Wire Bond Ability Enhancement of 8 Leads Small Outline Integrated Circuit and 14 Leads Thin Shrink Small Outline Package Using AuPd Coated Cu Wire Bonding for Automotive Devices

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ABSTRACT

This study shows the enhancement of the wire bonding process in the integrated circuit package with 2N AuPd coated Cu wire (2N-AuPdCu) for automotive devices based on standard AEC Q-100 Rev.G. Wire bonding is the electrical connection between pad and leadframe. Nowadays, Au wire is commonly used for interconnection, in the opposite gold price is still exorbitant which is the wire bonding cost concerned. Therefore, Cu wire is price-effective and is considered an alternative for interconnection, but the corrosion and reliability of Cu wire are still concerns. The 4N AuPd coated Cu wire (4N-AuPdCu) material has been introduced for automotive devices but perhaps the reliability problem has not been solved. The 2N AuPd coated Cu wire has been developed to enhance reliability for automotive devices. In the experiment, Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire were used for the wire bonding process on 8 leads Small Outline Integrated Circuit Package (8L-SOIC) and 14 leads Thin Shrink Small Outline Package (14L-TSSOP) to compare wire bond ability and reliability. In conclusion, the results performed well in wire bond ability and reliability for 2N AuPd coated Cu wire compared with Au wire and 4N AuPd coated Cu wire. Therefore, 2N AuPd coated Cu wire can enhance the quality and reliability of the 8L-SOIC package and 14L-TSSOP package for automotive devices based on standard AEC Q-100 Rev.G.

Keywords: AuPd coated Cu wire, Integrated circuit package, Small Outline Integrated Circuit Package (SOIC), Thin Shrink Small Outline Package (TSSOP)

1. INTRODUCTION

The wire bond process uses metallic wire to create an electrical connection between a die or package circuit with a leadframe. This process is crucial for electrical connection in electronic devices [1].

The wire being used for the electrical connection of semiconductor devices has many types of material that might be made from gold (Au), silver (Ag), copper (Cu), or aluminum (Al). All of the above materials have specific properties to support the application of IC packages in devices [2,3].

Wire bonding is the interconnection method, bonding wires carry power and signals between the active semiconductor circuits and the leadframe or substrate metallization. The Au wire has lower bond ability performance, such as high electric resistance and low bonding strength. In a few years, the 4N AuPd coated Cu wire (impurity 99.99% for copper base) was developed to fix the above problem. However, 4N AuPd coated Cu wire is still concerned about the Pd distribution problem causing the reliability or field failure problem [4-10].

A new wire material, named 2N AuPd coated Cu wire, is introduced to replace it with 4N AuPd coated Cu wire to improve the Pd distribution [11-15].

Therefore, this study used 2N AuPd coated Cu wire instead of 4N AuPd coated Cu wire to show more wire bond ability improvement as well as comparing 2N AuPd coated Cu wire and Au wire to see the bond ability and reliability performance [16-18].

The Small Outline Integrated Circuit or SOIC, is a small rectangular surface mount integrated circuit package with gull wing leads. The leads protrude from the longer edge of the package. This package type is one of the most frequently used surface mount packages.

SOIC packages are JEDEC compliant and come in various body widths, the most popular of which are 150 mils or 3.8 mm (narrow-body) and 300 mils or 7.5 mm (wide-body). The standard SOIC lead pitch is normally 50 mils (1.27 mm). The properties of some SOIC packages and illustrated pictures are shown in Table 1 and Fig. 1 [16].

The Thin Shrink Small Outline Package or TSSOP, is a rectangular surface-mount plastic package with gull wing leads. It contains a smaller body and lead pitch than the SOIC package.

The TSSOP comes in body lengths of 3.0 mm, 5.0 mm, and 9.7 mm with a width of 4.4 mm which has a typical thickness of 0.9 mm. TSSOP body lengths of 12.5 mm

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and 14.0 mm with a width of 6.1 mm have a typical thickness of 0.95 mm. TSSOP has lead counts from 8 to 56. The standard lead pitch is 0.5 mm and 0.65 mm. This package type is JEDEC compliance. A partial list of TSSOP package options and the properties of some TSSOP packages and illustrated pictures are shown in Table 2 and Fig. 2 [16].

(a) (b)

***Fig. 1**: (a) Examples of 8L-SOIC package (b) 28L-SOIC package.*

(a) (b)

***Fig. 2**: (a) Examples of 16L-TSSOP package (b) 48L-TSSOP package.*

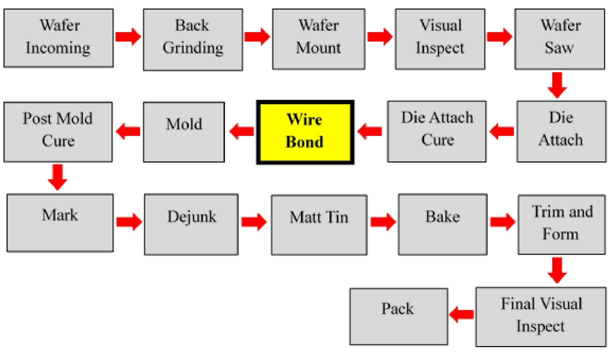


***Fig. 3**: General assembly process of SOIC package and TSSOP package.*

***Table 1**: Properties of some SOIC packages.*

No. of Pins	Body Sizes	Body Thickness	Lead Pitch
8	3.8 mm x 4.9 mm	1.45 mm	1.27 mm
14	3.8 mm x 8.6 mm	1.45 mm	1.27 mm
16	3.8 mm x 9.9 mm	1.55 mm	1.27 mm
20	7.5 mm x 12.8 mm	2.4 mm	1.27 mm
24	7.5 mm x 15.4 mm	2.5 mm	1.27 mm
28	7.5 mm x 17.9 mm	2.5 mm	1.27 mm
32	7.5 mm x 11 mm	2.35 mm	0.65 mm

***Table 2**: Properties of some TSSOP packages.*

No. of Pins	Body sizes	Body Thickness	Lead Pitch
8	4.4 mm x 3.0 mm	0.9 mm	0.65 mm
10	4.4 mm x 3.0 mm	0.9 mm	0.65 mm
14	4.4 mm x 5.0 mm	0.9 mm	0.65 mm
28	4.4 mm x 9.7 mm	0.9 mm	0.65 mm
38	4.4 mm x 9.7 mm	0.9 mm	0.5 mm
48	6.1 mm x 12.5 mm	0.95 mm	0.5 mm
56	6.1 mm x 14.0 mm	0.95 mm	0.5 mm

***Table 3**: Bond ability result after Wire Bond process for 8L-SOIC package.*

Bond ability result after wire bond process		Au wire	4N AuPd coated Cu wire	2N AuPd coated Cu wire
Wire pull test (specification control 4 grams minimum)	Min	8.8	16.0	16.3
	Max	13.6	19.3	19.4
	Avg	11.4	17.6	17.8
Stitch pull test (specification control 4 grams minimum)	Min	6.2	11.9	11.7
	Max	7.8	15.6	16.0
	Avg	6.9	13.7	14.0
Ball shear test (specification control 15 grams minimum)	Min	30.8	52.8	53.7
	Max	42.9	65.2	64.6
	Avg	38.0	59.3	59.5

***Table 4**: Bond ability result after the Wire Bond process for the 14L-TSSOP package.*

Bond ability result after wire bond process		Au wire	4N AuPd coated Cu wire	2N AuPd coated Cu wire
Wire pull test (specification control 4 grams minimum)	Min	12.4	15.3	15.1
	Max	15.0	18.9	18.3
	Avg	13.7	17.1	16.7
Stitch pull test (specification control 4 grams minimum)	Min	9.8	10.6	10.2
	Max	12.4	15.7	15.2
	Avg	11.6	13.0	12.5
Ball shear test (specification control 15 grams minimum)	Min	33.5	50.2	49.9
	Max	38.0	60.2	58.1
	Avg	35.7	55.0	53.9

2. EXPERIMENTS

This part describes the methodology of wire bond ability enhancement of the 8L-SOIC package and 14L-TSSOP package using AuPd coated Cu wire bonding for automotive devices. There will be three wire types: Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire to compare the wire bond ability test including wire pull test, stitch pull test, ball shear test, and reliability result. The general assembly process of the SOIC package and TSSOP package are shown in Fig. 3.

The experiment starts with selecting the wire type and diameter and continues with the SOIC and TSSOP assembly process until wire bonding is achieved. After

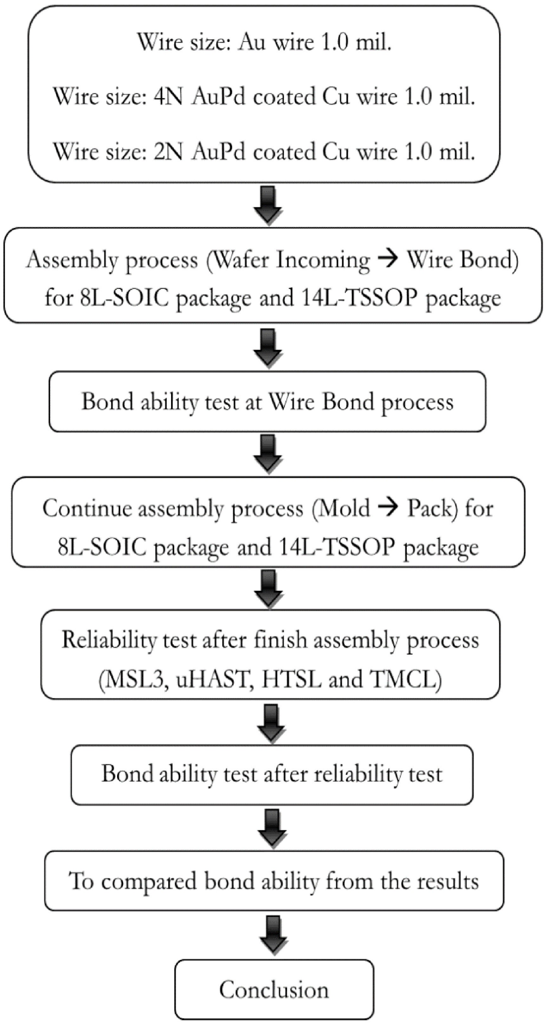


***Fig. 4**: Diagram of process experiment.*

***Table 5**: Bond ability result after reliability test for 8L-SOIC Package.*

Bond ability after reliability test		Au wire	4N AuPd coated Cu wire	2N AuPd coated Cu wire
Wire pull test (Spec control 4 grams minimum)	Min	6.2	10.4	12.5
	Max	8.9	13.2	13.6
	Avg	7.6	11.6	13.1
Stitch pull test (Spec control 4 grams minimum)	Min	5.4	7.5	10.4
	Max	6.8	10.5	12.0
	Avg	6.1	9.0	11.2
Ball shear test (Spec control 15 grams minimum)	Min	35.4	20.8	48.4
	Max	43.2	25.0	59.0
	Avg	39.7	22.9	54.5

that, move forward to check the bond ability test at each wire type's wire bonding process. Again, the assembly process from molding to packing SOIC and TSSOP packages will continue. Move forward to perform the reliability test after finishing the assembly process (MSL-3, uHAST, HTSL, and TMCL). Next, perform a bond ability test after reliability and compare each wire type's result. The diagram of the process experiment is in Fig. 4. The reliability test with MSL3 192 hours, 30℃, and

***Table 6**: Bond ability result after reliability test for 14L-TSSOP Package.*

Bond ability after reliability test		Au wire	4N AuPd coated Cu wire	2N AuPd coated Cu wire
Wire pull test (Spec control 4 grams minimum)	Min	8.7	11.8	12.4
	Max	10.7	13.7	14.8
	Avg	9.5	12.9	14.1
Stitch pull test (Spec control 4 grams minimum)	Min	6.9	8.8	9.5
	Max	9.3	11.7	12.0
	Avg	8.2	11.0	11.3
Ball shear test (Spec control 15 grams minimum)	Min	22.7	18.7	20.5
	Max	27.2	22.4	24.6
	Avg	25.4	14.5	22.3

***Table 7**: The comparison bond ability result after reliability test for the 8L-SOIC package and 14L-TSSOP package.*

Test condition	The comparison bond ability result after the reliability test (8L-SOIC and 14L-TSSOP packages)		
	Au wire	4N AuPd coated Cu wire	2N AuPd coated Cu wire
Wire pull test	Good	Best	Best
Stitch pull test	Good	Best	Best
Ball shear test	Best	Rather good	Best

Noted:
Wire pull and stitch pull test;
- Good = 5 to 8 grams.
- Best = 9 to 13 grams.
Ball shear test;
- Rather good = 20 to 25 grams.
- Best = 35 to 60 grams.

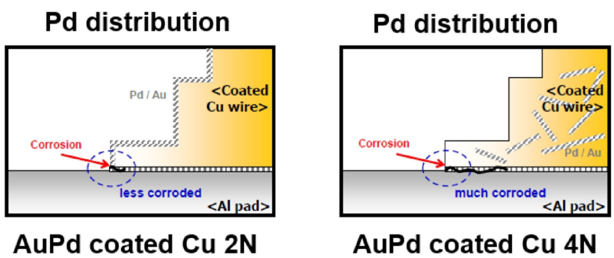


***Fig. 5**: Pd distribution comparison between 2N AuPd coated Cu wire and 4N AuPd coated Cu wire.*

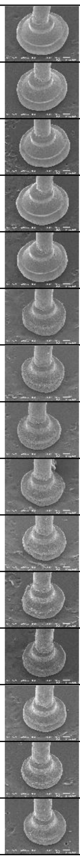
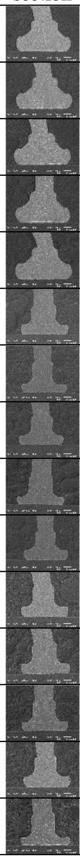
85%RH condition. uHAST 96 hours, temperature 130℃, 85%RH of humidity and pressure 15 PSI condition. HTSL 1000 hours with temperature 175℃ condition. TMCL 500 cycles with temperature during -65℃ to 150℃ condition.

3. RESULTS AND DISCUSSION

The results are shown in Table 3 and Table 4, the bond ability after the wire bond process, detail of the wire pull test, and stitch pull test are shown all three wire types pass the specification with standard JEDEC control all 4 grams minimum. Ball shear shows three wire types pass

***Table 8**: SEM and Cross section result for the 8L-SOIC package with three wire types.*

Wire type	Condition	SEM result	Cross section
Au wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		
4N AuPd coated Cu wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		
2N AuPd coated Cu wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		

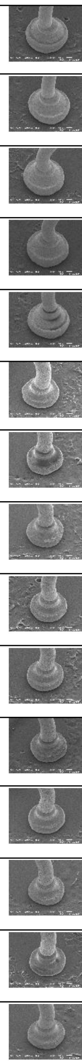
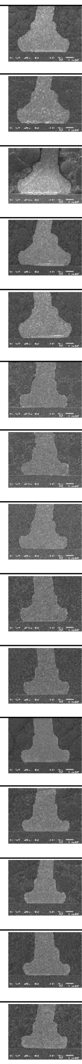
the specification with standard JEDEC control 15 grams minimum.

The bond ability results for the 8L-SOIC package after the reliability test referred to AEC-Q100 Rev.G is shown in Table 5, wire pulls and stitch pull results of 4N AuPd coated Cu wire and 2N AuPd coated Cu wire are higher than Au wire due to AuPd coated Cu wire has elongation of material less than Au wire and used bond force more than Au wire. Therefore, the tensile strength of AuPd coated Cu wire is higher than Au wire. For the ball shear result, all three wire types meet the specifications. Ball shear test results are shown higher than specification but if compared with bond ability test results after the wire bond process has significantly decreased.

The bond ability result for the 14L-TSSOP package after the reliability test is shown in Table 6, AuPd coated Cu wire had an elongation of material is less than Au wire, and used bond force is higher than Au wire created wire pull, and stitch pull result of 4N AuPd coated Cu wire and 2N AuPd coated Cu wire is higher than Au wire. Therefore, the tensile strength of AuPd coated Cu wire is higher than Au wire. For the ball shear result, all three wire types including Au wire, 2N AuPd coated Cu wire and 4N AuPd coated Cu wire pass specification. The ball shear test result shown is higher than the specification

***Table 9**: SEM and Cross section result for the 14L-TSSOP package with three wire types.*

Wire type	Condition	SEM result	Cross section
Au wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		
4N AuPd coated Cu wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		
2N AuPd coated Cu wire	Time zero		
	Moisture Sensitivity Level 3 (MSL3)		
	Unbiased Accelerated Stress Test (uHAST)		
	High Temperature Storage Life (HTSL)		
	Temperature Cycling (TMCL)		

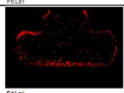
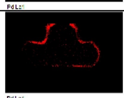
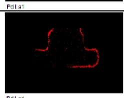
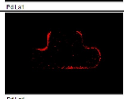
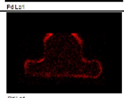
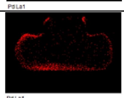
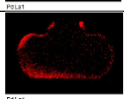
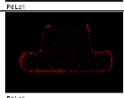
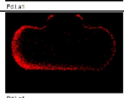
but if compared with the bond ability test result after the wire bond process, it has significantly decreased.

The comparison bond ability result after the reliability test between the 8L-SOIC package and 14L-TSSOP package with Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire are shown in Table 7. Due to Au wire having different coefficient thermal expansion between the wire and AlCu pad, the bond ability result is less than both AuPd coated Cu wire types. Moreover, Au wire has more elongation, which would affect tensile strength less.

The ball shear test result of 4N AuPd coated Cu wire found less than Au wire and 2N AuPd coated Cu wire. The cause of the event can be determined on the next page.

Tables 8 and 9 show the SEM and Cross section results for the 8L-SOIC package with Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire. The abnormality of the bond ball at several time points had not been

***Table 10**: Pd distribution result for the 8L-SOIC package with three wire types.*

Wire type	Condition	Pd distribution result
Au wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
4N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
2N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	

observed. The bond ball of three wire types is shown as no lifted ball.

Tables 10 and 11, are shown the Pd distribution test results for the 8L-SOIC package and 14L-TSSOP package with Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire, respectively. The result shows non-detected Pd distribution on the Au wire due to the Au wire not having the Pd ingredient. Moreover, 4N AuPd coated Cu wire has a Pd distribution that does not cover all bond ball areas while 2N AuPd coated Cu wire was covered by Pd distribution on all bond ball areas as shown

***Table 11**: Pd distribution result for the 14L-TSSOP package with three wire types.*

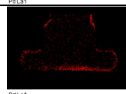
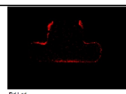
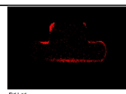
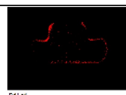
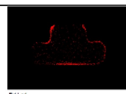
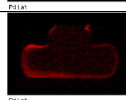
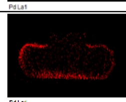
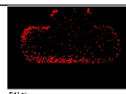
Wire type	Condition	Pd distribution result
Au wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
4N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
2N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	

***Table 12**: Delamination result for the 14L-TSSOP package with three wire types.*

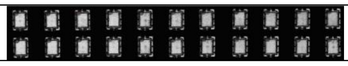
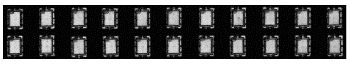
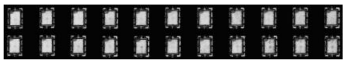
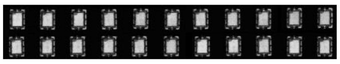
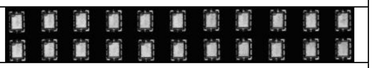
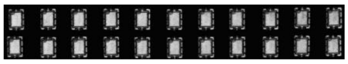
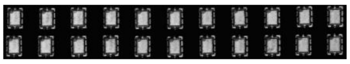
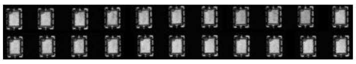
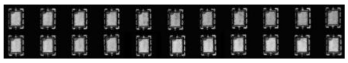
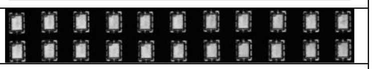
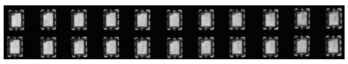
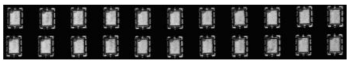
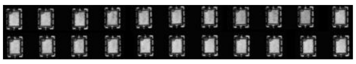
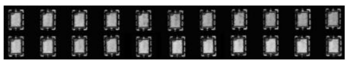
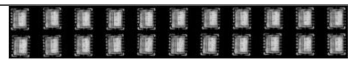
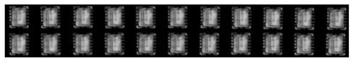
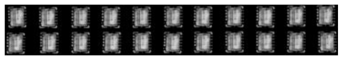
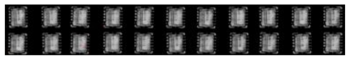
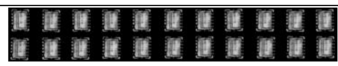
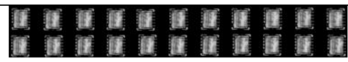
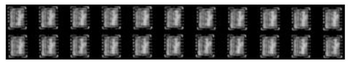
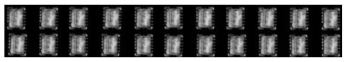
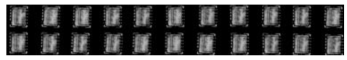
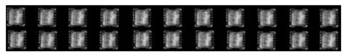
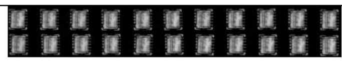
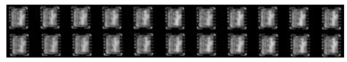
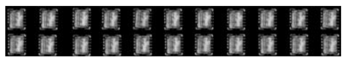
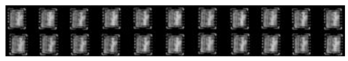
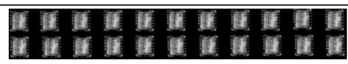
Wire type	Condition	Delamination result
Au wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
4N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
2N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	

***Table 13**: Pd distribution result for the 14L-TSSOP package with three wire types.*

Wire type	Condition	Delamination result
Au wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
4N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	
2N AuPd coated Cu wire	Time zero	
	Moisture Sensitivity Level 3 (MSL3)	
	Unbiased Accelerated Stress Test (uHAST)	
	High Temperature Storage Life (HTSL)	
	Temperature Cycling (TMCL)	

in the Pd distribution result.

Tables 12 and 13, are shown The delamination results for the 8L-SOIC package with Au wire, 4N AuPd coated Cu wire and 2N AuPd coated Cu wire are revealed. There is no delamination at time zero, Moisture Sensitivity Level 3 (MSL3), Unbiased Accelerated Stress Test (uHAST), High-Temperature Storage Life (HTSL), and Temperature Cycling (TMCL), due to it has not any lifted ball.

4. CONCLUSIONS

This experiment studied whether 2N AuPd coated Cu wire and 4N AuPd coated Cu wire comparison and Au wire bonding. The results have shown 8L-SOIC package and 14L-TSSOP package performed well in bond ability testing for 2N AuPd coated Cu wire compared with Au wire and 4N AuPd coated Cu wire. Therefore, 2N AuPd coated Cu wire can enhance the wire bond ability on the 8L-SOIC package and 14L-TSSOP package for automotive devices due to this wire has higher bond ability than 4N AuPd coated Cu wire as well as the effective cost when compared with Au wire. Moreover, Pd distribution for 2N AuPd coated Cu wire has shown Pd is a circulated ball bond and Pd can protect from corrosion on the bond ball area which is less corroded and improves the reliability result. However, 4N AuPd coated Cu wire shows Pd distribution is much corroded on the bond ball area which could create intermetallic compound layer cracking on the bond ball area as shown in Fig. 5.

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