Fine Gold and Coated-Ag Bonding Wire: Vertical Wire Bonding

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Abstract

Wire bonding is an important technique in microelectronics packaging; high precision vertical wire bonding (vertical array arrangements) is investigated in detail in the memory sector with stacked devices. This study focuses on the development of vertical wire bonding using bonding wires ranging from 18 to 30µm in diameter, including gold (Au), silver (Ag), and copper (Cu) based wires. The vertical wire bonding method is evaluated on four stacked and conventional devices. Factors such as vertical wire post height, wire diameter, and wire elongation are examined. Bonding assessments encompass a range of vertical wire post heights from 100µm to 1mm. A stable bonding process window is determined for a low variation in post height (ΔH) within 10µm for tested ranges from 150 to 500µm. Wires with moderate ductility, exemplified by a 4% Elongation (EL) in 4N (99.99%) Au and Coated-Ag, exhibited with low variation in X-shift and Y-shift, along with post height across the studied elongation range of 2-8% EL. All the examined wire types: 4N Au, 2N (99%) Au, gold coated silver (Coated-Ag), Alloyed-Ag, gold flash palladium (Pd) coated copper (AFPC), and bare Cu (soft 4N Cu), met the precision requirements for vertical wire bonding. The study reveals that vertical wire bonding, a key process for microelectronics assembly in stacked devices, can be achieved with a collection of wire materials, given that proper attention is directed towards optimizing factors such as wire diameter, elongation, vertical wire post height, and capillary types/dimensions.

Key words

Vertical wire bonding, stacked devices, vertical wire post height, bonding wire

I. Introduction

In the last few years, a new era in electrical interconnection is the assembling of bond arrays in die-to-die circuitry platform. The evolution of this technology is driven by the need for higher performance, greater miniaturization, and better reliability in microelectronics devices. The technological development supports electromagnetic interference (EMI) shielding, invented by Invensas (CA) with higher aspect ratio interconnection and higher input/output (I/O). Industrial demand is for balanced stiffness and a ductile bonding wire that could possess excellent free air ball formation, good ball bond bondability, pseudo stitch bond (un-bond), reverse bend to form vertical post, cut the wire with sharp fractured tip on pull without elongated edges, etc. Bare/doped/alloyed/coated gold, copper, silver based bonding wires are examined. However, palladium coated copper wire (CuPd) satisfied all the requirements in the initial stages of this approach – vertical wire bonding, especially for EMI shielding technology [1-3]. The diameter commonly examined was from 15 to 65µm. Epoxy molding compounds (EMCs) developed for copper and silver-based bonding wires limits chlorine and sulfur below 20ppm that is formulated with ion-catchers, demonstrated longer reliability life of copper/silver bonded balls [4]. The present study gives an outline of the findings on vertical wire bonding of fine bonding wires: 4N Au, 2N Au, Coated-Ag, Alloyed-Ag, soft 4N Cu and AFPC.

II. Materials and Method

Alloyed gold/silver/copper core was continuously cast using an induction furnace under high vacuum (greater than 10^{-4} torr). The continuous cast 7 to 25mm rod was drawn to fine wire diameter 15 to 50µm. At an intermediate wire drawing stage for diameter between 100 and 500µm, the silver/copper wire core was plated with noble metals, further drawn to fine wire size, annealed, and vacuum packed for bonding.

The units were bonded using Kulicke & Soffa (KNS) iConn+ bonder upgraded with “Vertical Connect” software to bond vertical array arrangement mode (vertical wire bonding). Bonded ball and free air ball (FAB) of 4N Au, 2N Au and Coated-Ag wires were processed under atmosphere. Alloyed-Ag, soft 4N Cu, CuPd and AFPC wires were examined purging protective or inert gases, firing 40 to 80mA EFO current, targeting 1.55-2.0 BSR, and maintaining 760µm (30mil) wand gap. All wires were bonded on BGA 2x2 and four stacked devices for bond pad pitch 80µm and 100µm, respectively. Ball shear was tested using DAGE4000-plus. FABs and bonded balls were observed in the Zeiss Sigma Model scanning electron microscope (SEM) for spherical shapes, off-centered balls, and vertical wire post height. Furthermore, the bonded balls were recorded/ measured using optical microscope and SEM.

III. Results and Discussion

A. Dimensions of vertical wire bonding using 25µm Coated-Ag wire.

Typical vertical wire bonded images are shown in Fig.1 using 4%EL, 25µm Coated-Ag wire. Interestingly, the wire bonds show excellent fractured tail cut portion without sharp extended edges on either side. From optical scope measurement, alignment of the wire post height (ΔH) showed <6µm accuracy for 500µm vertical wire post height. SEM observations showed vertical wire post remained nearly straight (mild bend). Wire near to bell revealed slight deformation (plastic) and mild reduction in wire diameter. Bonded ball bondability remained the same as conventional bonding.

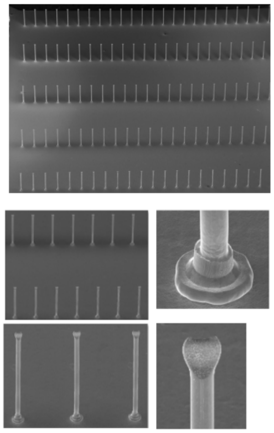
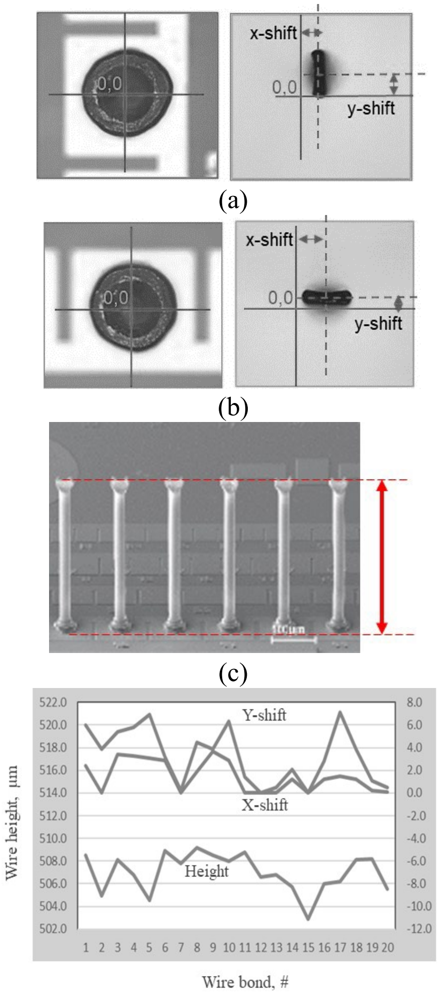


Fig.1 Typical vertical wire bonding using 25µm Coated-Ag wire, for 500µm vertical wire post height.

Three important features are measured using optical scope, from 100 to 1000X magnifications quantifying the dimensions of the variation in post height (ΔH), variation in displacement of wire fractured (cut) tip X-shift and Y-shift (Fig.2). The tip displacement is measured by first setting zero (0,0) on the focused exact center point of bonded ball. Next, the cut wire tip portion is focused marking the center of it, quantify the X-shift and Y-shift of the wire post with reference to (0,0) of the bonded ball center. Magnitude of the shift varies along the number of wires bonded along X-axis (X1 and X2) and Y-axis (Y1 and Y2) of the device. Similarly, variation in post height is measured manually with the digital reader attached to optical scope. First, focus bonded ball center then focus cut wire tip center, difference between the distance moved along z-axis provides vertical wire post height and its variation (Fig.2). The deviation of post height from target is measured as variation in post height (ΔH). Variation in wire tip displacement (X-shift and Y-shift) and post height, measured for 20 wire bonds along the bond line showed similar magnitude of variation less than 10µm, for 30.5µm diameter Coated-Ag and 500µm post height (Fig.2d).



(a)

(b)

(c)

(d)

Fig.2 Dimensions of vertical wire bonding: wire tip displacement (a) X-shift & Y-shift along Y-axis of the device, (b) X-shift & Y-shift along X-axis of the device, (c) vertical wire post height, and (d) measured values for 20wires along the bond line, bonded using 30.5µm diameter Coated-Ag wire, for 500µm vertical wire post height.

B. *Performance of 20µm diameter 4N Au, Coated-Ag and Soft 4N Cu wires, bonded for 150 to 280µm vertical wire post height.*

Table.1 provides the measured values of X-shift, Y-shift, and variation in post height (ΔH) for three different wires 4%EL 4N Au, 4%EL Coated-Ag, and 10%EL Soft 4N Cu, bonded using 20µm wire diameter for three vertical wire post heights 150, 210 and 270µm. Both X-shift and Y-shift revealed less than 6µm variation, while variation in post height showed up to 10µm value. Fig.3 shows the SEM image of the vertical wire bonds processed for three different vertical wire post heights. Plastic deformation with a bend and with mild wire diameter reduction near neck are evident.

Table.1 X-shift & Y-shift, variation in post height of 20µm diameter 4N Au, Coated-Ag and soft 4N Cu wires.

	Vertical post height, µm	X-shift, Y-shift and ΔH, µm		
		4N Au	Soft 4N Cu	Coated-Ag
%EL		4	10	4
X-shift, µm	150	0 to 4	0 to 2.5	0 to 3.5
	210			
	270	0 to 1.5		0 to 2.5
Y-shift, µm	150	0 to 5	1 to 5.5	0 to 5.5
	210			
	270			1.5 to 4.5
Variation in post height, µm	150	2 to 9	3 to 8	4 to 9
	210	2 to 4.5	2 to 6	2 to 6
	270	3 to 9	4 to 9	2.5 to 9

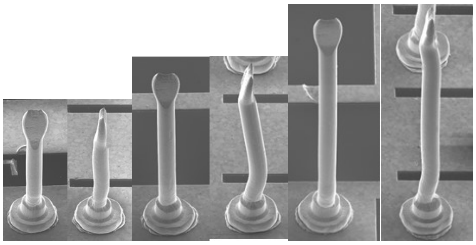
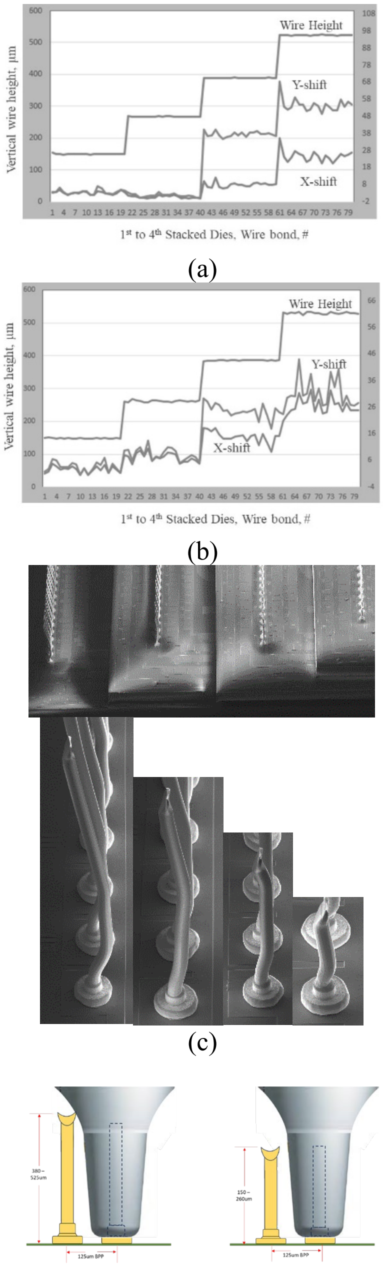

(a) (b) (c)

Fig.3 Vertical wire bonding of 20µm Coated-Ag wire for the vertical wire post height: (a) 150µm, (b) 210 µm, and (c) 270 µm.

C. *Performance of 18µm diameter 4N Au and Coated-Ag wires, for from 150 to 520µm vertical wire post height, bonded using four stacked devices.*

Vertical wire bonding approach is useful to bond stacked devices demanding different vertical wire post height from 100 to 500µm. Fig.4a indicates high variation in X-shift & Y-shift from 20 to 30µm for 3rd and 4th bonded stacked devices (388 to 520µm heights) when bonded using 18µm, 4%EL 4N Au wire for vertical wire post heights in the range from 150µm to 520µm. The variation in post height (ΔH) is within less than 10µm for all 4 stacks.



(a)
(b)
(c)
(d)

Fig.4 Variation of X-shift, Y-shift and post height of the wires bonded on to four stacked devices: (a) 4%EL, 18µm 4N Au wire, (b) 4.1%EL, 18µm Coated-Ag wire, (c) SEM observation of 4.1%EL, 18µm Coated-Ag wire bonded on four stacked devices, and (d) illustration on the limitation of capillary bottleneck.

Similar is the behavior with 18µm, 4.1%EL Coated-Ag wire bonds, revealed less than 10µm variation of X-shift and Y-shift for 1st and 2nd bonded stacked dies. Thus, X-shift and Y-shift have high impact on stacked wire bonds than post height, because of the limitations of capillary bottleneck dimension not adequately tall enough to bond high vertical wire post height (388 to 520µm), especially for 18µm diameter vertical wire bonding (Fig.4d). It is evident from SEM observations (Fig.4c) the angle of bend is clear for the four wire posts bonded for different heights.

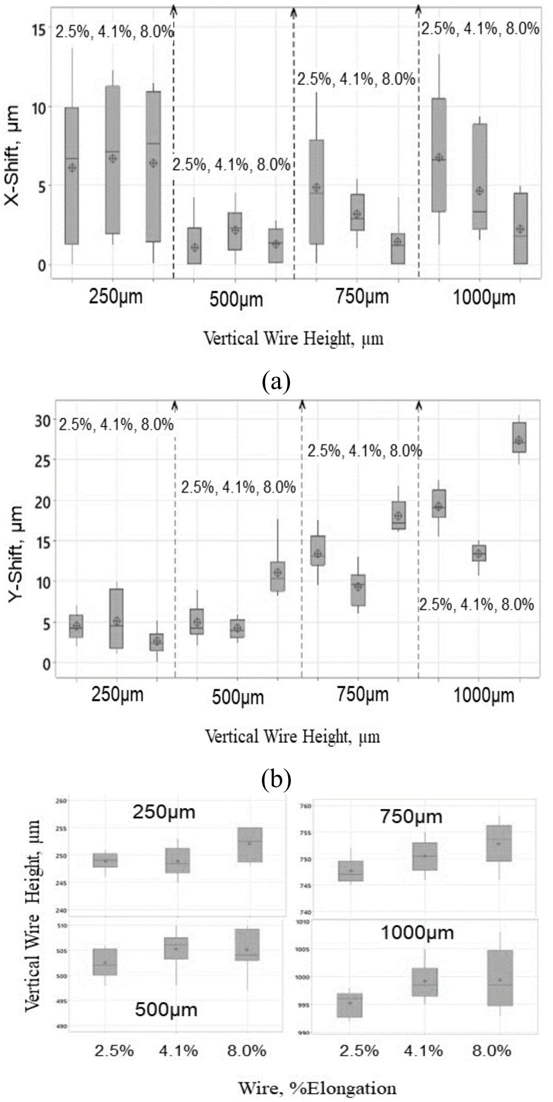
D. Performance of 30.5µm diameter Coated-Ag, between 250µm to 1mm vertical wire post height for varying %Elongation.

Surprisingly, the behavior is different when bonded the same wire type 4%EL Coated-Ag for thicker diameter 30.5µm, from 250µm to 1000µm vertical wire post height. Lower vertical post height of 250µm revealed (Fig.5) high variation of less than 15µm, could be due to steep bending stress occurred near the heat affected zone (neck) that causes high deformation of the neck portion, impacting X-shift & Y-shift. In addition, observed high variation in post height ΔH of ~30µm, for 1mm vertical wire post height, which might be due to high intensity of bending at mid of the loop (leading to high deflection at the mid of the loop). Perhaps, 400 to 500µm vertical wire post height is optimal to bond with minimal deformation/deflection.

Interestingly, X-shift, Y-shift and variation in post height are less than 15µm for 250µm vertical wire post height for 2.5 to 8%EL (14 to 17g break load), and 30µm diameter Coated-Ag wire. Moreover, variation of the shift and post height is less than 10µm for the bonds bonded using 2.5 to 4%EL wires, and for 500µm vertical wire post height. But variation increases to less than 20µm for higher 8%EL wire (Figs.5a & b). Higher the ductility (8%EL) higher the Y-shift variation of up to 30µm magnitude and bonded for 1000µm vertical wire post height. Thus, ductility (%Elongation) of the bonding wire predominantly influence the Y-shift (along the ultrasonic displacement of the capillary motion) compared to X-shift and variation in post height.

E. Performance of doped, alloyed, and coated Au/Cu/Ag based bonding wires studied using 30.5µm wire diameter and 500µm vertical wire post height.

Examined Au/Cu/Ag based five bonding wire types also revealed less than 10µm variation of X-shift, Y-shift, and post height (Fig.6) for 30.5µm diameter and 500µm post height. Gold flash palladium coated copper wire (AFPC) with 10%EL exhibited the lowest X-shift and Y-shift of less than 3µm being stiff in nature. Coated-Ag and 4N Au wires with 4%EL demonstrated lower shift values (less than 6µm) than Alloyed-Ag and 2N Au wire types (less than 10µm). Alloyed-Ag (94.5%Ag) with 10%EL revealed highest shift among the tested wires. Furthermore, variation in post height (ΔH) of 4N Au and 2N Au wires revealed low variation of about 3µm compared to other tested wires Alloyed-Ag, Coated-Ag and AFPC with less than 6µm (Fig.6c).



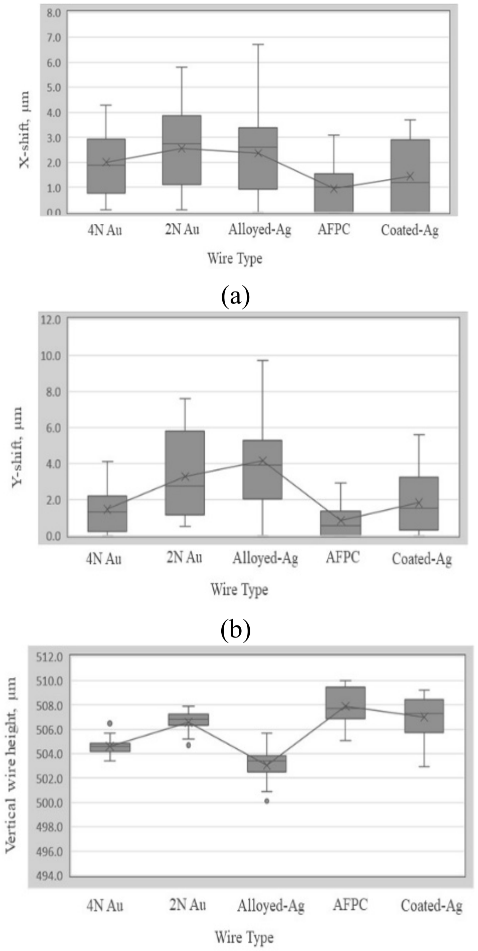
(a)

(b)

(C)

Fig.5 Measured dimensions of vertical wire bonding, distribution of variation of wire tip displacement (X-shift & Y-shift) and variation in post height (ΔH) of 30.5µm Coated-Ag wire with different ductility (%Elongation).

It appears that the present observations on vertical wire bonding behavior is similar to that recently reported by Kulicke & Soffa (K&S) [5] with the exception that there are slight increases in X-shift, Y-shift, while variation in post height remained the same. K&S demonstrated the capability of vertical wire bonding as an array for EMI shielding applications and as an interconnect with reference to Au, CuPd, Ag based bonding wires.



(a)

(b)

(c)

Fig.6 Variation of X-shift, Y-shift, and post height (ΔH) of 4N Au, 2N Au, Coated-Ag, Alloyed Ag, AFPC wire bonds bonded using 30.5µm wire for 500µm vertical wire post height.

Table.2 provides the properties of the tested bonding wires that perform well on vertical wire bonding of industrial requirements. Table.3 consolidates the values of X-shift, Y-shift, and variation in post height (ΔH) for the examined wire diameter and vertical wire post height. The table also provide expected magnitude of the X-shift, Y-shift and ΔH for the entire wire diameter and vertical wire post height in the present practice of EMI shielding and interconnect applications.

Table.2 Measured mechanical, physical, and electrical properties of tested bonding wires.

	Yield Strength, MPa	Elastic Modulus, GPa	Electrical Resistivity, µΩ.cm	Micro-hardness (10mN/5s), HV	%EL
4N Au	~210	90	2.36	90 - 100	4.0
2N Au	~190	90	3.24	95 - 105	4.0
Coated-Ag	~150	80	2.34	80 - 95	4.1
Alloyed Ag (94.5% Ag)	~190	80	3.87	70 - 80	8.0
Soft 4N Cu	~90	90	1.69	85 - 95	10.0
AFPC	~180	95	1.80	95 - 105	11.0

Table.3 Observed maximum X & Y shift and Z height consistency of bare, doped/alloyed, and coated Au/Ag/Cu based bonding wires on vertical wire bonding.

X shift and Y shift and Z height consistency, µm									
Vertical Wire Height, µm	Wire diameter, µm								
	15	18	20	23	25	30	33	38	50
100	<40	<30	<20	<20	<20	<15	<15	<10	<10
150	<40	<30	<20	<20	<20	<15	<15	<10	<10
250	<50	<30	<20	<20	<20	<10	<10	<10	<10
500	<50	<50	<20	<20	<20	<10	<10	<10	<10
750	<60	<40	<30	<20	<20	<20	<10	<10	<10
1000	<60	<40	<40	<30	<20	<20	<20	<20	<20
1200	<60	<40	<40	<30	<20	<20	<20	<20	<20

Even though, the tested doped/alloyed/ coated Au/Cu/Ag based wires show encouraging results, the evaluation is limited to the sample size of 200 bonds. Design of new chemistry of a wire is expected to produce controlled grain structure and consistent vertical wire bonding performance (less than 5 to 10µm). Where, X-shift and Y-shift to be less than 10µm, for thinner wire diameter (15 to 30µm), and for vertical wire post height of 150 to 300µm. Heraeus will be investigating to attain robust wire for vertical wire bonding practice.

III. Conclusions

The use of gold, silver and copper based doped, alloyed, and coated bonding wires in microelectronics packaging is critical for ensuring excellent electrical connections, especially vertical wire bonding in stacked devices. These types of bonds must be executed with precision. The factors that contribute to the variation in wire shift (X-shift, Y-shift) at the fractured tail ends and variation of post height (ΔH), are indeed important for the success of the vertical wire bonding process:

(a) **Vertical wire post height**: the feasibility of bonding within a range of 100µm to 1mm post height is an advantage. While, maintaining post heights from 150 to

280µm ensures consistency by less than 10µm. This consistency is fundamental for achieving physical interconnection without electrical failures.

(b) **Wire diameter and capillary selection**: It is possible to bond wires with diameter 15 to 50µm, but the choice of capillary, including its type and dimensions, is vital to prevent a bottleneck during bonding. Bonding wire between 18 and 30µm size ensures variation in X-shift, Y-shift less than 10µm.

(c) **Wire ductility and micro-hardness**: Ductility of wire impacts vertical wire performance, following range is suggested for the wire types:

- For 4N Au, 2N Au and Coated-Ag wires, an elongation ranges from 3 to 4%EL is recommended within the commercially available values, 2 - 8%EL.
- For soft 4N Cu and AFPC wires, perform optimally at 10 to 14%EL, suggests that they are ductile and can absorb bending stresses during bonding.
- Alloyed-Ag, with 94-96% Ag composition, is recommended to have an elongation between 8 and 11%
- The microhardness of these wires is between 70HV and 105HV
- Wire surface can affect the variation in post height (∆H) because of easier tearing at the wire surface defect on pulling and should be considered for optimal drawn quality.

(d) Bending stress exerted on the wire is a function of multiple variables, including vertical wire post height, wire diameter, and wire elongation. To achieve an effective vertical wire bonding (vertical array arrangement), these factors should be carefully optimized in conjunction with appropriate capillary type and dimensions.

(e) Furthermore, to investigate and develop robust wire with new chemistry that satisfies less than 10µm wire-cut shift (X & Y axis), especially for fine wire from 15 to 30µm diameter.

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