Working Around the Fluorine Factor in Wire Bond Reliability

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ABSTRACT

Fluorine contamination on integrated circuit chips has remained a critical problem for wire bond reliability, aggravated by the change from wet chemical etch on the part of the chip manufacturers. Yet, we have found that the phenomenon can be the result of different compounds with failure mechanisms that vary with the particular fluorine contaminant that happens to be present as well as the quantity of that contaminant. Our study analyzes aluminum fluoride and fluorocarbon polymer contamination and their associated failure modes on various hybrid products. It examines wire bond processing which, in some cases, can overcome certain levels of contamination to produce strong wire bonds with good reliability.

INTRODUCTION

In the midst of a successful history of wire bonding reliability on several different hybrids, we first experienced wirebond problems as an isolated instance on one particular hybrid. These problems were not evident at the assembly operation, and the wirebond schedule was in use for various programs being manufactured in the same assembly area.

Initial failures surfaced as wires on hybrids which became resistive during environmental testing. Failure analysis of these units did not reveal gross intermetallic formation but did reveal balls which had lifted from the aluminum pad of the integrated circuit. Although there was ball bonding in other areas of the circuit, these balls were not resistive and not lifted. Further testing of sample units with destructive bond pulls indicated that random, catastrophic failures (below 2.0 grams) of initial pulls were in evidence throughout the circuit. Failures occurred on the same circuits with average reported pulls in the 6.0 to 9.0 gram range.

A test cycle of microsectioning, SEM analysis, ESCA, and Auger was mobilized with two major goals: to define the problem itself, isolating its cause, and, once defined, to attempt to circumvent it without suffering in reliability or in circuit performance.

Eventually, we began to experience fluorine-related problems on other hybrid circuits with various levels of contaminant present. Our study examines attempts to achieve good bonding in spite of the contaminant, utilizing an array of thermocompression and thermosonic bond schedules.

Through SEM photographs, microsections, bond pulls and bond shears, we were able to target levels at which bonds were both strong (6.0 – 9.0 grams) and reliable.

TESTING AND RESULTS OF HYBRID A

We became alerted to the wirebond problem when approximately thirty percent of electrical test failures could be attributed to resistive or open wirebonds. Although compression and shape of the bonds were normal, sectioned bonds exhibited extremely limited intermetallic formation (See Fig. 1 and Fig. 2). The failures were attributed to contamination of the bond pad area.

Immediately an in-process non-destructive bond pull test was instituted to alert us to any discrepancies during the manufacturing cycle itself on a daily basis. In addition, Auger analysis was completed to determine the nature and extent of the contamination on the bond pads.

A destructive pull test on a sample of the parts revealed catastrophic failure of random ball bonds on hybrids where the overall average pull strengths were in the 6 – 9 gram range. Failures did not occur on bonds in other areas of the circuit, nor did they occur on the stitch area of the bonds. Failure mode for the majority of the bonds was the ball lifting from the aluminum pad on the integrated circuit.

Auger analysis was performed on unprocessed aluminum bond pads from the same wafer slice and

on a control sample, a totally different I.C. on which no failures had been experienced. Levels of oxygen and carbon were comparable on the both die. The only other contaminant present was fluorine on the die used to manufacture hybrid A. Our control sample registered no fluorine and our test sample had a fluorine level at approximately 6 – 8% by Atomic weight. Although the fluorine was present on the aluminum pads, none was reported on the passivation.

The next approach was to perform an ESCA analysis to determine exactly what specific type of compound was involved in the contaminant, to attempt to remove it, and to begin another lot of fabrication of I.C.'s.

Binding energy was reported to be that of a fluoropolymer. In addition to the fluoride, the ESCA detected oxide, nitride and carbon in the form of a hydrocarbon.

Initial fluorine removal attempts were unsuccessful with a water clean operation and an oxygen plasma etch. Auger analysis taken after each clean operation did not show any reduction in contamination level. However, an argon four minute sputter etch was able to successfully eliminate the fluorine. Unfortunately, it also eliminated electrical performance of the die. Four minutes of sputtering was the lowest level at which consistent good bond strengths (above 6 grams) were in evidence.

Meanwhile, a new lot of I.C. slices was released from fabrication. Auger analysis recorded fluorine levels at 3.0 – 4.0% Atomic weight on the Al pads.

The next step was to achieve good bonding in spite of this contamination level. Since successful bonding is a time/temperature phenomenon, it can be seen that an increase in the dwell time should achieve a positive effect in bonding strength given maintenance of the same temperature and pressure. However, no change in intermetalic formation was noted until we increased bond dwell time to 4 seconds per bond, which was not feasible for the production volumes and delivery schedule. At the time, our bonding profile was strictly

thermocompression with a 240ºC stage temperature, 300ºC capillary and 55 grams of force using 1.0 mil gold wire. Testing was performed using a manual thermosonic bonder which was found to be unsuccessful. All bonds exhibited limited intermetallic formation upon microsectioning; and within the test sample, approximately 7% of the bonds failed destructive pull testing (<5 grams) at the ball/pad interface.

The final step was to develop a thermocompression bonding test matrix. See Table I.

Destructive bond pulls were completed initially and after a 300ºC bake of four hours with 450 bonds pulled at each schedule. Results are tabulated in Table II.

For all schedules the greatest failure mechanism (70 – 80% bonds) initially was wire breakage. After the bake operation lifted ball bonds became the dominant failure mode in all but schedule D. Although lifted bond failures increased in (D) after baking, 55% of the bonds still failed due to wire breakage. Examining % bond lifts, we see that schedule D provided the best performance in ball adhesion.

Microsections showed that only with schedule D we achieved good intermetallic formation across the surface of the bond consistently.

The new schedule was implemented along with sample non-destructive pull testing during the assembly operation, sample destructive pull testing after 3 hour bake at 400ºC, and Auger analysis of each new slice lot of integrated circuits. Although the bond pads registered a fluorine contamination level at 3.0 – 4.0% atomic weight, with the new bonding schedule the resistive bond problem was virtually eliminated.

TESTING AND RESULTS OF HYBRID B

Hybrid B was a thermosonically bonded hybrid with a history of random wirebond failures. Intermittent ball failures which exhibited little of no intermetallic formation focused our attention to possible die pad

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contamination. An Auger analysis was then performed on several devices to identify possible surface contaminants, and SAM photos were taken of the bonding pad and the corresponding ball bond (see Fig. 3 and Fig. 4). The Auger analysis showed very high carbon contamination (60 – 80%) and approximately 5% fluorine to a depth of 150 Å on aluminum metallization. The Auger analysis for the pad and ball shown in Fig. 3 and Fig. 4 respectively can be found in Table III.

We immediately began investigating the history involved with the die that we were using, and found that they had been improperly stored for over a year, lot and slice traceability had been lost, and that these particular die had a history of fluorine contamination similar to hybrid A. Production bonding was stopped and a sampling plan to test all of the die prior to releasing them to production was instituted.

The die testing consisted of Auger and ESCA analysis on a selected sample which was followed by assembling and environmentally testing the remainder of that sample before the die would be released to production. This type of initial testing allowed us to establish threshold limits for various contaminant levels. Once an adequate data base was obtained with the above threshold limits, testing could be reduced without sacrificing reliability.

To overcome the excessive carbon contamination on the die, an oxygen plasma cleaning operation was performed just prior to bonding. This eliminated most of the surface contamination present at the surface. The Auger and ESCA analysis for two samples (Box 37 and Box 49) showed moderate levels of fluorine contamination and that the fluorine was bound as a metallic fluoride (binding energies for fluorine for Box 37 and 49 were 685.8 and 685.4 respectively). Once the binding energies for all of the elements were analyzed and compared it was apparent that the fluorine was bonded with aluminum. The results of the Auger and ESCA analysis can be found in Table IV.

Eighteen hybrids were then built using the standard assembly processes and sequence with Box 37 and Box 49 die. These units would establish the bondability of relatively low contaminated metal fluorine die. After the 18 devices were bonded, 4 units (2 from Box 37 and 2 from Box 49), were destructively bond pulled after they received the normal mil-std environmental conditioning. These devices were used as a control sample.

The sequence of assembly and environmental conditioning can be found in Table V.

Six units were then baked for one hour at 300°C, delidded, and destructively fore pulled. This conditioning would accelerate any die pad contamination to a failure point, and would allow us to study failure mechanisms. The remaining 8 units would then be baked an additional three hours at 300°C, delidded, and destructively pulled to further cull out any marginal bonds. After all of the devices were pull tested and the data analyzed, it was now evident that a moderate metal fluoride contamination could be bonded and produce reliable bonds. The wire pull analysis for the 18 units can be found in Table VI.

Additional testing was then performed identically to the previous units using die that had various fluorine contamination levels to determine, if possible, a maximum fluorine contamination level. The three groups of die used in these tests were Box X, Box 42, and Box 53. The Auger Data for these 3 boxes can be found in Table VII.

With each increase in fluorine level, the wire failure mode 1, ball lifts, increased until the device failed the .5 gm pull after the 4 hour bake at 300°C. Microsections of the bond s adjacent to ball failures, and pictures from a SEM (see Figs. 5, 6, & 7) showed the failure point to be the first intermetallic layer between the gold ball and the Au/Al intermetallic of the bonded aluminum pad.

CONCLUSION

Comprehensive testing of Hybrids A and B definitely show that the presence of fluorine on aluminum bond pads is detrimental to the reliability of gold wire bonds. Both the bonding state of the fluorine and the quantity of fluorine present will affect the ball bond failure mechanism.

Fluorine that is present as a fluorocarbon polymer forms a barrier to intermetallic formation and inhibits bonding performed on standard bond schedules. In spite of the barrier, a thermocompression schedule was developed that would produce reliable bonds on pads containing less than 4% fluorine.

Fluorine that is present as a metallic fluoride increases the rate of intermetallic formation rather than acting as a barrier to bonding. Thus, initial bond strengths are high but degrade severely over the life of the part. The maximum allowable amount of fluorine present as a metallic fluoride was found to be 6%. While reliable bonding can be accomplished when small quantities of fluorine are present, ideally, the bond pads should be free of fluorine. No practical method of cleaning was found that would remove either type of fluorine. It is clear that a team effort between both the hybrid manufacturers and the integrated circuit manufacturers will be needed to effect a long-term solution to this problem.

Table I.

Schedule	Temperature		Weight
	Capillary	Stage	
A	215°C	340°C	75g
B	300°C	240°C	55g
C	300°C	240°C	90g
D	power off	345°C	55g

Table II.

Bond Schedule	Before 300°C Bake		After 300°C Bake	
	Bond Lifts < 2 GR	Bond Lifts ≥ 2 GR	Bond Lifts < 2 GR	Bond Lifts ≥ 2 GR
B	13.6	11.4	78.4	18.2
C	21.3	8.2	53.1	18.4
D	1.6	0	11.1	9.5
A	9.8	4.5	41.8	11.9

Table III. Auger Analysis of Ball Failure

Wire No.	Location	Pull Strength	Sputter Level (Å)	Atomic Relative						
				C	O	F	Al	Cl	Au	N
29	Bond Pad	1.4 gms	0	47	20	2	31	-	-	-
			150	24	33	1	42	-	-	-
29	Ball	1.4 gms	0	86	5	-	9	-	-	-
			150	76	7	-	11	-	6	-

Table IV. Auger and ESCA Analysis of Boxes 37 & 49

Box No.	Analysis Type	Sputter Level (Å)	Atomic Relative						
			S	C	N	O	F	Al	Si
37	Auger	0	.4	50.8	.5	13.4	2.1	32.5	-
37	Auger	150	-	28.1	-	20.7	2.2	48.4	-
37	ESCA	-	-	45.0	3.1	38.0	0.3	10.0	5.0
49	Auger	0	-	44.3	-	14.3	2.8	38.4	-
49	Auger	150	-	11.2	-	31.7	3.3	53.6	-
49	ESCA	-	-	39.0	3.3	34.0	0.3	13.0	10.0