



**WEAROUT RELIABILITY STUDIES OF BONDING
WIRES USED IN NANO ELECTRONIC DEVICE
PACKAGING**

by

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TABLE OF CONTENTS

	PAGE
THESIS DECLARATION	i
ACKNOWLEDGMENT	ii
LIST OF TABLES	viii
LIST OF FIGURES	x
LIST OF SYMBOLS, ABBREVIATIONS OR NOMENCLATURE	xvi
ABSTRAK	xxii
ABSTRACT	xxiv
CHAPTER 1	
BACKGROUND	
1.1 Introduction	1
1.2 Introduction of Gold and Copper Wirebonding	1
1.3 Materials Properties of Au, Ag and Pd-coated Cu Wires	2
1.4 Bonding Processes with Au and Cu Wires	2
1.5 Reliability Testing and Weibull Analysis	5
1.6 AuAl and CuAl IMC Formation	6
1.7 Problem Statement	9
1.8 Objective	10
1.9 Research Scope	10
1.10 Thesis Organization	11
CHAPTER 2	
FUTURE AND TECHNICAL CONSIDERATIONS OF Au, Pd COATED Cu and SILVER WIREBONDING IN SEMICONDUCTOR PACKAGING – A COMPARATIVE REVIEW	
2.1 Abstract	14
2.2 Introduction	14
2.3 Copper Wirebonding	19
2.3.1 Copper Wire Reliability Performance	20
2.3.2 Cu Ball bond Failure Mechanism Post Reliability Stress Tests	21
2.3.3 Cu-Al IMC Corrosion under HTSL (High Temperature Storage)	26
2.4 Silver Wirebonding	27

2.5	Ball Bond Wearout Reliability	30
2.6	Evaluations with Bare Cu, Pd-coated Cu wire and Pd-doped Cu wire	31
2.7	Conclusion	32

**CHAPTER 3
TECHNICAL BARRIERS AND DEVELOPMENT OF Cu BALL BONDING
IN NANOELECTRONIC DEVICE PACKAGING**

3.1	Abstract	35
3.2	Introduction	35
3.3	Experimental	36
3.4	Results and Discussion	38
	3.4.1 Silicon Cratering and IMD Cracking	38
	3.4.2 Effects of Green Packaging Materials	40
	3.4.3 Effects of Post-Wirebond-Staging Time and Extra Thermal Treatment	43
	3.4.4 Failure Mechanism of Cu Ball Bond Wet Corrosion under UHAST	46
3.5	Summary and Conclusion	49

**CHAPTER 4
WEAROUT RELIABILITY AND INTERMETALLIC
COMPOUND DIFFUSION KINETICS OF Au AND PdCu BALL
BONDS**

4.1	Abstract	51
4.2	Introduction	51
4.3	Experimental	52
4.4	Results and Discussion	55
	4.4.1 Wearout Reliability of Au and PdCu Ball bonds in HAST and UHAST	55
	4.4.2 Weibull Plots Analysis and Characterization	55
	4.4.3 Wearout Failure Mechanisms in HAST and UHAST	58
	4.4.4 HTSL IMC Growth Thickness Study of Au and PdCu Ball bonds	62
	4.4.5 Post Extended Reliability Stresses Ball bond Shear and Wire Pull Strength Analysis (Au vs. PdCu Ball Bonds)	65
4.5	Summary and Conclusion	67

CHAPTER 5
EXTENDED RELIABILITY OF Au AND Pd-COATED COPPER WIRES IN DIFFERENT MOLDING COMPOUNDS

5.1	Abstract	70
5.2	Introduction	71
5.3	Experimental	72
5.4	Results and Discussion	73
5.4.1	Weibull Analysis	73
5.4.2	Failure Analysis and mechanisms of Au and Cu ball bonds	76
5.4.2.1	UHAST	76
5.4.3	Microstructural Analysis of Failed Ball Bonds	79
5.4.3.1	UHAST	79
5.4.3.2	Temperature Cycling	83
5.4.3.3	High Temperature Storage Life	84
5.4.4	Effects of molding compound on extended reliability	87
5.4.5	Effects of wire types on extended reliability	88
5.5	Summary and Conclusion	89

CHAPTER 6
RELIABILITY ASSESSMENT AND MECHANICAL CHARACTERIZATION OF Pd COATED Cu AND Au WIRES IN BGA PACKAGE

6.1	Abstract	91
6.2	Introduction	92
6.3	Experimental	93
6.4	Results and Discussion	94
6.4.1	Reliability Assessment: Unbiased HAST	94
6.4.2	Reliability Assessment: Temperature Cycling	95
6.4.3	Role of Pd-Coating in Cu wire for UHAST Reliability and Mechanical Strength	96
6.4.4	Wire Pull Test	97
6.4.5	Ball Bond Shear Test	100
6.4.6	Break Modes of Ball Bonds	102
6.5	Summary and Conclusion	105

CHAPTER 7

RELIABILITY ASSESSMENT AND ACTIVATION ENERGY STUDY OF Au AND Pd-COATED Cu WIRES POST HIGH TEMPERATURE AGING

7.1	Abstract	107
7.2	Introduction	107
7.3	Experimental	109
7.4	Results and Discussion	110
	7.4.1 Reliability Assessment: HTSL	110
	7.4.2 Lognormal Plot Analysis	111
	7.4.3 Effects of Wire Type used in Nanoelectronic Packaging	113
	7.4.4 Determination of Apparent Activation Energies of Au and PdCu Ball bonds in HTSL Test	116
7.5	Summary and Conclusion	118

CHAPTER 8

EFFECTS OF BONDING WIRES AND EPOXY MOLDING COMPOUND ON GOLD AND Pd-COATED COPPER BALL BONDS INTERMETALLIC GROWTH KINETICS IN ELECTRONIC PACKAGING

8.1	Abstract	121
8.2	Introduction	122
8.3	Experimental	124
8.4	Results and Discussion	126
	8.4.1 IMC Growth Kinetics of Au and PdCu Ball bonds	126
	8.4.2 IMC Growth Analysis and Plotting	127
	8.4.3 Pd-coated Cu and Au IMC Growth Mechanisms	129
	8.4.4 Derivation of PdCu and Au IMCs Growth E_{aa}	131
	8.4.5 Effects of molding compound on IMC thickness growth E_{aa}	135
	8.4.6 Effects of wire types on IMC Thickness Growth	136
8.5	Conclusion	136

CHAPTER 9

COMPARATIVE RELIABILITY STUDIES AND ANALYSIS OF Au, Pd-COATED Cu AND Pd-DOPED Cu WIRES

9.1	Abstract	138
9.2	Introduction	138
9.3	Experimental	140
9.4	Results and Discussion	142

9.4.1	IMC Growth Kinetics of Au, Pd-Coated Cu and Pd-Doped Cu Ball bonds	142
9.4.2	IMC Growth Analysis and Plotting	143
9.4.3	Wire Pull and Ball Bond Shear Strength Post Reliability Stresses	144
9.4.4	Biased HAST and TC Wearout Reliability Analysis	148
9.5	Summary and Conclusion	150

CHAPTER 10

THESIS CONCLUSION AND RECOMMENDATION FOR FUTURE WORKS

10.1	Introduction	152
10.2	Thesis Conclusion	152
10.3	Recommendation for Future Works	158

REFERENCES

159

APPENDIX A

List of Publications

167

APPENDIX B

Front pages of published papers

169

LIST OF TABLES

NO		PAGE
1.1	Material properties of bare Ag, Au and PdCu.	3
3.1	Cu wirebonding reliability development study.	37
3.2	EDX analysis of CuAl IMC crack region post UHAST 96hr opens: Non-green mold compound (Leg 4).	41
3.3	EDX analysis of CuAl IMC crack region post UHAST 96hr opens: Green mold compound (Leg 3).	43
4.1	Characteristics of the Weibull plots of various reliability test (Au and PdCu wires used in 110nm device)	54
4.2	Summary of IMC diffusion kinetics and activation energies comparing Au and PdCu ball bonds used in 110nm packaging.	63
5.1	Summary of experimental matrix (for Au and PdCu wires).	73
5.2	Summary of extended reliability results (mold compound type A, B of Au and PdCu wires).	74
5.3	Key material characteristics of Epoxy Mold Compound (EMC) A and B.	76
5.4	EDX analysis of failed PdCu and Au ball bonds after UHAST.	83
5.5	Summary of E_{aa} and HTSL failure mechanisms from previous studies	87
6.1	Experimental Matrix.	94
6.2	Wire pull strength summary.	98
6.3	Ball bond shear strength summary.	101
7.1	Characteristics of the lognormal plots of various aging temperatures (Au and PdCu wires used in 110 nm device).	111

7.2	Summary of apparent activation energies and associated failure mechanisms comparing Au and PdCu ball bonds used in semiconductor device.	117
8.1	Summary of experimental matrix (for Au and Cu wires): Effects of EMC and Wire Types.	125
8.2	IMC Diffusion Kinetics of Au and Cu wires used in 110 nm device.	127
8.3	Summary of apparent activation energies (E_{aa}) comparing Au and Cu ball bonds of IMC growth.	133
8.4	Determination of IMC diffusion coefficient for each elevated temperatures.	134
8.5	Key material characteristics of Epoxy Mold Compound (EMC) A and B.	135
9.1	Summary of experimental matrix.	141
9.2	IMC thicknesses of Au, Pd-coated Cu and Pd-doped Cu wires used in 110nm device.	142
9.3	Ball Shear Strength Summary.	146
9.4	Wire pull strength summary.	147
10.1	Wearout Reliability Summary.	153
10.2	Apparent activation energy (E_{aa}) and D_o summary.	155
10.3	Ball Shear and Wire Pull Strength Summary.	157

LIST OF FIGURES

NO		PAGE
1.1	Bathtub reliability curve (McPherson, 2010).	7
1.2	Weibull distribution plotting in terms of Weibits (Weibit = $\ln[-\ln(1-F)]$). Note that a Weibit = 0, produces t_{63} . The slope of the best linear fitting is β . (McPherson, 2010).	3
2.1	(a) Reliability tests of gold wirebond after temperature exposure at 150°C - shear test, (b) pull test, hook near ball bond.(Simons et al., 2000).	16
2.2	Ag-Al interface microcracking occurred as a result of interface corrosion. (Cho et al., 2010). (a) Cratering at both Cu ball bond edges of Leg 2 (b) and (c) IMD (Inter Metal Dielectric crater and crack) at silicon level.	28
3.1	Cratering at both Cu ball bond edges of Leg 2 (b) and (c).	39
3.2	Initial CuAl IMC formation starts at the both edges of bare Cu ball Bond periphery.	40
3.3	(a) EDX analysis at CuAl IMC crack region post UHAST 96hr opens (b) and (c) Cu ball bond corrosion and interface cracking between CuAl IMC of Leg 4.	41
3.4	(a) Bare Cu ball bond, (b) and (c) edges of bare Cu ball bonds - No Cu bond corrosion or weaknesses with Green molding compound (Leg 3).	43
3.5	Proposed Cu ball bond oxidation mechanism due to long staging at production floor and induce resistive opens after UHAST reliability test.	45
3.6	Proposed Cu ball bond corrosion failure mechanism in UHAST (Legs 4, 6 and 7).	45
3.7	The formation enthalpies of various IMCs of four Al-metal systems.	48
4.1	Package construction 110nm device encapsulated with Au and PdCu ball bonds.	54

4.2	Biased HAST (130°C, 85%RH, 3.6V Bias) Weibull plotting and its characteristics of PdCu and Au wires used in 110 nm device FBGA 64 package.	56
4.3	Biased HAST (130°C, 85%RH, 3.6V Bias) weibull plotting and its characteristics of PdCu and Au wires used in 110 nm device FBGA 64 package.	57
4.4	Component level temperature cycling (-40°C to 150°C) Weibull plotting and its characteristics of PdCu and Au wires used in 110 nm device FBGA 64 package.	58
4.5	Typical AuAl IMC micro-cracks post extended HAST stress (1553 hr).	59
4.6	Typical AuAl IMC micro-cracks post extended UHAST stress (2000 hours).	59
4.7	Typical CuAl IMC micro-cracks post extended HAST stress (1817 hr).	60
4.8	Typical CuAl IMC micro-cracks post extended UHAST stress (1000 hr).	61
4.9	Typical CuAl IMC micro-cracks post extended TC stress (9500 cyc).	61
4.10	Plots of thicknesses of intermetallic compound (IMC) against aging time of Au wire (a) and PdCu wire (b) used in 110 nm device packaging (c) Plot of $\ln D$ against $1/T$ for determination of D_0 values.	64
4.11	Box plots of ball bond shear (a) and wire pull strength (b) post reliability stresses for Au and PdCu wires in 110 nm device packaging.	66
5.1	Extended UHAST reliability plots of Au and PdCu ball bonds with different EMC (Epoxy Molding Compounds).	75
5.2	Extended TC reliability plots of Au and PdCu ball bonds with different mold compounds A and B.	75
5.3	Representative SEM image shows PdCu ball bond microcracking along AuAl interface after UHAST.	77
5.4	Proposed UHAST failure mechanism of PdCu ball bond.	78
5.5	Representative SEM image shows Au ball bond microcracking along AuAl interface after UHAST 2000 hours).	79
5.6	Representative SEM image shows PdCu ball bond microcracking initiate from edge of Cu ball bond (larger gapping) towards center of ball bond (narrower gapping).	79

5.7	SEM image shows PdCu ball bond open after UHAST test. Arrows indicate the evidence of possible hydrogen embrittlement induced micro cracking (between PdCu to CuAl IMC).	80
5.8	SEM image shows microstructure analysis of Au ball bond open after UHAST test. Thicker AuAl IMC is observed if compared to CuAl IMC in Cu ball bond.	81
5.9	Microstructural analysis of Cu ball bond open after UHAST test. EDX analysis on failed Cu ball bond indicates presence of O, Cu, Si, Ta and Cl elements. Presence of O and Cl elements proves internal oxidation of CuAl IMC under moist UHAST environment and corroded by Cl ⁻ .	82
5.10	Representative SEM image of Cu ball bond CuAl interfacial microcracking after TC 9000 cycles.	84
5.11	Arrhenius plot of Cu ball bonds in FBGA 64 package with EMC B.	85
5.12	Arrhenius plot of Cu ball bonds in FBGA 64 package with EMC A.	85
5.13	Arrhenius plot of Au ball bonds in FBGA 64 package with EMC A.	86
5.14	Arrhenius plot of Au ball bonds in FBGA 64 package with EMC B.	86
6.1	UHAST package reliability plot (fitted to Weibull distribution) comparing Au and Pd Cu wires.	95
6.2	TC package reliability plot (fitted to Weibull distribution) comparing Au and PdCu wires.	96
6.3	Wire pull strength box plot analysis of Au and PdCu ball bonds versus UHAST stressing hours.	99
6.4	Wire pull strength analysis (ratio to its initial values) of Au ball bonds versus HTSL stressing hours at different temperatures (150°C, 175°C and 200°C).	99
6.6	Ball shear strength analysis (ratio to its initial values) of Au ball bonds versus HTSL stressing hours at different elevating temperatures (150°C, 175°C and 200°C).	102
6.7	Breaking modes of ball shear and wire pull for Au ball bonds versus reliability tests.	103
6.8	Breaking modes of ball shear and wire pull for Cu ball bonds versus reliability tests.	104
7.1	Wirebond interconnection in FBGA 64 package.	105

7.2	High temperature aging (150°C, 175°C, 200°C) lognormal plots and its characteristics of PdCu used in 110 nm device FBGA 64 package.	112
7.3	High temperature aging (150°C, 175°C, 200°C) lognormal plots and its characteristics of Au used in 110 nm device FBGA 64 package.	112
7.4	Typical Au ball bond IMC voiding and cracks post extended HTSL stress (1500 hr, 200°C). Thicker AuAl IMC is formed with sign of Kirkendall micro voiding, micro cracking beneath Au ball bond after long duration of HTSL test.	114
7.5	Proposed failure mechanism of AuAl Kirkendall micro voiding and caused lifted ball bond.	114
7.6	SEM images show very thin CuAl IMC formation on as bonded stage of Cu wirebond package prior to reliability stress. No micro cracking beneath PdCu ball bond.	115
7.7	Typical CuAl IMC micro-cracks post extended HTSL stress (1500 hr, 200°C aging). Signs of micro cracking and micro voiding are observed.	116
7.8	Arrhenius plots of Au ball bond data against 1/kT aging time used in 110 nm semiconductor device.	118
7.9	Arrhenius plots of PdCu ball bond data against 1/kT aging time used in 110 nm semiconductor device.	118
8.1	FBGA 64 package constructions with PdCu and Au wires used in 110 nm device.	124
8.2	Measurement and E_{aa} calculation of AuAl and CuAl IMCs.	126
8.3	Box plot of CuAl and AuAl IMC against aging time, aging temperatures and EMC type.	128
8.4	Representative SEM measurement of CuAl IMC at Cu ball bond periphery.	129
8.5	Representative optical images with measurement of AuAl IMC on Au ball bond.	129
8.6	Proposed CuAl IMC growth mechanism 110 nm device FBGA 64 package.	130
8.7	Proposed AuAl IMC growth mechanism 110 nm device FBGA 64 package.	131
8.8	IMC thickness plots of $\ln D$ against aging time (1/T) of PdCu and Au wire types with different combinations of EMC Type A and B.	134

9.1	Wire constructions of Pd-coated Cu and Pd-doped Cu wires used in 110nm device. TOF-SIM results show more homogenous Palladium distribution in Pd-doped Cu wire compared to Pd-coated Cu wire in free air ball formation (FAB).	143
9.2	IMC thickness against aging time plotting of three wire types used in 110nm device FBGA 64 package.	144
9.3	Post stresses ball shear strengths (g) of Au, Pd-coated Cu and Pd-doped Cu wires.	145
9.4	Post stresses wire pull strengths (g) of Au, Pd-coated Cu and Pd-doped Cu wires.	145
9.5	Biased HAST weibull-fitted wearout reliability plot.	146
9.6	TC weibull-fitted wearout reliability plot.	147

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LIST OF SYMBOLS

Ag	Silver
Ag-Al	Silver-Aluminium
Ag-Pd-Cu	Silver-Palladium-Copper
Ag-Au-Pd	Silver-Aurum-Palladium
Al	Aluminium
Al ³⁺	Aluminium Ion
AlBr ₃	Aluminium tri-Bromide
[Al(Cl) ₄] ⁻	Aluminium tetra-Chloride Ion
Al(OH) ₃	Aluminium tri-Hydroxide
Al(OH) ₂ Cl	Aluminium di-Hydroxide Chloride Ion
Au	Aurum or Gold
Au-Al	Aurum-Aluminium
Au ₄ Al	Aurum Aluminide
AlCl ₃	Aluminium tri-chloride
Al ₂ O ₃	Aluminium (III) Oxide
Br	Bromine

Cu	Copper
Cu ⁺	Copper (I) Ion
Cu ₂ O	Copper (I) Oxide
Cu-Al	Copper-Aluminium
Cu-Al-Pd	Copper-Aluminium-Palladium
Cu ₉ Al ₄	Copper (IV) Aluminide
CuBr	Copper Bromide
Cu-Pd	Copper-Palladium
Cl ⁻	Chloride
cm ² /s	centimeter square per seconds
E_{aa}	Apparent activation energy
F	Failure Rate
H ₂	Hydrogen
H ⁺	Hydroxonium Ion
H ₂ O	Water
HCl	Hydrochloric Acid
Pd	Palladium
PdCu	Palladium Coated Copper

ppm	Parts per million
pH	Power of Hydrogen
D_o	Diffusion Coefficient
<i>exp</i>	Exponential function
F	Failure Rate
g	gram
gf	gram-force
K	Kelvin
<i>k</i>	Boltzmann Constant
O ₂	Oxygen Gas
OH ⁻	Hydroxide Ion
mg	milligrams
mm	millimeter
m ² /s	meter square per seconds
R	Ryberg gas constant
R _o	Constant
RH	Relative Humidity
t	Thickness
t _{first}	Time of first failure occurrence

t_{50}	median-time-to failure
$t_{63.2}$	characteristics life
T	Temperature
kHz	kilo Hertz
%	Percentage
ΔT	Delta in Temperature
Δx	Delta in Distance
α	characteristic life
β	weibull slope
η	characteristic life
eV	Electron Volt
$^{\circ}\text{C}$	Degree Celsius

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LIST OF ABBREVIATIONS

AECG1	Automotive Electronic Council Grade 1
Ag	Silver
BGA	Ball Grid Array
EFO	Electronic Flame Off
EMC	Epoxy Mold Compound
FAB	Free Air Ball
FBGA	Fineline Ball Grid Array
FEM	Finite Element Modeling
HAST	Highly Accelerated Temperature and Humidity Stress Test
HTSL	High Temperature Storage Life
IMC	Intermetallic Compound
IMD	Intermetal Dielectric
IUPAC	International Union of Pure and Applied chemistry
PCT	Pressure Cooker Test
TC	Temperature Cycling

TSOP	Thin Small-Outline Package
THB	Temperature Humidity Bias
UHAST	Unbiased Highly Accelerated Temperature and Humidity Stress

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Kajian Keboleharapan Hausan Dalam Pelekatan Wayer bagi Pembungkusan Peranti Nano Elektronik

ABSTRAK

Wayer kuprum secara tradisional adalah lebih senang mengalami pengaratan selepas kelembapan berbanding dengan wayer emas. Setakat ini, pengetahuan di bidang kajian keboleharapan adalah terhad terutamanya dalam antara-sambungan paras satu (ikatan bebola). Objektif projek ini bertujuan untuk menguji-kaji keboleharapan hausan, tenaga pengaktifan dan penumbuhan ketebalan bagi liputan antara logam (IMC) bagi wayer emas, wayer kuprum salutan Palladium (Pd) dan wayer kuprum dengan pendopan Pd dalam bidang pembungkusan semikonduktor. Skop penyelidikan meliputi penyelidikan pengaruh jenis wayer atas keboleharapan hausan bagi komponen flash, pencirian tenaga pengaktifan ketara (E_{aa}) bagi liputan antara logam (IMC), HTSL serta formulasi mekanisme kegagalan bagi wayer berlainan. Keboleharapan hausan bagi pincangan HAST; HAST tanpa pincangan, pengitaran suhu (TC) dan ujian simpanan pada suhu tinggi (HTSL) telah diciri. Sampel-sampel dimasukkan dalam mesin keboleharapan dan diuji sampai kegagalan hausan. Graf Weibull diplotkan bagi ujian-ujian keboleharapan untuk tiga jenis wayer. Masa kegagalan pertama (t_{first}), median masa hingga kegagalan (t_{50}), hayat karakteristik ($t_{63.2}$) serta kecerunan Weibull (β) dicirikan. Kajian seterusnya meliputi pengamalan suhu simpanan pada suhu 150 °C, 175 °C dan 200 °C untuk masa yang berlainan. Tenaga pengaktifan ketara telah ditentukan bagi HTSL dan ketebalan bagi liputan antara logam (IMC) bagi wayer emas, wayer kuprum salutan Palladium (Pd) dan wayer kuprum dengan pendopan Pd. Ketuhar Dispatch digunakan di dalam ujian HTSL. Keputusan analisis menunjukkan kecerunan weibull (β) bagi wayer pelekatan berlainan adalah melebihi 1.0 dan merupakan data untuk hausan dalam keboleharapan. Wayer kuprum dopan dengan palladium mempamerkan masa sehingga kegagalan dan kitar sehingga kegagalan yang lebih tinggi dalam pincangan HAST, HAST tanpa pincangan dan pengitaran suhu (TC) berbanding wayer emas dan wayer kuprum diplat dengan palladium. Ini membuktikan wayer kuprum didop dengan palladium mempunyai potensi dan keboleharapan hausan lebih tinggi berbanding wayer emas dan wayer kuprum diplat dengan palladium. Wayer kuprum asal dibuktikan dengan keboleharapan hausan yang paling rendah. Pertumbuhan ketebalan bagi liputan antara logam (IMC) telah ditentukan bagi pelekatan wayer yang berlainan. Tenaga pengaktifan ketara (E_{aa}) bagi wayer emas adalah dalam lingkungan 0.92 eV ~ 1.10 eV manakala 0.72 eV ~ 0.83 eV bagi wayer kuprum diplat dengan palladium dalam ujian HTSL. Bagi kajian ketebalan IMC, tenaga pengaktifan ketara (E_{aa}) bagi CuAl adalah 1.08 eV dan 1.04 eV masing-masing dengan EMC A dan EMC B manakala tenaga pengaktifan ketara (E_{aa}) bagi AuAl adalah 1.04 eV dan 0.98 eV masing-masing dengan EMC A dan EMC B. Kekuatan heretan dan cukuran wayer telah dianalisis dan mempunyai variasi lebih kecil bagi wayer kuprum dopan dengan palladium berbanding wayer emas dan wayer kuprum diplat dengan

palladium. Kesimpulannya, bebola emas juga dikenalpasti dengan penumbuhan liputan antara logam (IMC) yang lebih cepat berbanding dengan penumbuhan liputan antara logam (IMC) yang lambat di dalam wayer kuprum.

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Wearout Reliability Studies of Bonding Wires Used in Nano Electronic Device Packaging

ABSTRACT

Conventional bare Cu bonding wires, in general, are more susceptible to moisture corrosion compared to gold (Au) and Cu wires. There is very limited knowledge based reliability studies which have been carried out on 1st level interconnect (ball bond in this matter) on nano device semiconductor packages. The objective of this project is to evaluate the wearout reliability, apparent activation energy and Intermetallic compound (IMC) thickness growth of Au, Pd-coated Cu wire and Pd-doped Cu wire used in semiconductor packaging. Methodology of this work include investigation on the effects of bonding wires on wearout reliability of flash component, characterization of the apparent activation energy of IMC and HTSL test and formulation of the failure mechanisms in different wires. Wearout reliability of biased Highly Accelerated Temperature and Humidity Stress (HAST), unbiased HAST (UHAST), Temperature Cycling (TC) and High Temperature Storage Life (HTSL) have been characterized. Samples are loaded into each reliability chambers and stressed until wearout open failure. Weibull plot is plotted for each reliability stresses and for three wire types. First failure (t_{first}), median-time-to-failure (t_{50}) and characteristic life ($t_{63.2}$) and weibull slope (β) are calculated accordingly. Next study includes applying thermal storage conditions at 150 °C, 175 °C and 200 °C at various intervals time. The apparent activation energy (E_{aa}) has been investigated for HTSL and IMC thickness growth of Au, Pd-coated Cu wire and Pd-doped Cu wire. Dispatch oven is used in HTSL test. Results indicated that the obtained weibull slope (β) of three wire types are greater than 1.0 and belong to wearout reliability data point. Pd-doped copper wire exhibits larger time-to-failure and cycles-to-failure in HAST, UHAST and TC tests. This proves Palladium (Pd)-doped copper wire has a greater potential and higher reliability margin compared to Au and Pd-coated copper wires. Bare Cu wire is not observed with lowest wearout reliability performance. Intermetallic compound (IMC) diffusion kinetics has been established among the different bonding wires. E_{aa} obtained of Au ball bonds are ranging from 0.92 ~ 1.10 eV and 0.72 ~ 0.83 eV for Pd-coated Cu ball bonds in HTSL test. For IMC thickness growth study, E_{aa} obtained for CuAl IMC are 1.08 eV and 1.04 eV respectively with EMC A and EMC B. E_{aa} obtained are 1.04 eV and 0.98 eV respectively on EMC A and EMC B on AuAl IMC. Wire pull and ball bond shear strengths have been analyzed and we found smaller variation in Pd-doped copper wire compared to Au and Pd-doped copper wire. In conclusion, Au bonds were identified to have faster IMC formation, compared to slower intermetallic compound thickness growth compared to Pd-coated Cu wire and Pd-doped Cu wire.