Properties of Fine Bonding Wires

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Abstract

Wire bonding enables miniaturization in microelectronic packaging, enhancing reliability by ensuring fine wires with critical physical, thermal, electrical, and mechanical performance for improved yield. This paper examines key properties of fine bonding wires, including:

1. Fusing currents were evaluated for doped gold (4N Au), alloyed gold (2N Au), alloyed copper (2N Cu), palladium-coated copper (CuPd), alloyed silver (1N Ag), and gold-coated silver (AuAg) wires over lengths of 0.5–10 mm and diameters of 15–50 µm (0.6-2mil). For example, a current of 260 mA was measured for an 18 µm 4N Au wire at a 10 mm length.
2. Electrical resistivity was measured using Resistomat 2316. For instance, a value of 2.32 µΩ·cm was obtained for a 0.7 mil soft 2N Cu wire.
3. Tensile strength (stress) and elongation (strain) were determined using an Instron testing system.
4. Melting point and specific heat capacity (Cp) were measured using fine wire samples. For example, a melting point of 1073 °C and Cp of 0.376 J/g˚K, were obtained for a 0.7 mil soft 2N Cu wire.
5. Thermal conductivity (TC) and coefficient of thermal expansion (CTE) were measured using fine rod samples. For example, TC of 235 W/m˚K and CTE of 14.9 ppm/˚K, were obtained for an 18 µm soft 2N Cu wire.
6. Alpha particle emission in solid-solution-strengthened gold wires (4N Au, 2N Au) is expected to be below 0.0002 CPH/cm².

Key words

Coated & alloyed copper wire, coated & alloyed silver wire, doped & alloyed gold wire

I. Introduction

Coated and alloyed copper and silver wire bonding have advanced rapidly in microelectronics packaging and are increasingly replacing gold wire. The process involves four main steps: forming a consistent, axisymmetrical, spherical free air ball (FAB); creating the first (ball) bond; forming the second (stitch) bond; and establishing the loop, ensuring reliability under stresses such as high-temperature storage (HTS), bHAST, and temperature cycling (TCT). High-purity (bare), doped, alloyed, and coated Au, Cu, and Ag wires have demonstrated reliable performance across diameters of 15–50 µm (0.6–2 mil) [1-6]. Recently, finer wires (18–20 µm) have become widely used, offering improved reliability, easier deformation, and a broader process window [7-12].

In manufacturing, 4N–5N (≥99.99%) purity raw materials are melted in a vacuum induction furnace, alloyed as required, and continuously cast into rods. The rods are cold drawn into wire at room temperature, annealed, and wound onto clean, and anodized aluminum spools (50 mm diameter). The finished wires are vacuum-packed to preserve quality prior to bonding.

II. Electrical Properties of Fine Bonding Wires

Fusing current is the maximum current a wire can carry before melting. Figure.1 shows measured fusing currents for doped 4N Au wires with diameters from 0.6 to 1.2 mil (15–30 µm), demonstrating the expected increase with diameter. Bare, alloyed and coated Cu wires exhibit fusing currents approximately 50mA higher than doped and alloyed Au wires. Similar behaviour of alloyed and coated Ag wires fusing current is observed compared to doped and alloyed Au wires (10 mm length).

For wire lengths below 5 mm, fusing current increases exponentially as length decreases (Table.1). A slight increase is also observed when length extends from 3.8 mm to 10 mm. Moreover, increase in wire length from 10mm to 20mm longer reveals closer fusing current magnitude. Fusing current of 4N and 2N purity wires are nearly the same whether Au or Cu matrix. Measurements were conducted at

room temperature under atmospheric conditions using a 300 ms input pulse current for all wire sizes. The fusing current was measured using Keysight N6705C DC power analyzer with an N6786A measurement unit and gold-plated conductive clamps.

Several methods to estimate fusing current in fine metal wires have been reported [1-3]. Predicted values for bonding wires of varying diameters and lengths (Table.1) follow similar trends but show differences from experimental results. No published data currently exists for fusing current behavior of Ag, Cu or Au wires under epoxy-molded conditions.

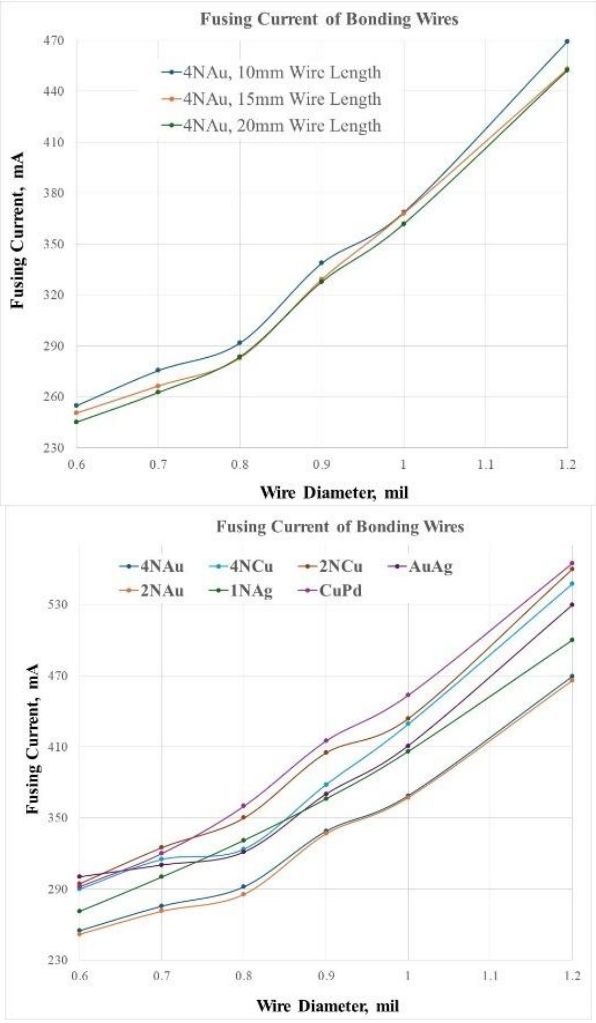


Fig.1 Fusing current of fine bonding wires as a function of diameter, measured using a Keysight N6705C power analyzer with an N6786A measurement module.

Electrical resistivity (ρ) is a key parameter for bonding wires, defined by $\rho = R \cdot A/L$, where R is the measured resistance, A is the cross-sectional area, and L is the wire length. Resistance is measured using Resistomat2316 with an appropriate gold-plated fixture surface to hold the fine bonding wire. Among high-conductivity metals such as Al, Au, Cu, and Ag. Gold, Cu, and Ag are preferred for ball bonding, as Al readily oxidizes during free air ball (FAB) formation. Although all four metals have a face-centered cubic (FCC) structure, they differ in atomic properties. Despite its higher oxidation tendency, aluminum remains widely used in wedge bonding due to its low cost.

The electrical resistivity of 4N Cu wire is approximately 1.69 μΩ·cm and is independent of wire diameter and length [4, 5]. Pd-coated Cu (CuPd) wire exhibits a slightly higher resistivity (~1.87 μΩ·cm) than 4N Cu wire. A key advantage of 4N Cu is its lower resistivity compared to other bonding wires, including 4N Au. Soft 2N Cu shows increased resistivity of 2.32 μΩ·cm, approaching that of 4N Au of 2.36 μΩ·cm.

AuAg (98.5% Ag) wire has a resistivity of approximately 2.34 μΩ·cm, like 4N Au, while alloyed 2N Au increases to about 3.1 μΩ·cm. The Ag core of AuAg is typically alloyed with 1.5 wt% Pd, resulting in higher resistivity than pure Ag [10]. Highly alloyed 1N Ag wires (e.g., 95.5% Ag) exhibit significantly higher resistivity of 3.87 μΩ·cm. For cost-effective applications requiring low electrical resistance, 4N Cu is the preferred; alternatively, AuAg wire offers a suitable balance of performance and cost.

Table.1. Predicted fusing current of fine bonding wires for varying diameters and lengths [4].

	Fusing Current (A)					
	Length, mm	Diameter, mil				
		0.6	0.7	1	1.5	2.0
4NAu	0.5	1.46	2.86	5.83	13.11	23.31
	3.8	0.19	0.38	0.77	1.73	3.07
	10	0.07	0.14	0.30	0.66	1.18
4NCu	0.5	2.36	3.21	6.55	14.74	26.20
	3.8	0.31	0.42	0.86	1.94	3.46
	10	0.12	0.16	0.33	0.75	1.33
AuAg	0.5	3.78	5.14	10.5	23.6	42.01
	3.8	0.50	0.68	1.38	3.11	5.53
	10	0.19	0.26	0.53	1.19	2.11

Inductance is primarily determined by geometry and is therefore largely independent of the bonding wire material, resulting in similar values for Au, Ag, Al, and Cu wires [4]. The inductance of a straight, non-magnetic wire can be calculated using standard analytical expressions based on its length and diameter.

$$L = l\left(\ln\frac{4l}{d} - 1\right)\cdot 200\times 10^{-9} \quad \text{..... Eqn.1}$$

where L is the inductance in nH, l is the length of the conductor in m, and d is the diameter of the conductor in m. Inductance remains the same for all fine bonding wires (type/length/diameter) of 1 nH.

Capacitance represents the energy stored between two surfaces at different electrical potentials. In straight conductive wires (e.g., Au, Ag, Al, and Cu), electrical energy is predominantly transmitted rather than stored. As a result, capacitance is typically negligible and is neither routinely measured nor calculated for such configurations.

III. Mechanical Properties of Fine Bonding Wires

In drawn, work-hardened state, the wire is stronger but more brittle, with ductility limited to about 1-2% elongation at fracture. Annealing reduces strength but significantly improves ductility, enabling easier deformation during bonding [4, 5]. Based on tensile testing conducted using an Instron-5400, the stress–strain behavior of annealed fine bonding wires (0.8mil) is presented in Fig.2. Table.2 compares the tensile response of fine 2N/4N Au wires with bare/alloyed/coated Cu wires of the same diameter. The malleable 5N Au raw material gold is doped to strengthen the 4N Au wire to be strong and stiff for excellent looping performance.

Soft 4N Cu and soft 2N Cu (2N Cu (S)) wires require the lowest deformation load, offering a processing advantage over standard 4N Cu wire (Fig. 2). The key approach involves reducing the stiffness of copper through annealing, enabling easier deformation during wire bonding (soft 2N Cu). Notably, the yield strength of soft 2N Cu (~80 MPa) is comparable to that of soft 4N Cu.

Literature data on Cu wires of varying purity (3N, 4N, and 5N) indicate only a marginal reduction in flow stress with increasing purity. This suggests that while 5N Cu wire is slightly softer than 3N and 4N variants, the difference is not significant on bondability [4].

The elastic modulus is similar across soft Cu, Au, and Ag wires. Alloyed 1N Ag and AuAg core wires exhibit enhanced deformability, as alloying facilitates easier deformation in the annealed state. During drawing, Cu shows distinct behavior, with its elastic modulus varying depending on processing conditions. For instance, soft 4N Cu can exhibit a modulus comparable to 4N Au and lower than that of standard (harder) 4N Cu. Additionally, soft 4N Cu demonstrates lower tensile strength than standard Cu at equivalent elongation (Table.2).

Surface quality is an important factor in the performance of annealed wires and is controlled through effective die management during the wire drawing process. The resulting wire surface is smooth, with a roughness <20 nm Ra [4].

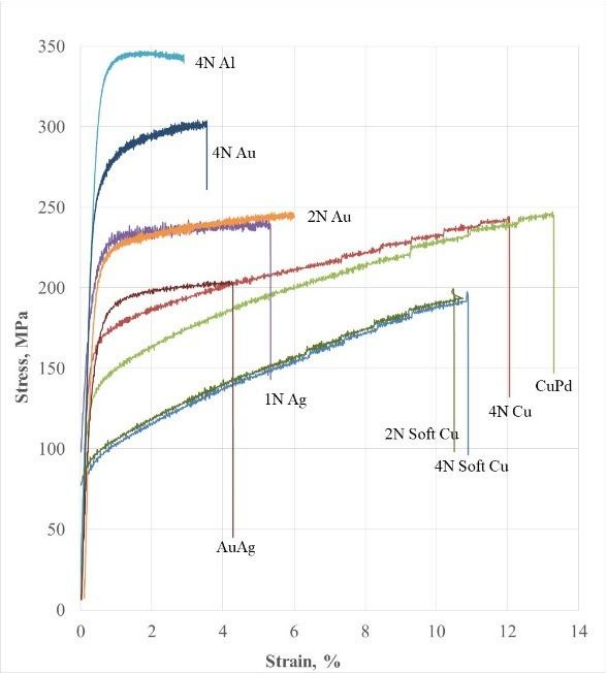


Fig.2 Stress-strain curve of all bonding wire types measured using 0.8mil diameter.

IV. Thermal Properties of Fine Bonding Wires

High purity 4N Cu wire exhibits melting point, thermal conductivity, coefficient of thermal expansion (CTE), and specific heat capacity (Cp) values comparable to bulk copper. In contrast, doped or alloyed Au, Ag, and Cu wires show deviations from their respective bulk properties, as summarized in Table.3. The reported properties for coated wires (CuPd and AuAg) correspond to their core materials.

Alpha particle emission in T6 SAC305 solder powder is controlled by using high-purity raw materials, specifically 4N Sn, 4N Cu, and 4N Ag, to produce the powder. Radioactive impurities such as lead (Pb), thorium (Th), uranium (U), and polonium (Po) are present at ppm to ppb levels. The measured alpha emission of T6 SAC305 solder powders (5 to 15µm particle size, ultra-low alpha (ULA) emission) exhibit an emission rate of approximately 0.00018 CPH/cm². The data is collected with several production batch powders for 99hours of test duration of a measurement. Thus, alpha emission rate of high purity bonding wires (5N Au, 4N Cu, and 4N Ag) with radioactive elements <1ppm level is expected to be at or below ultra-low alpha (ULA) levels of SAC305 say less than 0.0002 CPH/cm².

Table.3 Measured thermal properties of fine bonding wires.

Properties	4NAu	2N Au	4NCu	2NCu
Specific heat capacity (Cp), (J/g˚K)	0.129	-	0.385	-
Thermal Conductivity at RT, W/m˚K	220	290	400	370
CTE (20 to 100C), ppm	14.6	14.2	16.5	14.5
Melting Point, °C	1063	1063	1083	1054
	2NCu (S)	CuPd	1NAg	AuAg
Specific heat capacity (Cp), (J/g˚K)	0.376	0.352	-	0.23
Thermal Conductivity at RT, W/m˚K	235	400	360	330
CTE (20 to 100C), ppm	14.9	16.6	18.0	18.7
Melting Point, °C	1073	1081	1005	973

(* indentation load is 10mN for 5s)

Table.2 Measured mechanical properties of 18micron gold, bare/coated copper, alloyed silver bonding wires.

Properties	Units	4NAu	2NAu	4NCu	2NCu
Elongation	%	4	4	11	12
Break load	g	6	7 9	6.5	7
Tensile Strength	MPa	300	250	200	260
Yield Strength	MPa	180	180	70	135
Young's Modulus	GPa	88		85	95
Wire Hardness*	HV	95		90	98
FAB Hardness*	HV	65	65	90	95
	Units	2NCu (S)	CuPd	1NAg	AuAg
Elongation	%	11	12	6	4
Break load	g	6.5	6.5	5.5	5.5
Tensile stress	MPa	200	245	250	205
Yield Strength	MPa	80	110	180	100
Young's Modulus	GPa	85	95	80	88
Wire Hardness*	HV	90	100	80	88
FAB Hardness*	HV	90	99	80	68

In summary, fine bonding wires with the above properties are typically bonded to devices using the processing parameters specified in Table.4, [7-12].

Table.4 Bonding process parameters of fine bonding wires.

Units		4NAu	2NAu	4NCu	2NCu
Purging Gas	lpm	N.A.		Forming (95:5 | N2:H2)	
FAB EFO Current	mA	25	25	60	60
FAB EFO time	µs	490	500	230	240
1st Bond process window	(Force, g)	8 – 28	12 – 24	14 – 28	16 – 28
	(USG, mA)	40 - 115	50 - 115	110 - 125	115 - 125
2nd Bond process window	(Force, g)	30 – 150	35 – 150	60 – 120	60 – 125
	(USG, mA)	35 - 200	40 - 200	55 – 200	60 – 200
Units		2N Cu (S)	CuPd	1N Ag	AuAg
Purging Gas	lpm	Forming (95:5 | N2:H2)			N.A.
FAB EFO Current	mA	60	60	30	50
FAB EFO time	µs	235	240	460	205
1st Bond process window	(Force, g)	14 – 28	20 – 28	10 – 28	12 – 28
	(USG, mA)	110 - 125	115 – 135	55 - 115	70 - 115
2nd Bond process window	(Force, g)	60 – 120	60 -130	40 - 120	55 - 120
	(USG, mA)	55 – 200	60 - 200	45 - 180	50 - 180

In conclusion, 4N purity (99.99%) doped, alloyed, and coated Au, Cu, and Ag fine wires are all suitable for wire bonding applications. However, stringent process control is essential to ensure consistent wire quality and bonding performance. Mechanical and electrical property data demonstrate that alloyed and coated Cu and Ag wires can effectively compete with traditional Au wires. With Cu and Ag wire bonding technologies now reaching the same level of maturity as Au wire bonding, their bondability and overall performance are comparable, making them viable and cost-effective alternatives.

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