

Gold Wire for Room Temperature Wedge-Wedge Bonding

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Abstract

In recent years room temperature bonding of gold wires has been investigated several times [1]-[3]. A great deal of work has been done and published concerning room temperature ball-wedge bonding [3]-[6].

Our investigations are focused on wedge-wedge bonding at room temperature using gold wire. Several doped and alloyed gold wires have been bonded on LTCC substrates and stored at high temperature for 2000 hours. Only for comparison, standard AlSi1 bonding wire and an experimental wire have been included in the experiments.

We compared the pull forces for the selected wire bonded at room temperature (RT) with the pull forces obtained at 135 °C bonding temperature.

The results suggest that one of the investigated gold wires is well suited for room temperature bonding on gold metalized LTCC.

Room temperature wire bonding using gold wire has a remarkable application potential.

The promising results will be supplemented with additional studies.

Key words: Wire bonding, wedge-wedge, gold wire, room temperature, LTCC

Introduction

Since the invention of the wire bonding technique in 1957, a tremendous progress could be achieved regarding bonding temperatures and processing time. Gold wires are processed usually with the thermosonic ball-wedge technique and wires made from aluminum or aluminum alloys are used in the wedge-wedge bonding process. The focus of this paper is the use of gold wire in a wedge-wedge process at room temperature.

The advantages of bonding at room temperature are for instance shorter manufacturing cycles for components with a large heat capacity because heating is not required and the possibility to process very temperature sensitive substrates. We could show that it is possible to obtain reliable wedge-wedge bonds at room temperature using gold wire.

Commercially available Au-bonding wires

Existing gold wire types are originally designed for thermosonic bonding process. Both, long history and changing applications field led to a wide type range of different wire compositions. Alloying strategy could be divided in two directions – strength increasing and reliability improving. For pure 5N gold tensile strength is below 100 N/mm² and an addition of few ppm earth alkaline metals could increase it by two times. First generation of Au bonding wires has very high purity (4N5) and wide bonding window for thermosonic bonding process. High electrical and thermal conductivity is the positive aspect of high purity, but some improvable properties like long heat affected zone and low strength cause the limitation in applications with low loop, fine pitch requirements and for wire diameters below 20 µm. As improvement next class, 4N wires has been designed. Elevated alloying

element content enabled tensile strength between 220 and 340 N/mm² at 4 % breaking elongation. This wire class solved problems of geometrical and mechanical stability. Smaller packages with higher interconnection density could be realized. Testing procedures for many applications require high temperature storage stability for 1000 and more hours. Reliability issues, caused by material composition Al/Au are influenced by metallization type like pure Al, AlSi1, AlSi1Cu0.5, metallization thickness (0.8-4 μ m), but also by additional alloying elements in wire. With this background the 2N wire class have been developed. In this class up to 1 % alloying elements, for example Palladium, are used to inhibit diffusion between Au and Al. Higher mechanical strength, narrow bonding window and increased electrical resistivity are the consequence for the improvement of the reliability.

Bonding process

For thermosonic bonding elevated process with gold wire temperatures between 150 and 220°C are usual. This thermal energy is necessary for building of interconnection between wire and substrate, especially in ball area. Under specific circumstances, which are suitable substrate surface, sufficient possible range for bonding parameters, and bonding tool adequacy even room temperature bonding with gold wire should be possible. Here should be considered, that processing speed could be 10x smaller in wedge-wedge ultrasonic bonding due to complicated loop formation and asymmetrical bonding tool design. But especially for devices with low count of interconnections or high value processing speed is not the first priority. For temperature sensible substrates bonding at room temperature conditions is simply inevitable.

Investigated wires

Room temperature wedge-wedge bonding is well established for AlSi1 wires. Especially Al metallization on the chip side makes AlSi1 bonding wire an excellent choice for ultrasonic bonding at room temperature, the price difference in comparison to gold wire should be considered too. Weak points are higher reactivity of aluminum especially in humid environment as well, as lower thermal cycle reliability, caused by corrosion crack growth. So in many cases, aluminum wires can not be used, however.

In this study we investigate wedge-wedge bonding of commercially available gold wires at room temperature as well as 135 °C and compare the results obtained with room temperature bonding with standard AlSi1 wire as well as an experimental wire.

The bonding wires used for the experiments are listed in table 1:

Experiment (Row)	Bonding Wire	Tensile Strength	Bonding Temperature
A *	HD2 25 μ m	>11.2gf	135 °C
B *	HA3 25 μ m	>17.3gf	135 °C
C *	FP2 25 μ m	>18.4gf	135 °C
D *	HD5 25 μ m	>14.3gf	135 °C
E *	HA6 25 μ m	>10.2gf	135 °C
F *	Experimental	>14.3gf	23 °C
G **	Experimental	>14.3gf	23 °C
H *	HA3 25 μ m	>17.3gf	23 °C
I ****	AlSi1 32 μ m ⁺	>21.4gf	23 °C

* Tool 2145-1815-1.0-CG-F H

** Tool FP 45A-Ti-2015-1"

*** Tool 2145-W-2015

+ For comparison only

Table 1: Bonding wires used in this study

The experimental wire (row F and row G) were only available with a diameter of 32 μ m.

Experimental set-up

For our experiments we used thick-film gold paste DuPont®5734 on DuPont®951 tape using a test pattern shown in figure 1. We did not employ special cleaning procedures or plasma treatment for the substrate.

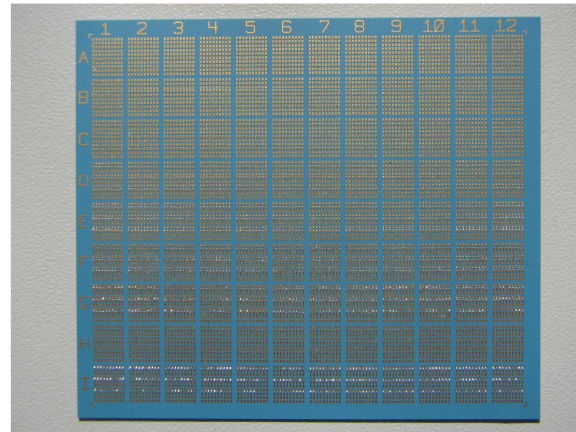


Figure 1: LTCC substrate 65 mm x 57 mm in size with wires on test pattern

For the experiments A to I, we bonded wire bridges with a loop length of 1 mm and a loop height of 0.3 mm (figure 2) using a BondJet 710 from Hesse & Knipps.

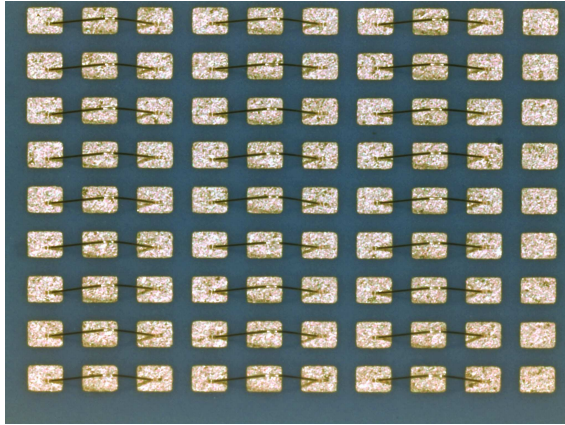
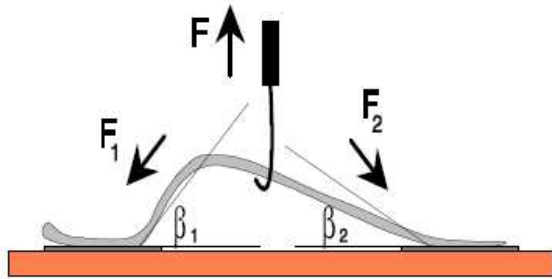


Figure 2: Wires bonded to the test pattern

The used loop geometry is conducive to a correction factor of 1.0 for the wire pull test as outlined in figure 3. Details can be found in the literature [7].



If $\beta_1 = \beta_2 = 30^\circ$ than $F_1 = F_2 = F$

Figure 3: Wire pull test-geometric relationship [7]

Figure 4 shows two single wires on the LTCC test substrate at high magnification.

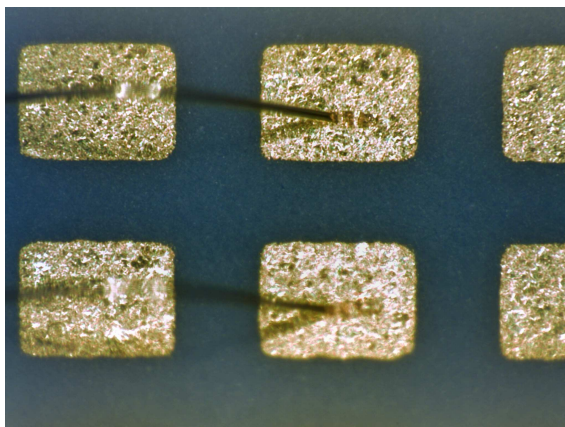


Figure 4: Wires on LTCC (magnification 80x)

From every row A to I, we pulled 60 wires each after 0 h, 70 h, 140 h, 350 h, 1000 h, and 2000 h high temperature storage at 125 °C, 150 °C, and 200 °C, respectively, using a pull tester Dage BT28.

Results

The results for samples stored at 125 °C dry heat are shown in figure 5 to 7. The sequence of the experiments is the same like in table 1:

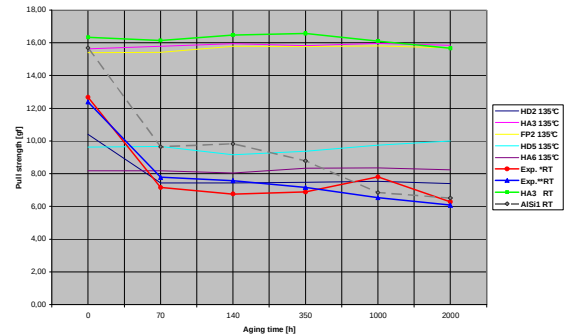


Figure 5: Mean of the pull strength in dependence from the aging time at 125 °C

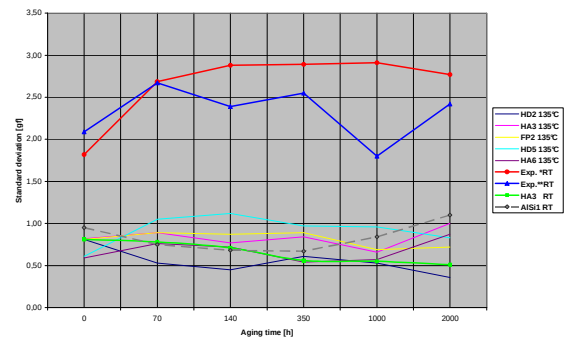


Figure 6: Standard deviation of the pull strength in dependence from the aging time at 125 °C

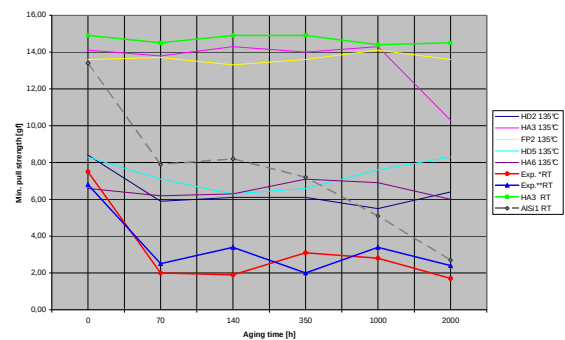


Figure 7: Minimum value of the pull strength in dependence from the aging time at 125 °C

All but the experimental wires performed well at 125 °C dry heat storage. After 2000 hours, one AISi1 wire did not meet MIL-STD-883G, method 2011.7, with a pull force of 2.70 gf, however.

The results for samples stored at 150 °C dry heat are shown in figure 8 to 10. The sequence of the experiments is the same like in table 1:

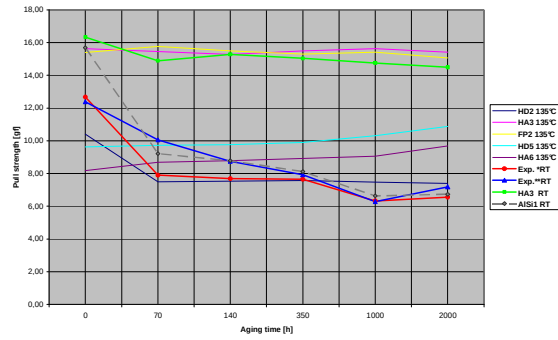


Figure 8: Mean of the pull strength in dependence from the aging time at 150 °C

The results for samples stored at 200 °C dry heat are shown in figure 11 to 14 (see table 1 also):

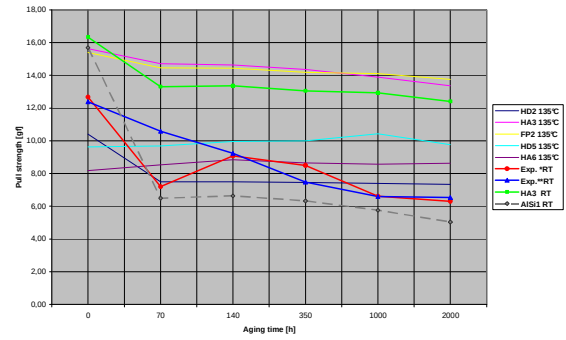


Figure 11: Mean of the pull strength in dependence from the aging time at 200 °C

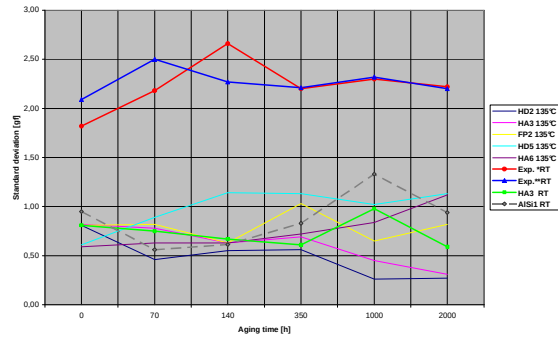


Figure 9: Standard deviation of the pull strength in dependence from the aging time at 150 °C

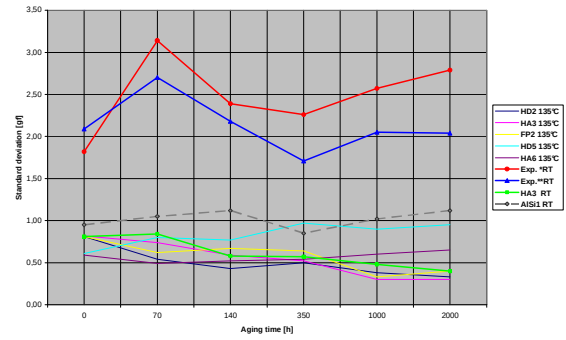


Figure 12: Standard deviation of the pull strength in dependence from the aging time at 200 °C

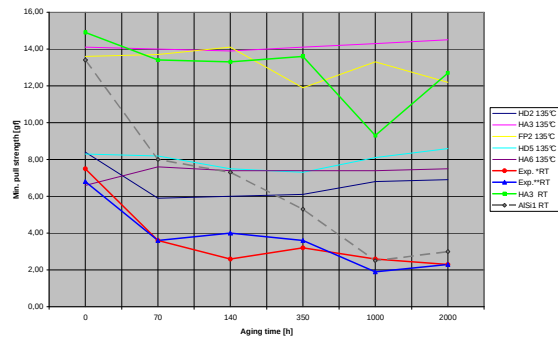


Figure 10: Minimum value of the pull strength in dependence from the aging time at 150 °C

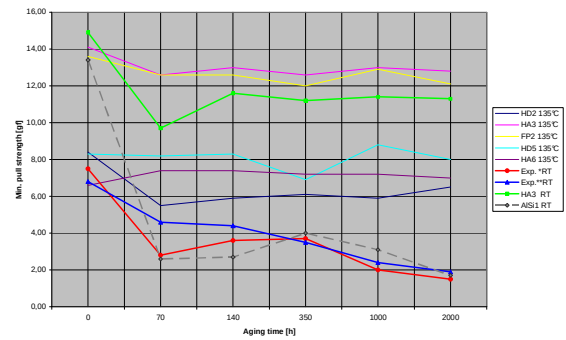


Figure 13: Minimum value of the pull strength in dependence from the aging time at 200 °C

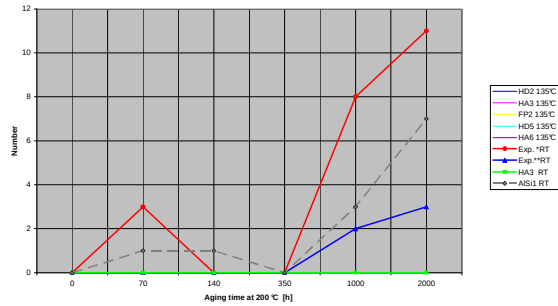


Figure 14: Number of bonds not meeting the required value of the pull strength of 3.0 gf according to MIL-STD-883G, method 2011.7

It can be seen easily, that for room temperature bonding the wire HA3 (green line in the diagrams, row H in table 1) delivers the best results.

Process capabilities

The values for the process capabilities for experiment H (25 μm wire HA3 bonded at room temperature) are listed in table 2:

	c_p	c_{pk} LSL	c_{pk} USL
Initial*	3.393	5.279	1.507
125 °C	5.408	7.979	2.836
150 °C	4.652	6.201	3.103
200 °C	6.877	7.427	6.327

LSL = 3.5 gf USL = 20.0 gf

Table 2: Values for c_p and c_{pk} after 0 hours, after 2000 h storage at 125 °C, after 2000 h storage at 150 °C, and after 2000 h storage at 200 °C

The values listed above indicate, that six Sigma manufacturing at room temperature using bonding wire HA3 should be easily possible.

Discussion

The initial pull strength obtained with the reference wire AlSi1 (bonded at room temperature) is excellent. Like expected, we observed a rapid degradation during high temperature storage, especially at 200 °C. The Au-Al contact system has been investigated in the literature many times [8]-[14], [17]. Therefore we do not explain the root cause for the degradation.

Results with the experimental wire (row F and row G in table 1), developed 2007 for room temperature bonding, are even worse. A tool change did not cause a significant improvement. This experimental wire is not suited for our high reliability applications.

With wire HA3 we obtained the best results for bonding at room temperature, comparable with wire bonds manufactured at 135 °C.

Verification of the Results

In order to be validated for high volume manufacturing, our results need to be verified for sample sizes larger than 60. In addition to that, other reliability tests like temperature cycling, mechanical alternating-load tests, and so on need to be carried out.

Investigations in the literature for ball-wedge bonds with HA3 gold wire onto aluminum and AlSi1Cu0.5 chip metallization [5]-[6] should be supplemented with own experiments employing wedge-wedge bonding.

Summary and Conclusion

We bonded six different gold wires on LTCC substrates at 135 °C or 23 °C, respectively. Only for comparison, we bonded at room temperature an AlSi1 wire as a reference.

At room temperature we did get very good initial pull values for the HA3 gold wire and the AlSi1 reference wire.

During high temperature storage, only the HA3 wire, bonded at room temperature, performed well. This is especially valid for the storage at 200 °C.

Our results suggest that Palladium alloyed gold wires are well suited for room temperature bonding on gold metalized LTCC.

Outlook

This paper presents current situation in the area of room temperature wedge-wedge bonding using gold wires. Room temperature bonding using gold wires has a remarkable application potential. A few examples are the wire bonding of components with very large heat capacity, Molded Interconnect Devices, and temperature sensitive semiconductors or sensors.

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