

Cu Wire Bond Reliability Improvement Through Focused Heat Treatment after Bonding

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Abstract

Currently, there is a great interest in applying copper material to wire bonding of fine pitch assembly packaging, particularly for cost saving purposes. However, the hardness property of copper is harder compared to the conventional gold wire. The hardness factor of copper, coupled with the work hardening effect of the USG power and force during wire bonding, is a major cause for bond pad crack and pad cratering, especially on sensitive pad devices.

Known methods to soften the FAB has been evaluated and discussed. Softening the FAB has proved to play a role in decreasing the bond pad cratering. However, it does not resolve the problem completely.

The proposed solution is to introduce heat after wire bonding to enhance the intermetallic adhesion strength between the copper to the Al bond pad.

Key words: Cu Bonding, FAB, Fine Pitch Bonding, Cu Wire.

Introduction

The hardness of copper material compared to gold is a significant problem to bonding on pad sensitive devices, and especially fine pitch pads. The hardness of a 25um, 4N Gold wire is about 65Hv¹, whereas, a standard 5N copper wire hardness is approximately at 83Hv, which makes copper at about 27% harder in comparison to gold. Refer to Figure 1 for the hardness comparison data between copper and gold.

It is however, possible to soften the copper before bonding. It is known that the softening temperature of copper occurs above 150C². At these temperatures, copper is highly susceptible to oxidation. Therefore, the usage of forming gas in replacement of dry air or nitrogen is recommended. In this evaluation, forming gas of mixture 5% Hydrogen, and 95% Nitrogen was used.

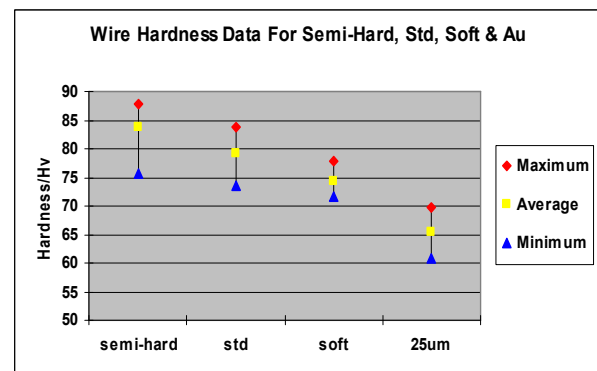


Figure 1. Hardness comparison data between copper and gold.

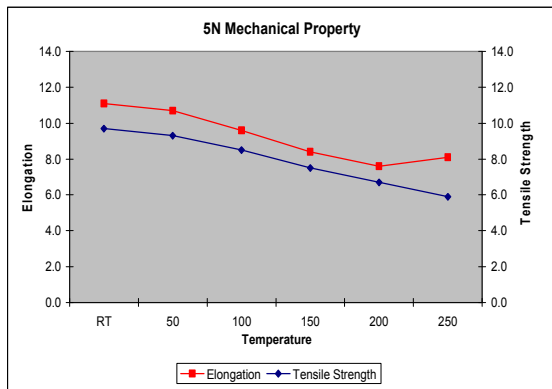


Figure 2. Tensile strength and elongation of copper with increasing temperatures.

Another test1 was conducted to understand the tensile strength and elongation of copper under various temperatures. From the graph (see Figure 2), we see that both the tensile and elongation decreases with increasing temperatures, indicating a ‘softening’ of the Cu structure has occurred.

An existing Patent US4976393(A), proposes a heater system which continually blows heated forming gas during and after the formation of the FAB (Free Air Ball) before bonding. See Figure 3. The purpose is to soften the FAB by a continuous flow of heated air before bonding.

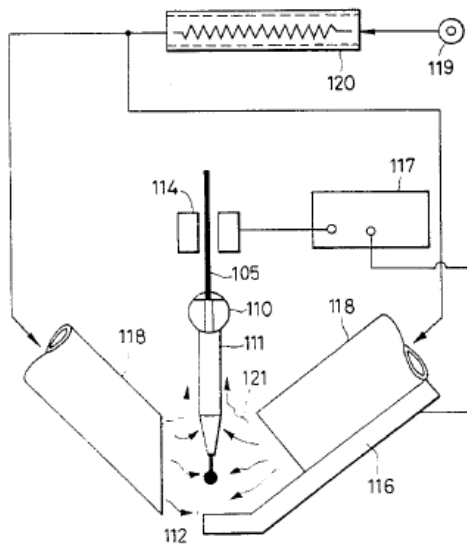


Figure 3. Patent US4976393(A) Heated Gas System directed at FAB

Another patent (US20060249561A1) which proposes spot heating by utilizing focused light/heat. This is performed by implementing an electromagnetic heat bulb as a heat source. Refer to Figure 4.

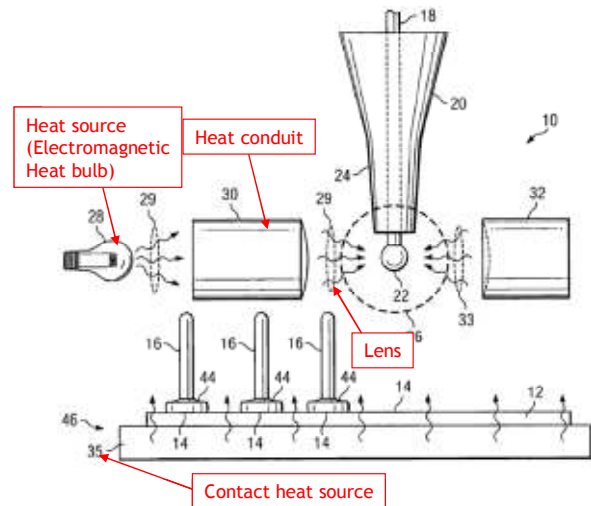


Figure 4. Spot heat wirebonding
US20060249561(A1)

2. Study Design

In this evaluation, a heated air system was designed and fabricated to evaluate this concept. A wrap-around coil type heater was used to heat the low-flow rate of the forming gas.

The maximum temperature achieved at the exit of the nozzle was 200 degree C. This is due to the limitation of the heater size, rated power, and space in the machine.

3. Subjects and Methods

The evaluation was run with a known pad-sensitive device. The wirebond pads has tungsten vias distributed through-out the entire pad surface. Cracks that occurs are usually observed at the Si-oxide (TEOS) material in between the tungsten vias.

Refer to Figure 5 for a typical crack on bond pad. The picture was taken after etching of the aluminum metallization. The crack appears thick due to the etching liquid which has seeped into the crack.

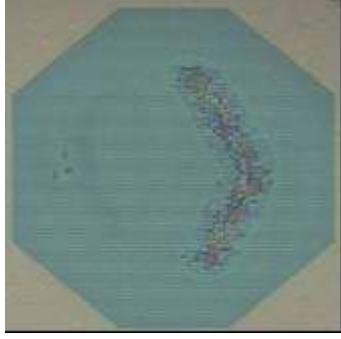


Figure 5. Typical Pad crack on TEOS (under the Aluminium bond pad.)

4. Results and Discussion

In the experiment, optimized bonding parameters were needed to ensure the forces, power and time do not initiate a crack to the underlying metallization and silicone oxides structure. Cracks created under the bondpad are a serious reliability issue to a semiconductor. Refer Figure 6 on the crack responses to heated and non-heated forming gases with varying USG forces.

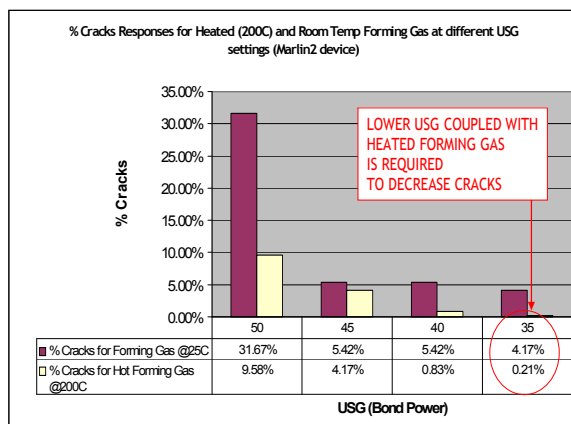


Figure 6. Comparison on Crack responses to heated and non-heated forming gases with varying USG forces

As illustrated in Figure 6, we observe that as the USG power decreases, the % of cracks decreases, which is a good trend. However, a lower USG corresponds to a weaker adhesion of the bonded ball to the die pad, which is a disadvantage. The weak adhesion would not perform well during a thermal stress cycle.

However, with the presence of the heated forming gas at 200 degree C, coupled with a lower

USG power, there is a significant reduction in cracks trend.

Another parameter which was optimized, was the pedestal temperature settings which conducts heat to the underside of the die during the wirebonding process. The wire bonding is performed to an optimized heated temperature on the die. However, this method has its limitations. Figure 7 shows that as the pedestal temperature increases, the pad crack % increases. On the other hand, if we were to decrease the temperature, NSOP (non-sticking on pad) starts to occur. To counter the NSOP, it will require a higher USG power, thus inducing higher % of cracks.

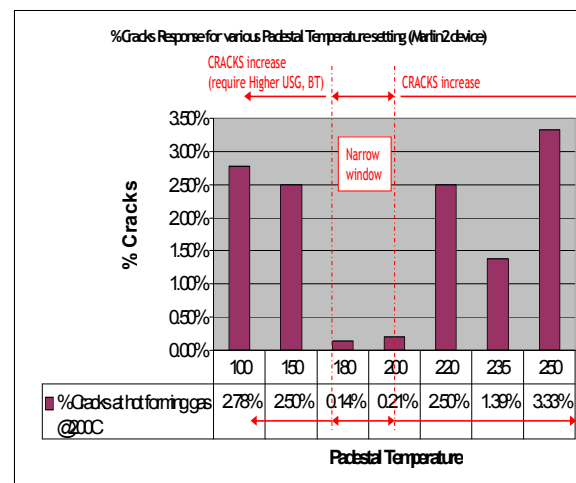


Figure 7. Cracks Response for various Pedestal Temperature setting

Also, an interesting observation was made during the thermal aging process at 175 degree C from T0 to T504 hrs. The ball shear readings exhibit a gradual increase in strength as the bonded ball is subjected to longer thermal aging. Refer to Figure 8 for the trend of device A. Note also, that both copper and gold wire samples in this evaluation were not subjected to heated forming gas. Only the optimized parameters were used to bond the sample device A.

Ball shear strength for copper increases with longer thermal aging, indicating an increasing adhesion strength between the Cu to Al bond pad. The intermetallic growth of Cu-Al seems to have increased in thickness and area. As for Gold, ball shear show a significant drop in strength at T504 hrs.

A similar observation on copper adhesion can be seen when running Device B. See Figure 9. However the ball shear for gold did not see a similar drop in strength at T504hrs.

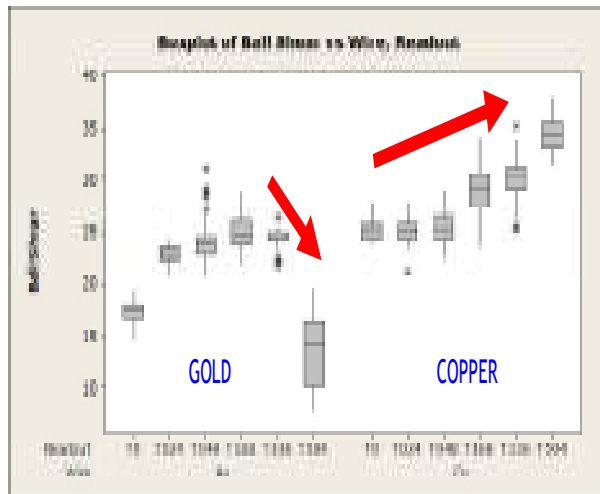


Figure 8. Ball Shear performance vs. Thermal Aging for both Gold and Copper for Device A

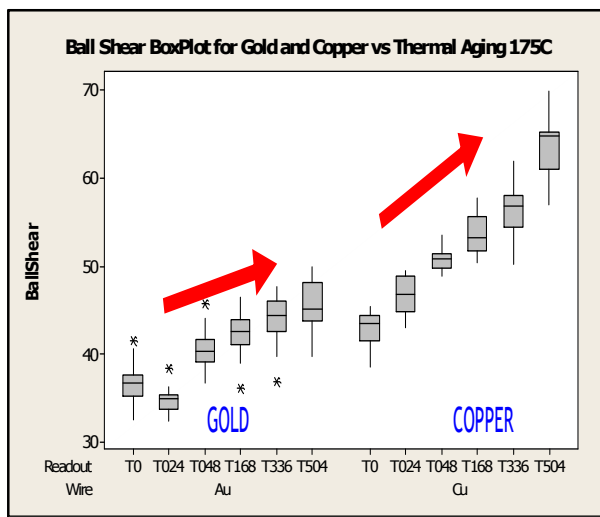


Figure 9. Ball Shear performance vs. Thermal Aging for both Gold and Copper for Device B

There has been studies³ on the effects of thermal aging on the IMC of Cu-Al. Through cross-sectioning, it was found that after 200hrs at 175 degree C, there was evidence of a thin grayish phase in the order of 0.4um thick.

Another experiment was conducted to accelerate the interfacial growth of Cu bonds. The experiment was run at 250 degree C from 2 to 2000 hrs. After 2 hrs at 250 degree C, the IMC has grown significantly.

This phenomena of accelerated IMC growth is of great interest to the enabling of a new and proposed method for Cu bonding.

Proposed Method

A typical semiconductor process flow is to perform diebond, wirebond, and mold. Some devices may include plasma after diebond. See Figure 10.

CURRENT PROCESS

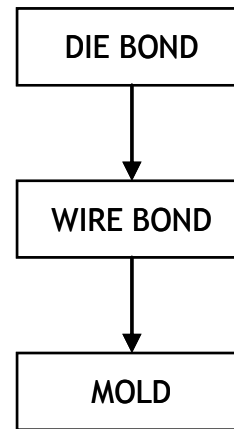


Figure 10. Typical Die bond to Mold process

The proposed solution is the introduction of a focused heat source on the bonded ball region after wire bonding to enhance the intermetallic adhesion strength between the Copper Ball to the Al bond pad. Refer to Figure 11 for the proposed process flow.

The solution utilizes a focused heat source targeted at the bonded ball region to accelerate the IMC growth¹ of Cu-Al to enhance the strength and integrity of the bond. This solution facilitates for wire bonding with lower USG power, thus, a lower impact (softer bonding) of the Cu FAB to the sensitive pad structure to prevent bond pad crack and pad cratering.

Through a simulated heated condition, the proposed method has shown promising outcome with actual experimental results.

A proposed method of heating the bonded wire is shown in Figure 12.

The experiment was run with a 25um 5N-Cu wire, standard production capillary, and an optimized recipe with a lower USG power to avoid pad cratering and cracks. The FAB was subjected to a continuous heated forming gas at 200C (or greater). Also, the dies were heated to an optimized pedestal temperature.

NEW PROCESS

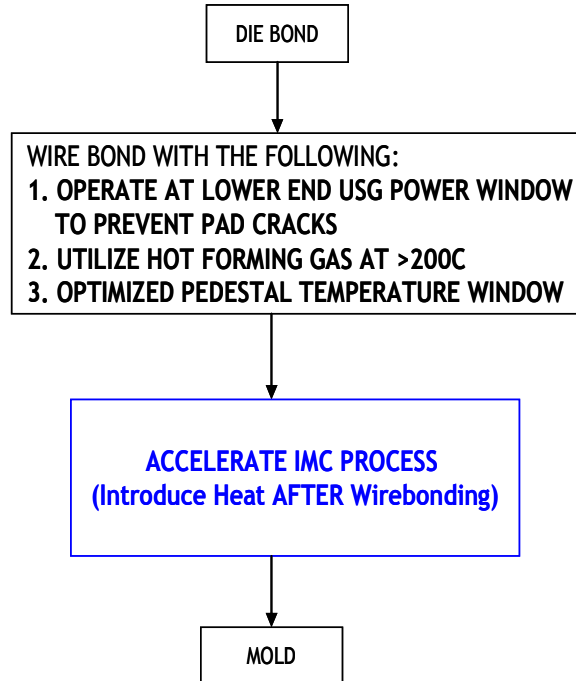


Figure 11. Proposed process to enhance IMC strength

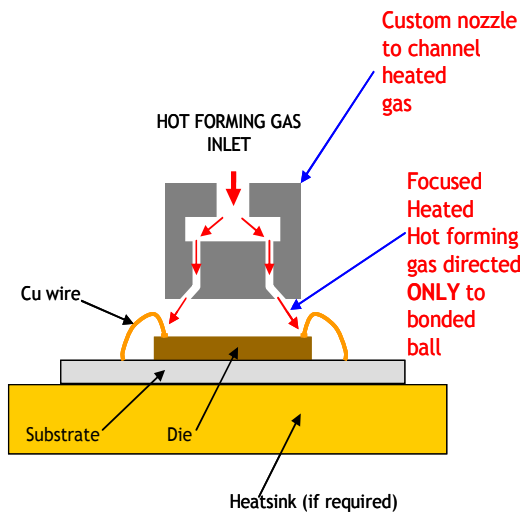


Figure 12. Focused Heatsource Concept

Evaluation was run with a sensitive bond pad device, which is prone to cracks when running Cu wires. An optimized recipe was then used to run the experiment. The optimized recipe generates very minimal bond pad cracks but performed poorly for ball shear due to the lower USG used. The following are the results for wire pull and ball shear for both control and evaluation.

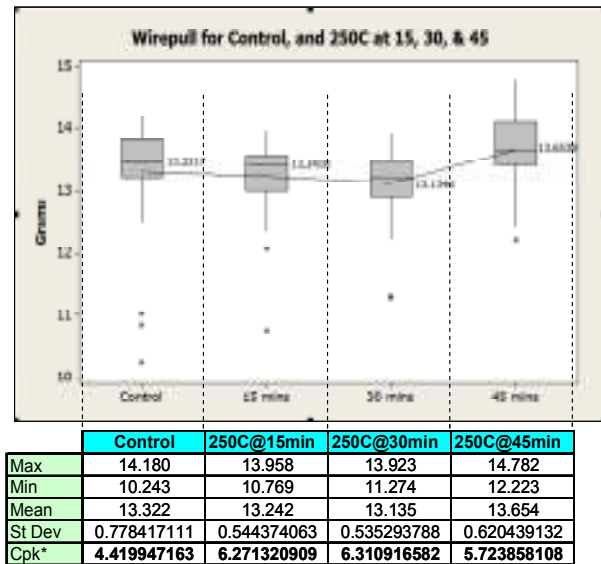


Figure 13. Wire pull for both Control and Evaluation.

Refer to Figure13 for the wire pull strength for both Control and Evaluation. Results indicate that both have similar pull strengths. However, subjecting the bond to longer heat treatment tend to shift the minimum values higher, hence smaller standard deviation.

Another interesting find was the mode of the failure for wire pull. The ball lift failure mode decreases as the duration of heating increases, indicating a stronger adhesion of the bonded ball to the pad. Refer Figure 14.

Subjecting the device to 250 degree C at 45mins, we see the ball lift occurrence declined to zero for this experiment.

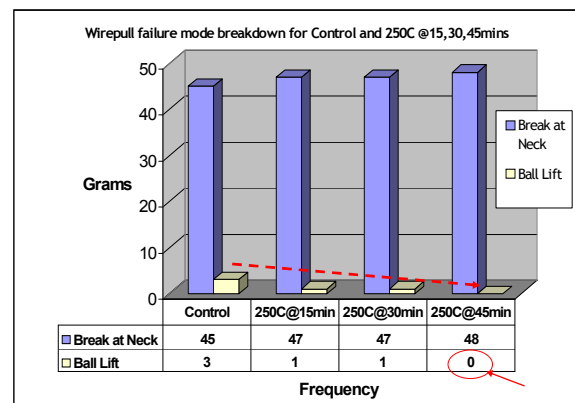
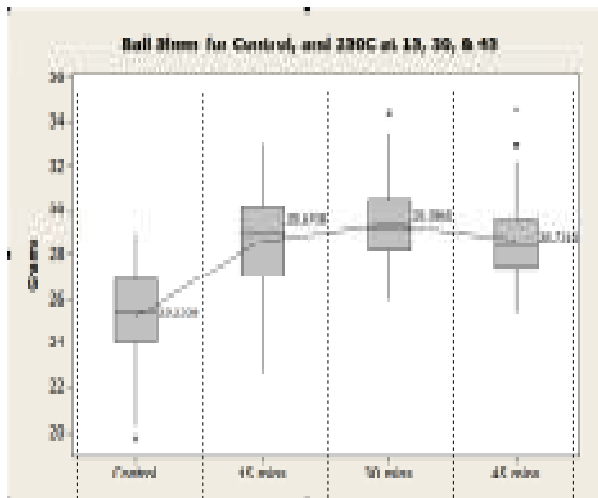


Figure 14. Wire pull failure mode breakdown for Control and 250C at 15,30, 45mins

As for ball shear data (refer Figure 15), it was observed that the control had an overall lower average compared to the evaluated parts. Shear strength and Cpk improved after heating at 250 degree C for 15 and 30min.

At 45 minutes, shear strength shows no further improvement. This could possibly be caused by the shearing of the copper, indicating metal strength of copper at this point.



	Control	250C@15min	250C@30min	250C@45min
Max	29.007	32.964	34.354	34.545
Min	19.762	22.761	26.015	25.355
Mean	25.234	28.671	29.396	28.732
St Dev	2.191910128	2.360181576	1.812303377	1.848918396
Cpk*	3.381186504	3.625536144	4.855051587	4.639018513

Figure 15. Ball shear data for Control and 250 degree C at 15,30, 45mins

Refer to Figure 16 for an example of bondpad after ball shear for a 250 degree C Thermal treatment for 45mins.

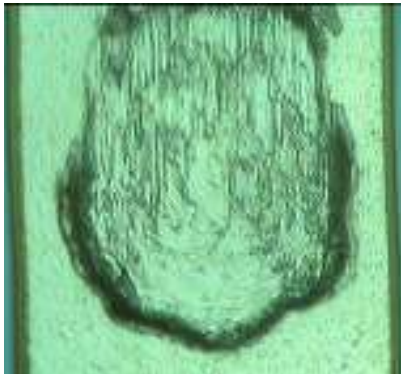


Figure 16. Bondpad after ball shear for a 250C Thermal treatment for 45mins

As for the ball shear failure mode, an interesting trend was observed between the control and evaluation. For the control, 100% of ball sheared experienced ball lifting. However, for the evaluation units, as we start to increase the duration of the heat treatment, we see a decreasing trend in ball lift from 32 to 0 at 45mins heat treatment, implying a stronger adhesion of the bonded ball to the bond pad. Refer Figure 17 for the graphical illustration.

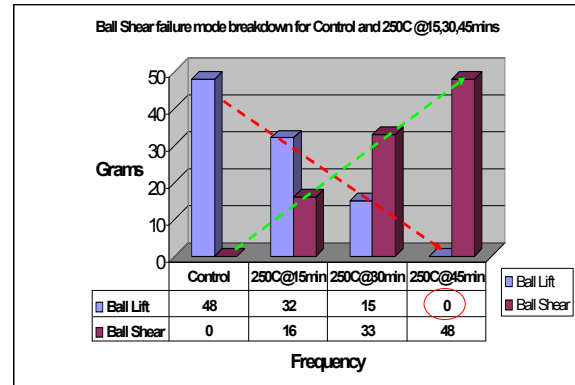


Figure 17. Ball shear failure mode for Control and 250C at 15,30, 45mins

Cross sectioning of the IMC for both control and 45mins heat treatment indicates a slight growth in IMC thickness. See Figure 18.

(Note that the clarity of the IMC could have been enhanced with the use of ION milling.)

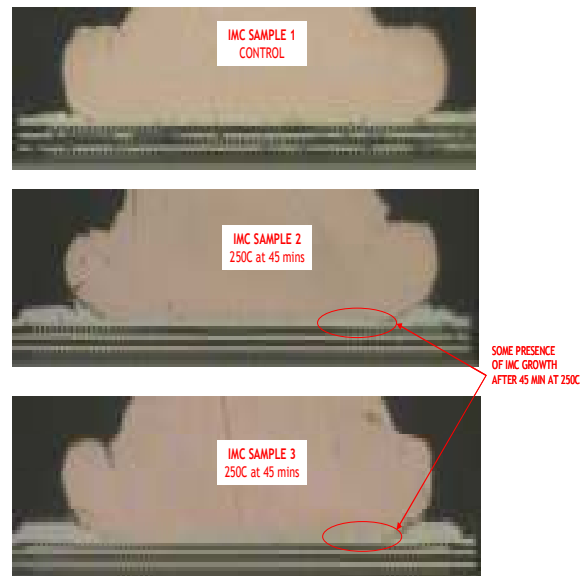


Figure 18. IMC growth for 45 mins heat treatment

Conclusions

Common conventional solutions for copper bonding is to introduce heated forming gas to soften the FAB (Free Air Ball) and heating the die during the bonding process by varying the work holder (pedestal) temperature.

The proposed method, is to introduce heat after wire bonding to enhance the intermetallic growth and thereby increasing the adhesion strength between the copper to the Al bond pad. This method will facilitate for lower USG power during wire bonding, thus, a lower impact (softer bonding) of the Cu FAB to the sensitive pad structure that has been proven to prevent bond pad crack and pad cratering. Results of wire pull and ball shear indicates a significant improvement in the shear strengths and failures modes.

Further optimization of this method is to be pursued to fully explore the potential of this process.

Acknowledgments

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