Reliability Study of Silver, Copper and Gold Wire Bonding on IC Device

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Abstract

Copper wire bonding in IC packages is not always suitable for devices with active circuit under bonding pad because higher bonding power required for copper wire bonding may cause top aluminum metal splash and mechanically impact the circuit underneath. Silver wire is an alternative solution to this problem based on its physical properties and lower cost compared to gold wire.

Ag88%Au8.5%Pd2.5%X1% and Ag95%Au1.5%Pd2.5%X1% alloyed silver wires are used in the study to compare with copper and gold wires of 99.99% in purity. As bonding power plays a dominating role in wire bonding, we focused on the effects of silver, copper and gold bonding wires with different bonding power on the top aluminum metal splash of power device by Optical Microscope(OM) and Scanning Electron Microscope(SEM). The ball shear strength of the bonding wires with different bonding power in samples without mold compound encapsulation was investigated before and after 24, 48, 96 and 192 hours of pressure cooker test (PCT). The intermetallic compound (IMC) formed between silver and aluminum was confirmed by focus ion beam (FIB) and transmission electron microscope (TEM). Although the top surface of the silicon device shows no significant difference after aluminum layer removal for all three wire types, the severity level of vertical deformation and side splash of aluminum layer due to copper wire bonding is much more than silver or gold wire using same amount of bonding power. Ball shear strength of non-encapsulated silver wire decreases dramatically after PCT aging compared with copper wire or gold wire and some samples show zero shear strength after PCT 96 hours and PCT 192 hours for silver wires doped with Pd/Au. Furthermore, larger bonding power induces higher ball shear strength. The major IMC compositions between silver and aluminum are Ag_3Al and Ag_2Al. A thermo dynamic model was built to explain why silver wire is prone to corrosion compared with copper wire by humidity although copper is easier to be ionized than silver. No electrical test was performed as the samples cannot be tested without package encapsulation and singulation.

Furthermore, silver wire samples in SO8 package with mold compound encapsulation were subjected to highly accelerated stress test (HAST), PCT, temperature cycle test (TCT) after MSL1 preconditioning test as well as high temperature operation life test (HTOL) according to JEDEC procedures. The encapsulated samples using either Ag 88wt% or Ag95wt% alloys all passed MSL1 and PCT/HAST/TCT/HTOL. Drain to source on-resistance (Rdson) of the device including package parasitics was measured and it has no significant difference between silver wire and gold wire. The results from this study shows promising data using silver alloy wires but care should be taken to further understand the degradation of silver-aluminum interface under severe humidity condition. Using other metallization on silicon top surface such as NiAu or CuAu can significantly alleviate the interface problem related to AgAl.

Keywords

Silver wire bonding, copper wire bonding, PCT, Al splash, reliability, Rdson

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I. Introduction

Gold wire bonding is the most popular way of making electrical connection in microelectronic packaging industry. However, the gold price is always running on the high level even though it ramps down in recent years as shown in Fig.1 [1]. Therefore, copper replacing gold wire bonding is expected to be the most cost effective alternative in power packages for power discrete (MOSFET, IGBT, Superjunction, etc) and power IC. But for power IC packages, copper wire bonding has some limitation because its higher hardness requires higher bonding power which can damage active circuit pad directly under top soft aluminum metal layer. Most recently, silver wire bonding draws attentions in power IC assembly field because it has both relatively lower price than gold and lower hardness than copper as shown in Table 1 [2], [3].

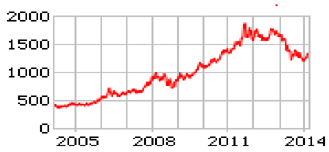
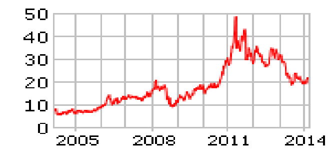
	Au (USD/oz)
	Ag (USD/oz)

Fig.1 Trend of gold and silver price

Table 1 Hardness of different bonding wires

Hardness (HV)	Au	Cu	88wt% Ag	95wt% Ag
FAB	45-50	65-70	50-55	44-54
Wire	50-55	70-76	55-60	50-60

II. Experimental

The samples used in this investigation are 1-mil diameter bonding wires. Gold wire of 99.99% in purity, copper wire of 99.99% in purity and silver alloy wires are manufactured by Tanaka, Tanaka and Heesung Co.,Ltd respectively. Two types of silver wires are made of 88wt% Ag+8.5wt% Au+2.5wt% Pd+1wt% X (simply called as 88Ag) and 95wt% Ag+1.5wt% Au+2.5wt% Pd+1wt% X (simply called as 95 Ag) respectively. The ball bonding processes are completed by the Elite machine from K&S Co., Ltd. Ball shear test is applied to check the bonding integrity based on JEDEC standard shown in Fig.2 [4]. After the ball bonding process, some samples are directly exposed in the PCT (Pressure Cooker Test) oven with the condition of 121 deg C/100%RH/2atm. The ball shear tests are applied at different time intervals, i.e., 24hours, 48hours, 96hours and 192hours. The rest of the samples are encapsulated by molding compound followed by curing process, grouped in four lots, then subjected to PCT 96hours, HAST (Highly Accelerated Temperature and Humidity Stress Test) (130degC/100%RH without bias) 100hours, TCT (Temperature Cycle Test) (-65degC~150degC air to air) 500cycles and HTOL (High Temperature Operation Life) (150degC) 1000hours respectively.

Silicon top bonding pads after wire bonding are examined by OM (Optical Microscope) after acid etching and the cross section of bonding interfaces are examined by SEM (Scan Electron Microscope), FIB (Focus Ion Beam) and TEM (Transmission Electron Microscope).

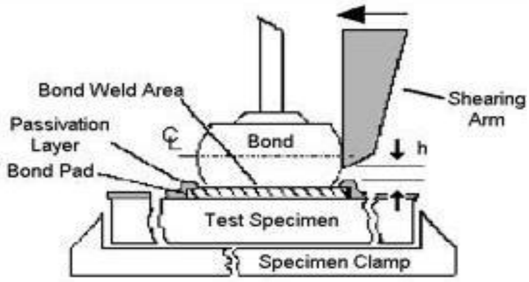
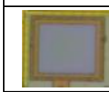
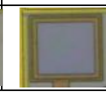


Fig.2 Ball shear test

III. Results and Discussion

1. Wafer bonding pads by different wire bonding with different bonding power

				
Au/ power 50	Cu/ power 100	Cu/ power 80	Cu/ power 50	88Ag/ power 80
				

88Ag/ power 50	88Ag/ power 35	95Ag/ power 80	95Ag/ power 50	95Ag/ power 35

Fig.3 Wafer bonding pad appearance (x100) vs bonding wire vs bonding power

Fig.3 shows the impact of different wire bonding with different bonding power on wafer top bonding pad. After Al layer is removal by acid, there is no significant difference observed by OM inspection for each condition.

2. Top Al metal cross section by different wire bonding with different bonding power

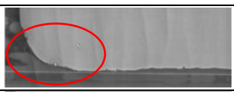
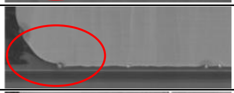
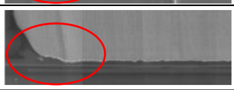
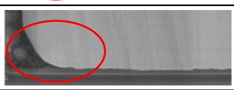
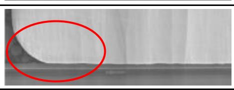
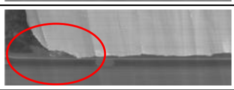
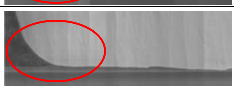
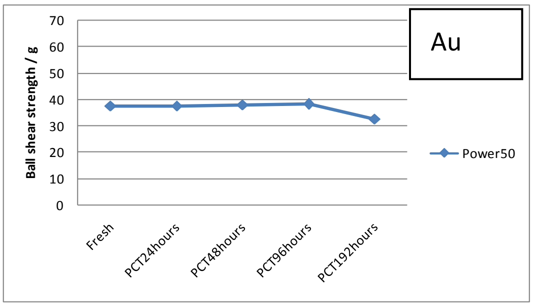
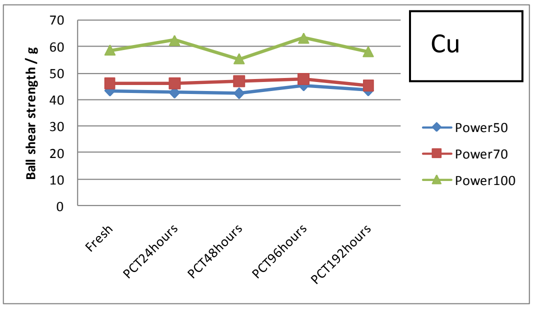
Picture (x1000)	Wire	Power	Splash or not
	Au	50	N
	Cu	100	YYY
	Cu	80	YY
	Cu	50	Y
	88 Ag	80	Y
	88 Ag	50	N
	88 Ag	35	N
	95 Ag	80	Y
	95 Ag	50	N
	95 Ag	35	N

Fig.4 Al metal splash vs bonding wire vs bonding power

Shown in Fig.4, the SEM photos are taken on the cross section of bonding area by different wire bonding with different bonding power. The remark Y in the column Splash or not means that there is Al splash after wire bonding, and N means no; number of Ys or Ns indicates the severity level of the aluminum splash. It is found that there is nearly no Al splash by Au wire bonding. For copper wire bonding, Al splash is found on all of three bonding powers 100, 80 and 50. As the bonding power is increased, the Al splash gets worse. As to the 88Ag wire bonding, there is slight Al splash found by bonding power of 80, and no splash by bonding power of 50 or 35. The phenomenon of 95Ag is similar to that of 88Ag wire. At a fixed bonding power of 50, copper wire bonding causes relatively severe Al splash and the remaining Al layer is significantly thin which may impact the circuit underneath for power IC devices, and for the gold wire or 88Ag or 95Ag wire bonding, there is no Al splash found and the remaining Al layer is relatively thicker. Therefore, for sensitive IC dies, copper wire bonding with highest hardness among the three may impact the circuit under the bonding pad which causes electric failure or reliability issue. Silver wire bonding is a safer way to protect the function area under bonding pad [5], [6].

3. Ball shear strength after PCT by different wire with different bonding power





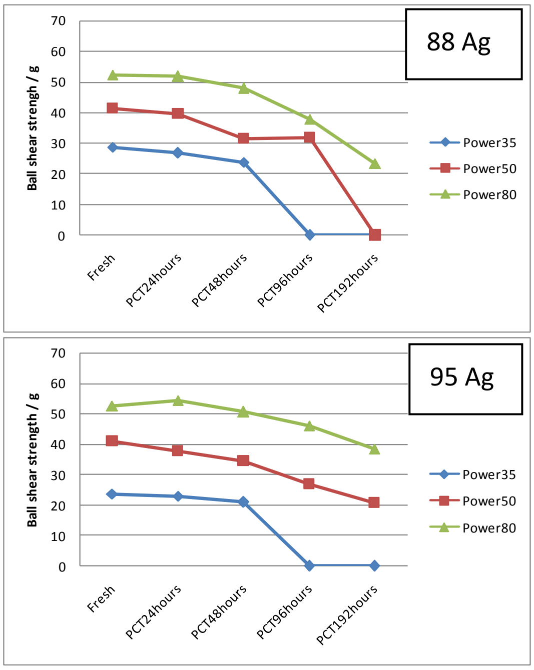


Fig.5 Ball shear strength vs PCT hours vs bonding power

Fig.5 shows the ball shear strength as a function of PCT aging time for gold wire, copper wire, 88Ag wire and 95Ag wire. In each plot, three bonding powers are indicated. These samples are as-bonded without package encapsulation. It is found that there is no significant reduction of ball shear strength from fresh to even 192 hours PCT aging for both gold wire and copper wire bonding. However, for both 88Ag and 95Ag wire bonding, the ball shear strength reduction is much more by PCT aging, 96 and 192 hours in particular. There is nearly zero ball shear strength after PCT96 or 192hours. It is believed that in PCT environment H_2O attaches and reacts with Ag/Al to form a corrosion layer which impacts the ball shear strength. The doping of Pd has benefit but cannot totally prevent interface depression as illustrated in Fig.6 [7], [8].

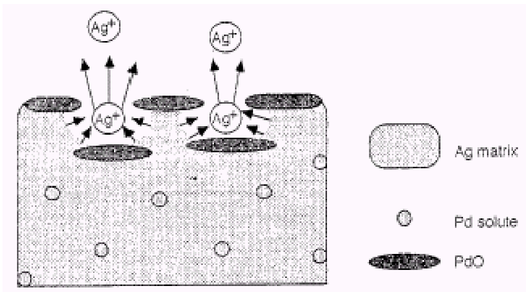


Fig.6 Pd doping effect on silver corrosion

As to the effect of bonding power on ball shear strength after PCT, both copper and silver wire bonding show that the ball shear strength decreases with decreasing bonding power. The downgrading degree for silver wire bonding is much more than copper wire bonding. With the decrease in bonding power, the interface becomes weaker which is easily attacked by H_2O.

4. Ball shear strength comparison after PCT by different bonding wire with same bonding power

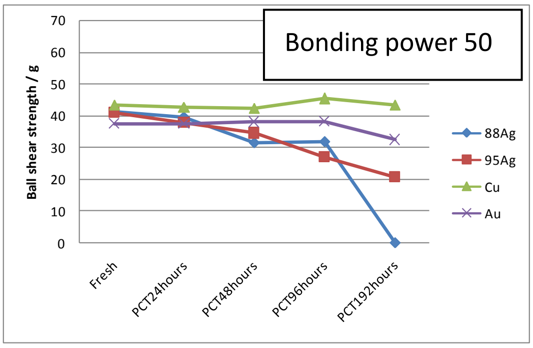
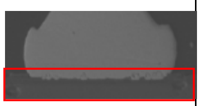


Fig.7 Ball shear strength vs PCT hours

The relationship between ball shear strength and PCT hours by different bonding wire with same bonding power of 50 are shown in Fig.7.

It is clear that the ball shear strength after PCT is as follows: Cu>Au>88Ag or 95Ag. Fig.8 shows the interface IMC (Intermetallic Compound) layer conditions after PCT 192hours for Au wire, Cu wire, 88 Ag wire and 95 Ag wire with the same bonding power. The IMC layer integrity is as follows: Cu>Au>88Ag or 95Ag which is accordance with the ball shear strength.

Picture (x500)	Wire	IMC	IMC integrity
	Au	Au_xAl_y	Good
	Cu	Cu_xAl_y	Very good
	88 Ag	Ag_3Al Ag_2Al	Poor

	95 Ag	Ag_3Al Ag_2Al	Poor

Fig.8 IMC layer integrity vs bonding wire

The Ag-Al IMC layer is closely observed by FIB as shown in Fig.9, and it is clear to see that there is a non-continuous interface between silver and aluminum layer. The IMC is highly corroded by humidity during PCT. It indicates that the interface between IMC and aluminum is more prone to be attached by humidity, instead of that between silver and IMC. And the IMC compositions are confirmed as Ag_3Al and Ag_2Al by TEM analysis which is indicated in Ag-Al phase diagram in Fig.10 [9].

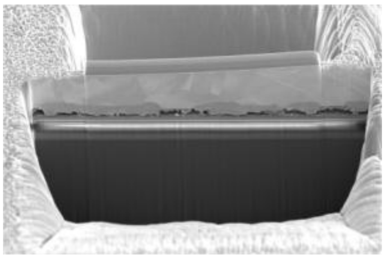
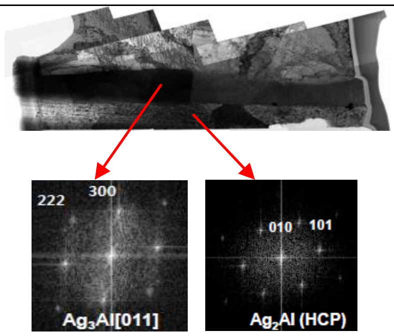
	Ag-Al IMC layer by FIB
	TEM analysis

Fig.9 Ag-Al IMC layer integrity magnification and TEM analysis

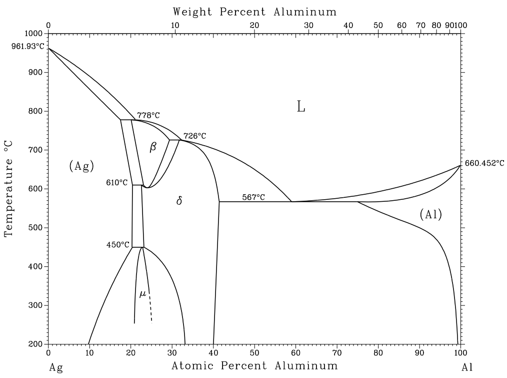


Fig.10 Ag-Al phase diagram

The IMC by silver wire bonding on aluminum is easier to be attacked by humidity than gold and copper wires as it provides channel for moisture to seep to the inside of the bonding interface by Kirkendall effect. Eventually it impacts the ball shear strength. Therefore, it indicates that silver wire, even doping with Pd or Au, the reliability is still poorer than both copper and gold wires. A thermodynamic mechanism model is illustrated in Fig.11 [10], [11]. Theoretically, copper is easier to be ionized than silver, but its oxide is harder to decompose. Therefore, silver is prone to be corroded by humidity compared with copper. As to gold, its higher potential makes it harder to be ionized.

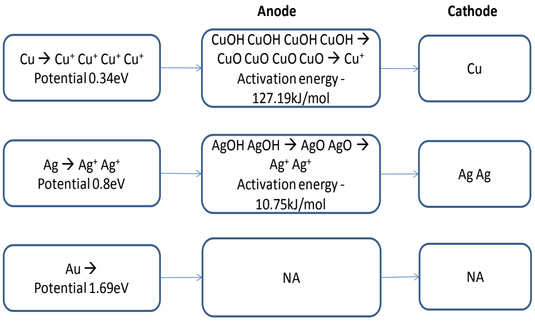


Fig.11 Thermodynamic mechanism illustration

5. Reliability check of actual devices with molding compound encapsulation

The reliability check is done on the actual devices with molding compound encapsulation based on JEDEC standard. Table 2 shows that the devices with either 88 Ag wire or 95 Ag wire pass the reliability test with MSL1 preconditioning. The test vehicle is SOIC8 and sample size is 246ea by three lots.

Table 2 Standard reliability test of silver wire built devices

Wire	PCT 96	HAST 100	TCT 500	HTOL 1000
88 Ag	Pass	Pass	Pass	Pass
95 Ag	Pass	Pass	Pass	Pass

6. Rdson (Resistance of Drain-Source On) comparison of actual devices with molding compound encapsulation

The Rdson check is done on the actual devices with molding compound encapsulation in table 3. It shows that there is no significant difference between silver wire and gold wire.

Table 3 Rdson of silver wire built devices

Wire type	Package type	Sample size	Rdson Avg/ mOhm	Rdson Std/ mOhm
88 Ag	SOIC8	3000ea	8.747	0.182
95 Ag	SOIC8	3000ea	8.73	0.172
Au	SOIC8	3000ea	8.735	0.323

Though the silver wire samples pass all the standard reliability tests, it still has some reliability concern based on low ball shear strength of as bonded samples after long- term high humidity and high temperature condition. Further prolonged reliability check such as PCT500hours, HAST 500hours and TCT 1000cycles will be carried out to find this new bonding wire limit.

IV Conclusions

1. The top aluminum metal splash becomes more severe with the increase in bonding power for both copper wire and silver wire.
2. At same bonding power, silver wire has less impact than copper wire on top aluminum metal splash and active circuit underneath (if any).
3. The ball shear strength decreases with the decrease in bonding power for both copper wire and silver wire bonding.
4. After PCT aging, the ball shear strength decreases for samples bonded with silver wire; after PCT 96hours or 192hours, it shows nearly zero ball shear strength as Ag-Al IMC is significantly impacted by humidity.
5. Packages with silver wire bonded on aluminum top metal of silicon device and epoxy molding compound encapsulation pass all standard MSL level 1 reliability tests.
6. There is no significant Rdson difference between samples using silver and gold wires.
7. The silver wire doping with Pd and/or Au is only recommended to be used in products for which bonding interface degradation after by humidity is not a concern. Further study need to be carried out to improve silver wire reliability either by modifying alloy composition or top metallization of silicon device.

References

[1] www.goldprice.com, Gold price history- gold price chart for the last ten years

[2] T. Suresh, “Low cost Pd coated Ag bonding wire for high quality FAB in air”, *ECTC*, 2012, P1103

[3] L.J. Kai, “Silver alloy wire bonding”, *IEEE*, 2012, P1163

[4] JESD22-B116, Wire bond shear test method

[5] K.A. Yoo, “Reliability study of low cost alternative Ag bonding wire with various bond pad materials”, *EPTC*, 2009, P851

[6] J.S. Cho, “Thermal reliability & IMC behavior of low cost alternative Au-Ag-Pd wire bonds to Al metallization”, *IEEE*, 2009, P1569

[7] Kim Vu, “Silver migration- the mechanism and effects on thick-film conductors”, *Material science engineering.* 2013, P234

[8] H.J. Kim, “Effects of Pd addition on Au stud bumps/Al pads interfacial reactions and bond reliability”, *Journal of Electronics Materials*, Vol.33, No.10 (2004), P1210

[9] www.crct.polymtl.ca, Ag-Al phase diagram

[10] Y.H. Lu, “Growth of CuAl intermetallic compounds in Cu and Cu(Pd) wire bonding”, *EPTC*, 2012, P1481

[11] J. Brusic, “Corrosion and protection of a conductive silver paste”, *Journal of electrochemical society*, No.8, 1995, P2591