Journal of Metals, Materials and Minerals, Vol.23 No.1 pp.13-17, 2013

Parameters Optimization of Copper Wire Bonding on Thin Small Outline Package

Sorasit SRIKAMONSIRISAK[1], Ubonwan TANTINUCHAWONG[2] and Yuparwadee SATIRAKUL[3]

Spansion (Thailand) Limited, 229 Moo 4, Changwattana Road, Nonthaburi 11120, Thailand

Abstract

With significant rising of Au price, there is growing demand to implement Cu wire bonding as an alternative method for Au wire bonding. However, there are several challenges to overcome because Cu is easily oxidized and its property is harder than Au. The oxidation deteriorates bondability and bond reliability, while the greater wire hardness leads to the more severe wire bonding parameters (higher force, higher power, higher temperature), which results in physical damage of the bond pad and underlying layers. This paper reveals wire bonding parameters optimization in order to implement Cu wire bonding in high volume production environment with good bondability and bond reliability. The experiments were focused on Cu free air ball (FAB) formation and ball bonding process. The parameters of interest were Electronic Flame-Off (EFO) gap, flow rate of mixed gas 95%N2/5%H2 during FAB formation and force profile. The response to be characterized were FAB surface, FAB shape, FAB diameter, bond integrity testing (BIT) including Al splash and Al remaining after bonding. The EFO gap 20-35 mils, the mixed gas flow rate 0.5-0.7 L/min and the force profile with ramp-down force and low ultrasonic generator (USG) power were determined to be an optimum parameter concept for the selected product. This parameter set was applied to bonding process of Cu wire 0.9 mils diameter on AlCu0.5% metallization pad 0.65 um thickness, assembled in thin small outline package (TSOP). Bond reliability after environment stress tests was characterized through BIT, Al splash and Al remaining on pad. Electrical performance of Cu wire product was also characterized and compared to the result of Au wire product.

Key words : Cu Wire, Bonding Parameter, Bondability, Reliability

Introduction

In integrated-circuit packaging, wire bonding is the main technology to make electrical connections between designed circuits and substrate/lead frame. Au is the most popular interconnection material in wire bonding because of its stability. However, its price has risen significantly over the last few years, this forces manufacturing demand for lower-cost material increased. Regarding the better electrical and mechanical properties and cost saving, Cu wire has become one of the preferred materials for wire bonding interconnection but there are several challenges to be overcome before implement Cu wire bonding in high volume manufacturing environment because Cu is easily oxidized and its property is harder than Au. For the comparison of relevant Cu and Au physical properties, they are shown in Table 1.[(1)] In ball bonding process, ball formation process is achieved by ionization of the air gap in a process called Electronic Flame-Off (EFO). The resulting ball is known as a free air ball (FAB). FAB is compressed on Al pad by force with the aid of ultrasonic wave. Since Cu is susceptible for oxidation, FAB formation of Cu wire has to be performed under oxygen free environment which can be achieved with the installation of Cu-kit connected with the gas delivery system to the conventional wire bonder. Shape of Cu FAB depends on the heat flow condition and gaseous ambient during formation. Forming gas or mixed gas at concentration of 95%N2 and 5%H2 is widely used, where the hydrogen acts as a getter for the oxygen.[(2)] The flow rate of the mixed gas also play important role in configuration of FAB, it should be optimized for each specific process. EFO gap which is the distance between EFO tip and Tail length as shown in Figure 1. is another key factor for wire bonding process to produce the consistency FAB from the firing. The value used for Au wire may not suitable for Cu wire. The evaluation is required when convert from Au wire to Cu wire. In addition, the greater hardness of Cu than Au requires more severe wire bonding parameters which may lead to physical damage of the bond pad and underlying layers.

* Corresponding author E-mail : Sorasit.Srikamonsirisak@spansion.com; E-mail : Ubonwan. Tantinuchawong @spansion.com; E-mail : Yuparwadee.Satirakul@spansion.com

In this study, EFO gap, mixed gas flow rate and force profile which is a combination of initial force, bond force and ultrasonic generator (USG) power of Thermosonic ball bonding were optimized. The results were characterized through bondability, bond reliability and manufacturability in the existing production environment.

Table 1. Physical properties of Cu and Au

Physical Properties	Cu	Au
Atomic weight	63.55	196.97
Crystal structure	FCC	FCC
Thermal conductance (kW/m^2K)	39.4	31.1
Density (g/cm^3)	8.92	19.3
Melting temperature (ºC)	1085	1064
CTE ($\times 10^{-6}/K$)	16.5	14.2
Electrical resistivity at 20ºC ($\times 10^{-8}\Omega m$)	1.7	2.2
Electrical conductivity at 20ºC ($\times 10^{7}/\Omega$)	5.88	4.55
Young's modulus (GPa)	130	78
Tensile strength (MPa)	210-370	120-220
FAB hardness (HV)	85	60
Bonded ball hardness (HV)	100-130	70-85
Reaction rate for IMC formation with Al at 150ºC ($\times 10^{-16}$ cm^2/s)	1.88	110

Materials and Experimental Procedures

The test vehicles were live dies with AlCu 0.5% metallization pads 0.65 um thickness. The bonding was performed using bare Cu wire 0.9 mils diameter and K&S wire bonder equipped with Cu kit which included gas tube control flow rate of mixed gas 95%N2/5%H_2. The EFO gap was firstly optimized, followed by gas flow rate and force profile respectively. Bondability as-bonded state of the first bond was characterized through bond integrity testing (BIT) in cooperated with Al splash and Al remaining. With the optimized parameter settings, the test vehicles were assembled in TSOP and subjected to environment reliability testing. Bond Reliability was characterized through BIT and electrical testing, and compared to those of Au wire bond package.

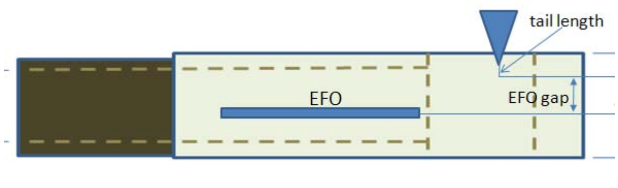


Figure 1. Schematic of EFO gap

EFO Gap Optimization

The shape and size of FAB formation deeply affect the quality of wire bonding. Spherical, non-blemish shape of FAB is ideally desired to ensure good bondability. EFO gap is a key factor that has effect on FAB. In this study, EFO gap was varied in range of 10-40 mils while the other factors like gas flow rate at 0.5 L/min, tail length at 20 mils, EFO current at 60 mA and EFO time have been fixed at 200 µsec. The result in Table 2 shows that the EFO gap in the range of 20-35 mils leads to consistent FAB shape. The FABs with EFO gap at 10, 20 and 40 mils are in Figure 2. Asymmetry was created due to surface tension disrupt whereas at the higher EFO gap the oxidation ball can be observed due to the ball forming near the end of tube which tend to have higher oxygen level.[3] In order to constrict the arc discharge around tip and to minimize heat loss which can cause inconsistency FAB size, the smallest EFO gap 20 mils is selected for the subsequent experiment.[3]

Table 2. Test result of EFO gap study

Run	EFO gap [mils]	Tail length [mils]	Result
1	10	20	Pointed ball
2	15	20	Pointed ball
3	20	20	Good ball shape
4	25	20	Good ball shape
5	30	20	Good ball shape
6	35	20	Good ball shape
7	40	20	Oxidation ball

a) EFO gap = 10 mils b) EFO gap = 20 mils c) EFO gap = 40 mils

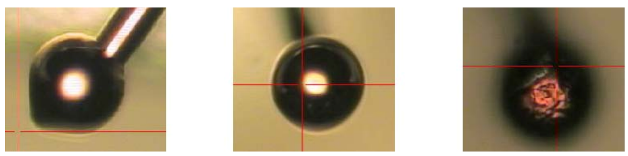


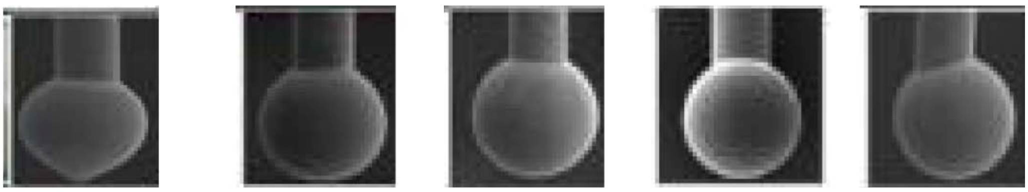
Figure 2. Optical Microscope of FAB with varied EFO gap

Mixed Gas Flow Rate Optimization.

Mixed gas flow rate is another parameter to be controlled to prevent FAB oxidation and to obtain the consistent FAB diameter. In this experiment, the gas flow rate was varied in the range of 0.4–0.8 L/min. Shape and surface of FABs were firstly verified. All FABs formed under flow rate 0.5–0.7 L/min were in spherical shape without oxidation while some FABs formed under flow rate 0.4 and 0.8 L/min were oxidized and not in spherical shape. Sample FABs formed under different flow rates are illustrated in Figure 3. Insufficient flow rate, 0.4 L/min in this study, tends to create oxidation ball due to non-flourishing of mixed gas inside tube. On the other hand, too high flow rate would create off center ball due to tail displacement.(5) With above result, further evaluation on FABs diameter and BIT was performed with flow rates in the range of 0.5–0.7 L/min. The results are in Figure 4. From the result, FAB diameters are in the required range, moreover, there is no significantly different in the results among those three flow rates. So the gas flow rate 0.5–0.7 L/min is considered to be the optimum range for the selected product. To allow process window of ±0.1 L/min, gas flow rate at 0.6 L/min was selected and applied to the consequent experiment.

and the USG power. Initial force is the force applied soon after wire contact to the pad. Bond force is the force that ramped up or down from initial force. USG power is the parameter for control energy y used in ball bond formation after wire contact to the pad. In this study, three different sets of force profiles as shown in Table 3 were employed under Thermosonic bonding process. The other factors e.g. bonding temperature set at 200 C, gas flow rate set at 0.6 L/min, EFO gap set at 20 mils were kept constant. Since Cu wire is generally harder and requires higher force than conventional Au wire, it could affect Al thickness remaining and Al splash after completed wire bond. Less Al thickness tends to generate failure and causes reliability issue due to affection on intermetallic formation, like Al splash which should be kept less to ensure no shortage issue between bonded balls especially for product that has smaller bond pad pitch. Hence, Al thickness and Al splash were also characterized.

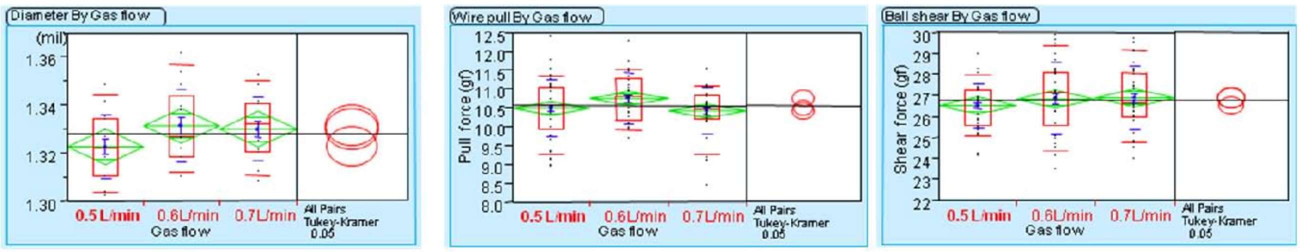
a) 0.4 L/min b) 0.5 L/min c) 0.6 L/min d) 0.7 L/min e) 0.8 L/min



Pointed/Oxidized Normal Normal Normal Off-center

Figure 3. SEM images of sample FABs formed under different gas flow rates

a) FABs diameter(control:1.3-2.5 mils) b) BIT (spec for Au wire 0.9 um: wire pull – 2.7 gf, ball shear – 6 gf)



Note : Failure mode for wire pull is neck break, failure mode for ball shear is bond lift

Figure 4. FABs diameter and BIT result with flow rate 0.5 -0.7 L/min

Force Profile Optimization.

With the thinner thickness of Al at 0.65um is one of the thinnest that has been studied and can't use any normal bonding like the thicker Al. So this study has been conducted to find the bonding concept for such a thin Al thickness. Force profile is a combination of initial force, bond force

Table 3. Wire bond parameter setting for thermosonic bonding at 200C

Set	Initial Force	Force	USG
1	High	Low	Low
2	High	Low	High
3	Low	High	Low

Bondability of each parameter set is shown in Figure 5. The average pull forces of all sets are not significantly different and are greater than specification. The average shear forces of all set are significant different but all are greater than specification. Al splash and Al remaining of sample ball bonds are shown in Figure 6. With High USG, high Al splash will be created at ball peripheral and result in low Al remaining on that position as same as high force base the bonded ball will be squashed out at capillary tip position which also makes the Al remain lower on that particular position. While gradually reduce in force like parameter set 1 incorporate with low USG will help to solve this issue to get the uniformm Al thickness remaining and less Al splash. Parameter set 1 was selected since x-section result shows good uniformity of the Al thickness and less Al splash when compare with others.

flow and compared to the results of Au wire product. As shown in Table 4, all samples passed electrical test with a good BIT result.

Table 4. Reliability stress test and result

Leg	Test	TC 500 cyc	HA 264 hrs	HTB 168 hrs	HTB 500 hrs
Cu wire Lot 1	Bondability	Pass	Pass	Pass	Pass
	Electrical test	0/77	0/77	0/77	0/77
Cu wire Lot 2	Bondability	Pass	Pass	Pass	Pass
	Electrical test	0/77	0/77	0/77	0/77
Cu wire Lot 3	Bondability	Pass	Pass	Pass	Pass
	Electrical test	0/77	0/77	0/77	0/77
Cu wire Lot 4	Bondability	Pass	Pass	Pass	Pass
	Electrical test	0/77	0/77	0/77	0/77
Au wire	Bondability	Pass	Pass	Pass	Pass
	Electrical test	0/77	0/77	0/77	0/77

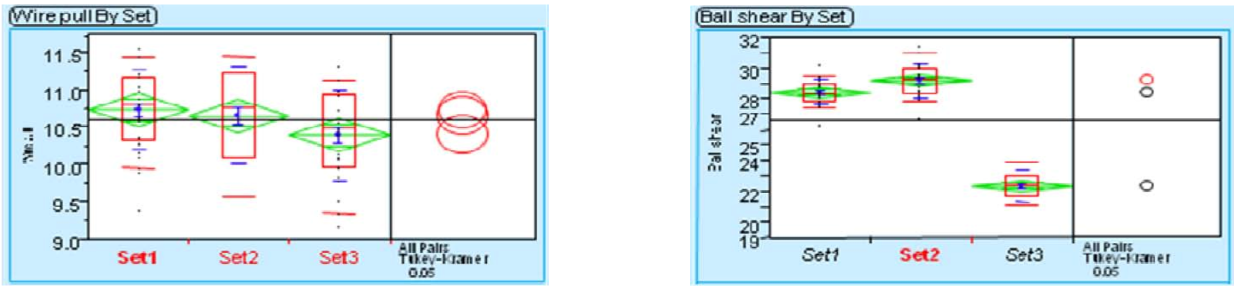


Figure 5. Ball she ear and wire pull results for each force profile set

Parameter Set 1 Parameter Set 2 Parameter Set 3

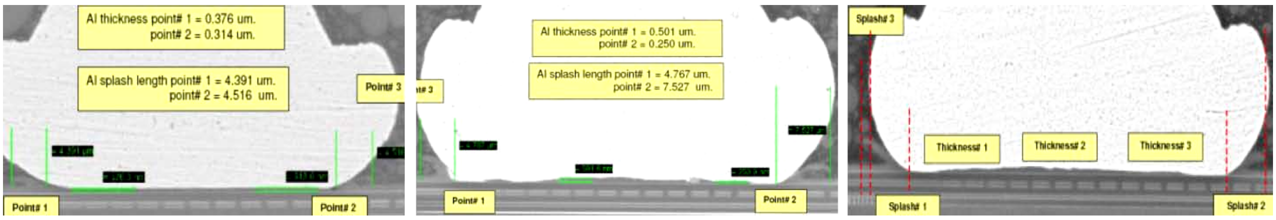


Figure 6. Al Splash and Al remaining of sample ball bond with 3 sets of force

Package Reliability Stresses

With the optimized parameter set, Cu wire 0.9 mils diameter was bonded on AlCu 0.5% metallization pad 0.65 um thickness of live dies from 4 different lots and assembled in TSOP for environment reliability testing. The reliability stresses are Temperature cycle (TC, -40C/150C) 500 cycles, HAST (HA, 130C/85%RH) 264 hours and High temperature bake (HTB, 150C) 168/500 hours. The sample size is 77 units per stress test per lot. BIT and electrical performance were characterized with standard manufacturing test

Conclusion

Three bonding parameters which are EFO gap, mixed gas flow rate and force profile were optimized to identify the potential parameter range for Cu wire bonding in high volume manufacturing.

− EFO gap in one parameter that has effect on FAB. In this study, it was found that EFO gap ranging from 20-35 mils results in good FABs and EFO gap 20 mils was selected in order to minimize the heat loss.

− Mixed gas flow rate is another parameter that plays important role on FAB. From the experiment, consistent FABs were formed under flow rate 0.5-0.7 L/min.

− Force profile with ramp-down force and low USG were determined to be an optimum parameter set for the selected product.

Bondability and bond reliability including electrical performance of product with the optimized bonding parameter set were verified, with comparable result to those of Au wire product.

References

1. Thomas, S. and Reynoso, D. (2009). Reliability of Cu wire bonding on active area for automotive applications. *Proc. of 11th EPTC* : 363-368.

2. Hang, C., Wang, C., Shi, M., Wu, X. and Wang, H. (2004). Study of copper free air ball in thermosonic copper ball bonding. *Proc. of 6th IEEE* : 414-418.

3. Foley, J., Clauberg, H. and Chylak, B. (2010). Enabling high volume fine pitch copper wire bonding: Enhancements to process and equipment capability. *Proc. of 3rd ESTC* : 1-4.

4. Xu, H., Liu, C., Silberschmidt, V. V. and Wang, H. (2008). Effects of process parameters on bondability in thermosonic copper ball bonding. *Proc. of 58th ECT*C : 1424-1430.

5. Li-ning, S., Yue-tao, L. and Yan-jie, L. (2009). Factors governing heat affected zone during wire bonding. *Trans. Nonferrous Met. Soc. China.* **19** : s490−s494.

6. Uno, T., Terashima, S. and Yamada, T. (2009). Surface-enhanced copper bonding wire for LSI. *Proc. of 59th ECTC*. 1486-1495.

7. Pequegnat, A., Kim, H.J., Mayer, M., Zhou, Y., Persic, J. and Moon, J.T. (2011). Effect of gas type and flow rate on Cu free air ball formation in thermosonic wire bonding. *Microelectronics Reliability*. **51(1)** : 43-52.