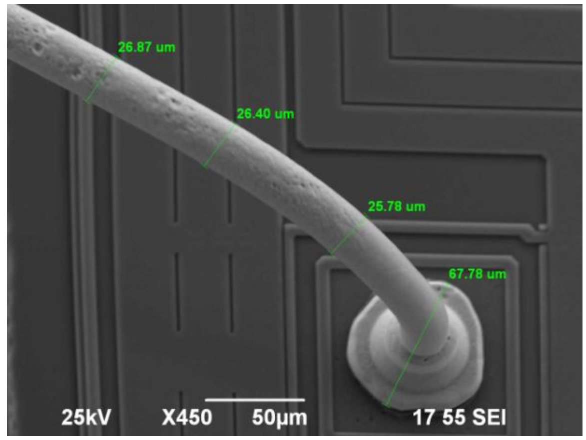
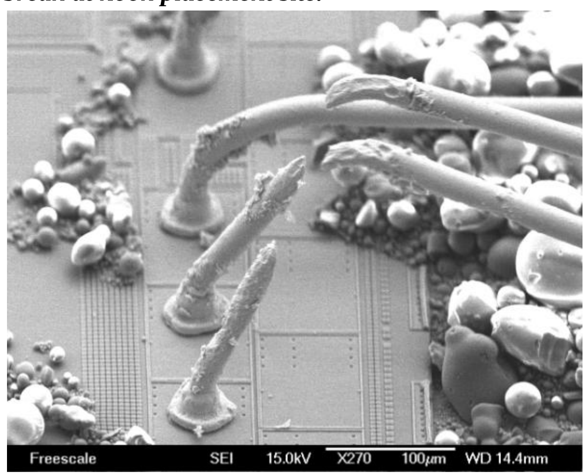
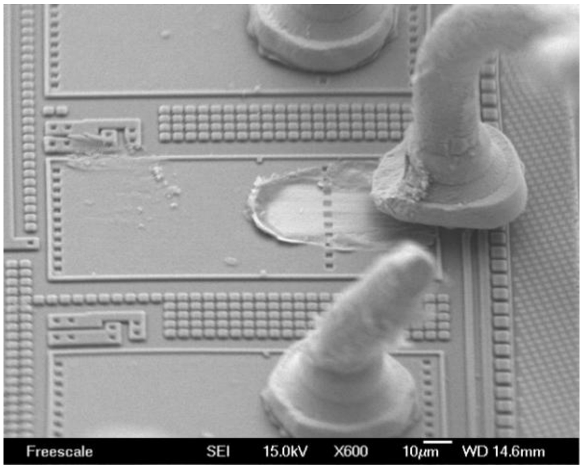


Figure 12. Copper wirebond after mold compound removal and wire-pull. Note elongation of wire and break at hook placement site.



The wirebond ball-shear failure-mode with copper wire can also be different than that seen with gold wire. Because of the thinner, more robust copper-aluminum intermetallic compared to gold-aluminum and the increased hardness of the copper ball bond, the shear failure mode is sometimes through the aluminum pad. As a result, copper may or may not be present on the remaining bondpad after ball-shear (figure 13).

Figure 13. Copper-aluminum bond after ball-shear. Failure-mode is through aluminum pad.



Copper Wirebond Package Reliability

Freescale performs the same package integrity tests for copper and gold wires. Table 2 shows package qualification integrity test data for an 11x11 BGA with 0.9mil diameter copper wire. All integrity tests exceed requirements. Process Capability (Cpk) values are above 2.0.

Table 2. 11x11 BGA 0.9mil copper wire package integrity test results

TEST GROUP C - PACKAGE ASSEMBLY INTEGRITY TESTS					
Stress Test	**Reference**	**Test Conditions**	**Minimum Sample Size** (Note 1)	**# of Lots**	**Results** Lot ID-(#Rej/SS) NA=Not Applicable
WBS	JESD22 B116	**Wire Bond shear (WBS)**	30 bonds from minimum 5 units	3	Lot A - Cpk = 4.72 Lot B - Cpk = 3.65 Lot C- Cpk = 5.23
WBP	JESD22 B116	**Wire Bond Pull (WBP):** Cond. C or D	30 bonds from minimum 5 units	3	Lot A - Cpk = 5.27 Lot B - Cpk = 4.94 Lot C- Cpk = 4.92
PD	JESD22-B100	**Physical Dimensions(PD):** PD per FSL 98A drawing	10	3	Lot A - Cpk = 2.60 Lot B - Cpk = 2.67 Lot C- Cpk = 2.35

Based on current testing, Freescale copper wire reliability appears to be equivalent or superior to gold wire in the same package. The slow diffusion rate of the copper-aluminum system results in a very stable bond in High Temperature Storage Life (HTSL) and Temperature Cycle (TC) testing. The affect of possible corrosion of copper wire during product lifetime is tested in the Biased Highly Accelerated Stress Test (Biased HAST). This corrosion mechanism is well understood and controlled by Freescale with careful specification and control of materials used in the packaging process. Table 3 shows package qualification environmental stress test data for an 11x11 BGA with 0.9mil diameter copper wire. All items were completed to the industrial tier level.

Table 2. 11x11 BGA 0.9mil copper wire package environmental stress test results

GROUP A - ACCELERATED ENVIRONMENTAL STRESS TESTS					
Stress Test	**Reference**	**Test Conditions**	**Minimum Sample Size** (Note 1)	**# of Lots**	**Results** Lot ID-(#Rej/SS) NA=Not Applicable
PC	JESD22-A113 J-STD-020	**Preconditioning (PC) :** PC required for SMDs only. MSL 3 @ 260°C, +5/-0°C (Note 3)	All surface mount devices prior to THB, HAST, AC, UHST, TC, PC+PTC and as required per test conditions. SAM SS=11 units for each stress test for each lot when required.		
HAST	JESD22-A110	**Highly Accelerated Stress Test (HAST):** PC before HAST (for SMDs only): Required HAST = 130°C/85%RH 48 hrs. for Commercial Tier; 96 hrs for Industrial Bias = Vddd = 1.6V *Electrical test must be performed within 48hrs after stress.*	77+3	3	Lot A - Passed 80/80. Lot B - Passed 80/80. Lot C- Passed 80/80.
TC	JESD22-A104	**Temperature Cycle (TC):** PC before TC (for SMDs only): Required TC = -65C to 150°C for 500 cycles.	77+3	3	Lot A - Passed 80/80. Lot B - Passed 80/80. Lot C- Passed 80/80.
HTSL	JESD22-A103	**High Temperature Storage Life (HTSL):** 150°C for 1008 hrs *Electrical test must be performed within 96hrs after stress.*	77+3	3	Lot A - Passed 80/80. Lot B - Passed 80/80. Lot C- Passed 80/80.

Conclusion

The performance data, quality data and reliability data collected to date indicates copper wire wirebonded devices from Freescale are equivalent if not superior to devices with gold wire in the same package.

Freescale has invested a significant amount of effort in developing a high quality, reliable copper wirebond product. We have already qualified and are shipping wirebond packaged products with copper wire.

Freescale is in line with the industry as it converts to wirebond packages with copper wire. The customers will be seeing an increasing percentage of wirebonded products with copper wire.

References

[1] Fine Pitch Copper Wire Bonding; Clauberg, Qin, Reid and Chylak [Kulicke and Soffa Industries, Inc.]; Chip Scale Review, Volume 14, Number 6, Nov/Dec 2010

[2] CRC Handbook of Chemistry and Physics, 81st Edition; David R. Lide, Editor