Fine Pitch Vertical Wire Bonding

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Abstract

Vertical wire bonding for fine pitch application is examined in memory sector focusing on the development of using half-cut capillary and 18µm bonding wire. Factors such as vertical wire post height and wire types are mainly investigated. A stable bonding process window with low variation in post height (ΔH) within 10µm is observed for 150 to 350µm post height. Wires with moderate ductility of 4N gold (Au), 2N Au and Coated silver (Ag) exhibited low variation in X-shift, Y-shift, and post height. All other examined wire types: Alloyed-Ag, soft 4N copper (Cu), 2N Cu, gold flash palladium (Pd) coated copper (AFPC) met the requirements for vertical wire bonding on optimizing the key factors, wire diameter, wire elongation, vertical wire post height, and capillary type.

Key words

Fine pitch bonding, half-cut capillary, vertical wire bonding, stacked devices, vertical wire post height

I. Introduction

The use of Au, Ag and Cu based doped, alloyed, and coated bonding wires in microelectronics packaging is critical for ensuring excellent electrical connections, especially vertical wire bonding in stacked devices (Fig.1). 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 [1-5]:

(a) Bonding within a range from 100µm to 1mm vertical wire post height is feasible. While, maintaining post heights from 100 to 400µm ensures consistency. This consistency is fundamental for achieving physical interconnection without electrical failures.

(b) It is possible to bond wires with diameter 15 to 50µm, but capillary type and dimensions is vital to prevent a bottleneck during bonding. Bonding wire between 18 and 30µm size ensures low in variation in X-shift and Y-shift.

(c) Ductility of wire impacts vertical wire performance, following range is suggested for the wire types:
   - 4N Au, 2N Au and Coated-Ag wires with moderate ductility recommended within the commercially available ranges in technical data sheet.
   - Soft 4N Cu and AFPC wires, perform optimally at moderate ductility recommended in the technical data sheet, suggests that they are ductile and can absorb bending stresses during bonding.

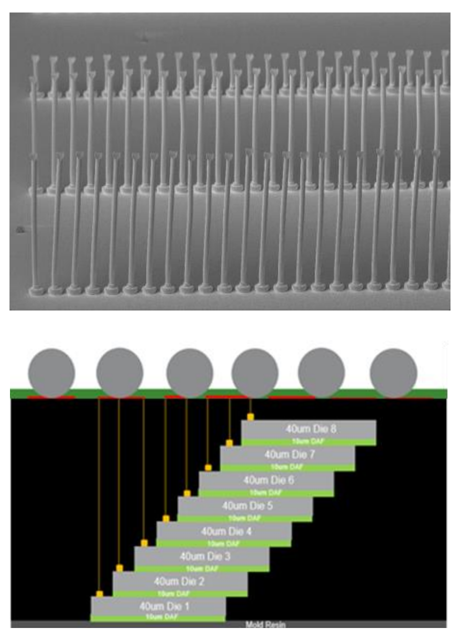


Fig.1 Typical vertical wire bonding of memory devices.

- Elongation for Alloyed-Ag (94-96% Ag content) wire also recommended with moderate ductility to perform well.
- Microhardness of these wires are between 70HV and 110HV

Wire diameter, wire elongation, vertical wire post height, capillary type and dimensions are vital factors to be considered to attain good vertical wire bonding [1].

The present study discusses the benefits of using half-cut capillary and Pro-Vertical Loop software on vertical wire bonding of fine bonding wires (4N Au, 2N Au, Coated-Ag, Alloyed-Ag, soft 4N Cu, 2N Cu and AFPC).

II. Materials and Method

Alloyed gold/silver/copper was continuously cast using an induction furnace under high vacuum (greater than 10^{-4} torr). The continuous cast 6 to 25mm rod was drawn to fine wire diameter 18 to 30µm, further drawn to fine wire size, annealed, and vacuum packed for bonding. At an intermediate wire drawing stage for diameter between 100 and 500µm, the silver/copper wire core was plated with noble metals to develop coated wires.

The units were bonded using Kulicke & Soffa (KNS) half-cut capillary (Fig.2). iConn+ bonder upgraded with "Pro-Vertical Loop" software was used 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, 2N Cu, and AFPC wires were processed 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 3x3 and four stacked devices for bond pad pitch of 60µm. 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 dimensions of the bonded balls were observed/recorded using optical microscope and SEM.

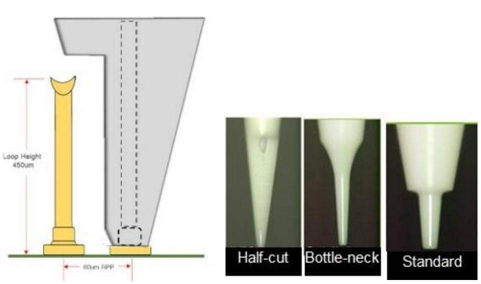


Fig.2 Illustration of fine pitch 60µm bond pad pitch (BPP) vertical wire bonding using half-cut capillary.

III. Results and Discussion

First and foremost, bond quality of vertical wire bonded units is observed for half-cut capillary against standard capillary. Loss of ultrasonic power is anticipated during bonding with half-cut capillary compared to standard capillary application. Therefore, 25 to 30% more power is supplied to bond fine wires using half-cut capillary than standard capillary. Fig.3 shows the performance of 4N Au wire bonded using half-cut capillary on ball size, ball height, and ball shear. Similar bondability is observed between standard capillary and half-cut capillary.

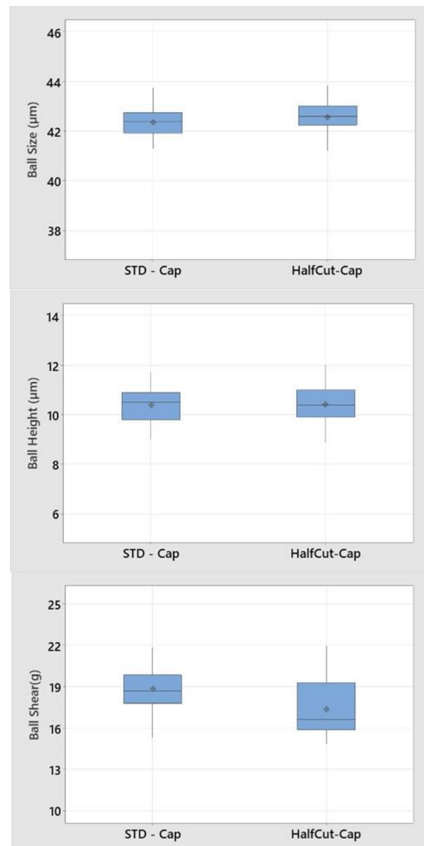


Fig.3 Bondability of vertical wire bonded using 18µm 4N Au wire for 250µm vertical wire post height.

The important features variation in post height (ΔH), and variation in displacement of wire fractured (cut) tip X-shift and Y-shift are measured using optical scope (50X to 1000X magnifications) quantifying the dimensions of the bonded wires [1].

A. Performance of 18µm diameter for three different wire types of 4N Au, bonded for 150 to 350µm post height.

Table.1 provides the measured values of X-shift, Y-shift, and variation in vertical wire post height (ΔH) for three different 4N Au wire types. Wires are bonded using 18µm diameter, for 150, 250 and 350µm post heights. Both X-shift and Y-shift revealed less than 6µm variation, while variation in post height showed up to 10 µm variation. Fig.4 shows the SEM image of the vertical wire bonds processed for different vertical wire post heights. Plastic deformation with a bend and with mild wire diameter reduction near neck are evident even when bonded using half-cut capillary.

Table.1 X-shift, Y-shift, and variation in post height of 18µm 4N Au wire, bonded using 3 types of wires A, B, and C.

	Vertical post height, µm	Variations in X-shift, Y-shift and ΔH, µm		
		A	B	C
X-shift, µm	150	<3	<2	<2
	250	<3	<3	<3
	350	<4	<4	<4
Y-shift, µm	150	<3	<3	<2
	250	<4	<3	<3
	350	<6	<5	<5
Variation in post height, µm	150	<10		
	250			
	350			

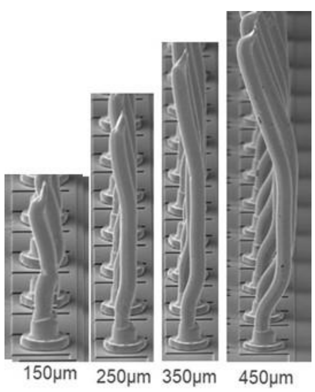


Fig.4 Vertical wire bonding of 18µm 4N Au wire for varying vertical wire post height from 150µm to 450 µm.

B. Performance of 18µm diameter 2N Au wire, bonded for 150 to 350µm vertical wire post height.

Table.2 indicates low variation in X-shift and Y-shift when bonded using 18µm 2N Au wire for vertical wire post heights in the range from 150µm to 350µm. The variation in post height (ΔH) is within 8µm. It is well known that bonding 2N Au wire to aluminum pad possess longer reliable life on high temperature storage (HTS) test forming slower rate of formation of intermetallic compounds and Kirkendall voids [6]. Au-1wt%Pd, 2N Au wire do possess longer reliable life on uHAST and PCT evaluations.

Table.2 X-shift & Y-shift, variation in post height of 18µm 2N Au wire.

	Vertical post height, µm	Variations in X-shift, Y-shift and ΔH, µm
X-shift, µm	150/250/350	<3
Y-shift, µm		<4
Variation in post height, µm		<8

C. Performance of 18µm diameter Alloyed-Ag and Coated-Ag wires, bonded for 150 to 350µm post height.

Similar is the behavior between Coated-Ag and Alloyed-Ag wire bonds, revealed less than 5µm variation of X-shift, less than 8µm variation of Y-shift, and less than 9µm variation of vertical post height, tested for 150 to 350µm wire post height (Table.3). Interestingly, Coated-Ag wire bonds on HTS of the un-molded device at 200°C revealed zero ball/stitch pull and ball shear until 4000 hours of storage. The slower rate of formation of silver-aluminide of <5.2 µm without Kirkendall voids is noticed [7]. On epoxy molded device with 5 to 7 pH green epoxy molding compound (low chlorine and sulfur), Coated-Ag passed 4000 hours on HTS test at 175°C, 480 hours on bHAST at +20V, 130°C, 85%RH, and 1000 hours on uHAST at 130°C, 85%RH, with respect to electrical resistance measurement. Cross-section of all the passed reliability tested devices revealed absence of Kirkendall voids and cracks related to galvanic corrosion [7].

Table.3 X-shift & Y-shift, variation in post height of 18µm diameter of alloyed and coated Ag bonding wire.

Wire types		Vertical post height, µm	Variations in X-shift, Y-shift and ΔH, µm
Alloyed-Ag (94.5% Ag), and Coated-Ag	X-shift, µm	150/250/350	<5
	Y-shift, µm		<8
	Variation in post height, µm		<9

D. Performance of 18µm diameter bare, alloyed, and coated Cu wires, bonded for 150 to 350µm post height.

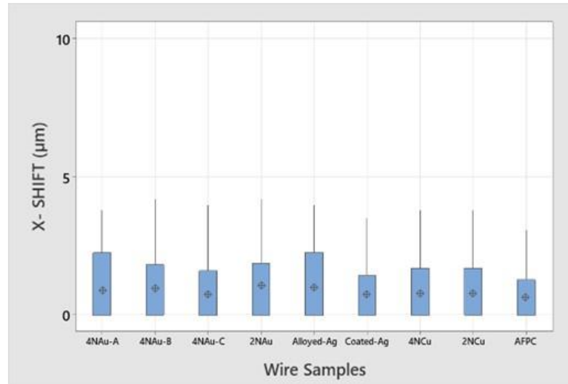
Examined 3 types of Cu wires bare, alloyed and coated also revealed less than 5µm variation of X-shift, and Y-shift. As well as less than 10µm variation in post height for 18µm diameter and 150 to 350µm post height when bonded using half-cut capillary (Fig.5).

All the tested wires showed nearly the same behavior when bonded with half-cut capillary and using Pro-Vertical Loop software, the elongation of the wires followed technical data sheet practice (Table.4).

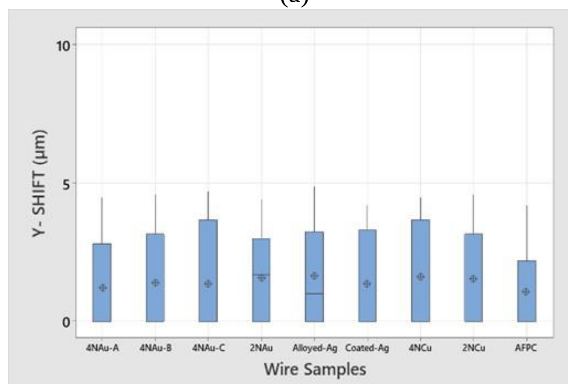
Table.4 Mechanical properties of the tested bonding wires.

		Yield Strength, MPa	Micro-hardness, HV (10mN/5s)
4N Au	A	210	90 – 100
	B	200	
	C	210	
2N Au		190	95 – 105
Coated-Ag		150	80 - 95
Alloyed-Ag (94.5%)		190	70 – 80
Soft 4N Cu		90	85 – 95
2N Cu		90	85 – 95
AFPC		180	95 - 105

In summary, detailed vertical wire bonding evaluation with bare, doped, alloyed, coated Au/Cu/Ag based wires, bonded with half-cut capillary and using Pro-Vertical Loop software of fine wires from 18 to 30µm diameter revealed consistent wire bonding performance (Table.5, Fig.5). The uniqueness of attaining fine pitch application of this novel vertical wire bonding primarily depends on the controlled processing of the wire with moderate ductility within the commercial range defined in the technical data sheet.



(a)



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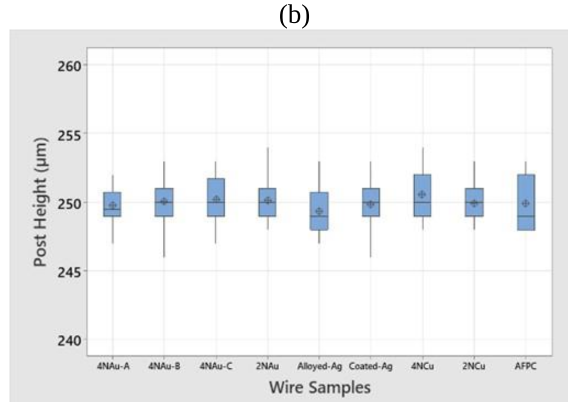

(c)

Fig.5 Variation of X-shift, Y-shift, and post height (ΔH) of 4N Au, 2N Au, Coated-Ag, Alloyed-Ag, soft 4N Cu, 2NCu, AFPC wire bonds bonded using 18µm wire for 250µm post height.

Table.5 Overall behavior of bare/doped/alloyed and coated Au/Ag/Cu based bonding wires on vertical bond arrangements using half-cut capillary.

X shift and Y shift, µm					
Vertical Wire Height, µm	Wire diameter, µm				
	18	20	23	25	30
150	<3	<3	<3	<3	<3
250	<4	<4	<4	<3	<3
350	<5	<5	<5	<4	<4
Z height consistency, µm					
Vertical Wire Height, µm	Wire diameter, µm				
	18	20	23	25	30
150	<6	<6	<5	<5	<5
250	<7	<6	<6	<6	<6
350	<10	<10	<8	<8	<8

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V. References

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